Det Kongelige Danske Videnskabernes Selskab
Matematisk-fysiske Meddelelser, bind **26**, nr. 6

Dan. Mat. Fys. Medd. **26**, no. 6 (1951)

MAXIMUM AND MEAN ENERGY OF THE RECOIL NUCLEUS IN THE BETA-DECAY OF KR^{89}

BY

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1742

København
i kommission hos Ejnar Munksgaard
1951

Printed in Denmark
Bianco Lunos Bogtrykkeri.

Introduction.

The maximum and the mean energy of the recoil in the β-decay of Kr^{89} have been measured.

The decay of Kr^{89} and its daughter substances can be summarized in the following scheme$^{(1, 2)}$:

$$Kr^{89} \xrightarrow[3.18^{m}]{\beta} Rb^{89} \xrightarrow[15.4^{m}]{\beta} Sr^{89} \xrightarrow[55^{d}]{\beta} Y^{89} \text{ stable.}$$

Kr^{89} is much more shortlived than Kr^{88} which has a half-life of 166^{m} (3). Consequently, although the same experimental methods have been used as in the investigation of the recoil in the β-decay of Kr^{88} (4), a number of experimental problems has to be considered much more closely for the experiments with Kr^{89} than for those with Kr^{88}. Therefore it is the intention in this article to give a rather detailed account of some methods which are used in this work and are applicable to other shortlived inert gases.

The β-spectrum of Kr^{89} is complex(2) and just as in the case of Kr^{88} (3, 5) this brings about some uncertainty in the interpretation of the results with respect to the angular correlation for the angle $\theta_{\beta\nu}$ between the directions of emission of the electron and the neutrino. However, some tentative conclusions will be drawn in the last section of the paper.

The Maximum Energy.

The principle of the method is the same as in the measurement of the maximum energy of the recoil in the β-disintegration of Kr^{88}.

Fig. 1 illustrates the vacuum system. An evacuated container, U, is filled with uraniumhydroxide, mixed with a small portion of ammonium carbonate. The container is placed between the coils of the cyclotron magnet, as close to the beryllium target as possible. The container is surrounded by a few centimeters of parraffin. U is connected to the other parts of the apparatus through a stopcock S_1. The pumps are connected to the system by a second stopcock S_2. L_1, L_2 and L_3 are liquid air traps.

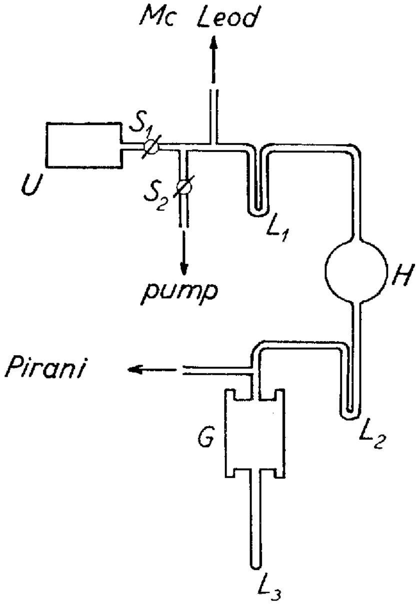

Fig. 1. The vacuum system for the measurement of the maximum recoil energy.

After the cyclotron irradiation is stopped, S_2 is closed and S_1 is opened. Due to the presence of the dissociation products of the ammonium carbonate the liquid air traps work as pumps and the radioactive inert gases are pumped off from the uranium and collected in the main apparatus. The bulb H is introduced in order to slow down the flow of gas passing through the liquid air trap L_1. The pressure in the system is controlled by a Pirani and a McLeod manometer. G is the main apparatus. It is shown in more detail in Fig. 2. The apparatus has axial symmetry about the line a-a, of course apart from the two tubes leading to the uranium-container and to the liquid air trap L_3 respectively. The central box, G, is closed by flanges, one of which carries a wire gauze which covers the area close to the symmetry axis a-a. G is continued by isolating flanges C which are sealed to G. The flanges C carry two metal plates D and the two collectors A and B. A potential difference V is maintained between the central box G and the collector system A-B-D. The two plates D are connected by a metal wire which is not shown in the figure. The potential difference V is taken from a battery of dry cells which is connected between A and some point of G. At the same time V is measured by a voltmeter connected between B and some other point of G. This arrangement ensured that no part of the system A-B-D was electrically insulated from the others and consequently all parts of the system had the correct potential.

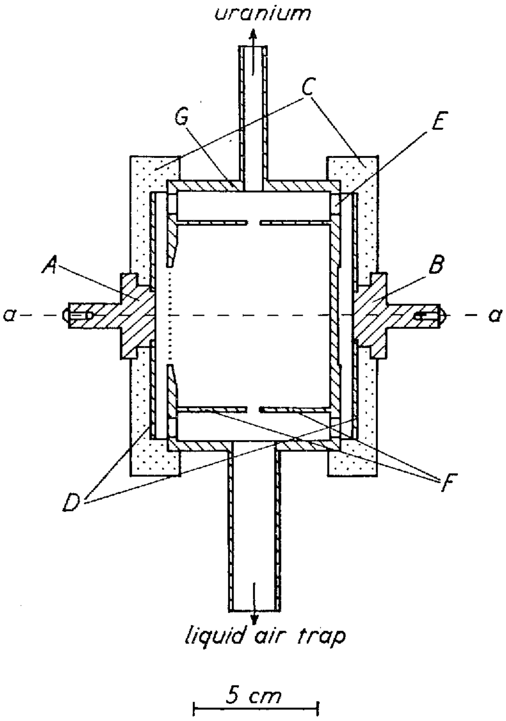

Fig. 2. The main apparatus for the measurement of the maximum recoil energy.

It is very important to ensure a rapid and free passage of the gas to all parts of the instrument when operating with short lived gases. Therefore, a large number of holes E connect the spaces between D and G with the interior of G. During the experiment the β-disintegrations of the short lived gas takes place everywhere in the apparatus. Some recoils hit the collector plates A and B. The electron work function of the metal surface of the collector used is smaller than the ionization potential of rubidium. Consequently, a recoil atom that is reflected from these surfaces is almost certain to be neutral. From the average energy measurements it may be concluded that neutral recoil atoms are very rare and that they play no measureable role in these experiments. Consequently, we may conclude that when a recoil nucleus hits a metal surface in the apparatus it is collected on this surface. The number of recoils accumulated on A and B can be determined by the radioactive decay of Rb^{89}. The radioactivity of the plates is measured after the main experiment by dismounting the collectors A and B and carrying them to a counter. The activity N_B on B is due to those recoils produced in the space between B and G which are able to surmount the potential difference between the point where they are created and B. The activity N_A on A equals N_B plus a certain number N_I of recoils coming from the interior of G. It is desirable that all the recoils N_I originate in field free space. Therefore, the shields F are introduced in the apparatus to prevent recoil particles created between D and G from passing through the holes E into the interior of G and out through the wire gauze towards plate A.

The main apparatus G is completely surrounded by cadmium shields in order to prevent the slow neutron flux from the cyclotron from generating any activity in the material of the collectors.

The general course of an experiment is as follows. After the apparatus has been assembled and evacuated, the uranium is irradiated with neutrons from the cyclotron for 3 minutes. Let us call that instant of time when the cyclotron was stopped $t = 0$. The stopcock S_1 has been closed since the start of the cyclotron irradiation and the liquid air traps are immersed in liquid air. Between $t = 0$ and $t = 1^m$ the stopcock S_2 has been closed and at the time $t = 1^m$ S_1 is opened and closed again at $t = 3^m$. During this interval of time L_1 acts as a pump in the way described above and the main apparatus is filled by gases originating from the fission process at a pressure of ~ 10^{-3} mm Hg. The pressure in the apparatus as close as possible to G is read on the Pirani manometer. The result is shown in Fig. 3. The potential V is kept at 1000 volts until the pressure in G is constant. This happens at $t = 3^{m}$ and at $t = 3^{m}.25$ the potential V is lowered to the value desired in the experiment in question and kept at this value until $t = 8^{m}$ and at this time it is raised again to 1000 volts. At the same time the gas is pumped off and afterwards the experiment is interrupted and the collector plates A and B are dismounted and carried to the counters. Here the ratio N_A/N_B is determined. The result is plotted as a function of V in Fig. 4.

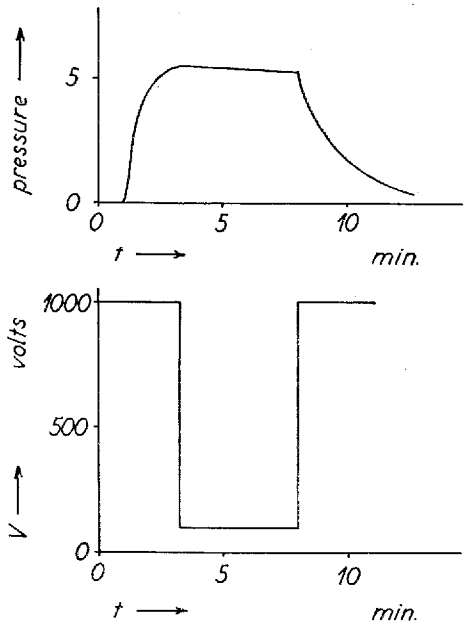

Fig. 3. The pressure and the potential difference V as a function of time during the course of an experiment.

During the intervals of time when V = 1000 volts very few recoils can reach the plates A and B due to the strong repulsive force from these plates. Furthermore to the first approximation the few recoils reaching the plates A and B during this interval of time give the same contribution to N_A as to N_B the difference being due to concentration differences between the spaces close to A and B. These concentration differences arise from the non-static situation during the inlet of the radioactive gas, and the application of the strong repulsive potential is a very important precaution when working with short lived activities where the time used for the inlet of the gas is of the same order of magnitude as the life-time of radioactive gas.

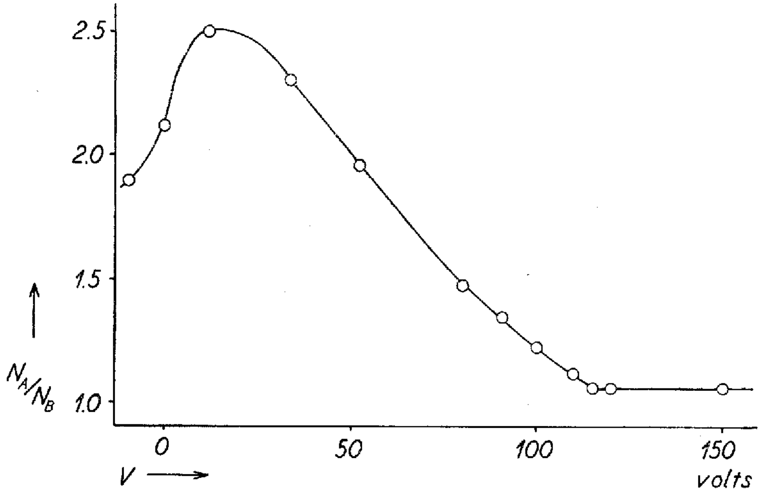

Fig. 4. N_A/N_B as a function of V.

During the interval of time from $t = 3^m.25$ until $t = 8^m$ the main experiment goes on. The pressure is constant and the differences in concentration of the radioactive gas may be neglected. It is noticed that N_A/N_B is constant and equal to 1.05 for $V > 115$ volts. This result means that above this voltage no recoils can surmount the potential difference between G and A and we may conclude that the maximum recoil energy equals 115 ± 5 eV. Due to a small inaccuracy in the mechanical construction of the apparatus the volume between A and G was 4 % bigger than the volume between B and G. This is in agreement with the above mentioned value 1.05 of N_A/N_B for $V > 115$ volts.

Of course it is important to examine the purity of the Rb^{89} activity on the collectors. First of all we cannot avoid contaminations of Rb^{88} from the decay of Kr^{88}. However, the maximum energy of the recoils of Kr^{88} is considerably lower than the maximum energy of the Kr^{89} recoils. Consequently this impurity has no influence on the measurement of the maximum energy. For the mean energy the contamination of Rb^{88} gives rise to an important correction. This is the reason for the examination of this particular point described in the next section. The half-lives of the krypton isotopes with mass number higher than 89 are very short and consequently contaminations from daughter substances from these isotopes are excluded. Impurities from Xe^{138} and Xe^{139} might however occur, but the liquid air traps together with the CO_2, NH_3 and H_2O dissociation products from the ammonium carbonate remove all traces of Xenon. This was checked by following the decay curve of the activities of the plates A and B and was further controlled by some measurements carried out in connection with the average energy determination. The decay curves of the collector plates did not show the slightest sign of impurities of a 7^m Cs^{139} or a 33^m Cs^{138} isotope.

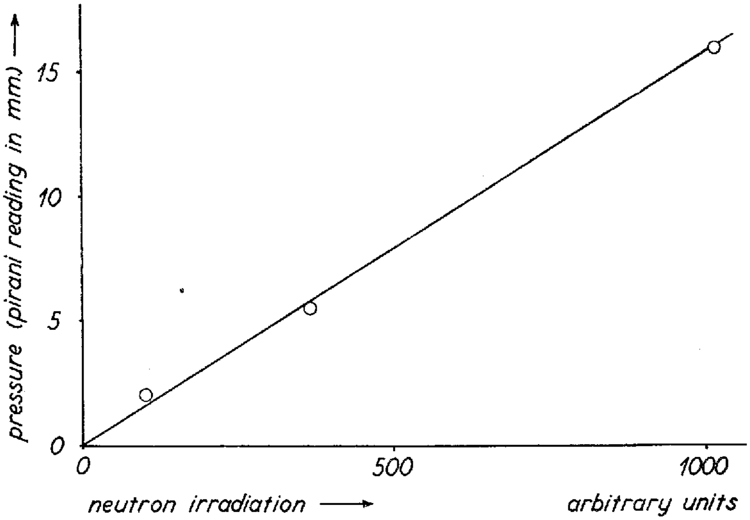

Fig. 5. Minimum pressure obtainable in the apparatus as a function of the total neutron irradiation in terms of the cyclotron beammeter reading.

The experiments were carried out at a pressure of 10^{-3} mm Hg. We have to notice an important point in this connection.

With the present method for obtaining the radioactive gases it is not possible to obtain as low a pressure as one might want to and at the same time get sufficient radioactive material. Fig. 5 shows the minimum pressure obtainable after different neutron irradiations. It is seen that the minimum pressure is proportional to the irradiation.

However, the pressure 10^{-3} mm Hg is not unreasonably high. This will be illustrated in one of the following sections in connection with some experiments carried out during the investigation of the mean energy. In these experiments the influence of the pressure on the average energy is measured directly. It is concluded from the results that only a small fraction of the recoils has suffered collisions with the residual gas molecules in the experiments described in this section. Consequently the maximum energy cannot be influenced by the pressure in the apparatus.

Relative Yield of Daughter Substances from Kr^{88} and Kr^{89}, Half-Life of Kr^{89}, Relative Fission Yields of Kr^{88} and Kr^{89}.

We have mentioned that the rubidium activity on the collector plates consists of a mixture of Rb^{89} and Rb^{88}. The half-lives of these activities are practically the same namely 15.4^{m} and 17.8^{m} respectively. Consequently the ratio of the contributions from Rb^{89} and Rb^{88} cannot be determined very accurately from an analysis of the decay curve of the activity on the collector plates. Therefore an apparatus was designed for the determination of the ratio of the activity of Rb^{89} to the activity of Rb^{88} deposited on the surface of a field free space. A diagram of the vacuum system is shown in Fig. 6.

The system U-S_1-S_2-pump-McLeod-L_1 is the same as that described in the previous section. From this point and further on the apparatus has been augmented by a complete system of bulb H, liquid air trap L_2 and main apparatus M. The liquid air trap L_3 has been left out and some stopcocks S_3 and S_4 have been introduced. The main apparatus is shown in more detail in Fig. 7. It consists simply of a box A closed with a flange C. In the center of C is placed a small disk B. When the apparatus is opened the disk can be unscrewed and carried to the counter.

The general course of an experiment is as follows. The system is assembled and evacuated and irradiated with neutrons. The cyclotron irradiation lasts 3^m. Again let us call that instant of time when the cyclotron was stopped t = 0. The stopcocks S_1, S_2 and S_4 are supposed to be closed, the stopcocks S_3, however, are open. The liquid air traps are cooled by liquid air. At the time $t = 1^m$ the stopcock S_1 is opened and at the time $t = 2^m$ it is closed again. During this interval of time the bulbs H are filled with gas from the uranium container. Soon after this the stopcocks S_3 are closed and S_2 is opened. This means that equal amounts of gas are enclosed in the two bulbs H and that the volume between S_1 and S_3 is evacuated. At a certain time t_0 the stopcock S_{4a} is opened and the gas in the bulb H_a is let into the main apparatus M_a. The pressure in a system very similar to M_a, namely the average energy apparatus described in the following section, is shown in Fig. 8 with $t_0 = 4^m$. At the time

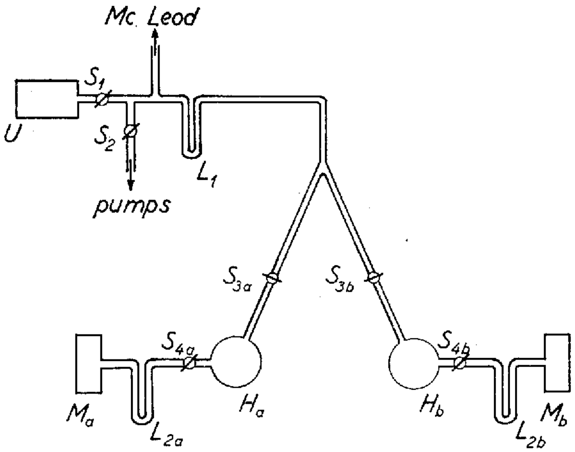

Fig. 6. The vacuum system for the determination of the relative yield of mass numbers 88 and 89.

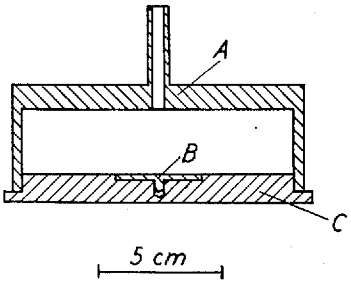

Fig. 7. The figure shows the main apparatus used for the determination of the relative yield of Kr^{88} and Kr^{89}.

$t = t_0 + 4^m$ the stopcock S_{3a} is opened and the gas is pumped off. At the time $t = t_0 + 5^m$ the vacuum in M_a is opened and a large amount of air is allowed to flow through the apparatus so that all traces of radioactive gas are removed from the system. M_a is opened, the plate B_a is unscrewed and brought to the counting equipment and the radioactivity N_a of this plate is measured from the time $t = t_0 + 10^m$ and until $t = t_0 + 50^m$. The shape of the decay curve is followed during this interval of time. At the time $t'_0 = t_0 + 54^m$ exactly the same procedure is carried through with the system labelled b. The result is the activity N_b on plate B_b. The volumes of the corresponding parts of the instruments a and b are equal within the accuracy necessary in this experiment.

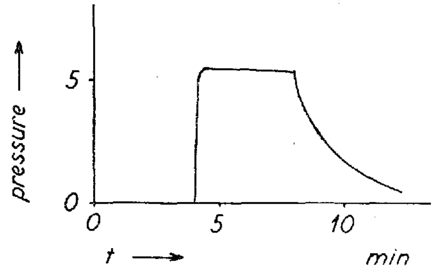

Fig. 8. Pressure curve showing the gas inlet and outpumping in the average energy apparatus.

The ratio

$$J_{Rb^{89}}/J_{Rb^{88}} = (N_a - N_b \exp(\lambda_{Kr^{88}} \cdot 54^m))/N_b \exp(\lambda_{Kr^{88}} \cdot 54^m) \quad (1)$$

is plotted as a function of t_0 in Fig. 9. The exponentials $\exp(\lambda_{Kr^{88}} \cdot 54^m)$ take into account the decay of Kr^{88} between the starting times t_0 and t'_0. The time variation of the curve in Fig. 9 is given by the expression

$$J_{Rb^{89}}/J_{Rb^{88}} = \text{const} \cdot \exp(-(\lambda_{Kr^{89}} - \lambda_{Kr^{88}})\, t_0) \quad (2)$$

and from the knowledge of $\lambda_{Kr^{88}}$ (4) and the curve in Fig. 9 it is possible to find the half-life of Kr^{89}. The result is 3.14^m in agreement with the result from measurements on mass separated krypton isotopes (2).

One can also estimate the relative fission yield of mass numbers 88 and 89 from this measurement. It can be shown that the rubidium activity A_R on the collector plates is connected with the yield y_K of the corresponding Kr-isotope by the following expression

$$\left.\begin{aligned} A_R = y_K \lambda_R (1 - \exp(-\lambda_K T)) \exp(-\lambda_R t) \cdot \\ \cdot \int_{t_0}^{t_1} P(t) \exp(-(\lambda_K - \lambda_R) t)\, dt; \end{aligned}\right\} \qquad (3)$$

here λ_R and λ_K are the decayconstants of the rubidium and the krypton isotope respectively, T is the time interval used for neutron irradiation, t_1 is the instant of time when the experiment is interrupted and P(t) is the pressure function as shown in Fig. 8

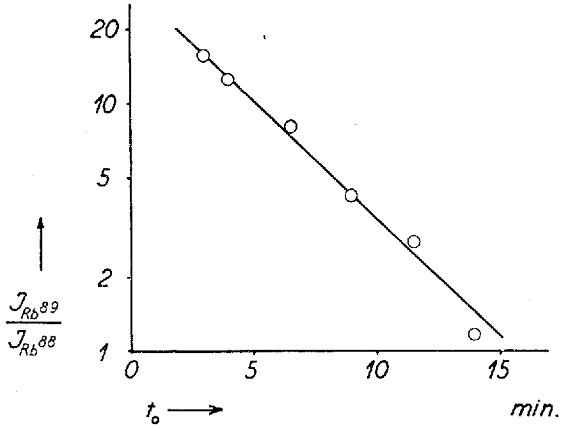

Fig. 9. $J_{Rb^{89}} / J_{Rb^{88}}$ as a function of t_0.

normalized in some way which, however, does not matter because we are interested in relative fission yields only. The expression (3) is valid for $t \gg t_1$. An evaluation of the numercial data gives

$$y_{89} / y_{88} = 1.5 \pm .2. \qquad (4)$$

All predecessors of our two krypton isotopes are very short lived (6) compared with the time intervals t_0 used in the determination of the curve in Fig. 9. Also our two krypton isotopes lie rather close to the stable isotopes and it can be assumed that the main part of the primary fission products have $Z > Z_{Rb} = 37$ so that (4) may be taken as a representative of the fission yields of mass numbers 88 and 89.

For the following experiments it is of some importance to notice that the inevitable contamination of Kr^{88} in the present experiments for $t_0 = 4^m$ amounts to 8.0 $^0/_0$ when measured by the Rb^{88} activity in the standard manner discussed above.

The Mean Energy.

The principle of the method is again the same as has been applied to Kr^{88} before.

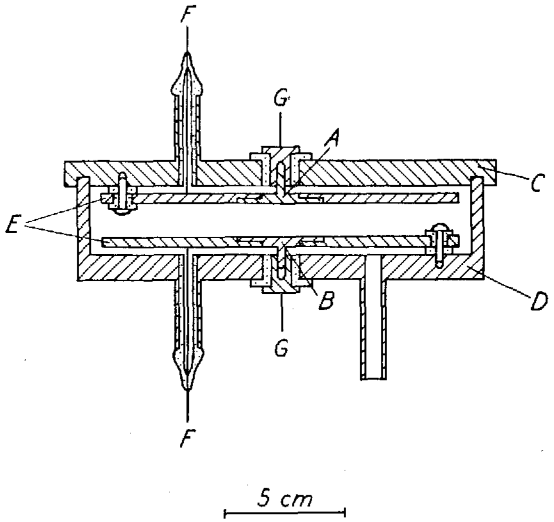

Fig. 10. The main apparatus for the measurement of the average energy.

The vacuum system consists simply of one of the systems shown in Fig. 6 and applied in the experiment described above. The system labelled b is left out and also the stopcock S_{8a} is left out. The main apparatus is of course changed and the average energy apparatus is shown in Fig. 10. It consists of a metal box D with a lid C. Isolated from this box are placed two metal plates E which form a plane parallel condenser. The central part of the plates, A and B, can be removed and carried to the counters. An electrical potential difference V is applied across the condenser. The voltage V is connected between the wires F-F and measured between G-G. Consequently, a current is drawn through the plates and all parts of the condenser plates have the correct potential.

When $Ve \gg E_R^{max}$ the ratio of the number of recoils collected on the positive plate N_+ to the number collected on the negative plate N_- gives a direct measure of the mean value of the energy E_R divided by the charge z_R of the recoils. This connection is expressed by the following formula (7)

$$\langle E_R/z_R \rangle = 6\,VN_+/(N_+ + N_-), \qquad (5)$$

where $\langle\rangle$ denotes the average value.

For singly charged recoil atoms the method gives directly

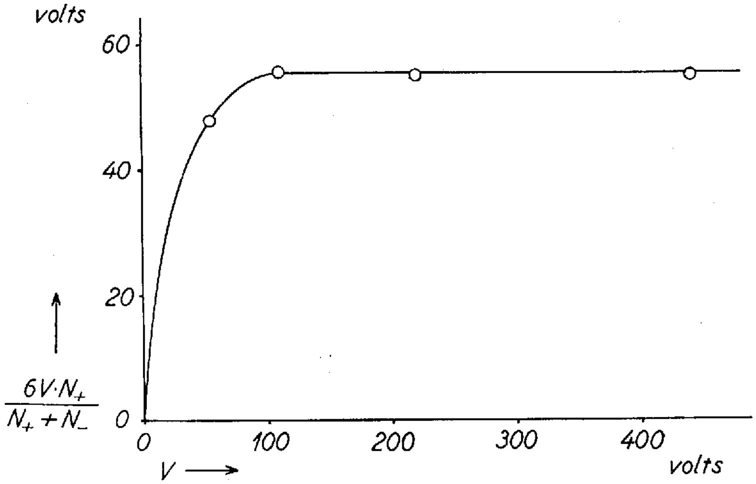

Fig. 11. $6\,VN_+/(N_+ + N_-)$ as a function of V.

$\langle E_R \rangle$. In the case of Kr^{88} the β-decay is sometimes followed by internal conversion (5) and consequently also by Auger effect. The result is a rather high charge on some of the recoils. Also, for theoretical reasons (8), it might be expected that already the β-emission itself might give rise to some ionization of the electron shells of the recoiling atom. This means that (5) cannot in general be taken as a measure of $\langle E_R \rangle$.

The general course of an experiment is exactly the same as for the measurement of the relative yields of Rb^{88} and Rb^{89}. It is furthermore specified by putting $t_0 = 4^m$. The activity of the plates is measured in the standard way described above so that the contamination of Rb^{88} to the activity is well known.

The results for the expression $6VN_+/(N_+ + N_-)$ are shown in Fig. 11. For potential differences V below E_R^{max} the curve in Fig. 11 lies below $\langle E_R/z_R \rangle$ and for $V \rightarrow 0$ it goes towards zero.

The connection between the shape of the curve in Fig. 11 and the recoil energy distribution will be discussed elsewhere(7). However, we shall mention that the expression $6VN_+/(N_+ + N_-)$ deviates from $\langle E_R/z_R \rangle$ for V slightly smaller than E_R^{max} only to higher order in the difference $E_R^{max} - V$. This means, that even if V is 5—10 volts below the maximum energy of 115 volts the results are not affected within the accuracy of these experiments and consequently we may use the measurements at $V = 110$ volts and higher values of V for the determination of $\langle E_R/z_R \rangle$.

The result is seen to be $\langle E_R/z_R \rangle = 55.6$ eV for the natural mixture of Kr^{88} and Kr^{89} measured in the standard way discussed above consisting of 92 % Kr^{89} and 8 % Kr^{88}. With the value $\langle E_R/z_R \rangle = 29$ eV for Kr^{88} we get

$$\langle E_R/z_R \rangle_{Kr^{89}} = 58 \pm 2 \text{ eV}. \tag{6}$$

It has already been mentioned that the pressure in the experiments was $\sim 10^{-3}$ mm Hg. A series of average energy measurements were carried out at various pressures. Higher pressures than 10^{-3} are obtained by letting a small amount of air leak into the uranium container before the cyclotron irradiation was started. The results for $\langle E_R/z_R \rangle$ as a function of the pressure are shown in Fig. 12. It is found empirically that the correction has the following form as a function of the pressure p and the potential difference V:

$$\Delta \langle E_R/z_R \rangle = -28\, p/V, \tag{7}$$

where V is measured in volts and p in mm Pirani deflection (1 mm Pirani deflection $\sim 0.6 \cdot 10^{-3}$ mm Hg).

The results given in Fig. 11 have been corrected for the influence of the pressure by means of the expression (7). The corrections are smaller than 1 %.

The order of magnitude of the effect (7) seems to be reasonable. The mean free path for alkali ions at a pressure of $\sim 10^{-3}$ mm Hg is of the order of 20 cm(9). This is of interest for the measurement of the maximum energy and it leads to the conclusion that only a few per cent. of the particles reaching plate A in the maximum energy apparatus suffer collisions. Consequently the determination of the maximum energy is not influenced by the pressure.

We have mentioned above that possible effects from Xe^{138} or Xe^{139} are very small. To establish this fact further some experiments were carried out with $t_0 = 1^m$, 8^m and 27^m. In the experiment with $t_0 = 1^m$ the stopcock S_1 was open during the cyclotron irradiation. From these experiments it can be concluded that any effect from Xe^{138} or Xe^{139} in the standard experiment with $t_0 = 4^m$ is less than $2\,^0/_{00}$. Consequently we can neglect all effects on the average energy measurement from these Xe-isotopes.

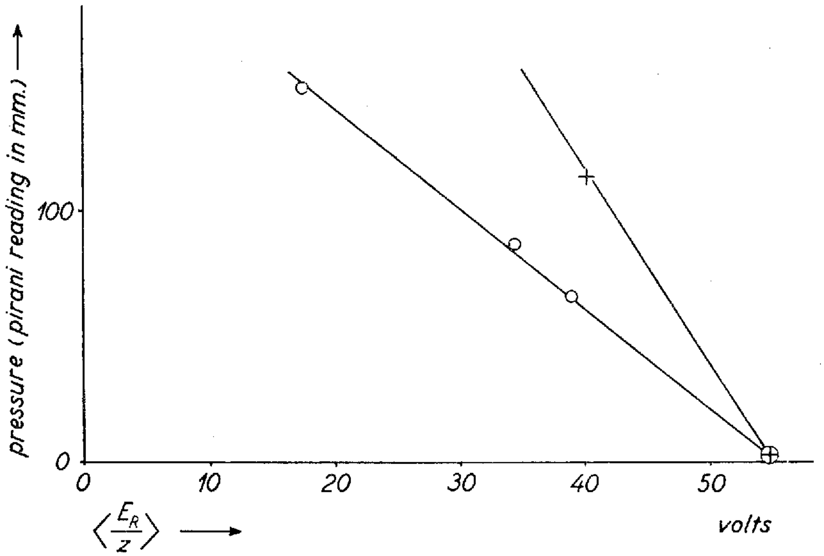

Fig. 12. $\langle E_R/z_R \rangle$ as a function of the pressure. The points ○○ correspond to V = 110 volts and ++ corresponds to V = 220 volts. The straight lines represent formula (7) for V = 110 volts and V = 220 volts respectively.

At last we may mention an experiment carried out at V = 0. This experiment gave the result that $N_+ = N_-$. The accuracy is limited to $1\,^0/_0$ for statistical reasons. From this experiment it can be concluded that the contact potential difference between the plates A and B is negligible.

Conclusions.

The only important conclusion which can be drawn from this experiment is a further establishment of the relation between the maxim recoil energy and the maximum β-energy. Assuming that the neutrino leaves the nucleus with zero momentum when the β-particle has its maximum energy we find that the maximum recoil energy 115 ± 5 eV corresponds to a maximum β-energy of $3.9 \pm .1$ MeV. This is in good agreement with the energy found from absorption measurements on isotope separated kryptron(2) leading to $E_\beta^{max} = 4.0$ MeV. From this result we may conclude that the group of β-rays having $E_\beta^{max} \simeq 4$ MeV leads to the ground state of Rb^{89}.

The result $\langle E_R/z_R \rangle = 58 \pm 2$ eV cannot be used for an exact determination of $\langle E_R \rangle$ since $\langle 1/z_R \rangle$ is unknown. (In rough estimates one may neglect a possible slight correlation between E_R and z_R.) However, we can find a lower limit of $\langle E_R \rangle$ since $\langle 1/z_R \rangle$ is smaller than unity. Calculations by Winther(8) show that for the β-decay $He^6 \rightarrow Li^6$ one would expect that $\langle 1/z_R \rangle = 0.95$. In our case we may assume that the ionization is even larger since the effect is supposed to increase with Z. Also internal conversion processes following the γ-ray emission might lower the $\langle 1/z_R \rangle$ value. Thus we put $\langle 1/z_R \rangle < 0.95$ and we get $\langle E_R \rangle > 60$ eV.

The β-decay of Kr^{89} is complex(2) and probably consists of two spectra one with $E_{\beta 1}^{max} = 3.9$ MeV and another one with $E_{\beta 2}^{max} \simeq 2$ MeV. It is known that the decay is followed by γ-rays, and since we have concluded that the 3.9 MeV group leads to the ground state of Rb^{89} we may assume that the 2 MeV group is followed by a 1.9 MeV γ-ray. According to formula (8) of reference 10 we find the average value of the recoil energy after the combined action of the β-decay and the γ-ray emission simply by adding the average energies obtained in each single process. The average energy from the β-disintegrations alone depends on the angular correlation between the directions of emission of the β-particle and the neutrino. If we assume a spherically symmetrical neutrino emission we find an average recoil energy of 18.8 eV corresponding to $E_{\beta 2}^{max} = 2.0$ MeV. The recoil from the γ-ray emission gives $E_{R\gamma} = 21.7$ eV if we make the assumption that the energy is carried away by a single γ-ray. If several quanta are emitted the energy is even lower. The final result is $\langle E_R \rangle_2 \leqslant 41$ eV. Furthermore, this result is quite insensitive to possible uncertainties in the maximum energy of the low energy group.

We still get a lower limit for $\langle E_R \rangle_1$ if we take the lower limit 35 % for the branching ratio of the low energy group. This gives after a simple calculation $\langle E_R \rangle_1 > 72$ eV.

The assumption of a $(1 + v_\beta/c \cdot \cos\theta_{\beta\nu})\, p_R^2$ angular correlation together with $E_R^{max} = 115$ eV would yield $\langle E_R \rangle = 89$ eV. This correlation is the most strongly foreward neutrino emission probability for 1. forbidden spectra. The symmetrical neutrino emission would give $\langle E_R \rangle_1 = 65$ eV and the correlation $(1 - v_\beta/c \cos\theta_{\beta\nu})$ which corresponds to a strongly backward neutrino emission gives $\langle E_R \rangle_1 = 46$ eV. Due to the incompleteness in the knowledge of the decay scheme the lower limit 72 eV is subjected to some uncertainty and must be taken with all due reservation. Nevertheless it seems to be safe to conclude that it would be difficult to fit the results with the assumption of a backward neutrino emission. It should be added that a forward neutrino emission would also in general be expected if the β-decay is forbidden as seems to be the case for Kr^{89} judging from the ft-value.

We wish to thank Professor N. Bohr for his interest in our work and we are also indebted to Professor J. C. Jacobsen. The present experiments represent a continuation of the work on Kr^{88} carried out by Professor J. C. Jacobsen and one of us.

Summary.

Experiments on the energy of the recoil nucleus in the β-decay of Kr^{89} are described. This maximum energy was found to be 115 ± 5 eV, in good agreement with the previously measured maximum β-energy. The average value of the recoil energy divided by the charge of the recoil atom was determined as 58 ± 2 eV. In connection with the latter experiment the relative yield of mass numbers 89 and 88 in the fission of uranium was

measured, with the result $y_{89}/y_{88} = 1.5 \pm .2$. At the same time the half-life of Kr^{89} was determined as 3.14^{m}.

The results support a forward neutrino emission with respect to the direction of emission of the β-particle, in agreement with the assumption that the decay is forbidden.

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Indleveret til selskabet 1. december 1950
Færdig fra trykkeriet den 11. maj 1951.