CONVEYOR BELT METHOD FOR STUDYING SRORT-LIVED ACTIVITIES: Ag^{108}, Ag^{110} AND In^{116}

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INTRODUCTION

IT is difficult to study in detail the radiations in the decay of short-lived isotopes with half-lives ranging from a second to several minutes. It is necessary to have a high initial source strength in order to allow for the rapid decay in the interval after production and before measurements of its radiations can commence. Some mechanical device has to be used for quickly transferring the source after irradiation to the place of observation. Laborious corrections have also to be made to allow for the decay of the source during measurements. These difficulties have been partly overcome by the use of elaborate electronic devices which permit measurements in a brief period of observation.

It is, however, possible to use a mechanical device in which at one point in a continuously moving sample, spread on an endless conveyor belt, radioactivity is induced, say by (n, γ) reaction, and at another point it is detected and measured. It can be shown that in this case for a given geometrical arrangement and a given speed of the moving belt, a steady equilibrium counting rate is obtained. Usual techniques for measurement of beta and gamma radiations can be employed and apart from the question of source strength, difficulties arising from the rapid decay of a short-lived isotope are eliminated.

In some experiments based on this principle (Nahmias and Walen,[1] and Holmes[2]) the sample was spread on the rim of a rapidly rotating circular hoop, the neutron source and the detector being at opposite ends of a diameter. At the detector, the background counting rate due to the neutron source was high, often higher than that due to the induced activity. The technique of a moving conveyor belt described in this paper makes it possible to choose a distance between the neutron source and the detector such that adequate lead shielding can be installed to reduce the background counting rate to a negligible value. Feeble induced activities can therefore be studied.

This method also affords greater mechanical flexibility as regards the disposition of the source inducing activity and the detector.

Some results with short-lived isotopes of silver and indium obtained by using this technique are described. Our equipment as now set up is suitable for measuring activities with half-lives ranging from a second to several minutes.

THEORY OF THE METHOD

Consider an arrangement as shown in Fig. 1, in which a conveyor belt of total length L passes near the neutron source R and the counter C. Let the portion of belt within the neutron flux at any instant be of length l_1 and let the portion 'seen' by the counter be l_3, each of these being small compared to L. The length of belt from R to C is l_2.

$\left(\text{In the present arrangement } l_2 \text{ is about } \frac{L}{2}\right)$.

The probability that an activated atom emerges from the region of neutron flux is

$$P = \int_0^{l_1} F \, . \, \sigma \, . \frac{dl}{V} \cdot e^{-\frac{\lambda l}{L} \cdot \tau}$$

where $V = \frac{L}{\tau}$, τ being the period of revolution of the belt.

$$\therefore P = \tau \frac{F\sigma}{L} \int_0^{l_1} e^{-\frac{\lambda l}{L} \cdot \tau} \, dl$$

$$\therefore P = \frac{F \, . \, \sigma}{\lambda} \left(1 - e^{-\frac{\lambda l_1}{L} \cdot \tau}\right). \qquad (1)$$

Here, F is the neutron flux, σ is the capture cross-section for neutrons and λ the decay constant of the induced activity.

The probability that an activated atom leaving the region of neutron flux decays in front of the counter is

$$q = e^{-\lambda \frac{l_2}{L} \cdot \tau} - e^{-\lambda (l_2 + l_3) \frac{\tau}{L}}$$

$$\therefore \quad q = e^{-\frac{\lambda l_2 \cdot \tau}{L}} \cdot \left(1 - e^{-\frac{\lambda l_3}{L} \cdot \tau}\right).$$

The probability that this happens during the second revolution is $q \cdot e^{-\lambda \tau}$.

Hence the total probability that an activated atom decays in front of the counter is

$$Q = e^{-\frac{\lambda\, l_2 \cdot \tau}{L}} \cdot \left(1 - e^{-\frac{\lambda l_3}{L}\cdot \tau}\right)\left(1 + e^{-\lambda\tau} + e^{-2\lambda\tau} + \ldots\ldots\right)$$

$$\therefore \quad Q = e^{-\frac{\lambda\tau}{L}\cdot l_2}\left(1 - e^{-\frac{\lambda\tau}{L}\cdot l_3}\right)\frac{1}{1 - e^{-\lambda\tau}}\,. \qquad (2)$$

If N_0 is the number of inactive atoms of the sample per unit length of the belt then the number of disintegrations per second counted by the detector is

$$C = K.N_0 \cdot \frac{L}{\tau} \cdot P{\cdot}Q$$

where K is a constant depending on counter geometry and efficiency.

$$\therefore \quad C = K.N_0 \frac{LF.\sigma}{\tau.\lambda}\left(1 - e^{-\lambda\tau\frac{l_1}{L}}\right)\frac{e^{-\lambda\tau\frac{l_2}{L}}}{1 - e^{-\lambda\tau}},\ \left(1 - e^{-\lambda\frac{\tau}{L}l_3}\right) \qquad (3)$$

If $\lambda\tau \cdot \frac{l_1}{L} << 1$ and $\lambda T \cdot \frac{l_3}{L} << 1$

$$C = KN_0\, F\,.\,\sigma\,.\,\frac{l_1\, l_3}{L}\cdot \lambda\tau\,\frac{e^{-\lambda\tau\cdot\frac{l_2}{L}}}{1 - e^{-\lambda\tau}}\,.$$

Putting $x = \frac{\lambda\tau}{2}$ and $l_2 = \frac{L}{2}$,

$$C = \left(KN_0\, F\sigma\,\frac{l_1\, l_3}{L}\right)\frac{2x\cdot e^{-x}}{1 - e^{-2x}}$$

$$\therefore \quad C = C_0\,\frac{x}{\sinh x}\,. \qquad (4)$$

C_0 is a constant depending on counter geometry and efficiency, thickness and density of the sample, neutron flux and capture cross-section and is independent of decay constant and period of revolution of the belt, provided $\lambda\tau\frac{l_1}{L}$ and $\lambda\tau\frac{l_3}{L}$ are small compared to unity.

When a single activity of decay constant λ is present the variation of $\frac{x}{\sinh x}$ with the period of revolution τ is that shown in curve *a* of Fig. 2. At high speeds of the belt $\frac{x}{\sinh x}$ approaches unity and the saturation counting rate C_0 is reached. One can see that when $\frac{\tau}{T} = 0{\cdot}1$, where T is the half-life, $\frac{x}{\sinh x}$ is very nearly equal to unity. When $\frac{\tau}{T} = 1$ this differs very little from unity. Therefore, to obtain saturation counting rate C_0, the period of revolution τ must not be more than T. This falls to half the saturation value $\frac{C_0}{2}$ at $\tau = 6 \cdot 3$ T, where T is half-life of the activity. Any deviation from this would indicate the presence of more than one short-lived activity. When one activity is present it is possible to calculate the half-life from observations of the counting rate at different periods of revolution of the belt.

When two short-lived activities are simultaneously present, at high speeds of the belt (when $\tau < T_1$ or T_2), the saturation counting rate due to each of them individually can be calculated from the observed saturation rate if the relative isotope abundance and capture cross-sections are known. As the period of the belt is increased the contribution to the counting rate from the shorter-lived activity decreases more rapidly than that from the longer-lived one. It is possible in favourable cases to choose a period of the belt at which the contribution from the shorter-lived activity is negligible and the longer-lived activity can be investigated without interference from the former. It is also possible to calculate the half-life of one of the activities if that of the other is known, making use of known relative isotope abundance and capture cross-sections.

EXPERIMENTAL ARRANGEMENT AND OBSERVATIONS

Fig. 1 shows the experimental arrangement used for the present investigations. The endless belt B, 20 feet in length, runs over two pulleys A, each 1 foot in diameter. One of the pulleys is coupled to a motor specially designed for this purpose and capable of giving continuously variable speeds up to a maximum of 1400 rev. per minute. The belt passes through a cavity in a paraffin block P which also contains at R, just below the belt, a Radium-Beryllium source of neutrons of strength 500 m.c. L is a heavy lead shield surrounding the paraffin block. The pulleys A were arranged in two adjacent rooms with the wall W separating them for better shielding. At C an end-window Geiger counter was used for beta-ray counting and a scintillation counter for gamma-ray measurements. The length of belt from R to C was half its total length. The counter C, which was adequately shielded by surrounding lead, was so arranged that aluminium absorbers could be interposed between its window and the sample on the belt.

With the Ra-Be source in position the background counting rate was determined for no sample on the belt, both when the belt was at rest and in motion. The background rate in both the cases was found to be 25 counts per minute, only a few counts more than the natural background.