Reports

Beryllium-10 in a Manganese Nodule

Abstract. *Analyses of beryllium-10 activity in two sections of a manganese nodule indicate an accumulation rate that compares well with such rates measured by other methods on different nodules. The observed specific activity of beryllium-10 in the nodule is in accord with the calculations based on the production of beryllium-10 by cosmic rays in the atmosphere and with the geochemistry of beryllium in the ocean.*

Radioactive beryllium-10 produced by cosmic rays has been detected in marine deposits (*1*), and its potentialities for dating ocean sediments have been explored (*2*). The ferromanganese minerals form from dissolved species in sea water (*3*). Since the concentrations of stable Be appear to be of the same order as those in pelagic sediments (*4*), the search for Be^{10} in these minerals was attempted.

The DODO 15-1 manganese nodule, obtained by dredge haul from a depth of 4160 m at 19°23′N, 162°20′W, has a 2-cm thick, flat, rectangular crust of about 50-cm^2 area; this crust covers a base of altered basalt. The chemical and mineralogical analyses (*5*) showed that it contains 29.5 percent Mn and 20.5 percent Fe, with δ-MnO_2 being the principal mineral phase. The crust was sliced horizontally into two sections: a 0−1 cm section and a 1−2 cm section. Each section weighed about 120 g.

For analysis of Be^{10} the nodule material was dissolved in 250 ml of concentrated HCl, and 30 percent H_2O_2 was slowly added. The solution was centrifuged, the insoluble phases were washed with double-distilled water, and the washings were added to the main solution. The insoluble phases amounted to 12 percent of the nodule material on a dry-weight basis. To 90 percent of the solution, beryllium nitrate carrier (53.4 mg BeO) was added; the hydrogen peroxide was decomposed by heating, and a hydroxide was precipitated with ammonium hydroxide. Iron was removed by extraction with isopropyl ether, Al was separated by the Gooch Haven method and Be was separated and purified by cation- and anion-exchange methods and thenoyltrifluoroacetone extraction (*2*). The beta activity of the samples was measured with a rectangular, flat, gas-flow counter (*6*) having a background counting rate of 4 counts/hour. In order to check on the energy of the beta radiation, absorption measurements were carried out with polyethylene absorbers of 12 and 24 mg cm^{-2}. The samples were then subjected to further chemical purification (*2*) and recounted. Yields were 60 and 30 percent, respectively, before and after the second purification (Table 1). Blanks of the chemical reagents of the initial purification cycle showed no measureable activity.

Table 1. Beryllium-10 analysis of DODO 15-1 manganese nodule. Weighted means are shown in parentheses.

Sample	Net β activity (count/hr)	Be^{10} concentration × 10^3 (dpm/g nodule)	
0–1 cm	12.8 ± 0.7	9.6 ± 0.6	(9.2 ± 0.5)
0–1 cm*	5.4 ± 0.6	8.2 ± 1.0	
1–2 cm	3.5 ± 0.8	2.1 ± 0.5	(2.0 ± 0.6)
1–2 cm*	1.7 ± 0.6	1.8 ± 0.6	

* After 2nd purification.

The absorption measurements before and after the second purification process yielded half-thickness values 17 ± 4 and 24 ± 7 mg cm^{-2}, respectively, for the β-activity of the 0–1 cm sample. The half-thickness for a sample of synthetic Be^{10} was measured by Arnold (*1*) and found to be 21 ± 0.3 mg cm^{-2}. In view of the low activity, no absorption measurements could be made on the 1–2 cm sample.

The close agreement between the measured half-thickness and that of the radiation of synthetic Be^{10} with the observation that the specific activity remained unchanged after recycling suggests that the activity is due to Be^{10}.

The 0–1 cm sample has about five times more activity than the 1–2 cm sample (Table 1). On the assumption that the manganese nodule and the isotopes of Be, Be^{10}, and Be^9 have accumulated at a uniform and constant rate the expected concentration *c* of Be in the nodule is given by

$$c^* = \frac{R^*}{\lambda\rho\,(x_2 - x_1)}\left(\exp\frac{-x_1\lambda}{S} - \exp\frac{-x_2\lambda}{S}\right) \quad (1)$$

$$c = R/S\rho \quad (2)$$

where *R* is the rate of accumulation of Be atoms in the nodule, ρ is the specific gravity of the nodule, λ is the disintegration constant for Be^{10}, and *S* is the accumulation rate of nodule (millimeters per million years). The asterisk is used for the radioactive species and x_1 and x_2 are the depth intervals of the slice ($x = 0$ at the surface) analyzed.

From Eq. 1 and the observed Be^{10} activity in the nodule in the 0–1 and 1–2 cm sections, it is deduced that the rate of accumulation of this nodule is 1.8 (+ 0.5, − 0.2) mm per million years. This compares well with the measured rates of accumulation of different nodules by other radioactive methods (in millimeters per million years): that is, 6 to 8 by the ionium-thorium method (*7, 8*); 27 by the U^{234}/U^{238} activity ratio method (*8*); 0.5 to 3.5 by K–Ar dating of the volcanic minerals in the cores of nodules (*8*); and 2.5 to 3.0 by gross counting of alpha (*9*).

The calculated value of R^*/R, the specific concentration of Be^{10} in sea water, is 3300 ± 750 disintegrations per minute of Be^{10} per gram Be^9, if the concentration of Be^9 is 5.5 ppm (*4*) and the specific gravity is 2.5 g cm^{-3} (*10*) for this nodule. This value is in good agreement with the calculated value of 1600 dpm (*11*), if one considers the uncertainties in the residence time and concentration of beryllium in sea water. The calculated specific activity of Be^{10} in the nodule at the surface, C_o, is (18 ± 4) × 10^{-3} dpm of Be^{10} per gram of nodule.

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Efflux Time of Soap Bubbles and Liquid Spheres

Abstract. *The efflux time,* T, *of gas from soap bubbles of radius,* R, *through their blow tube of length,* l, *and radius,* ρ, *is given by the equation*

$$T_{start \rightarrow end} = \frac{2 \cdot \eta \cdot l}{\sigma \cdot \rho^4}(R^4_{start} - R^4_{end})$$

where η *is the viscosity of the gas and* σ *the surface tension of the bubble solution, all in centimeter-gram-second units. Similar relations between time and diameter were established for the flow from one bubble to another or from one bubble within another. The same relations hold for the flow of liquid spheres, suspended in another liquid of equal density, following Plateau's classic method. They have been extended to the flow of spheres to cylinders and catenoids of rotation. In all these cases the driving force is the surface or interfacial tension, creating an excess pressure as defined by Laplace's equation.*

During my recent experiments on the solidification of soap bubbles (*1*), I could not find any published information on the shrinkage in size of soap bubbles, as the air flows out of them through the blow tube, as a function of time (*1–4*). Likewise Plateau's (*2*) liquid spheres suspended at zero gravity in a nonmiscible liquid, and the flow from one sphere to another, either a soap bubble or a liquid, or from a sphere to a cylinder have not been studied. Furthermore, the change in shape, for example from a cylinder to catenoid of rotation, has not been investigated. Even the much simpler two-dimensional analogon, that is, the flow of the Langmuir liquid lens through a channel into another lens, floating on a nonmiscible liquid, has not been investigated. Yet similar systems, where the flow is determined by surface tension forces, may occur in biological systems [for example, the giant cell with a channel (*5*)].

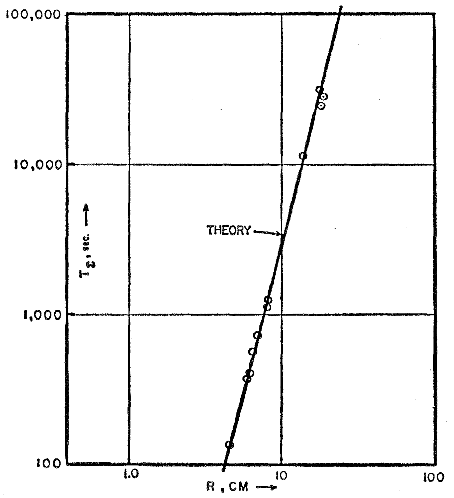

Fig. 1. Experimental efflux time of soap bubbles, in seconds, plotted against their radius, in centimeters.

I measured the efflux time of soap bubbles and other liquid spheres through the blow tube as a function of the diameter of the bubble or sphere. Efflux time is the time necessary for air (or any other gas) to flow out of the bubble as it is pressed out by its surface tension, σ, through the open blow tube of uniform inner radius, ρ, and length, l, as its radius at the start (R_{start}) is diminished to R_{end}, at the instant the tube is closed again. The total efflux time, T_Σ, is the time necessary for the complete disappearance of the bubble, that is, $R_{end} = 0$.

Soap bubbles were blown from a diameter of a few millimeters to 50 cm from soap solutions (*1, 6*). For protection, they were blown in (i) a rectangular glass fish aquarium, (ii) in a clear Plexiglas cube with a 55.9-cm edge made for me by the Dynalab Corporation of Rochester, New York, and (iii) in a 72-liter pyrex flask manufactured and donated by the Corning Glass Works.

The diameter of bubbles was first measured with two sliding plumb bobs, and later with a cathetometer. The image of small bubbles was magnified and projected onto a screen. Efflux times were measured with a watch or stopwatch in the range of a few seconds to over an hour. Four calibrated flow tubes were used. All results were monitored to a standard tube which has a length, l, of 29.0 cm and an inner radius, ρ, of 0.205 cm (its tube funnel had a tip with an outside radius, ρ_{out}, of 1.93 cm).

The efflux times obtained with the other tubes were multiplied by the ratios of the experimental flow tube constants and all results are shown on a log–log plot in Fig. 1. The experimental results with this standard tube alone are given by the equation:

$$T_\Sigma = 0.27 \cdot R^{3.96} \tag{1}$$

The exact theoretical line is given by the expression $T_\Sigma = 0.31 \cdot R^4$ (T is in seconds, R in centimeters).

In view of the good agreement, I conclude that the total efflux time is proportional to the fourth power of the radius (or diameter) of the bubble.

The exact law and the interpretation of the constant, c, can be arrived at by simple mathematics. The decrease in volume of a bubble sphere, dV, if its radius, R, is decreased by an amount, dR, is:

$$dV = 4\pi R^2 \cdot dR \tag{2}$$

The same volume element of gas, dV, of viscosity, η, flowing through a tube l cm long and with a radius, ρ, in the time, dt, equals, following Poiseuille's law (*7*):

$$dV = \frac{\Delta P \cdot \rho^4 \cdot \pi}{8 \cdot l \cdot \eta} \cdot dt \tag{3}$$

From these two expressions and since for a soap bubble $\Delta P = 4\sigma/R$, I obtain, after integrating,

$$T_{start \rightarrow end} = \frac{2 \cdot \eta \cdot l}{\sigma \cdot \rho^4}(R^4_{start} - R^4_{end}) \tag{4}$$

Therefore $c_{theory} = 2 \cdot \eta \cdot l / \sigma \cdot \rho^4$ and I obtain the value 0.31 sec/cm^4, using 28.6 dyne/cm for σ and 183 μpoise for η (air, 20°C), in close agreement with the experimental value in Eq. 1. It should be remembered that only a 1-percent error in both R and ρ causes an 8-percent error in the con-