THE IONIZATION CHAMBER WHEN PLACED IN A MAGNETIC FIELD

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Pulsed ionizations chambers are widely used for the study of nuclear reactions and for investigating the α -spectra of both long- and short-lived isotopes, which are frequently obtained in very small quantities. The reason for this is the high luminosity of ionization chambers. The improvements in the energy resolving power /1,2/ achieved over the last few years (1,2) has widened the scope of ionization chambers. The technique is being developed, in particular, toward the exploration of α -particle coincidences with conversion electrons /3/. The conversion electrons are recorded by means of a proportional counter located inside the ionization chamber.

To increase the energy range of recorded electrons and reduce the background of soft electrons, a proportional counter can be placed in the magnetic field /4/. In the case of $\alpha - e_k$ coincidences, the ionization chamber is also located in the magnetic field. This raises the question of the operating characteristics of the ionization chamber in the magnetic field. It is essential to study the operation of the ionization chamber in the magnetic field in order to ensure that the correct design and operating conditions are selected for the chamber. Furthermore, when the ionization chamber is located in the magnetic field, the influence of conversion electrons on the α -spectrum can be reduced. It is a known fact /2,5/ that conversion electrons accompanying α -decay distort the energy distribution of α -particles, namely, several energy values will correspond to a single group of α -particles. When the ionization chamber is located in the magnetic field, the conversion electrons (which normally follow helical trajectories) will twist back to their source, and the ionization they produce will be reduced because not all of the electron's path will be contained within the volume of the chamber. Consequently, the conditions for separating the thin structure of the α -spectra should improve.

The effect of the magnetic field on electronic equipment.

Location of the ionization chamber in the magnetic field (H_{max} = 3.5 kOe) called for special precautions to ensure that it

did not affect the electronic equipment. The pre-amplifiers for both channels, which were fixed directly to the chamber body, were in the magnet's strongest stray field. These were the first components to receive attention. The body and casing of the pre-amplifiers were made of iron of the type used for magnetic shielding. The latter was, however, found inadequate. The electronic tubes (6 ZH 1 P) were placed inside cans made from Armco iron (wall thickness 1.5 mm). If these precautions are not taken, the anode current and amplification factor decrease under the effect of the magnetic field. The remainder of the equipment was moved to a point 3 m away from the magnet. To check that the operation of the electronic equipment was not affected by the magnetic field, a standard pulse from a generator was fed into the input of the preamplifier. When the magnetic field was switched on, the pulse height remained constant to within 0.05%. Furthermore, no changes were noted in the r.m.s. value of the radio noise.

Movement of ionization electrons in the presence of the magnetic field.

Let us consider the effect of the magnetic field on the trajectory of the ionization electrons. It is essential to answer this question to ensure that the chamber intended for use in the magnetic field is correctly designed. The trajectory must be known in order to ascertain the effect of the magnetic field on the pulse height.

In the presence of the magnetic field, which is directed perpendicularly to the electrical lines of force, the electrons are subjected to two forces, each of which is perpendicular to the other, namely the electrical and magnetic forces. These cause the electrons to drift at a certain angle γ in relation to the lines of electrical force (Fig.1). The duration of electron movement increases and this leads to an increase in the rise-time of the pulses on the electrodes. By measuring this time it is possible to determine the direction of electron movement.

It can easily be shown that the drift speed of electrons in a gas, in the presence of a magnetic field, is:

$$W_H = \frac{W_E}{1 + \gamma^2\tau^2}, \qquad (1)$$

where $\gamma = eH/mc$; τ is the mean time between neighbouring collisions of an electron with the atoms of the gas; W_E is the drift speed of the electrons when there is no magnetic field.

It follows from formula (1) that the duration of electron movement from the high-voltage electrode to the grid is:

$$t_H = \frac{d}{W_H} = t_E\,(1 + \gamma^2\tau^2), \qquad (2)$$

where t_E is the same time when there is no magnetic field.

For the experimental determination of t_H , use was made of pulses produced on the high-voltage electrode. The pulses were fed from the output of a wide-band amplifier into an IO-4 oscillograph and photographed. A whole set ("rectangle") of pulses appeared on the photograph. The highest pulses correspond to α -particles emitted parallel to the plane of the source and the lowest to those which were emitted perpendicularly. The rise-time of the largest pulse and its height were determined as a function of E/p (E = electric field intensity; p = gas pressure in the chamber).

Fig.2 shows one of the photographs of the pulses at the high-voltage electrode. The effect of the magnetic field can be clearly seen (increase in the rise time and decrease in the pulse height). The results of the experiments are shown in Figs.3 and 4. The data obtained show that, in a certain range of values of E/p, the duration

of electron movement in the magnetic field increases considerably. If use is made of narrow-band amplifiers (the normal operating conditions) this will lead to a deterioration in the energy resolving power /5,6/. As Fig.4 shows, saturation is reached at high values of E/p.

By studying the pulse rise-time and the distance between the electrodes, the electron drift speed can be determined. (Figs.5 and 6). Fig.6 also shows the dependence on E/p of the speed of the electron drift in the magnetic field, calculated in accordance with the formula (1). There is good agreement between the experimental and theoretical dependences. Once it has been established in this way that electron mobility (or drift speed) falls in the magnetic field, a quantitative explanation can be given for the drop in the pulse height in the magnetic field. (Fig.4). The reason for this may be an increase in re-combination. In the presence of a magnetic field, the electrons remain around the positive ions for a longer time, and consequently this increases the probability of re-combination.

If the ionization chamber is placed in a magnetic field, the diffusion process by which the electrons in the region between the high-voltage electrode and the grid are "blown" against the chamber wall assumes a particular importance. For example, when $d = 5.5$ cm (Fig.1) the height of the pulses on the collecting electrode dropped by almost half in the presence of the magnetic field, and the resolving power fell sharply. It should be noted that the height of the pulse on the high-voltage electrode remained unchanged. This is, of course, understandable. The deposition of electrodes on the chamber walls does not affect the height of the pulse on the high-voltage electrode, since the pulse on the high-voltage electrode is caused by the positive ions.

When the distance d was reduced to 3 cm no drop was observed in the height of the pulse on the collecting electrode.

Influence of the magnetic field on conversion electrodes.

As an accurate examination of the influence of the magnetic field on conversion electrons appeared complex, we adopted the following assumptions in our examination.

1. Ionization is uniform along the track.
2. The electrical field has no influence on the trajectory of conversion electrons.
3. The movement of the electrons is considered to occur in a vacuum (from the aspect of constant energy).

Let us look more closely at these assumptions. The first enables us to consider the pulse from the conversion electrons as being proportional to the residual path. In reality, the specific ionization increases towards the end of the path. This leads to divergence from the linearity of the drop in the pulse from the conversion electrons as the magnetic field grows, but will not alter the nature of the dependence.

For a strict solution of the problem, the movement of the conversion electrons should be examined in crossed electric and magnetic fields. In such a combination of fields, the electrons will describe a trochoidal movement. It can, however, be shown that in our case (E_{ek} = 30 ÷ 50 keV; E = 100 ÷ 200 V^{-1}cm; H ≈ 3 kOe) the trochoid in one period differs only very slightly from a circle. This, then, explains the second assumption.

The third assumption is the most serious one. As the conversion electron moves through the medium, it gradually loses its energy. At the same time the curvature radius of its trajectory decreases, and the electron follows a spiral path. In this way, the greatest divergence of the electron's trajectory from the circle will occur at the end of the path. However, as the magnetic field increases in the working volume of the chamber there remains that

part of the path which corresponds to the increasingly small energy loss, and the divergences of the trajectory from the circle decrease. Thus with the increase in the magnetic field, our examination will correspond increasingly to the truth.

It is easy to obtain from the equation for the movement of the electron in a magnetic field the dependence of the residual path of the electron R on the magnetic field:

$$R = 2\rho(\pi - \varphi), \tag{3}$$

where ρ is the curvature radius of the electron's trajectory in the magnetic field (the directions of the electric and magnetic fields are shown in Fig.7).

By taking into account, by means of equation (3), the isotropy of electron irradiation, the energy spectrum of conversion electrons can be constructed for a given value of the magnetic field. If the electron energy spectrum is known, the α -particle spectrum can be constructed taking into account the effect of conversion electrons (Fig.8).

When the spectrum was constructed, it was considered that the half-width of an individual α -line was equal to 30 keV. A line of Gaussian form was used (the dotted curve shows the α -spectrum when the conversion electrons have no influence whatsoever). It follows from Fig. 8 that the intensity of the group α_1 should increase in the presence of the magnetic field.

The experimentally recorded spectrum of α -particles of U^{234} is shown in Fig. 9. In the magnetic field, an increase is, in fact, observed in the intensity of group α_1 , and the relative increase in intensity coincides with the calculated value obtained from Fig.8.

Effect of the magnetic field on the δ -electrons

During ionization, the α -particle produces, together with the slow electrons, fast ones too; these are the so-called δ -electrons, whose maximum energy for α -particles with an energy of 5 MeV is 2.5 keV. Almost 70% of the α -particle's energy goes towards the formation of δ -electrons. These electrons also cause ionization of the gas. Measurements are made of the total ionization in the ionization chamber. In this connection, when the ionization chamber is placed in the magnetic field, the total ionization may be reduced as a result of the twisting of the δ -electrons back to the source, which leads to a reduction in the height of the pulse from the α -particle. It is obvious that the ionization from a parallel-emitted α -particle will be the most strongly reduced.

In order to assess this effect, recordings were made of those pulses from the collecting electrode, which correspond to the α -particles emitted at an angle ranging from 90° to 90° - β where β is a few degrees (the angle is measured in relation to the normal to the particle source). The reduction in pulse height when the ionization chamber is placed in the magnetic field is less than 1%. The effect of the magnetic field on the δ -electrons can therefore be disregarded. It should be pointed out that the α -particle trajectories remain virtually unchanged in the presence of the fields used in our experiment.

Conclusion

1. The experimental results obtained provide a means of selecting the correct design and working conditions for the ionization chamber in a magnetic field.

2. If the correct design and working conditions are selected for the chamber, the magnetic field has no influence on the resolving power of the equipment.

3. The influence of conversion electrons can be reduced by using a magnetic field.

4. It should be pointed out that the installation of the ionization chamber in the magnetic field is particularly useful when working directly on an accelerated particle beam, and when investigating α -spectra when there is a strong β -background.

In conclusion, the authors wish to express their thanks to A.P. Komar for devoting his attention to this work.

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References

1. Engelkemeir D.W., Magnusson L.B., Rev. Scient. Instrum., 26, 295 (1955).

2. Bochagov B.A., Komar A.P., Kocharov G.E., Zh. Eksper. Teor. Fiz. (USSR) 32 5 (1957).

3. Komar A.P., Korolev G.A., Kocharov G.E., Izv. Akad. Nauk SSSR Ser. Fiz. 22 7 (1958).

4. Curran S.C., Cocroft A.L., Insch. G.M., Proc. Phys. Soc. A, 63, 845 (1950).

5. Kocharov G.E., Komar A.P., Korolev G.A., Zh. Eksper. Teor. Fiz. (USSR) 35 3 (1957).

6. Harvey B.G., Jackson H.G., Eastwood T.E., Hanna G.S., Canad. J. Phys., 35, 3 (1957)

Figures

Figure 1. Block-diagram of the experimental lay-out:

1 - collecting electrode;
2.- high voltage electrode;
3 and 3' BSE-2500;
4 and 4' pre-amplifiers;
5 and 5' amplifiers;
6 - limiter;
7 - single-channel analyser;
8 - 28-channel analyser
- angle between the direction of electron movement in the presence of the magnetic field and the normal to the high-voltage electrode.

Figure 2. Oscillograms of the pulses on the high-voltage electrode:

a - H = 0;
b - H = 3500 Oe.

Figure 3. Duration of ionization electron movement as a function of E/p

Figure 4. Height of pulses on the high voltage electrode as a function of E/p; 1 - H = 0; 2 - E = 3500 Oe.

Figure 5. Dependence of the electron drift speed on E/p in chemically pure argon. W_E H = 0; W_H-H = 3500 Oe.

Figure 6. As in Figure 5. The dotted line represents the calculated dependence.

Figure 7. Illustration relating to the calculations of electron trajectories in a magnetic field. The magnetic field is directed along the line OZ, whereas the electrical

field is directed along Oy; φ is the angle between the projection of the speed of the electron on the plane xOy and axis Ox.

Figure 8. Spectrum of α -particles of U^{234} (calculated, taking into account the resolving power of the equipment). The distance between the lines α_0 and α_1 is 50 keV;

1 - α -spectrum, with no influence from conversion electrons;

2 and 3 - α -spectrum, taking into account the influence of conversion electrons : 2 - H = 3500 Oe; 3 - H = 0.

Figure 9. Experimental α -spectrum for U^{234}: 1 - H = 3500 Oe; 2 - H = 0.

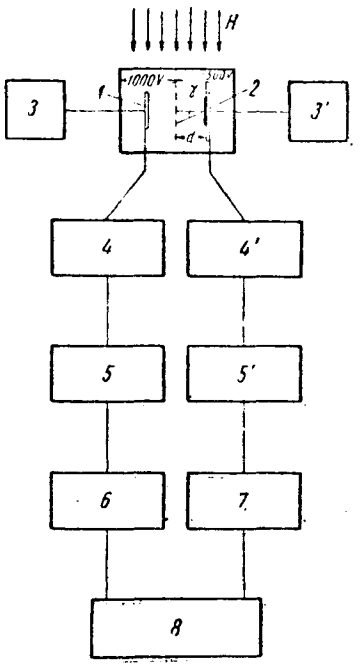

Fig. 1

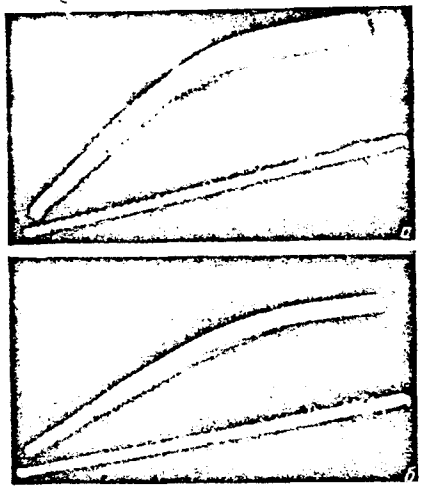

Fig. 2

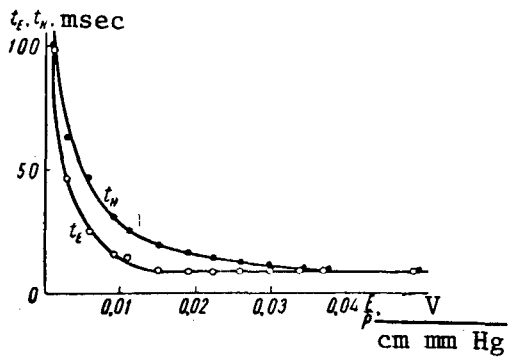

Fig. 3

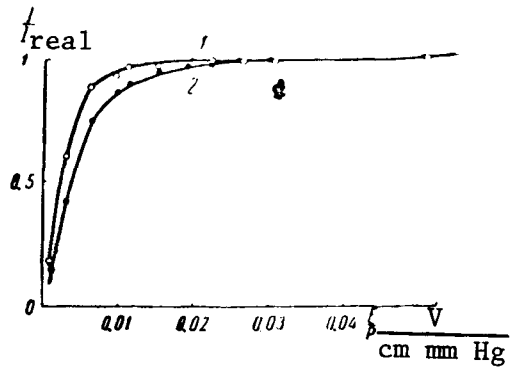

Fig. 4

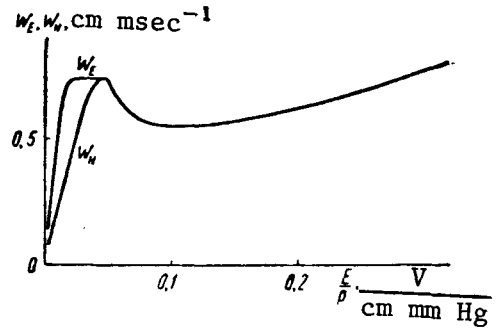

Fig. 5

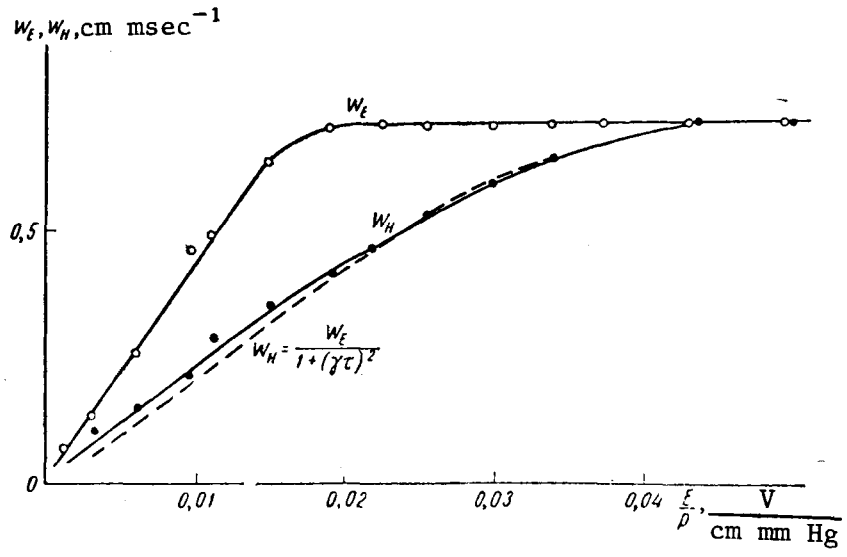

Fig. 6

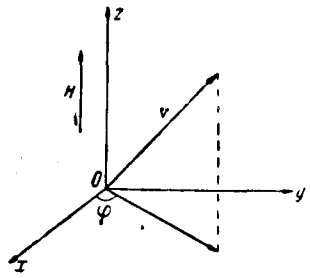

Fig. 7

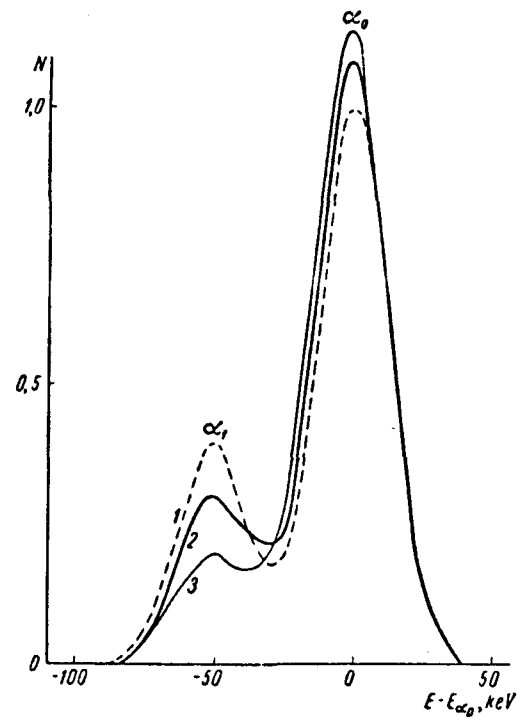

Fig. 8

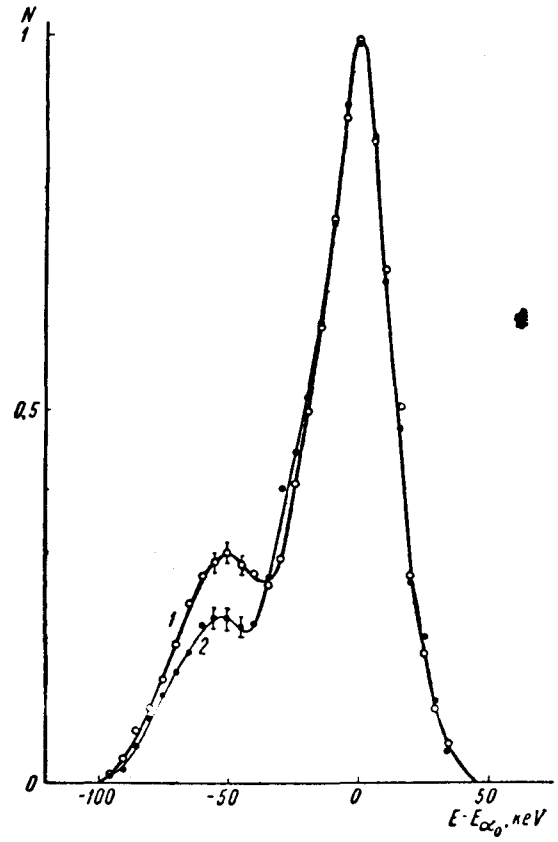

Fig. 9