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TABLE OF CONTENTS

	Page
The Effects of Photoperiod, Temperature, and Thyroxin on the Transformation of Laval <i>Ambystoma annulatum</i> Patrick H. Ireland	5
Characterization in the Children's Books of A. A. Milne Marie W. Nelson.....	13
The Negro in the Prohibition Party A Case Study of the Tennessee Prohibition Party Hanes Walton, Jr.....	23
An Inquiry Into Burma's Policy of Neutralism Hanes Walton, Jr.....	35
Undergraduate Nuclear Experiments with ^{210}pb - ^{210}Bi Equilibrium Mixture M. P. Menon	53

Undergraduate Nuclear Experiments with ^{210}Pb - ^{210}Bi Equilibrium Mixture

M. P. Menon

Department of Chemistry, Savannah State College
Savannah, Georgia

It has been recognized by many teachers and scientists that nuclear education be made a part of undergraduate chemistry curriculum (1). Although most of the larger colleges and Universities have been offering at least one undergraduate course in nuclear science for several years undergraduate students of smaller colleges are not often exposed to radioisotope techniques. In a recently introduced "Radioisotope Technology" course at this college we have developed several experiments with ^{210}Pb - ^{210}Bi equilibrium mixture which may be useful for similar courses in undergraduate curriculum.

Several laboratory experiments have been suggested by various authors, in the past, for an undergraduate course in radiochemistry (2-6). The $^{137\text{m}}\text{Ba}$ equilibrium mixture suggested for demonstration of parent-daughter equilibrium studies and half-life determination (2,3) is not very convenient due to the short half-life of $^{137\text{m}}\text{Ba}$ daughter. The half-life determination of ^{234}Th (5) is based on the measurement of the daughter, ^{234}Pa , activity after it reached equilibrium with its parent and it usually takes about two months to finish the experiment. The ^{210}Pb - ^{210}Bi equilibrium mixture offers a better choice for the radioactive equilibrium studies and half-life determination provided a rapid and convenient method for the radio-chemical separation of ^{210}Bi is available. The dithiazone method for the separation of bismuth(7) is tedious and more time consuming. An ion-exchange batch method has been developed in our laboratory for a rapid separation of ^{210}Bi from its parent. The isolated ^{210}Bi which has a convenient half-life ($T_{1/2} = 5\text{d}$) may be used for half-life determination. The long-lived ^{210}Pb component stripped out of the ion-exchange by ammonium citrate solution may be used to study the growth of the daughter reaching secular equilibrium with the parent. It is clear from the decay scheme of ^{210}Pb shown in Fig. 1 that out of the three radioisotopes resulting from the decay of ^{210}Pb only the beta activity of ^{210}Bi can be detected by a G. M. counter. Beta rays from ^{210}Pb are too soft to be detected by an end-window G. M. counter. This permits the radiochemical measurement of the distribution coefficient of Bi(III) between the ion-exchange resin and the aqueous solution. The ^{210}Pb - ^{210}Bi mixture was also used as an ideal sample for the determination of E_{max} of beta radiation from ^{210}Bi by absorption measurements.

EXPERIMENT

a) Purification of Ion-exchange Resin:

Dowex 50W-x4 cation exchange resin, 50-100 mesh, was purified as follows: About 20 g of the resin was washed several times with deionized water and decanted. It was then washed three times with 10% solution of ammonium citrate (pH \sim 3.5). The resin was thereafter stirred with 3 M HCl to convert the resin into the H⁺ form and the mixture decanted. It was finally washed with water several times until the washings did not give a positive test for chloride with silver nitrate solution. The resin was dried in the air and stored in a bottle.

b) Procedure for the Separation of ²¹⁰Bi:

Two milliliters (\sim luC) of ²¹⁰Pb-²¹⁰Bi mixture in very dilute nitric acid solution (pH \sim 4) was diluted to 6 ml with water in a centrifuge tube. Half a gram of the purified and dry resin was added to the solution and the mixture was stirred for two minutes. It was centrifuged and the supernatant was transferred to another test tube. Half a milliliter of this solution was dried on a flat planchet, mounted on a cardboard and counted in a G. M. counter. This sample, labelled ²¹⁰Bi, was used for the determination of the half-life of ²¹⁰Bi.

The residual resin in the centrifuge tube was washed 3 times with water to remove any unabsorbed activity in the mixture. It was then treated with 5.5 ml of 10% ammonium citrate solution whose pH was adjusted to 5.8 with ammonia and the total volume made up to 6.5 ml, same as before, including the volume of the resin (0.5 ml). The mixture was stirred for two minutes and then centrifuged. Half a milliliter of the supernatant was dried on a planchet, mounted on a cardboard and this ²¹⁰Pb sample counted in the same G. M. counter under identical geometry. The above experiment was repeated three times. The data obtained from these experiments were also used to calculate the distribution coefficient of Bi(III) between the ion-exchange resin and the aqueous solution.

c) Measurement of E_{max} of Beta Radiation from ²¹⁰Bi:

Two milliliter (\sim luC) of the same tracer solution (²¹⁰Pb-²¹⁰Bi) mixture) was diluted to 6.5 ml. Half a milliliter of the diluted solution was dried on a planchet, mounted on a cardboard and counted under the same geometry for several days to show the equilibrium nature of the tracer solution. The same sample was used, under different geometry, for absorption measurements with aluminum absorbers. A standard source of 3.75y ²⁰⁴Tl, a monoenergetic beta-emitter with E_{max} = 0.765 Mev, was used for the analysis of absorption data by Feather's method(8).

RESULTS AND DISCUSSIONS

The growth and decay curves of ²¹⁰Bi obtained from the counting data of typical ²¹⁰Bi and ²¹⁰Pb samples along with the equilibrium activity of ²¹⁰Pb-²¹⁰Bi as a function of time are

presented in Fig. 2. The decay curve "a" shows that there is no contamination from ^{210}Pb from which it may be inferred that the lead ion is completely absorbed on the ion-exchange resin. The half-life of ^{210}Bi obtained from curve "a" is in good agreement with the reported value (5.0d). It is to be pointed out that there is good agreement between the total activity of the ^{210}Pb sample after reaching equilibrium and the equilibrium activity of the tracer sample. However, it is evident from curve "b" that the isolated ^{210}Pb sample also contains a fraction of ^{210}Bi activity initially in equilibrium with ^{210}Pb . Since the beta activity from ^{210}Pb is not counted in the G. M. counter this represents the ^{210}Bi activity absorbed on the ion-exchange resin. Curve "b" may be represented by the equation:

$$A_t = A_{\text{Bi}(r)} + (A_{\text{Bi}(e)} - A_{\text{Bi}(r)}) (1 - e^{-\lambda_{\text{Bi}} t}) \quad \dots(1)$$

Where A_t is the total activity at any time t , $A_{\text{Bi}(r)}$ the activity of ^{210}Bi absorbed on the column, $A_{\text{Bi}(e)}$ the total equilibrium activity of ^{210}Bi in the ^{210}Pb sample, λ_{Bi} is the decay constant of ^{210}Bi . The distribution coefficient, K_d for Bi was calculated from the following relation(9):

$$K_d = \frac{\text{Amt. of metal per g of resin}}{\text{Amt. of metal per ml of solution}} = \frac{A^*_{\text{Bi}(r)} \cdot v}{A^*_{\text{Bi}(a)} \cdot m} \quad \dots(2)$$

where $A_{\text{Bi}(r)}$ is the activity absorbed in "m" g of resin, $A_{\text{Bi}(a)}$ is that in V ml of the solution. The average value of K_d obtained from three experiments is 12.9 ± 2.0 .

Fig. 3 shows the absorption curves of the standard source, ^{204}Tl , and of ^{210}Pb - ^{210}Bi sample. The range of the beta radiation from ^{204}Tl was calculated from its known energy using the following equation developed by Glendenin(10):

$$R = 0.407 E_{\text{max}}^{1.38} \quad \dots\dots\dots (3)$$

where R is the range in g/cm^2 and E_{max} is the maximum energy of beta radiation. The range and energy of beta particles from ^{210}Bi were computed using Glendenin's modified method of Feather analysis of the beta absorption curve(10). The E_{max} of beta radiation from ^{210}Bi obtained from the analysis was 1.10 mev which is in a good agreement with the reported value of 1.16 Mev.

In summary the ^{210}Pb - ^{210}Bi equilibrium mixture was shown to be an ideal source to conduct several experiments in any undergraduate course which deals with radioisotope techniques. Although the yield is about 50% the proposed ion-exchange batch method may be used for a rapid separation of ^{210}Bi from the ^{210}Pb - ^{210}Bi equilibrium mixture.

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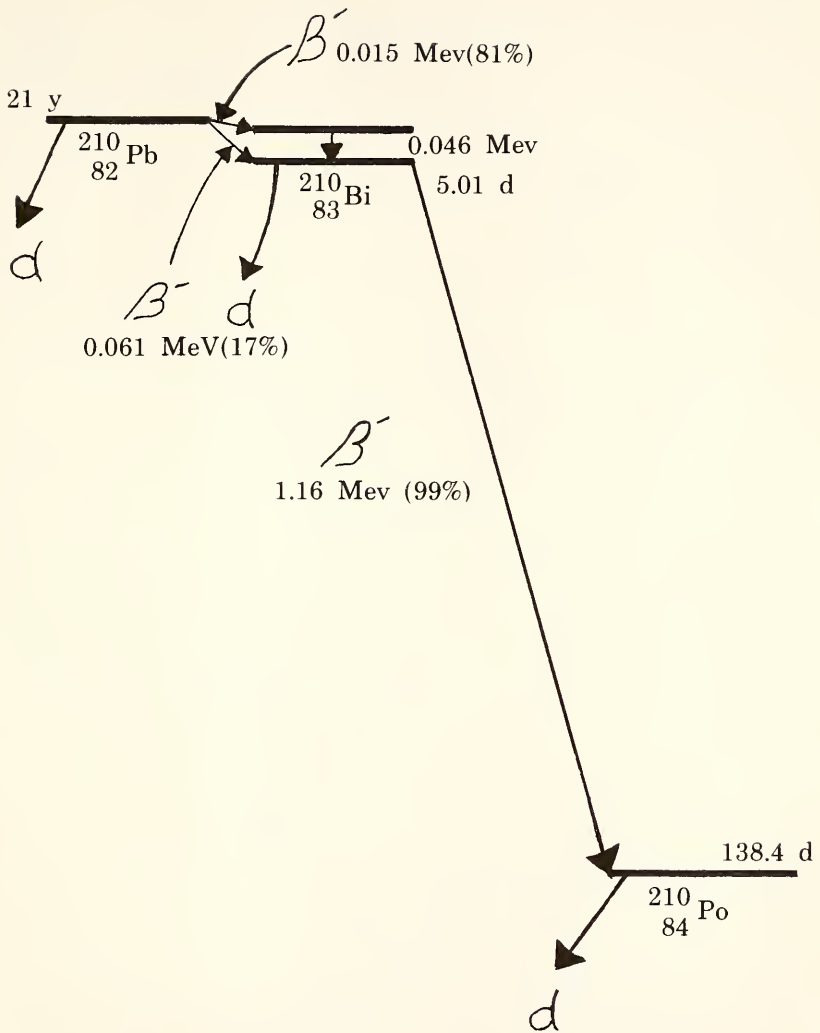


Fig. 1. Decay scheme of ^{210}Pb .

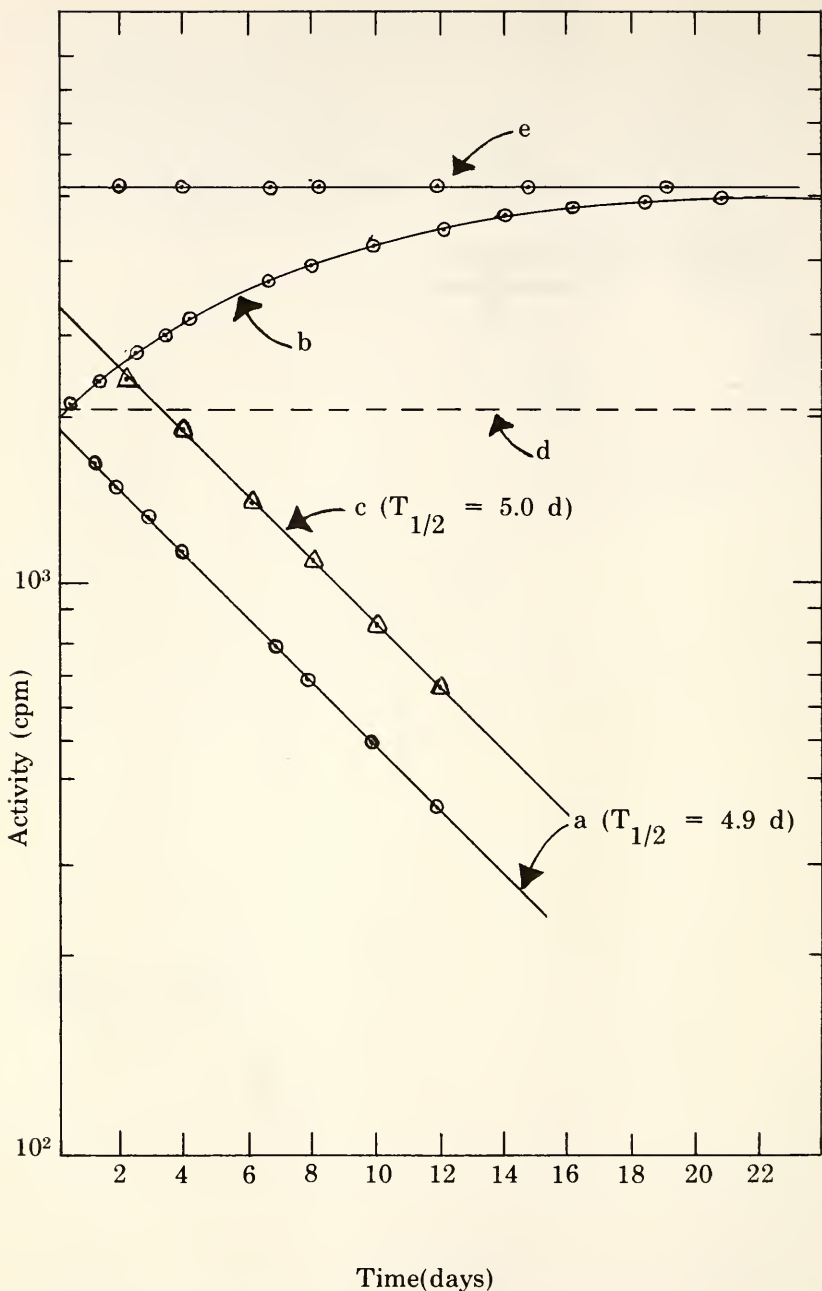


Fig. 2. Growth and decay of ^{210}Bi ; (a) Decay curve of ^{210}Bi isolated from the mixture, (b) Growth curve of the daughter, ^{210}Bi , (c) Decay curve of ^{210}Bi by subtraction of growth from equilibrium activity, (d) ^{210}Pb - ^{210}Bi equilibrium activity from the ion-exchange as a function of time, (e) Equilibrium activity of the tracer.