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METHOD FOR THE MEASUREMENT OF THE MEAN IONIZING CROSS-SECTION OF FAST PARTICLES AND OF THE CORRESPONDING CHARGE PRODUCED

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Résumé. — Une méthode utilisant un microphone capacitif comme chambre d'ionisation rend possible l'observation de la collision ionisante d'une particule rapide sur un atome de gaz. La probabilité de cette collision et le nombre correspondant d'électrons arrachés ont été mesurés dans l'air, pour des particules alpha de 4 MeV issues d'une source radioactive.

Abstract. — A method using a capacitive microphone as an ionization chamber enables the ionizing collision of a fast particle with a gas atom to be observed. The probability of this collision and the corresponding number of electrons removed were measured in air, for 4 MeV alpha particles leaving a radioactive source.

Introduction. — It has been shown in a previous paper [1] that a capacitive microphone can be used as an ionization chamber to investigate the ionizing action of fast particles in a gas. In fact, a particle reaching the outer plate of the microphone passes through it and creates a number of electron-ion pairs in the interelectrode space, which are carried off by the polarization electrical field to the external circuit. Actually, since the interelectrode distance is small, the effect of a particle is itself very weak and cannot be observed by itself : the method is therefore based on the measurement of a mean effect in the presence of a high flux of incident particles. It is summarized briefly here. Let $x(t)$ be the effect, in the external circuit, associated with the arrival at random of an ionizing particle at the microphone. If all the effects are identical and if their frequency, ρ , is such that they are independent, the external circuit detects a total effect, $X(t)$, whose mean values in time are given by Campbell's theorems :

$$\overline{X(t)} = \rho \int_0^\infty x(t) dt \quad (1)$$

$$\overline{X^2(t)} - \overline{X(t)}^2 = \rho \int_0^\infty x^2(t) dt. \quad (2)$$

Under these conditions, it is clear that the simultaneous measurement of the average value of $X(t)$ and the mean square value of the fluctuation about this average allows the frequency of elementary effects and the amplitude of each to be determined. The frequency, ρ , is the product of the frequency of arrival of the particles, ρ_i , and the probability that they ionize the gas located between the electrodes of the microphone. By varying the pressure until this probability is low, hence comparable to the probability of a single ionizing collision $P(1)$, it is then easy to conceive that the proposed method enables $P(1)$ as well as the corresponding number of removed electrons to be measured.

Experimental. — The foregoing principle is applied by means of an experimental setup shown schematically in figure 1. A monoenergetic unidirectional beam of ionizing particles arrives at normal incidence, striking the active part of a capacitive microphone, located in a chamber filled with a gas of variable type and pressure. Through vacuum tight electrical passages, the polarization of the microphone is achieved by a power supply unit mounted in series with a picoammeter. The analog output of the picoammeter supplies a voltage, $V(t)$, which is analysed in two separate circuits : one measures the d.c. compo-

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FIG. 1. — Experimental apparatus. A. — Detailed diagram of the basic set up : a) diaphragm, b) back plate, c) hole for pressure equalization, d) housing, e) insulator, f) Ti foil, g) 244 cm. B. — Electronic block diagram.

ment, V_0 , of $V(t)$ by means of a voltmeter ; the second filters the a.c. component of $V(t)$ in a frequency range Δf centred on the value f , with gain $1/\sqrt{\Delta f}$, and measures its r.m.s. value, V_f , averaged with an adjustable time constant. An analog system provides the ratios V_0^2/V_f^2 and V_f^2/V_0 at the input Y of a dual recorder for which the variable X consists of a signal proportional to the pressure. From equations (1) and (2) and the electrical block diagram, one can easily show that the signals V_0 and V_f are simply associated with the average charge, Q , deposited on the microphone plates after the passage of a particle, by equations :

$$V_0 = \rho |h(0)| \quad (3)$$

$$V_{f \neq 0} = \sqrt{2} \rho |h(f)| \quad (4)$$

where $h(f)$ is the Fourier transform, at frequency f , of signal $x(t)$ which, as f approaches zero, itself approaches the value $h(0)$ given by the equation :

$$|h(0)| = TQ(C_{in} + C_M)/C_M \quad (5)$$

where T is the transfer impedance of the picoammeter in the d.c. mode, C_M designates the capacitance of the microphone, and C_{in} the input capacitance of the pico-

ammeter. The ratio $|h(f)/h(0)|$ depends exclusively on the electrical characteristics of the experimental setup, independent of the pressure and polarization voltage of the microphone. By means of prior calibration making it possible to determine this ratio and the values of C_{in} , C_M and T , the recorded curves of V_0^2/V_f^2 and V_f^2/V_0 thus show respectively the relationship of ρ and Q with pressure. Let ρ_i be the number of ionizing particles arriving per second at the microphone, and $P(k)$ the probability that each of these particles makes k ionizing collisions between the electrodes, thus :

$$\rho = \rho_i \{ 1 - P(0) \} = \rho_i \sum_{k=1}^{\infty} P(k) \quad (6)$$

$$Q = Ze \{ 1 + 2 P(2)/P(1) + \dots + kP(k)/P(1) + \dots \} \quad (7)$$

where Z is the average number of electrons with charge e stripped during a collision. Equation (7) implies that the charge collected is strictly equal to the charge created, i.e. that there is neither avalanche nor recombination effect between the plates. As shown in reference [1], this condition can be satisfied with a careful choice of the polarization voltage of the microphone, for pressure values ranging in a ratio of 1 to 10. If one assumes that this range of pressures includes a value, p_c , at which the mean free path of the ionizing particles approaches the interelectrode distance, d , two alternatives occur. When $p \gg p_c$, $P(0) \rightarrow 0$, $\rho \rightarrow \rho_i$, and the main contribution in equation (7) derives from the terms of high k values. If I_s denotes the specific ionization the charge created is :

$$Q = I_s ed. \quad (8)$$

Curve $\dot{Q}(p)$ is hence a line passing through the origin, if I_s/p varies only slightly in the energy range of the incident particles corresponding to the assumed range of variations in p . On the other hand, when $p \ll p_c$, $P(0)$ is no longer negligible. When $p \rightarrow 0$, it even happens that $P(0) \gg P(1) \gg P(2)$, so that $\rho \rightarrow \rho_i P(1)$, $Q \rightarrow Q_0 = Ze$. In this pressure range, the measurement of ρ , compared to its saturation value, ρ_i , gives the probability of an ionizing collision, related to the corresponding effective cross-section $\sigma(1)$ by the equation :

$$P(1) = n_0 \sigma(1) d \quad (9)$$

where n_0 denotes the neutral density and d the interelectrode distance. Note that, in relation to the usual measurements of total effective cross-section of electron production :

$$\sigma_i \simeq \sigma_{01} + 2 \sigma_{02} + \dots + n \sigma_{0n} + \dots \quad (10)$$

where σ_{0n} denotes the effective cross-section corresponding to the equation :

this method makes it possible to attain a more precise level of information ⁽¹⁾, since it leads to the determination of :

$$\sum_n \sigma_{0n} = \sigma(1) \quad (11)$$

and :

$$\sigma_i \left| \sum_n \sigma_{0n} = Z. \quad (12) \right.$$

Validity test of the method. — The fast beams from accelerators are the most convenient for applying the method described above. As a test, and for reasons of availability, we nevertheless used the isotopic source of reference [1], consisting of a 0.5 cm² disc covered with 130 mCi of Cm-244. The microphone (diameter 3.2 mm, $d = 13 \mu\text{m}$) is placed coaxially facing this source, at a distance which is variable. It thus receives a flux of α particles which, after passing through its outer diaphragm, have an energy of about 4 MeV. Owing to the weakness of the flux, special care was applied in selecting a sensitive picoammeter for measuring currents of a few 10^{-15} ampere. Figure 2 shows one example of recordings for a pressure p ranging from 0 to 80 torr of air, for a source/microphone distance of 2 mm, a polarization voltage of 10 V, and an integration constant of 300 seconds. As one can see, the curves break down into two parts on either side of a critical pressure p_c , approaching 40 torr : (i) when p rises above p_c , the ratio V_0^2/V_f^2 , which is proportional to ρ , tends toward a saturation value. Simultaneously, the ratio V_f^2/V_0 , which is proportional to Q , increases proportionally with p ; (ii) the zone of pressures below p_c , on the other hand, is characterized by a variation in ρ which is practically proportional to pressure, as the latter tends towards zero, whereas the charge Q assumes a constant value Q_0 . These results agree with the predictions of

FIG. 2. — An example of recorded curves giving the frequency of ionization effects ($\rho \propto V_0^2/V_f^2$), and the corresponding average charge deposited on the microphone ($Q \propto V_f^2/V_0$), as a function of pressure, p , of the air in the microphone.

the previous paragraph. Despite various causes of error associated with the source (weakness of the flux, energy and directional dispersion of incident particles) it is thus possible to provide an indicative value for Z and $\sigma(1)$ in air. A mean determination from a number of recording similar to those in figure 2, gives the following values with a dispersion of about 20 % : $Z \simeq 2.8$, $\sigma(1) \simeq 6 \times 10^{-16} \text{ cm}^2$.

The product $\sigma(1) Z$ compares satisfactorily, considering the remarks made earlier, with the value of $13 \times 10^{-16} \text{ cm}^2$ which were measured in reference [2] for 1 MeV alpha particles impinging on a N₂ target. Our results should be improved subsequently with the use of a Van de Graaf type accelerator.

⁽¹⁾ The hypothesis that all elementary effects are equal is never thoroughly checked because the charge Q , deposited on the microphone plates, exhibits a statistical distribution. It can be shown that the error corresponding to this assumption never exceeds 10 % for realistic relative values of effective cross-sections σ_{0n} .

References

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