# The Pair Internal Conversion Coefficient in the F+H′ Reaction and Measurements on the Gamma-Ray Spectrum

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The gamma-radiation from F+H′ was studied by the cloud-chamber method and was found to consist of a single line at 5.8 Mev. The group of electrons at about 4 Mev found by Gaerttner and Crane was confirmed, and it is shown that this group probably consists of the negative members of internal conversion pairs. The coefficient for pair internal conversion was measured and found to be about 1 pair per 100 gamma-ray quanta, which is greater than the theoretical value. A search was made for gamma-radiation down to 0.5 Mev, and for delayed emission of electrons by the $CaF_2$ after bombardment, with negative results in each case.

IT is a well established fact that fluorine bombarded with protons emits a strong gamma-ray line at 5.8 Mev. There has also been some indication of a lower line, at about 3.8 Mev, but the evidence on this point is conflicting. As a result of the experiments to be described here, it has become clear that the coefficient for the internal conversion of the 5.8 Mev gamma-ray into pairs, in the field of the emitting nucleus, is unexpectedly high, and that it was this process which gave rise to electrons which were interpreted as indicating a second gamma-ray line. We shall give the evidence for this and also arrive at a value for the interval conversion coefficient.

## CONFIRMATION OF PREVIOUS RESULTS

The cloud-chamber experiment of Delsasso, Fowler and Lauritsen[1] was repeated with the arrangement shown in Fig. 1, which is essentially the same as theirs. We used a 6″ diameter cloud chamber[2] with a magnetic field of 1850 gauss. The sheet of scattering material placed across the center of the chamber was carbon, 1.5 mm thick. The target ($CaF_2$) was bombarded with protons of approximately 0.6 Mev energy from the high voltage accelerating tube.[3] The tracks of the electrons ejected from the carbon sheet by the gamma-rays were measured, and the results

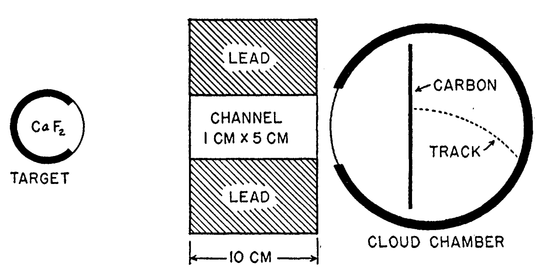


FIG. 1. Experimental arrangement.

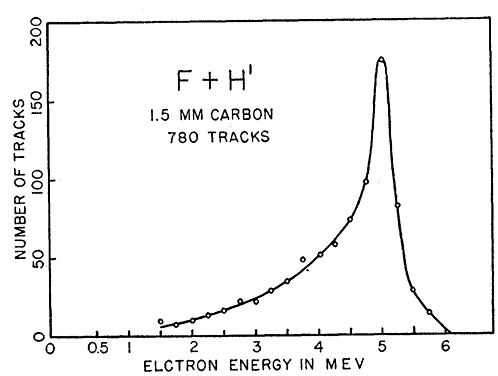


FIG. 2. Energy spectrum of recoil electrons from 1.5 mm carbon, obtained with the arrangement shown in Fig. 1.

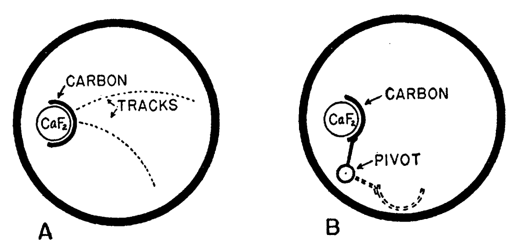


FIG. 3. A Diagram showing the target inside the cloud chamber. The cylindrical piece of carbon, 1.5 mm thick, yields recoil electrons. B The carbon is supported on a shaft which can be rotated from outside the chamber. It is placed in the two positions shown in B on alternate expansions of the chamber.

[1] L. A. Delsasso, W. A. Fowler and C. C. Lauritsen, Phys. Rev. **51**, 527 (1937).
[2] H. R. Crane, Rev. Sci. Inst. **8**, 440 (1937).
[3] H. R. Crane, Phys. Rev. **52**, 11 (1937).

are shown in Fig. 2. The distribution clearly indicates a single gamma-ray line, and is in complete agreement with the results of Delsasso, Fowler and Lauritsen.

The experiment of Gaerttner and Crane,[4] which indicated the presence of a lower line, was next repeated. The experimental set-up is indicated as A in Fig. 3; the essential feature is that the target is inside the cloud chamber, and is immediately surrounded by the scattering material, 1.5 mm of carbon. The distribution of negative electrons found is shown in Fig. 4, and confirms that found by Gaerttner and Crane.

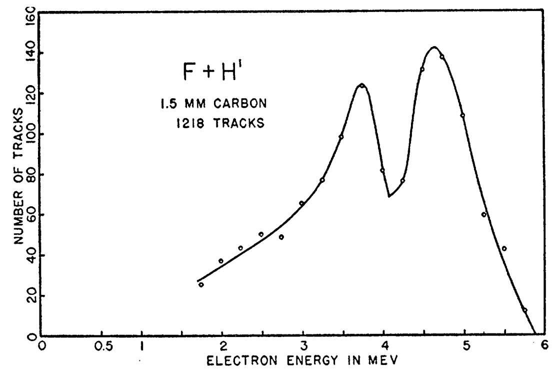


FIG. 4. Energy spectrum of the negative electrons obtained with the arrangement shown in Fig. 3 A.

A small number of tracks obtained by Gaerttner and Crane with the arrangement of Fig. 1 seemed also to indicate a second line, but this seems to have been incorrect in view of the distribution shown in Fig. 2, which contains a much greater number of tracks.

## New Experiments

To determine whether the lower energy peak in Fig. 4 is composed of electrons originating in the carbon scatterer or in the $CaF_2$ target itself, the following experiment was performed. In an arrangement shown as B in Fig. 3, the carbon scatterer was attached to a moveable arm so that it could be placed close to the target on alternate expansions of the cloud chamber, and could be removed on the other expansions. When the carbon was removed, there remained only a thin aluminum wall between the target and the chamber. Both positive and negative electron tracks are recorded in Fig. 5. The higher energy peak in the negative electron distribution is decreased by nearly a factor of two by removal of the carbon. The lower energy peak does not seem to be decreased at all. Our conclusion is that the higher energy peak is composed of Compton recoil electrons and is therefore dependent upon the amount of material surrounding the target; that the lower energy peak is composed of electrons which have originated in the $CaF_2$ target and have passed *through* the carbon scatterer.

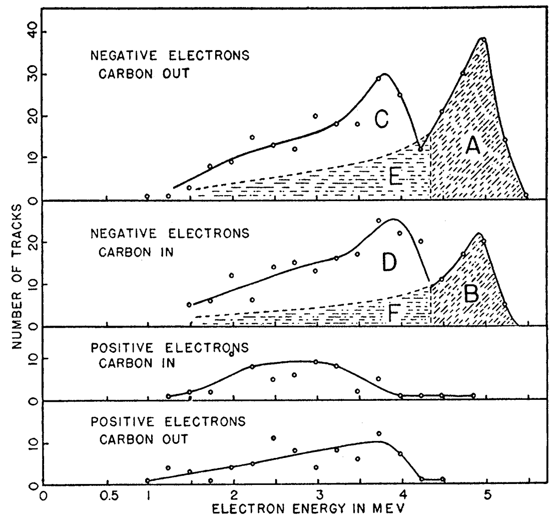


FIG. 5. Positive and negative electrons obtained with the arrangement shown in Fig. 3 B. Equal numbers of photographs were taken with the carbon in the two positions shown.

A glance at the plots of positrons will indicate two things: that the number of them is insensitive to the amount of material surrounding the target, and that the plot formed by them is not significantly different from that of the negatives comprising the lower energy peak, *C* or *D*. This approximate equality of positives and negatives makes it unnecessary to postulate any other process than pair formation to account for the effect in question. Gaerttner and Crane have already demonstrated that pair formation by internal conversion takes place in the F+H′ reaction. The only item which does not seem to fit this explanation is the somewhat excessive sharpness of the lower energy peak (especially in the data of Gaerttner and Crane) as compared with that expected from the theoretical distribution of energy between members of pairs.

[4] E. R. Gaerttner and H. R. Crane, Phys. Rev. **52**, 582 (1937).

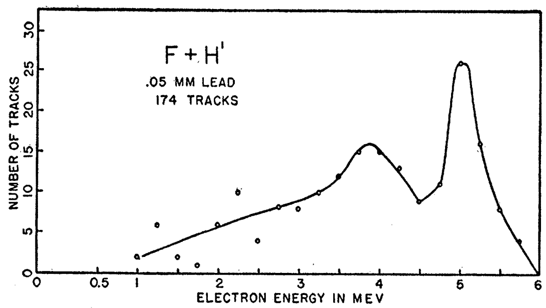


FIG. 6. Energy spectrum of negative electrons obtained with the arrangement shown in Fig. 1, except that a 0.05-mm lead scatterer was used instead of the carbon scatterer.

This however, is too uncertain to cause serious concern.

As a further check upon the notion that the lower energy peak is due to negative members of pairs, a series of photographs were taken under the arrangement of Fig. 1, but using a 0.05-mm lead sheet instead of carbon. The negative electrons appearing in this experiment were a mixture of Compton electron and pair members, but the pairs were formed in the lead instead of in the target as before. The plot of negative electrons, given by Fig. 6, shows that the negative members of pairs give rise to a second peak in the distribution in this case also.

## THE COEFFICIENT FOR PAIR INTERNAL CONVERSION

By comparing the curves in Fig. 5 the ratio of the number of pairs to the number of gamma-rays can be determined. The area $E+A$ in Fig. 5 represents approximately those electrons due to Klein-Nishina absorption in the 1.5-mm carbon absorber plus the other material surrounding the gamma-ray source. The difference in areas, $(E+A)$ minus $(F+B)$ gives the absorption in 1.5 mm carbon alone. By using the Klein-Nishina absorption coefficient, the number of gamma-rays emitted by the source (in the interval of time and solid angle determined by the experimental arrangement) is found. The number of pairs emitted under the same conditions should be given by either of the positron plots. It should also be given by either of the areas $C$ or $D$, since these are thought to be composed of negative members of pairs.

It is desirable to introduce a refinement in the above computation, for the following reason. There is no doubt that many of the electrons and positrons of very low energy are lost in the experiment, due to stopping and scattering in the material surrounding the source. The fact that the positron plots fall off rapidly at low energy is an indication that this is true. Therefore better estimates of the true areas under the curves are obtained by using the areas $A$, $B$, and the upper halves (2.25 to 4.5 Mev) of the pair plots, and calculating the total areas from these with the aid of the theoretical forms of the Klein-Nishina and pair curves, respectively. This treatment gives a ratio of 11 pairs per 1000 gamma-ray quanta, which is the pair internal conversion coefficient.

Several theoretical calculations of the coefficient have been made,[5] and indicate that for the fluorine radiation the value should lie between 1.2 and 2 pairs per 1000 gamma-rays, depending only slightly upon whether dipole or quadrupole radiation is assumed. Our value of 11 per 1000 does not seem to be compatible with the theoretical value, on the assumption that the angular momentum change is not greater than 2 units and that either $Ne^{20}$ or $O^{16}$ emits the radiation.

## SEARCH FOR LOW ENERGY GAMMA-RADIATION AND FOR DELAYED ACTIVITY

The reaction giving rise to the gamma-radiation remains a mystery. A number of possibilities have been discussed,[6] but none seems to give a satisfactory energy balance. We have searched for gamma-radiation of low energy which might have escaped attention previously, and have found nothing down to 0.5 Mev. We have also tested for delayed emission of electrons or gamma-radiation by placing the $CaF_2$ inside the cloud chamber about 5 minutes after bombardment. In this case electrons of energy as low as 5 or 10 kev could have been detected. No activity was observed.

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[5] L. Nedelsky and J. R. Oppenheimer, Phys. Rev. **44**, 948 (1933); M. E. Rose and G. E. Uhlenbeck, Phys. Rev. **48**, 211 (1935); J. C. Jager and H. R. Hulme, Proc. Roy. Soc. **148**, 708 (1935).

[6] A complete discussion has recently been given by Professor G. Breit, in a paper published by E. J. Bernet, R. G. Herb and D. B. Parkinson, Phys. Rev. **54**, 398 (1938).