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An Experimental Study of the Backscattering of 5.3-MeV Alpha Particles from Platinum and Monel Metal

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The angular and energy distribution of the α-particles backscattered from essentially weightless sources of polonium-210 deposited on platinum and on monel metal have been measured. It was found that the backscattering occurs only at angles close to the plane of the mounting, i.e. within 15°, and that the backscattered α-particles are distributed over the entire energy range. Numerical integration of the angular distribution gives 3.1 percent and 2.1 percent backscattering for platinum and monel, respectively.

UNE ETUDE EXPERIMENTALE DE LA DISPERSION EN REFLEXION DES PARTICULES α DE 5,3 MeV DU PLATINE ET DU METAL MONEL

On a mesuré la distribution angulaire et la distribution énergique des particules α dispersées en réflexion de sources de polonium-210 effectivement sans poids déposées sur du platine et sur du métal Monel. On a trouvé que cette dispersion prend lieu seulement à des angles près du plan du montage, c'est-à-dire à moins de 15°, et que les particules α dispersées sont distributées à travers toute la gamme énergique. L'intégration numérique de la distribution angulaire donne 3,1 pour cent et 2,1 pour cent de dispersion en réflexion pour le platine et le métal Monel, respectivement.

ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ОБРАТНОГО РАССЕЯНИЯ α ЧАСТИЦ (5,3 МЕГА-ЭЛЕКТРО-ВОЛЬТ) С ПЛАТИНЫ И С МОНЕЛЬ-МЕТАЛЛА

Было измерено угловое рассеяние и распределение энергии α частиц, обратно рассеянных с существенно невесомых источников полония-210, отложенных на платине и на монель-металле. Было найдено, что обратное рассеяние случается только под углами, близкими к плоскости отложения, т.е. в пределах 15°, и что обратно рассеянные частицы α распределяются по всему диапазону энергии. Числовая интеграция углового распределения дает 3,1 процента и 2,1 процента обратного рассеяния соответственно для платины и. монель-металла.

EXPERIMENTELLE UNTERSUCHUNG DER RÜCKSTREUUNG VON 5,3 MeV α TEILCHEN DURCH PLATIN UND MONELMENTALL

Die Winkel- und Energieverteilung von α Teilchen die von praktisch gewichtslosen Quellen von auf Platin und Monelmetall niedergeschlagenem Polonium-210 rückgestreut wurden, sind gemessen worden. Es wurde festgestellt, dass die Rückstreuung nur bei Winkeln die nahe der Halterungsebene liegen stattfindet, d.h. in dem Bereich von 15° und dass die rückgestreuten α Teichen über den gesamten Energiebereich verteilt sind. Eine numerische Integration der Winkelverteilung ergab 3,1 Prozent und 2,1 Prozent Rückstreuung für Platin und Monel.

INTRODUCTION

Since the earliest investigations involving the counting of α-particles, there has been concern as to the effect of the backing material on the counting rate. Ideally, one would like to measure only the total α-particle radiation emitted by the source. This is best achieved by mounting the source on an extremely thin film of low atomic weight and counting in a 4π geometry. However, very thin backings are not very durable and in the case of polonium-210, backing materials of low atomic weight have been found to yield sources that are quite unstable. In order to achieve a stable and durable polonium-210 source that will stand up to repeated use as a reference source, it is necessary that the backing material be fairly rigid. Polonium-210 sources are usually deposited on metal backings and counted in a 2π geometry. The difficulty arises that the counting efficiency of such α-particle sources in a 2π geometry is more than 50 percent. These extra counts arise from backscattered α-particles.

Attempts have been made to use low-geometry counters to alleviate the problem of backscattering. Low-geometry counters accomplish this by limiting the acceptable solid angle and counting only those α-particles that are emitted essentially normal to the source backing. However, the use of low-geometry counters requires that the geometry be calculable from the measured dimensions. It has been pointed out by Robinson[1] that uncertainties are introduced when the source is not uniformly spread and when there is a lateral displacement of the source, but that these uncertainties can be greatly reduced by modifications in the design of such counters.

The 12-cm diameter 2π continuous-flow proportional counter used for calibrating α-particle reference sources at the National Bureau of Standards (Fig. 1)[2] overcomes the problem of source displacement from the center. This chamber also allows accurate calibration of large area sources (sources up to 6-cm diameter have been calibrated). Its geometry can be accurately evaluated; and because of the inherently low background of $2\pi\alpha$-proportional counters, sources of relatively low activity can be measured. For these reasons, the 2π proportional counter is ideally suited for our purpose. However, for absolute counting, corrections may be necessary for source self-absorption and for backscattering.

Since our sources are essentially weightless, the amount of self-absorption is assumed to be negligible.

Now, let us consider the backscattering factor, for which we shall determine an experimental value. The backscattering factor has been found to be ≥ 1 by several experimenters. Rutherford[3] and Deruytter[4] have shown experimentally that these backscattered α-particles undergo multiple scattering at small angles, i.e. at grazing angles close to the surface of the source backing.

Crawford[5] has shown theoretically that α-particle backscattering is due to multiple scattering at small angles. He considered the multiple scattering from an infinitely thick source backing using the experimental results of Geiger[6]. From Geiger's data he estimated a statistical lower limit for the backscattering. He considered the amount of backscattering as a function of the atomic weight of the backing material and as a function of the range of the α-particles. His calculations indicate that α-particles with an energy of 5.2 MeV are backscattered from a platinum sample mounting to the extent of 3 to 3.5 percent.

The validity of Crawford's theoretical calculations has been substantiated experimentally by Deruytter[4] and Curtis[7]. Not only does the backscattering vary with the atomic weight of the backing, but the amount observed will also be a function of the sample thickness and the smoothness of the backing. Curtis[7] has observed twice the backscattering from highly polished tantalum as from her original tantalum foil. When the source backing is not smoothly polished, the active material will be deposited in the scratches in the surface and some absorption will occur at small angles of emission. This effect is classified with self-absorption since it is peculiar to the specific sample. However, this type of absorption will tend to minimize the effective backscattering since backscattering is a low-angle phenomenon.

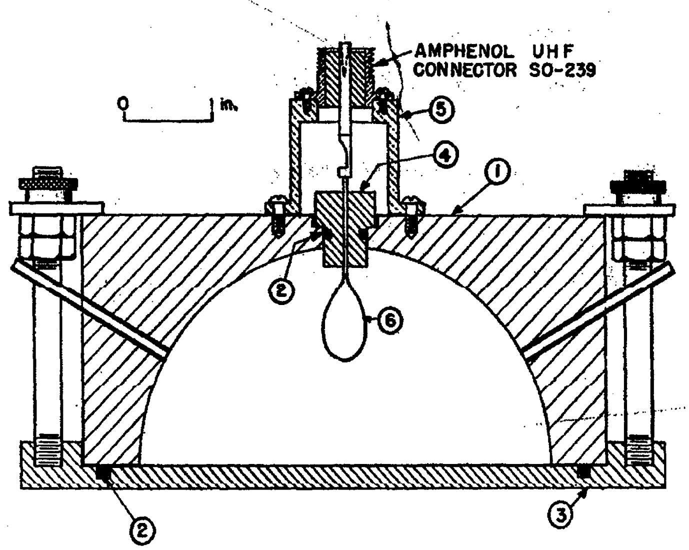

FIG. 1. 12-cm diameter proportional-counter chamber. 1. Stainless steel, 2. Rubber "O" ring, 3. Aluminum, 4. Plexiglass, 5. Brass, 6. Tungsten 0·002 in. diameter wire. (The source is placed on the base plate (No. 3) with its center approximately under the wire loop.)

Since the α-particle sources calibrated at the National Bureau of Standards are quite widely distributed, it is of interest to know what the effects might be of measuring these sources in various types of counters. More generally, it is of interest to know how the emission of backscattered α-particles varies as a function of the orientation of the source.

Also at the present time there is little, if any, information about the interesting question of the amount and distribution of the energy loss of the α-particles that are backscattered. In the past, indirect backscattering measurements have been made by using apertures of differing sizes or by varying absorber thickness. Now, new methods of detection and the ability to make a point source of sufficient strength make it possible for the first time to make a simple and direct measurement of the angular and energy distribution of backscattered α-particles. Monel metal and platinum were selected for this experiment so that measurements could be made on both a low Z material (av. $Z_{monel} = 29$) and on a material of high Z ($Z_{pt} = 78$).

BACKSCATTERING CHAMBER AND COUNTING EQUIPMENT

A schematic diagram of the counting chamber used in this experiment is shown in Fig. 2. The chamber is a closed brass cylinder with an internal source holder that can be rotated by a dial on the top of the chamber. The chamber was designed so that the vacuum outlet could be used to visually center and align the source, the collimator and the detector. For this purpose the vacuum outlet intersected the

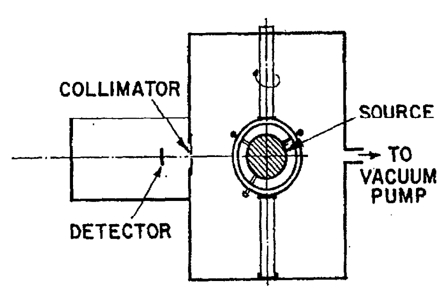

FIG. 2. Schematic diagram of backscattering chamber.

vertical axis of the chamber. With a light placed in the bottom of the chamber, it was possible to focus a cathetometer along the vacuum outlet and to align the other three elements along its axis. First, a 5 mm × 5 mm silicon semiconductor detector was positioned. It was mounted in the cylindrical sleeve, perpendicular to the chamber. Next, the collimator was fixed into position. The collimator, a 0.040 in. hole cleanly drilled into a sheet of aluminum foil 0.006 in. thick, was attached to the inner wall of the chamber at a distance of 0.25 in. from the detector (see Fig. 2). Since the exact location of the radioactive material was not clearly visible, it was necessary to make autoradiographs of each source. The autoradiographs, which clearly defined the source areas, were placed in position over the respective sources and aligned. Each source was mounted so that the face lay on the axis of rotation. The distance from the source to the collimator was 4 in.

If the detector, the collimator and the source were each aligned with respect to the vacuum outlet, symmetry could be achieved.

The top of the chamber was graduated in gross divisions of 10° and in fine divisions of 2°. One degree was easily approximated. The angle subtended by the collimator to the source was approximately 1°. Thus, by rotating the source relative to the detector, one could sample the counting rate through 180° in steps of 1°. When the chamber was evacuated, the mean free path of the α-particles was long compared to the distance from the source to the detector.

The detector bias was 50 V, furnished by a regulated power supply. A special low-noise preamplifier designed by Oak Ridge National Laboratory for use with semiconductor detectors was used. The α-particle spectra were analyzed with a 512-channel analyser. The resolution obtained with this system, [$(\Delta E/E)$ at one-half the peak maximum] was 1.2 per cent.

SOURCE PREPARATION

In order to minimize the penetration of the α-activity into the minute pits of the source backings, it is desirable to deposit the polonium onto highly polished surfaces. Both the monel metal (*K*-monel, approximately 60 per cent nickel and 40 per cent copper) and the platinum were polished by the Engineering Metallurgy Section of the National Bureau of Standards.

Both the platinum and the monel were approximately $\frac{1}{4} \times \frac{1}{4}$ in. mounted in Bakelite. They were polished in the following manner:

(i) Wet grinding papers (silicone carbide) in the order 200, 300, 400 and 600.
(ii) This was followed by hand polishing with black velvet and Linde A polishing compound.
(iii) The final finish was achieved by further hand polishing with Linde B polishing compound.

The source backings were cleaned by washing with carbon tetrachloride and rinsing first with acetone and then with ethyl alcohol.

Polonium-210 was used as the source of essentially monoenergetic α-particles ($E = 5.30$ MeV). The polonium solution was in the form of the chloride in 0.1N HCl ($1 \geq \text{pH} \geq 2$), and was of very high specific activity. A drop of this solution was put on each of the source mounts and deposited without an applied voltage. It is reported by GMELIN[8] that polonium deposits spontaneously (electrochemically) on nearly all metals if the metals are saturated with gaseous hydrogen or if the electrode potential is increased by complex ion formation. According to ERBACHER[9] polonium and radium *E* are completely deposited on nickel from 0.1N HCl. From our experience, it is estimated that this spontaneous electroplating was completed in approximately 30 sec. The sources were dried slowly under a heat lamp. They were then washed with distilled water and gently dried with a cleansing tissue. The average diameter of the sources was approximately 1/8 in., with an average counting rate of about 10^5 α-particles per second. At this level of activity, because of the high specific activity of the polonium, the sources were essentially weightless.

EXPERIMENTAL PROCEDURE

The present experiment can be divided into three parts. In the first part, the amount of backscattering of polonium-210 α-particles was measured as a function of angle for platinum and monel. The integral counts were measured at various angles, θ, from θ equal to −90° to θ equal to $+90°$, where θ is the angle between the normal to the plane containing the face of the source backing and the axis through the centers of the source, collimator and detector. The total increase in the counting rate at angles close to the surface of the backing is a measure of the contribution of backscattered radiation.

In the second part of the experiment, energy spectra were sampled at 0° and at angles at which backscattering was observed, in order to determine the amount of energy lost by the ackscattered α-particles as a function of angle.

Part three of the experiment consisted of hecking the time dependence of diffusion of olonium-210 into the source backings.

RESULTS AND DISCUSSION

The real significance of our work is shown in Fig. 3, which shows the distribution of the counting rate as a function of angle, and in Figs. 4 and 5 which show the energy spectra. The distribution in Fig. 3 shows the anticipated result that backscattering occurs only at angles close to the plane of the backing and that the backscattered α-particles are distributed over the entire energy range. YAFFEE[10] has found that a majority of the backscattered particles occur within 25° of the backing plate. We see that this is quite the case in the present experiment as illustrated in Fig. 3, where all the backscattering occurs within 15° of the backing plate.

It is also seen in Fig. 3 that the gross angular dependence of the backscattered radiation of polonium-210 from platinum and monel backings are quite similar for the two materials. The main difference is in the magnitude of the effect. Our measurements were not intended to give the total backscatter with any great accuracy, but a numerical integration of the angular distribution gives 2.1 per cent and 3.1 per cent of the total α-particle radiation for monel and platinum respectively, i.e. the total area of the angular distribution was divided into the area under the peaks which occur at extreme angles and are assumed to be due entirely to backscattering. This means that for every 100 α-particles emitted in the forward direction, there will be included 2 to 3 α-particles that have been backscattered.

In spite of the care taken in centering the source, there was a slight asymmetry as evidenced by the data in Fig. 3. This is probably due to the fact that the source holder was slightly off axis. Since the asymmetry in the backscattering peaks is consistent and reproducible for both backing materials, it was concluded that this asymmetry is due to the inherent geometry of the counting chamber.

We note in Figs. 4 and 5, which show the energy distribution of the backscattered α-particles from monel and platinum respectively, that although the sources are essentially weightless, the intensity of the high energy edge of the peak diminishes somewhat at extreme angles. This is perhaps an indication of diffusion into the backing. In order to check this, a new source was made and counting was begun as quickly as possible after preparation of the source (approximately 40 min elapsed during alignment of the source and evacuation of the chamber). The counting rate of the source was followed for 15 days. Spectra were taken at θ equal to 0° and at θ equal to 89°; the latter angle being that at which the greatest amount of backscattering had been detected. From the first set of counts, the maximum energy of the peak at θ equal to 89° was less than at θ equal to 0°. During the fifteen days that followed there was no further broadening of either peak and no decrease in the counting rate other than the half-life decay. We may conclude that if the lower energy of the peak at extreme angles is due to diffusion into the backing, this diffusion occurs very shortly after the source is prepared, most likely when the source is under the heat lamp. It is possible that the actual amount of backscattering may have been greater than we were able to measure since the backscattering and the diffusion compensate each other to some extent.

We can see in Fig. 6, which gives greater detail of the low-energy backscattered α-particles and in Fig. 7, which displays the relative energy at 85° and 89°, that most of the backscattered α-particles lose a significant fraction of their energy. Although the backscattered α-particles lose energy, they still have sufficient energy to be counted in a 2π geometry. This has been borne out by YAFFEE[10] and CURTIS[7] who have designed low-geometry

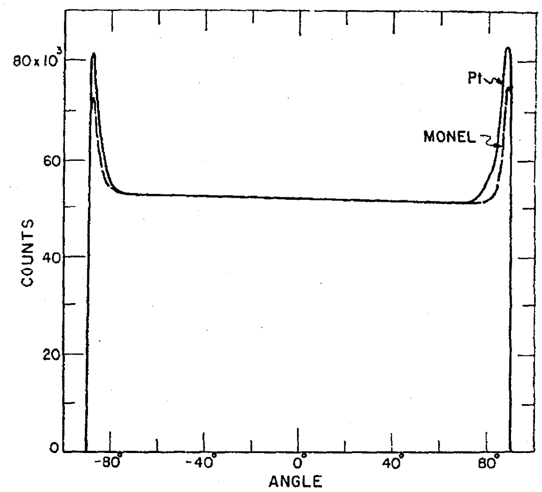

FIG. 3. Variation of the counting rate as a function of the angle.

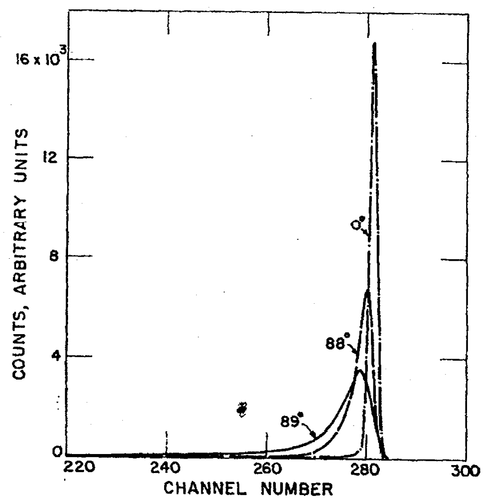

FIG. 4. Energy spectra of the polonium-210 α-particles backscattered from monel at 0°, 88° and 89°.

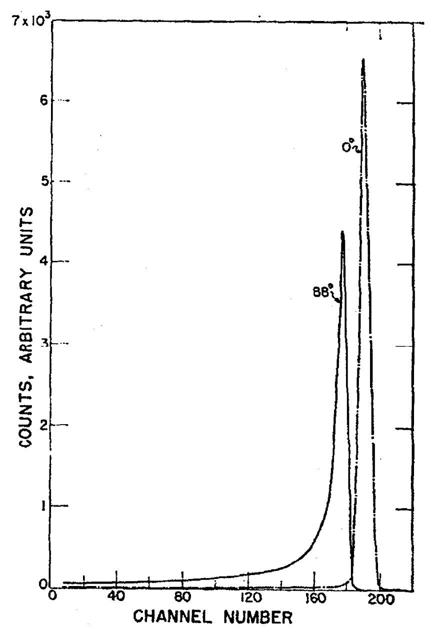

FIG. 5. Energy spectra of the polonium-210 α-particles backscattered from platinum.

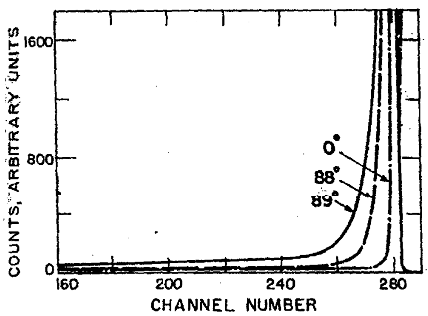

FIG. 6. Detailed view of the low-energy edge of the energy spectra of polonium-210 from monel.

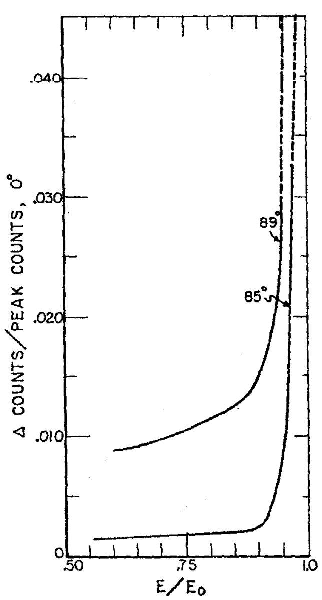

FIG. 7. Relative energy of backscattered α-particles at 85° and 89°.

α-counters and compared them with 2π counters; and by ROBINSON[1] who has designed an α-counter of about 1π steradians with an acceptance angle of 120°. With low-geometry counters such as these, virtually no backscattered α-particles are detected.

We may conclude from the results of others and from our own, that when α-sources on metal backings are counted in counters such as those of YAFFEE, CURTIS, and ROBINSON, absolute counting can be done without regard to backscattering corrections. If absolute calibrations of α-particle sources are required from counters of 2π geometry, it is necessary to make a backscattering correction for each source.

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