Excitation of γ-Rays by Neutron, II.
The Interaction of Neutron with Proton.

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ABSTRACT.

The γ-rays emitted by proton-neutron interaction were observed. The cross-section for the process was found to lie between $10^{-10} \times 10^{-15}$ cm$^2$. The energy of the γ-ray quantum emitted by this interaction was determined by the method of coincidence of two counters and was found to be $(3.2 \pm 0.1) \times 10^6$ eV. The absorption curves of the secondary electrons due to γ-rays excited in Cd, Cl, Cu and Fe by slow neutrons were also determined. In the cases of Cd, Cu and Fe, we observed that there existed γ-rays of more than $1 \times 10^7$ eV. in quantum energy.

1. Introduction.

Recently, many works have been published as to the γ-rays excited by neutrons in various substances. Lea$^{(1), (2)}$ has for the first time observed that appreciable amount of γ-rays was emitted from paraffin or liquid hydrogen when traversed by neutrons. To explain this phenomenon, he has assumed that a proton emits a γ-ray on combination with a neutron forming a deuteron. As the idea of slow neutrons was not yet known at that time, Lea has considered that the proton might combine directly with a neutron of ordinary energy, and he has estimated from the intensity of γ-rays emitted that one out of four of the recoil tracks of neutrons in hydrogen atmosphere must be a deuteron. Auger$^{(3)}$ has searched for such tracks in Wilson chamber photograph in vain and called Lea’s suggestion in question.

The discovery of slow neutron, however, changed the point of view. Fleischmann$^{(4), (5)}$, on confirming Lea’s result experimentally, has pointed out that the opposition of Auger loses its basis of argument, if a neutron is captured after it has been slowed down losing most of its energy. Furthermore, if we recall of the intense action of slow neutrons

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(3) Auger: Compt. Rend. 198, 869 (1934).
(4) Fleischmann: Naturwiss. 50, 879 (1934).
in some nuclear processes, we could even suspect that the $\gamma$-rays observed by Lea and Fleischmann might be due to some secondary effects caused by slow neutron generated in paraffin or liquid hydrogen. In fact Amaldi and others has observed that some substances emit $\gamma$-rays in the presence of slow neutron.

In our previous papers\(^{(2,3)}\), we have reported the results of our experiments investigating the emission of $\gamma$-rays from various substances under the action of slow and fast neutron separately. On account of the presence of background radiation of unknown origin, however, the results were in many respects not definite. By Cd, Hg, Au, Cu, Fe and Ni, we could confirm the emission of $\gamma$-rays in the presence of slow neutron and could give approximately the cross-section of slow neutron for exciting $\gamma$-rays in these elements. In cases of Pb, Al and H, we could observe no detectable $\gamma$-rays and only the upper limit of the cross-section could be given. With regards to the effect of fast neutron, no conclusive results were obtained.

The object of experiments reported in the present paper is firstly to establish the emission of $\gamma$-rays by the interaction of proton with neutron, and secondly to determine the cross-section for the named process, and finally to measure the energy of a quantum of $\gamma$-rays emitted.

A great advantage for the present purpose of our method of using D-D reaction, as compared with that of other authors, is that this neutron source is accompanied by no primary $\gamma$-rays.

As our experiments were nearly finished, the result of Fleischmann\(^{(4)}\) came to our knowledge, in which he has confirmed the $\gamma$-rays emitted by neutron-proton interaction, and from the absorption measurement of $\gamma$-rays he has obtained the value $1.5 \times 10^4$ e.V. for the quantum energy of the $\gamma$-rays. The comparison of the results with ours will be given later.

2. Experimental arrangements and methods.

As in the previous work, D-D neutron was used as our source, in which following rather serious improvements were made. Firstly, the capacity of the condenser used in the high tension apparatus of Cockcroft’s type was increased from 0.002 µ F. to 0.022 µ F., to obtain higher effici-

\(^{(4)}\) loc. cit. (in Zeit. f. Phys.).
ency. Secondly, we have used as a substance to be coated on a target, a thin film of D$_2$O cooled with liquid air instead of (ND$_4$)$_2$BO$_4$ cooled with water at room temperature. Owing to these improvements, we could obtain neutron intensity of about 10 times stronger than that used in the previous experiment. The ion current received on the target was usually some ten microamperes with the accelerating voltage of 300 K.V. The intensity of the neutron under these conditions might be comparable with that from beryllium bombarded by α-particles of Rn and its product in equilibrium with a few gram of radium.

A great advantage of this source for our purpose is, as mentioned above, the absence of any primary γ-rays. A serious disadvantage is that its intensity fluctuates not only with the intensity of ion beams, but with the condition of the surface of the target and some other factors, which are not yet clear.

In the previous experiment the Geiger counter, by which γ-rays were measured, was shielded from X-rays from accelerating tubes by Pb plate 5 mm in thickness and was placed inside a box protected from slow neutrons by layers of H$_2$BO$_4$ of few centimeter in thickness, as shown in Fig. 1. As already mentioned in the previous work, the number of discharge of the counter increased by a considerable amount when the discharge was commenced even in the case, where there was nothing inserted in place A of Fig. 1. Therefore if we put certain material under examination in A, the change of the number of kicks of the counter would be an algebraic sum of the increase due to γ-rays emitted from the substance and decrease due to the absorption of background in it. Therefore, the conclusive results could be obtained only in the case, where the emission of γ-rays overcame the absorption of background. On account of weak intensity, it was not possible to place the materials so that it did not affect the intensity of background radiations.

As to the origin of the background radiation, we could not give any reasonable explanation. Though it was thought quite reasonable to consider that lead emits γ-rays under the bombardment of fast neutrons, some controlling experiments indicated that it was not likely to be so. Therefore, as it was confirmed that Fe and Cu emit appreciable amount of γ-rays in the presence of slow neutron, we have tentatively assumed that backgrounds might be due to γ-rays excited
by stray slow neutrons in various parts of the apparatus, which was chiefly made of iron and brass. For instance the target, made of iron and brass, surrounded by cooling water, and oil diffusion pumps made of iron cooled with water might emit appreciable amount of γ-rays.

In the present experiment, therefore, we shielded the counter by thick layers of lead as shown in Fig. 2. The thickness of the lead layers was 5 cm, except a side just facing to the target, where it was 2 cm thick. Moreover, we kept the pumps away from the counter system as far as possible, and by means of a fairly long glass tube T (see Fig. 2) the target was separated from other metal parts of the apparatus as far as possible. As the target was cooled with liquid air, the slow neutron was not generated at this part of the apparatus.

To protect the counter and space inside the lead box from slow neutron, layers of H₂BO₃ were properly used. We have however afterwards noticed that the space inside the lead box was not free from slow neutron, for we observed that the number of kicks of the counter increased by a small but definite amount when a thin Cd-sheet was placed before the counter.

The error caused by the fluctuation of the neutron source was eliminated by using another counter of similar construction and shieldings as standard. Before the standard counter was placed a small block of paraffin rapped by thin sheet of Cd. The γ-rays emitted from Cd excited by slow neutrons generated in the block of paraffin indicated the intensity of neutron source.

The counter was Geiger Müller type, 3 cm. in length and 1 cm. in diameter filled with argon 8 cm. Hg. The walls were made of thin aluminium sheet of 0.1 m.m. thick. The counter was covered by a lead sheet of 1 m.m. thick, which served as the emitter of secondary electron. The distance between the counter and the target was 27 cm.
To determine the energy of the $\gamma$-ray quantum, we have measured the maximum energy of the secondary electron by usual method of coincidence of two counters.

3. Experiments with paraffin and water.

With the object of confirming the $\gamma$-rays emitted by neutron-proton interaction, the change in number of kicks of the counter was investigated as the function of thickness of the layers of paraffin or water placed inside the lead box between the counter and the source. The sectional area of the layers was $10 \times 15 \text{ cm}^2$ in both cases. In the case of water a rectangular vessel made of water proof paper filled with water were used.

To make the argument definite we must specify not only the thickness but the position of the layers relative to the source and the counter. In our case the blocks or vessels were always placed so, that the surface of the layer nearest to the source came in contact with the inner face of the lead wall just facing to the source.

The results are shown in Fig. 3. o and x correspond to paraffin and water respectively. In these curves natural effect of the counter is subtracted. As will be seen from the curves, the number of kicks was not equal to 0 even in the case of 0-thickness. By discharging current of 30 &. a. and accelerating potential of 800 K.V., the number of kicks at 0-thickness amounted to about 100 per min., while the natural countings were about 10 per min. These background radiations might be of the same character as that observed in the previous experiment, and whose elimination was the object of our re-arrangements of the counter system. Though it was a great pity, that after all we could not get rid of background radiations, it was possible this time to investigate the change in number of kicks as the function of the thickness, on account of the
stronger intensity of the source, making it possible to separate the effect of emission of y-rays to a certain degree from the absorption of background. It was afterwards confirmed that this radiation was also detectable by the coincidence method, indicating that it cannot be ascribed to n-coil atoms due to collision of fast neutrons. It was confirmed moreover that the maximum energy of the secondary electron of this radiation was about 1.0 x 10^7 e.V., which value is much smaller than that of y-rays from other substances we have investigated. The activity did not remain after the bombardment was ceased.

Though no decisive conclusion can so far be drawn with regards to the origin of the backgrounds, it might be reasonable to consider, either that y-rays are emitted from lead under the bombardment of fast neutron, or that beta-rays are ejected in some way from the substance constituting the counter under the action of fast neutron.

Now, returning to Fig. 3 the number of kicks decreases for the first few centimeter and then begins to increase till 14 cm., which was the limit of our observation. In the case of 14 cm. a trace of induced activity was sometimes observed after the bombardment was ceased, but its intensity was so weak, that we could neglect this effect at all. The initial decrease is no doubt due to the absorption of background radiations. Though one might consider it hard to account for, that y-rays of 1.0 x 10^7 e.V. in quantum energy were absorbed by such an amount by a layer of paraffin or water of few centimeter thick, it can be understood easily, if we consider that y-rays were not emitted from the target but from lead box or elsewhere, where fast neutron traversed and the observed decrease corresponds to the absorption of fast neutron in paraffin or water. As regard to the subsequent increase in number of kicks, following possibilities are to be considered.

(a) Slow neutrons generated in paraffin or water act directly upon the counter system.

(b) Slow neutrons generated in paraffin or water act upon lead box. In fact Fleischmann(1) reported that lead emits y-rays by the bombardment of slow neutron.

(c) y-rays are emitted from paraffin or water itself. The initial decrease of the curve indicates, that even in this case slow neutrons, and not fast neutrons, are concerning.

If (a) is true, the number of kicks must be proportional to the

(1) loc. cit. (in ZS. f. Phys.)
number of slow neutron diffusing out of the paraffin or water, reaching the counter system. We have therefore investigated the change in number of kicks in the case, where a sheet of Cd was placed before the counter. As Cd emits intense γ-rays in the presence of slow neutron, we can measure in this way the intensity of slow neutron reaching the counter system. The results are shown in Fig. 4. The lower curves are the same curves shown in Fig. 8. It is noticeable that the number of kicks at 0-thickness is larger in the case, where there was a Cd sheet in front of the counter. This shows that there were appreciable amount of slow neutron existing inside the lead box, even when there was no hydrogenous substance in it. It is not yet settled, if these slow neutrons are coming from outside or created in lead walls themselves. In fact Amaldi(1) and others and Chadwick and Goldhaber(2) observed, that slow neutrons were created in lead.

The number of kicks increases slowly at first and then rapidly till it reaches maximum at the thickness of about 10.0 cm., and then it begins to decrease. This curve is quite similar to that obtained by Bjørge and Westcott(3,4) in their experiments on slowing down of neutrons, in spite of great difference in geometrical conditions. The absence of any maximum at the thickness of about 10 cm. in the curves without Cd sheet shows that the increase in number of kicks is not proportional to the number of slow neutrons reaching the counter system. Thus, the 1st possibility is excluded.

To examine the 2nd possibility the arrangement shown in Fig. 5 was adopted, and the change in number of kicks of the counter was investigated as the function of the thickness of the layer of paraffin

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1. loc. cit.
or water placed between the target and the small lead box, in which the counter was placed. The curves obtained were quite similar to that shown in Fig. 3, and when there was a sheet of Cd at the front face of the lead box, we obtained again the curve similar to that shown in Fig. 4. The ratio of the number of kicks with Cd-sheet before the counter to that without it was nearly equal to the same ratio obtained by the experiment carried out with the arrangements described before. These facts indicate that the most of the observed γ-rays are not those emitted from k walls.

Thus, only the 3rd possibility remains; namely, γ-rays are emitted from paraffin or water itself. One cannot yet say, that these γ-rays are emitted by the interaction of neutrons just with a proton; for carbon oxygen atoms in paraffin or water may emit γ-rays by the interaction with slow neutrons. To decide this point we must compare the curves obtained by using paraffin and water more closely. We notice that the initial decrease as well as the subsequent increase is stronger in the case of paraffin than in the case of water. The magnitude of this difference can be just accounted for by the difference in number of protons and other atoms contained in unit volume of paraffin and water.

We have therefore two alternatives. Either, both oxygen and carbon emit no γ-rays at all and the observed γ-rays are solely due to proton or both oxygen and carbon emit equal amount of γ-rays. To decide these two alternatives, emission of γ-rays from glycerin was investigated. Glycerin contains besides proton, oxygen and carbon, and the density of proton is nearly equal to that of water; the total number of oxygen atoms in glycerin is 1.5 times that of oxygen in the same volume of water. Therefore, if both carbon and oxygen emit γ-rays we must observe much more intense γ-rays in case of glycerin than in case of water. On the other hand, if γ-rays are emitted or by the neutron-proton interaction the emission of γ-rays must be equal in both cases. The result of the experiment was conclusively in favor of the latter case. Furthermore, it was confirmed by the experiments described later, that the γ-rays from paraffin and water were equal
quantum energy.

After all, we may safely conclude that most of the γ-rays, if not all, observed by us were those emitted by neutron-proton interaction.

4. The cross-section of the proton-neutron interaction.

From the general point of view it is quite important to determine the cross-section for neutron-proton interaction. In the previous work we have given the value $0.5 \times 10^{-24}$ cm$^2$ for the upper limit of the cross-section. We have now determined the upper and lower limits of the cross-section more closely by the method described below.

In the foregoing paragraph, we have seen that when a layer of water of sufficient thickness was placed before the counter the number of kicks increased by an appreciable amount, on account of the γ-rays emitted from water by the proton-neutron interaction. Now, if we dissolve a small amount of Cd salt in water the intensity of γ-rays increases, as it should be. If the concentration of Cd is so small that the presence of Cd atoms does not affect the density distribution of slow neutrons in water, the increase in the intensity of γ-rays should be proportional to the concentration.

Now, let $I_1$ and $I_2$ be the number of kicks of the counter in the case of Cd solution and pure water respectively, and $N_p$ and $N_{Cd}$ be the number of protons and Cd atoms in unit volume of Cd solution. Further, if the number of slow neutrons, whose energy lies between $E$ and $E+dE$ be given by $N(E)dE$, and the cross-section of Cd atoms and protons for the interaction with slow neutron resulting emission of γ-rays, be expressed in the form $\sigma_p(E)$ and $\sigma_{Cd}(E)$ respectively, we get

$$I_1 - I_2 = \frac{N_{Cd}}{N_p} \int N(E)\sigma_{Cd}(E)dE$$

We assumed that the efficiency of the counter is equal for both γ-rays, and that only one quantum of γ-rays is emitted by every interaction process. As we know very little about $N(E)$ and $\sigma(E)$, we introduce simplifying assumptions that $\sigma_p(E)$ and $\sigma_{Cd}(E)$ differ appreciably from 0 only for some energy intervals, in which $N(E)$ does not vary very much. If we denote the total number of slow neutrons in these intervals by $n_p$ and $n_{Cd}$, and mean cross-section by $\sigma_p$ and $\sigma_{Cd}$ respectively, we get
On assuming that \( n_\text{av} / n_\text{a} \) nearly equal to 1, we obtain

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\frac{I - I_0}{I_0} = \frac{N_\text{av}}{N_\text{a}} \frac{n_\text{av} \sigma_\text{av}}{n_\text{a} \sigma_\text{a}}
\]

One may be able to discuss many things about the assumption that \( n_\text{av} / n_\text{a} \) is nearly equal to 1. It depends closely upon the position and breadth of the absorption band of these atoms for slow neutrons. In future, we may be able to draw some conclusion about these things by comparing the cross-section obtained in this way with those obtained by other methods. Here we assume that \( n_\text{av} = 1 \) without any necessary reasons.

Now, Dunning, Pegram, Fink and Metcalfe\(^{(1)}\) have obtained the value \( 3300 \times 10^{-24} \text{ cm}^2 \) for the absorption coefficient of slow neutrons for Cd. They have also observed that in the case of Cd the scattering coefficient is much smaller than that of absorption. As it is reasonable to assume that \( \gamma \)-rays are associated to every absorption process, we can put the value \( 3300 \times 10^{-24} \text{ cm}^2 \) for \( \sigma_\text{av} \) in the above equation. As we know \( \frac{I}{I_0 - I} \) and \( \frac{N_\text{av}}{N_\text{a}} \) experimentally, we can obtain the numerical value of \( \sigma_\text{a} \).

Fig. 6 shows the result of our experiment, showing the increase in number of kicks with the concentration of Cd in water. In this case thickness of the layer of water was 14 cm. The abscissa indicates the value of \( N_\text{av} / N_\text{a} \). The increase in number is already detectable for the concentration of the order of \( 10^{-5} \). As will be seen, the intensity of \( \gamma \)-rays does not increase linearly with the concentration. This fact indicates, that the density distribution of slow neutrons is affected by the presence of Cd atoms, even for the concentration of the order of \( 10^{-4} \), or in other words, even in the case of pure water, the number of slow neutron captured by protons in water is not small compared with those diffusing out of the water.

\(^{(1)}\) Dunning and others: Phys. Rev. 48, 266 (1935).
From the gradient of the curve at 0-concentration, we can calculate the increase in intensity of γ-rays for infinitely low concentration, to which we can apply the equation obtained above. We can not, however, put the intensity of γ-rays at 0-concentration to be equal to $I_0$ of the above equation, on account of the presence of background radiations, whose amount were not clear. Anyhow, we can obtain the upper limit of $\sigma_p$ by putting the number of kicks at 0-concentration to be equal to $I_0$. By doing this we obtain

$$\sigma_p (\text{upper limit}) = 0.3 \times 10^{-4} \times \sigma_{an}$$
$$= 1.0 \times 10^{-20} \text{ cm}^2.$$

To obtain the lower limit of $\sigma_p$, we dissolved H$_3$BO$_3$ in water, and reduced the amount of γ-rays emitted from proton. The amount of reduction is shown in Fig. 6, which is the lower limit of γ-rays emitted from proton. Putting this to be equal to $I_0$, we get evidently lower limit of $\sigma_p$,

$$\sigma_p (\text{lower limit}) = 0.12 \times 10^{-4} \times \sigma_{an}$$
$$= 0.28 \times 10^{-20} \text{ cm}^2.$$

The error involved in these figures may not exceed 20%.

Bjerga and Westcott\(^{(1)}\) have obtained the value $8.0 \times 10^{-24}$ cm$^2$ for the cross-section of water molecule H$_2$O. On considering that oxygen atoms play no part, we obtain $4.0 \times 10^{-24}$ cm$^2$ for the cross-section of proton, which is four times greater than our upper limit.

The values obtained here can not directly be compared with that obtained by Chadwick and Goldhaber\(^{(2)}\) for the inverse process; for in their case the photo-neutron has much higher energy than our “slow neutron”.

5. The quantum energy of the γ-ray.

Now, we proceed to the determination of the energy of the γ-ray quantum emitted by the neutron-proton interaction. To do this, the method of coincidence of two counters devised by Bothe and Becker\(^{(3)}\) was used. The counters were the same as that described before. The distance between the axes of the counters was 3 cm and the distance between the target and the center of the counter system was about

\(^{(1)}\) loc. cit.
\(^{(2)}\) loc. cit.
The separation factor of our counter system was measured by giving known numbers of kicks to each counter independently and measuring the number of accidental coincidence in unit time. It was found to be $0.7 \times 10^{-4}$ sec.

Proton-neutron $\gamma$-rays were created by inserting in the lead box a block of paraffin $10 \times 15 \times 7 \text{cm}^3$ between the counter system and the target and another block of same size behind the counter system. By ion current of $30 \mu \text{A}$ and accelerating potential of $300 \text{K.V.}$ we obtained about $30$ coincidence per min. with no absorber between the counters.

The curve I of Fig. 7 was obtained by plotting a diagram of number of coincidences against the thickness of aluminium absorber inserted between the counters. The end part of the curve is given with 10-fold enlargement in Fig. 8. The number of coincidences decreases till to the absorber thickness of $2.8 \text{m.m.}$ and further increase of the thickness of the absorber does not affect the number of coincidences. Adding $0.2 \text{m.m.}$, which is twice the thickness of the walls of the counters, to $2.8 \text{m.m.}$, we get $3.0 \text{m.m.}$ for the maximum range of secondary electron in aluminium. As carbon was used as emitter of the secondary electron, we may consider that this corresponds to the Compton recoil electron ejected in the direction of primary $\gamma$-rays.

Now, according to Van der Zee, the energy of electrons having the maximum range $3.0 \text{m.m.}$ in aluminium is equal to $2.0 \times 10^6 \text{e.V.}$ From this value we obtain $2.2 \times 10^6 \text{e.V.}$ for the energy of the $\gamma$-ray quantum.

To check the correctness of our procedure we measured the absorption

![Graph](image-url)
of secondary electrons due to \( \gamma \)-rays from \( {}^1\text{Ra}(\text{B+C}) \) (Fig. 7, 8 curve II) and \( \text{ThC}'' \) (Fig. 7, 8 curve III) after filtering through a lead absorber 5 cm. in thickness. From the curve of Fig. 6 we located the end points at 2.4 m.m. for \( \text{Ra}(\text{B+C}) \) and 2.7 m.m. for \( \text{ThC} \). The energy of the \( \gamma \)-ray quantum deduced from these values by the same procedure as before are \( 1.9 \times 10^4 \) e.V. for \( \text{Ra}(\text{B+C}) \) and \( 2.7 \times 10^4 \) e.V. for \( \text{ThC} \). These values are in agreement within the experimental error with the values known from \( \beta \)-ray spectrum of these substances; namely \( 1.8 \times 10^4 \) e.V. and \( 2.6 \times 10^4 \) e.V.

We conclude, after all, the energy of the \( \gamma \)-ray quantum emitted by proton-neutron interaction is \( (2.2 \pm 0.1) \times 10^4 \) e.V. This is in good agreement with the value obtained by Chadwick and Goldhaber\(^1\) for the energy of dissociation of the deuteron into a proton and neutron. This fact suggests that our \( \gamma \)-rays are emitted by the combination of the neutron with a proton to form a deuteron.

Our value is not in agreement with the value \( 1.5 \times 10^4 \) e.V. obtained by Fleischmann\(^2\) by the absorption measurement on \( \gamma \)-rays.

6. \( \gamma \)-rays from other substances.

We have further determined the absorption curve of secondary electrons of \( \gamma \)-rays excited in \( \text{Cd}, \text{Cl}, \text{Cu} \) and \( \text{Fe} \), and also that of background \( \gamma \)-rays.

In the case of \( \text{Cd} \) and \( \text{Cl} \) a vessel of \( 10 \times 15 \times 7 \) cm\(^3\) in size filled

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\(^1\) loc. cit.
\(^2\) loc. cit.
with water solution of CdSO₄ and NaCl of proper concentration was placed inside the lead box between the counter system and the target. In these cases practically all of the slow neutrons created in water would have been captured by Cd or Cl atoms, so that the contribution of proton-neutron γ-rays were exceedingly small.

In the case of Cu and Fe the wall of the lead box facing to the target was replaced by a layer of paraffin 10 cm in thickness, and plates of Cu or Fe were placed before the counters. Most of the γ-rays excited in paraffin would have been absorbed by these plates.

Results are shown in Fig. 9. As will be seen, the background γ-rays are soft compared with other γ-rays. Its quantum energy was estimated to be about 1 × 10⁶ e.V.

In the case of cadmium the general feature of the curve is quite different from the case of proton-neutron γ-rays. Till to the thickness of absorber of 3 m.m., the number of coincidences decreases quite rapidly and then rather gradually till to 9 m.m., where the number of coincidences is still larger than the number of accidental coincidences, which was determined by inserting a lead absorber of 5 m.m. between the two counters. The quantum energy of the softer component was estimated to be 2.0 × 10⁶ e.V. As to the harder component, though it was rather difficult to determine the maximum range of secondary electrons accurately, a rough estimation from the gradient of the curve at 9 m.m.
gave 14 m.m. for the maximum range, which corresponds to quantum energy of $\gamma$-rays of $1 \times 10^7$ e.V.

With regard to Cl, the $\gamma$-rays seem to be homogeneous. The maximum range of the secondary electron could be determined fairly accurately, namely 7·0 m.m. corresponding to the quantum energy of $5 \times 10^6$ e.V.

As to Cu and Fe we have observed again harder components, whose quantum energy might exceed $1 \times 10^7$ e.V.\(^{(1)}\)

As to the discussion about the nuclear processes by which these $\gamma$-rays are emitted will be given in another opportunity. It might be probable that the $\gamma$-rays of high quantum energy observed by us correspond to those observed by Joliot and Kowarski\(^{(2)}\) in their Wilson-chamber experiments.

Recently, Rasetti\(^{(3)}\) has reported the similar experiment to determine the quantum energy of the $\gamma$-rays excited in some substances. The common elements which were investigated by Rasetti and by us were Cd and Cl. In the case of Cd, it seems that he has overlooked the presence of harder component, while in the case of Cl, his value is somewhat higher than ours. He has determined the energy by comparing the half value thickness of the absorption curve of secondary electron with that of $\gamma$-rays of known quantum energy. This procedure is only allowed in the case, where the $\gamma$-rays are homogeneous.

In conclusion we wish to express our thanks to Imperial Academy of Japan for the grant which enabled us to cover the cost of heavy water, to Hattori Hōkō Kwai for the grant which was used in setting up the high tension apparatus and finally to Nihon Gakujutu Shinkō Kwai for the grant which was chiefly used in setting up the insulation transformer of big capacity which supplied the power to high tension side of the apparatus.

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\(^{(1)}\) In the cases of Cu and Fe we have used as secondary electron emitter Cu resp. Fe plates themselves, while in all other cases carbon plates of 1 cm. thickness were employed throughout.
