at the center of gravity of the $1s \rightarrow 5p$, $6p$, etc., transitions, a result which could hardly be accidental. However, these maxima are generally not very pronounced and for this reason the analysis into component absorption lines is not unique and therefore not of any great interest. One might just as well take such maxima as they are measured and attempt to correlate them with possible transitions.

The work is being extended to other crystals. If, as appears likely, the symmetry of the crystalline field, by determining the splitting of the excited levels, has an important effect on the shape of the absorption edge, then x-ray absorption measurements should find interesting applications in structural chemistry.

In conclusion, we wish to thank the Machlett Laboratories for kindly supplying the beryllium sheet used on the x-ray tube window and to express our particular appreciation of the many suggestions offered by Mr. J. P. Foerst, department mechanician, during the design of the spectrometer and of his excellent workmanship in its construction.

PHYSICAL REVIEW VOLUME 67, NUMBERS 7 AND 8 APRIL 1 AND 15, 1945

A Simple Counting System for Alpha-Ray Spectra and the Energy Distribution of Po Alpha-Particles

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(Received December 29, 1944)

An alpha-ray counting system, consisting of parallel wire electrical counters and amplifying circuits, etc., is described. The conditions of reliable operation have been carefully examined and well defined. The mechanism of the counters as to why they answer only to alpha-particles but not to even strong beta- or gamma-rays is generally discussed. The distribution form of the Po-alpha particles determined by these counters in conjunction with an alpha-ray magnetic spectrograph agrees well with that obtained from a photographic line. The resolving power for the alpha-ray lines is very high, owing to the small active region of the counters.

1. INTRODUCTION

To count alpha-particles a parallel plate ionization chamber, a ball counter, or a tube counter is generally used. However, in the first case, the chamber is usually operating with such a small total charge that the change of potential is only of the order of a few micro-volts. Such a small change of potential is ordinarily made recordable only by means of a well-built linear amplifier of four or five stages. In the second and third cases the proportionality of counting depends on an appropriate working potential applied to the counters and the characteristics of the counters.[1] They also need an amplifier of several stages to magnify the initial electrical pulses in order to actuate a mechanical device. All of them are very liable to either mechanical or electrical disturbances.

When the counting method is employed in the case of an alpha-ray magnetic spectrograph, a great saving in time as well as other advantages can evidently be secured, if several counters are operating at the same time. These counters must be closely spaced, and each of them must be sensitive along a line of considerable length and coupled to an amplifier, preferably one which is easily built and inexpensive. These conditions are not easily fulfilled by counters of the above types. However, in the following, we shall describe a system of counters which is very simple in construction and economical in cost and has been shown to be satisfactory for determination of alpha-ray spectra. A spark counter of similar principle has been very generally described by Greinacher.[2]

2. THE COUNTER

If a thin wire is stretched in front of, and insulated from a smooth brass plate, it is found to

[1] S. A. Korff, Rev. Mod. Phys. **14**, 1 (1942).

[2] H. Greinacher, Zeits. f. tech. Physik **16**, 165 (1935).

answer very well to alpha-particles (with audible and visible sparks) but to be not affected at all by even very strong beta- or gamma-rays. The wire is at a positive potential of the order of 3000 volts with respect to the brass plate, and the counter operates in air at atmospheric pressure.

Figure 1 represents a side view of the longitudinal section of a counter which was actually used. A is a plate of hard rubber having a thickness of 2.5 cm. A rectangular trough of a length about 5 cm, a width about 2 cm and a depth about 1 cm was cut, in which a tungsten wire W of $7\frac{1}{2}$ mils diameter was stretched in front of the brass plate B and held firmly by the two springs S. The length of the wire actually exposed to the plate B was about 4 cm. The two glass tubes g of about 4 mm diameter served for adjusting the spacing between the wire and the brass plate; mica sheets could be introduced between the glass tubes and the tungsten wire. The separation of the wire from the brass plate was about 1.5 mm. It was estimated that the active region around the wire was of the order of the thickness of the tungsten wire. This small active region offers another advantage for determining an alpha-ray spectrum (cf. Section 5).

When a capacity of about 500 cm was connected across the counter, a total change of potential due to the discharge produced by an incident alpha-particle could be of the order of 50 volts. If a reasonable fraction of this change of potential is applied to the grid of a power amplifying tube, e.g., a 2A3, the power output is large enough to operate a 73511 Cenco high voltage impulse counter. However, to match the high d.c. resistance (about 3300 ohms) of the Cenco counter, it is better to use a power tube of higher plate resistance. A tube of the type 6AG7, which has a plate resistance of about 0.1 megohms and a much higher amplification, was

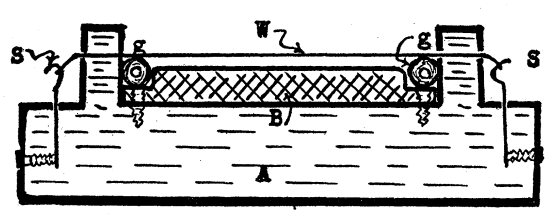

FIG. 1. Construction of the counter.

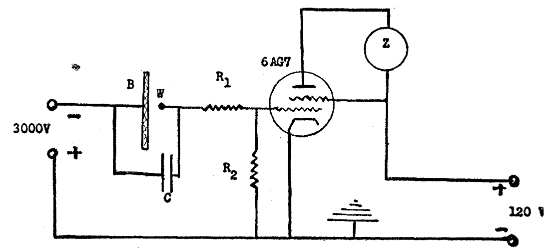

FIG. 2. Single stage amplifier: $R_1=10^7-10^8$ ohms, $R_2=10^6$ ohms, $C\sim200$ cm, Z is Cenco counter.

found to be very satisfactory. In this latter case, the capacity across the counter could be reduced considerably (to about 150 cm) and hence the resolving time of the counter became smaller. It was found that in this arrangement the counting set could record the incoming alpha-particles at a rate of about 600 per minute without appreciable loss. The background was about 1 in 3 minutes if the working potential was less than 100 volts above the threshold potential, and became higher (even up to 5 per minute) as the working potential was further increased. Figure 2 shows the arrangement suitable for low rate counting.

To apply a larger fraction of the total change of potential to the amplifying tube, R_2 may be increased relatively to the extinguishing resistance R_1 (10^7 to 10^8 ohms) if a high cathode bias is used.

The condenser across the counter was made of a mica sheet with two copper foils pressed on its opposite sides, the whole being then immersed in paraffin. The electrical insulation between the two plates of the condenser is obviously very important.

3. THE HIGHER RATE COUNTER—THE MULTIVIBRATOR

In order to make the counter capable of counting alpha-particles at a higher rate, the capacity across the counter must be reduced to the minimum or even taken off. The electrical pulses produced by the discharges due to the incident alpha-particles will then be very much smaller, however, and an amplifier of higher amplification must be used. An amplifier of the multivibrator type was found to be very satisfactory.

Figure 3 shows the amplifier coupled to the

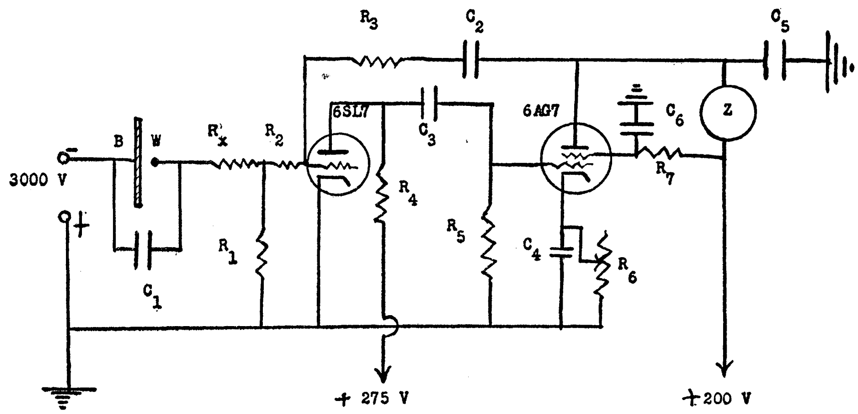

FIG. 3. The multivibrator. $R_x = 10^6 - 10^7$ ohms; $R_1, R_2, R_3, R_5 = 0.1 \times 10^6$ ohms; $R_4 = 10^4$ ohms; $R_6 = 2 \times 10^3$ ohms; $R_7 = 4 \times 10^3$ ohms. $C_1 = 0$–30 cm; $C_2 = 0.00015$ μf; C_3, $C_5 = 0.5$ μf; $C_4 = 0.1$ μf; $C_6 = 0.35$ μf. Z is Cenco counter.

electric counter with the values of the constants listed. Since the incoming pulse to the grid of the first tube was negative, the grid resistance and the anode potential of the first tube (6SL7) were so chosen that the operating point was at the top part of a longer straight portion of the I_p vs. V_g curve, while that of the second tube (6AG7) were adjusted so that the operating point was at the bottom part of a longer straight portion. In actually working condition, the plate current of the 6SL7 was about 10 ma (the two triodes being in parallel) and that of the 6AG7 about 3 ma. The residual oscillation between the two stages was eliminated by introducing the resistance R_3 in the feed-back circuit. C_6 and R_7 in the screen grid circuit of the output stage were necessary only when two or more such units were supplied with the same power pack and coupled to two or more electrical counters (cf. Section 4), while C_5 was found useful in either case in by-passing the low frequency oscillation to the earth. As before direct coupling assured more satisfactory operation than capacity coupling.

In the above arrangement the extinguishing resistance R_x could be lower than 10^7 ohms and the condenser C_1 across the counter could even be removed. The power output was still big enough to actuate the mechanical counter, and the counter was not affected again either by a strong source of beta-rays or by that of gamma-quanta. To assure reliable operation a capacity of about 30 cm was used. Under such circumstances the counting system responded to the incoming alpha-particles at a rate of about 1500 per minute or higher.

Some particular features of the above arrangement are obvious: It can lengthen the incoming pulses so as to give a better assurance of the operation of the mechanical counter. It may also help to extinguish the discharge in the counter so that a smaller value of R_x can be used and hence a smaller resolving time of the counter may be effected. The variable cathode resistance R_6 provides a convenient device for selecting the pulses of different sizes.

4. A SYSTEM OF SEVERAL COUNTERS

To determine an alpha-ray spectrum in a magnetic spectrograph, it is evidently more advantageous to use several counters at the same time than a single counter. For this purpose eight tungsten wires of the above mentioned size were stretched in front of a smooth brass plate. The arrangement of each wire with respect to the brass plate was very similar to that shown in Fig. 1. The wires were equally spaced, the distance between two adjacent wires being 5 mm. All the wires could be adjusted to work at approximately the same potential by changing their relative distances from the brass plate, mica sheets of different thicknesses being introduced into the space between the wires and the glass tubes *g*.

It was found that when one wire was responding to an incoming alpha-particle, the other wires near by were also answering simultaneously. This trouble was eliminated by erecting aluminium walls between any two adjacent wires. These walls were set into the brass plate. The reason for their effect was not clear. It might be either due to some mechanical vibrations in the air of the counter box, or due to some alteration of the electric field in the near-by counters. The photoelectrons (or light) emitted from the counter which was actually working might not affect the near-by counters, for as mentioned above, none of the counters responds to even strong beta- or gamma-rays.

Figure 4a represents a side view of a transverse section of the counters, which have been actually used (cf. Section 5). A is the box (cf. A in Fig. 1) made of transparent Plexiglas, B the brass plate and W the wires. The actual length of each tungsten wire was about 4 cm, and the diameter $7\frac{1}{2}$ mils. When actually used, the counter box was put in the evacuated deflection chamber of an alpha-ray magnetic spectrograph with air of atmospheric pressure inside the counters and vacuum outside. Hence the box had to be air tight. A window with parallel slits, each of $\frac{1}{2}$ mm width and just opposite as well as parallel to each of the wires, was made of a brass plate having a thickness of about 7 mm. The slits were the narrow gaps between the halves of brass rods about 4 mm diameter, the ends of which were fixed into the brass frame by means of screws. The round side of each rod was directed toward the incident beam of alpha-particles, and hence would prevent the particles scattered from the surface of the rod from going into the counters. Figure 4b shows a bottom view of the window. N is a Neoprene strip in the form of a closed square; this made the air tight joint when the window was pressed upon the counter box by six screws. A thin sheet of mica sufficiently big to cover the whole window (having a stopping power of about one cm air equivalent) was waxed on to the bottom of the window. The distance of each wire from the window was about 5 mm. The operation was found to be more satisfactory if the window was at the same negative potential as the brass plate behind the wires. The transparency of the counter box allowed one to observe each wire inside the box when the counter was working.

Two multi-vibrators were built and coupled to any two wires. They were supplied with the same power pack but well shielded from each other (cf. Section 3). When the counting rate is not high, of course an amplifier of a single stage as shown in Fig. 2 can be used for each electrical counter. As the single stage amplifier is simple and inexpensive, more sets could be built up and coupled to more wires. Figure 5 shows two or more wires coupled to two or more amplifiers, and the stabilizer for the counter voltage. In the stabilizer, the plate voltage of the 6C6 tube was between 100 and 250 volts and was indicated by a home-made electrometer; the grid voltage was a 45 volts B battery.

When the counters are used in the deflection chamber, the long leading wires, particularly the H. T. lead, between the counters and the amplifying and high voltage sets should be well insulated and shielded. C_1 and R_x should be put as near as possible to the counters so that the

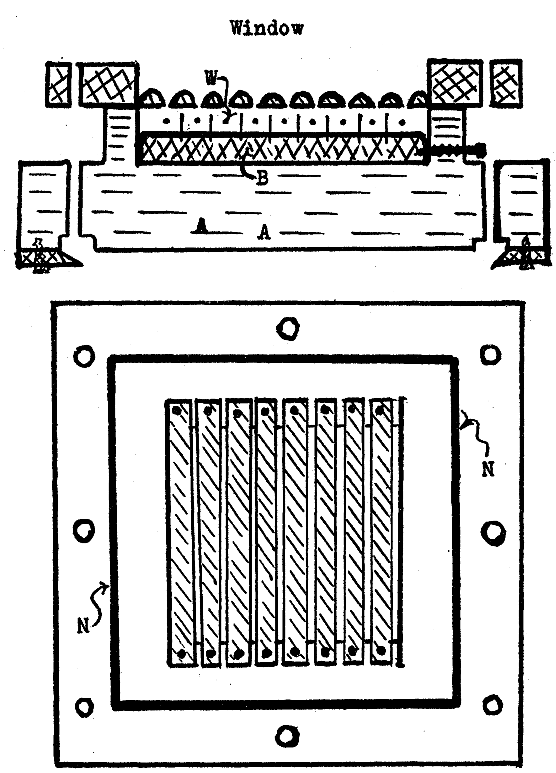

FIG. 4. (a) (above) Side view of transverse section; (b) (below) Bottom view of the window.

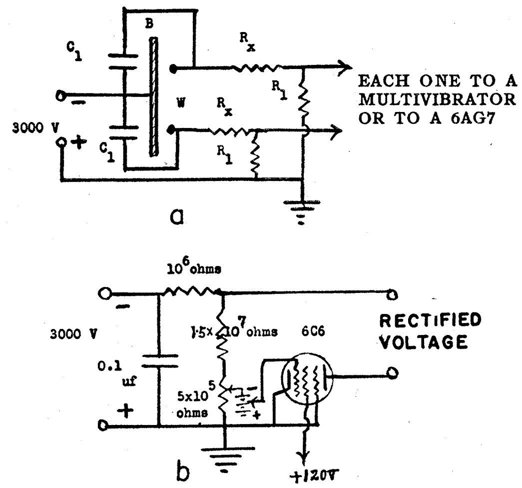

FIG. 5. (a) Coupling to multivibrator or 6*A*G7; (b) Stabilizer for counter voltage.

potential difference developed between the leads and the earth, when the counters are working, would be small. As mentioned above, if a high cathode bias is provided, a larger fraction of the total change of potential can be applied to the first tube by increasing R_1 relatively to R_x.

5. THE SPECTRUM OF THE PO ALPHA-PARTICLES

As mentioned above, the counter box should have air at atmospheric pressure inside and vacuum outside, when it is used in the deflection chamber of an alpha-ray magnetic spectrograph. Hence it has to be air tight. This was tested beforehand in a desiccator, which was evacuated by a small pumping system and made to permit electrical leads to come out. A Po source was put in front of the window of the counters. A shutter for the source was made of an iron sheet and could be controlled by a magnet outside the desiccator. The sensitivity of one of the counters was checked frequently over a long period, say 24 hours; the constancy of the sensitivity certainly indicated the air tightness of the counter box.

This system of counters has been used by one of us (W.Y.C.) together with an alpha-ray magnetic spectrograph to determine the alpha-ray spectra of natural radioactive substances. This spectrograph consists of the Princeton cyclotron magnet and a large Plexiglas deflection chamber and will be described elsewhere.[3] Figure 6 shows two distribution curves of the same group of Po alpha-particles, which were determined simultaneously by using two adjacent counters respectively. These two counters were coupled to the two multi-vibrators, and readings from both mechanical counters were taken at the same time after the counter box was moved to each new position. The form of the distribution curve is in agreement with that found from a photographic line, i.e., the microphotometric result, and with that from the tracks method.

The width at half intensity is less than $\frac{1}{2}$ mm, which is equivalent to about 0.01 Mev, according to the energy of Po alpha-particles (5.303 Mev) and strength of the magnetic field (about 12,000 gauss).[4] This sharpness of the line must also indicate that the effect of scattering from the residual gases in the deflection chamber and from the window surfaces into the counters on the width of the line was very small. In fact it was found that the counters would not hold a voltage of about 3000 volts unless the vacuum outside the counters was better than 10^{-3} mm Hg. When the pressure outside was higher than 10^{-3} mm Hg, corona discharge occurred at the metal parts and the electrical leads of the counters. Therefore, the satisfactory operation of the counters automatically guaranteed a good vacuum in the deflection chamber and hence very small scattering of the alpha-particles from

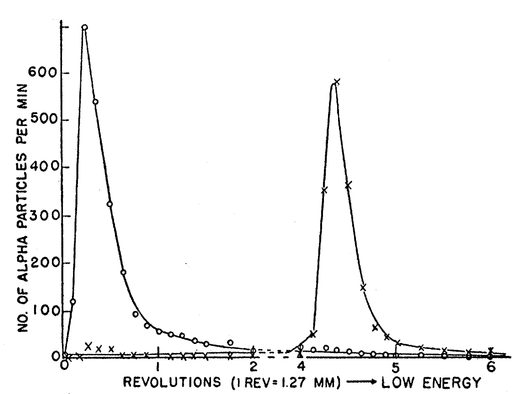

FIG. 6. Energy distribution of Po-alpha-particles. × results from Counter No. 3, ○ results from Counter No. 4.

[3] For a brief description see W. Y. Chang, Phys. Rev. **67**, 58A (1945).

[4] Relation between $H\rho$ and E in Mev is given by $H\rho=1.436\times10^5E^{\frac{1}{2}}$ without relativistic correction. Hence $2d\rho=1.436\times10^5dE/(HE^{\frac{1}{2}})$, ρ being in cm.

the residual gases in the chamber, for the mean free path of an alpha-particle at this pressure or lower is very large.

As to the background, at an energy of about 5 percent lower than the main group energy the intensity is less than 0.1 percent of the main intensity. This result is quite different from that obtained by Roy Ringo.[5] His intensity at this energy is as high as 10 percent of the main intensity. However, we feel that our result is reliable, as it is reproducible when the source is properly prepared. These will be discussed elsewhere by one of us (W. Y. Chang) together with the spectrograph. It is seen that the background of one curve under the maximum of the other becomes slightly higher. This was found to be due to the pick-up by one multivibrator from the other, which was responding to the maximum number of alpha-particles. This disturbance could be cured, however, by increasing the cathode resistance R_6 of Fig. 3.

6. DISCUSSION

The exact mechanism of such counters is not completely clear. However, the reasons why they answer to alpha-particles but not to beta-particles or gamma-quanta may be easily understood from the following consideration. Since, as mentioned above, the active region of the counter is confined close to the wire, where the greater part of the counter potential drop occurs, a beta-particle or a gamma-quantum when passing through such a small region may produce too few or even no ions at all. The situation is different for an alpha-particle. Owing to its much higher ionizing power, an alpha-particle in traversing this region will produce a relatively sufficient number of primary ions, which will in turn then produce secondary ions by collision. Since the fall of potential near the wire is very steep, the secondary ionization so produced is expected to be big enough to send a spark across the counter.

The small active region of the counter has another advantage (cf. Section 2). Since the region is so narrow, the chance for several beta-particles or gamma-quanta to be incident simultaneously into this region must be very small. Hence there is no ambiguity as to whether all of the pulses are due to alpha-particles or some of them are due to simultaneous incidence of several beta-particles or gamma-quanta. In a parallel-plate ionization chamber, however, the situation is different. In this latter case, the active region is practically the whole volume between the two parallel plates. Consequently some of the pulses are inevitably originated by the simultaneous incidence of several beta-particles or gamma-quanta.

The region over which the sensitivity of the counter is more or less independent of the voltage is small, i.e., about 100 volts. Independence of sensitivity over a wider range might be expected if some other gas, e.g., air mixed with a certain organic vapor or hydrogen gas, was introduced into the counter. It might also be expected that the counter would answer to beta- or gamma-rays if the pressure was reduced from the atmospheric pressure. It is hoped that more work will be done along these lines.

We wish to express our thanks to Professor R. Ladenburg for his interest in this work and for his useful criticism and advice about the manuscript. We are also indebted to the former cyclotron group for putting some of their apparatus at our disposal and to those friends in the Electronic Division for their useful discussion about the electric circuits.

[5] Roy Ringo, Phys. Rev. 58, 942 (1940).