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An Arrangement with Small Solid Angle for Measurement of Beta Rays

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An arrangement using a Geiger-Müller counter witn small aperture with a radioactive source at some distance from it is described for counting beta particles. Sources emitting only beta rays with maximum energies above 1 million electron volts of the order of 1 millicurie can be measured in terms of the disintegration rate from the observed counting rate and the solid angle as calculated from the dimensions of tne apparatus. An independent check of the arrangement shows that this can be done reliably. A suggestion for discarding the use of the curie and substituting a unit consisting of 10^6 disintegrations per second to be called the "rutherford" is made. The curie is properly applicable only to members of the radium family.

I. Introduction

The development of improved methods for the production of radioisotopes, resulting in an increase in the use of such radioactive materials, has led to a demand for better methods of measurement. In the simple case where a radioelement emits only beta particles of fairly high energy, as in the case of P^{32}, it should be comparatively easy to measure the strength of radioactive sources in terms of disintegrations per second, even for fairly strong sources. This has not yet been accomplished, however. Disagreements of the order of 300 percent have come to the attention of the authors. The need for reliable methods of measuring the strength of sources of P^{32} is accentuated by its newly developed use in the treatment of leukemia. It is of considerable importance that the amounts of P^{32} as measured by various laboratories should be in reasonable agreement. Otherwise, clinical results obtained in various parts of the country from the use of this element cannot be compared.

The writers have undertaken to develop an arrangement, comprising a Geiger-Müller counter and source holder, with a sufficiently low solid angle that sources of the order of 1 millicurie can be counted in it directly. The number of disintegrations per second will then be obtained from the observed counting rate and the solid angle determined from the dimensions of the arrangement.

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II. Geometrical Arrangement

Figure 1 is a diagram of the counter, chamber, and source holder built to test the effectiveness of this method of measuring beta-ray sources. A brass tube approximately 60 cm long and 4-cm internal diameter constitutes the chamber. In this a number of baffles, *B*, are mounted with a movable shutter, *Sh*, of 3-mm brass at the end where the source, *S*, is mounted. This shutter permits a measurement of background with a source in place. The opposite end of the chamber is closed by a steel plate, *P*, 6 mm thick with an aperture, *A*, 4 mm in diameter in the center. A counter, *C*, is mounted concentric with *A*, which is covered by a mica window of approximately 2 mg/cm^2. The chamber can be evacuated during observations. The construction of the source holder is shown in figure 2. It is made of Plexiglas and designed to reduce back-scattering from various parts.

The most important spurious effect to be anticipated in this arrangement is small-angle scattering from the walls of the tube. The very small solid angle used makes this a serious difficulty. Consequently, a series of studies was made of the effect of baffles of various materials, at different locations in the tube, on the counting rate. These studies revealed that Plexiglas and soft-wax baffles were equally effective in producing a definite minimum counting rate when the source was in full view of the aperture.

Typical results are shown in table 1 for equally spaced baffles, consisting of disks ¼ in. thick

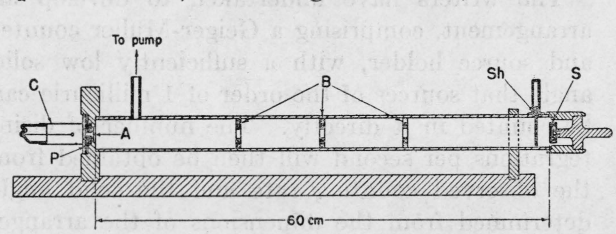

Figure 1.—*Arrangement of counter, vacuum chamber, and source holder.*

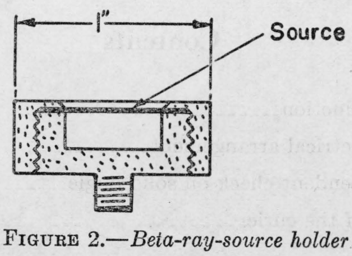

Figure 2.—*Beta-ray-source holder*

closely fitting the internal diameter of the tube with a central hole ½ in. in diameter. The diameter of the source was 1 cm.

The optimum diameter of the circular opening in the baffles was found to be slightly greater than the diameter of the source. Small changes at this approximate diameter had no effect on the counting rate.

Table 1.—*Relative scattering for different arrangement of baffles*

Material	Number of baffles	Relative counting rate
	0	1.27
Brass	3	0.56
Plexiglas	3	.50
Do	4	.50
Do	12	.56
Wax	3	.50

The effect of internal scattering along the tube was further tested by changing the source-to-aperture distance from 60 to 40 cm by mounting the source on a rod extending 20 cm into the tube. The counting rate observed under these conditions agreed within less than 1-percent with that calculated from the ratio of the calculated solid angles and the counting rate observed at 60 cm.

From the actual dimensions of the aperture, diameter $=4.06 \pm 0.01$ mm, and source-to-aperture distance equals 60.0 ± 0.2 cm, the solid angle divided by 4π is computed as 2.86×10^{-6}. Multiplying the observed counting rate by the reciprocal of this number, 3.49×10^{5}, gives the number of disintegrations per second. If it is desired to express this value in millicuries, the observed count is multiplied by 9.44×10^{-6}, assuming the curie as 3.7×10^{10} disintegrations per second. This practice of expressing all activities in terms of curies is to be condemned, as will be explained later.

There are at least three disturbing effects, common to all Geiger-counter measurements of beta rays, which must be considered in connection with the present arrangement. These are back-scattering from the source and support, absorption in the mica window and in some cases self-absorption in the source. In the present case the back-scattering from the support for the source was reduced to a minimum by the selection of

Plexiglas with a considerable cavity behind the source to reduce this effect. The sources were deposited on aluminum 0.00035 in. thick. However, the material of the source itself would cause considerable back-scattering, as the phosphorus used did not have a high specific activity, and there also would be some self-absorption. These effects tend to counteract each other.

III. Independent Check on Solid Angle

A number of P^{32} sources were measured in the arrangement as described. The values obtained were in general agreement with those expected, but it became obvious that some independent check was required to establish the reliability of the measurements. For this purpose a thin mica-window counter of the bell type was constructed and arranged so that a source could be mounted very close to the window in an accurately reproducible location. This was achieved by mounting the counter with the mica window up and laying the sources, properly centered, directly on the counter. The curvature of the mica window provided a small but definite separation between it and the source. This arrangement is represented in figure 3, where S is the source and M the mica window.

To determine the solid angle for this position of the source a sample of RaD was prepared from lead extracted from pitchblende to be used as a standard. The radium content of this ore was carefully measured, and the total amount of lead was determined quantitatively. From the above data and the known weight of lead in the standard, the number of beta rays per second from the RaE in equilibrium with the RaD could be calculated.

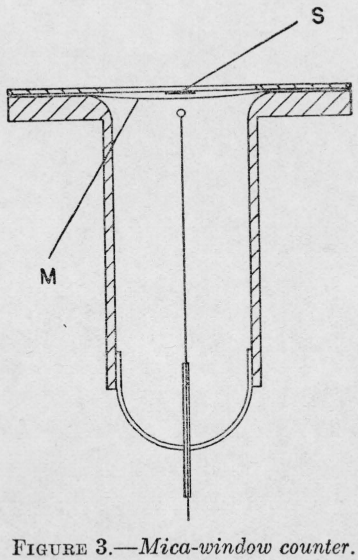

FIGURE 3.—*Mica-window counter.*

The ratio of the observed number of counts to this calculated value gives the effective aperture of the counter. With this information available, an aliquot was taken from one of the P^{32} solutions, of such amount to give a convenient counting rate in the inverted mica-window counter. The counting rate multiplied by the above ratio gives the number of disintegrations per second in the aliquot of P^{32}. Multiplying again by the aliquot ratio, the number of disintegrations is obtained in the original P^{32} sample, which had previously been measured in the chamber with small solid angle. In making these measurements in comparison with the RaD+E standard, care was taken to deposit the P^{32} on the same backing material as was used for the standard and over the same area. This reduces the back-scattering correction to a small value, dependent only on the difference in energies of the RaE and P^{32} beta rays. The mica window had a thickness $\sim$ 6 mg/cm ^{2}, so that the absorption corrections would also be nearly the same.

When comparing the measurements in the arrangement with large solid angle with those obtained in the apparatus with small solid angle, it is to be noted that whereas the effect of back-scattering in the former has been reduced, this is not true for the small-angle arrangement as there were several milligrams of phosphorus in the sources of approximately 0.5-millicurie strength. Therefore, we would expect the value obtained in this case to be somewhat higher than that obtained from comparison with the RaD+E standard. On the other hand, for the large solid angle arrangement there is almost no self-absorption of beta rays in the material of the source due to the smallness of the sample, whereas in the small solid-angle apparatus a source of approximately 0.5 mc weighs about 30 mg and extends over a little less than a square centimeter. The self-absorption will be considerable under these conditions. A measurement gave 0.489 mc for 30 mg in the high, large solid-angle arrangement and 0.488 mc for the low solid-angle arrangement. Under the conditions of these measurements the results can only be explained if the back-scattering effect was approximately offset by self-absorption within the source. The agreement might be regarded as fortuitous. Therefore, the comparison was repeated from the beginning, using freshly prepared sources from the same original solution of P^{32} in both pieces of apparatus. The measurements gave 0.504 mc in the large solid-angle counter and 0.502 mc in the low solid-angle arrangement. This makes it quite certain that the low solid-angle chamber gives a reliable measurement of beta rays from P^{32} or any source emitting only beta rays of approximately the same energy. Furthermore, this counting arrangement is independent of any standard and gives the disintegration rate simply by multiplying the observed counting rate by the solid angle computed from the dimensions of the apparatus.

IV. Use of the Curie

It has become the practice to express the strength of all radioactive sources in terms of curies. Actually, the curie can be applied logically only to members of the radium family. This arises from the fact that the curie was originally defined as "That quantity of radon in equilibrium with 1 of radium." Therefore, only members of the radium family in equilibrium with 1 g of radium can have this disintegration rate. A further disadvantage in the use of this unit is that it is uncertain to at least 4 percent and values are in current use which fall well outside these limits.

The solution of this difficulty is remarkably simple. The intensity of radioactive sources is measured actually in terms of disintegrations per second. Therefore, all that is required is to designate some convenient rate and give it a name. We suggest that a convenient rate is 10^6 disintegrations per second, and that the unit be called a "rutherford," abbreviated as "rd." The microrutherford then is the amount undergoing 1 disintegration per second and a kilo rutherford, 10^9 disintegrations per second. In the future it is anticipated that even those nucleii having fairly complex disintegration schemes will be measurable in terms of disintegrations per second, and many can already be treated in this way. Thus all confusion that has arisen from the false application of the curie can be eliminated.

This subject has been discussed by the National Research Council Committee on Radioactivity, which, in turn, has suggested that the National Bureau of Standards recommend the use of the "rutherford" as a general unit for the measurement of radioactive sources. This recommendation was published in Science **103,** 712 (1946), and will appear shortly in other journals.

WASHINGTON, May 23, 1946.