Table 1. Bacterial cultures isolated from carbonaceous meteorites. Each value represents the average of four different determinations on four different small samples of the same meteorite. No colonies were obtained from the solvent or the nutrient agar.

Sample	Wt. (10^{-3} g)	Colonies per milliliter	
		Fragment washings	Powder washings
Murray	89.5	0	530
Mokoia	84.6	20	150
Orgueil	138.7	0	0

published in the scientific literature except that of Roy (*10*), who found *Bacillus subtilis* and *Staphylococcus albus* as contaminants in the Johnstown meteorite, a noncarbonaceous, achondritic stone. Our report constitutes the first definite identification, known to us, of viable ordinary bacterial contaminants in carbonaceous chondrites, specifically the Murray and Mokoia meteorites. It is of interest that similar strains of microorganisms have been found in these two independent studies, despite the fact that the meteorites examined are quite different.

Although the number of viable contaminants per gram of meteorite is relatively low, it remains to be seen whether the intermittent and repeated contamination of carbonaceous chondrites by microorganisms, which eventually leave their residues in these stones, may have contributed to any significant degree to the formation of some of the organic compounds which have been detected in these meteorites (*4*). On the basis of this and related work (*7–10*) it appears that future analyses of organic compounds in meteorites should be preceded by careful microbiological examinations.

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Exchangeable Mass: Determination without Assumption of Isotopic Equilibrium

Abstract. *The method of isotope dilution for determining the exchangeable mass of different substances in living organisms is, at best, approximate. A formally exact method, defining the otherwise vague concept of exchangeable mass, is proposed. The new method may serve as a standard for determining errors in results obtained by the earlier method.*

In considering potassium metabolism in man, if we assume steady state, the total potassium pool (that is, the body's total content of potassium) is constant in time. This pool may be regarded as two mutually exclusive subpools: exchangeable and nonexchangeable potassium. Total body potassium can be determined, at least in principle, by whole-body counting techniques, and usually the exchangeable mass has been determined by so-called isotope dilution. However, as explained below, the dilution method is based on a theoretically incorrect assumption, and in this report I present an alternative method in which this assumption is relaxed. The theory precisely defines exchangeable mass and gives some rules for design of experiments; for instance, the form of tracer supply may be significant (a special concept, "equivalent tracer supply," is introduced for this purpose).

In the following discussion, the population of isotopes naturally present in the body is referred to as "mother substance." The dilution method proceeds as follows: A small amount of a ^{42}K salt is injected into the body; the population of injected ions ($^{42}K^+$) is referred to as "tracer." The total-body content of tracer is observed, as well as the specific activity of blood (specific activity is the ratio between the amount of tracer and the corresponding amount of mother substance). It is assumed that after a time—perhaps 24 hours—"isotopic equilibrium" is reached; that is, specific activity is equal throughout the exchangeable potassium pool. On the basis of this assumption, measurements made at that time will permit determination of the amount of mother substance in the exchangeable pool; the intuitive concept of exchangeable mass thus becomes operationally defined.

In 1956 Berman and Schoenfeld (*1*) showed that the idea of isotopic equilibrium in terms of equal specific activity is justified only when the system is closed (an additional necesary assumption is that the system is irreducible). The metabolic system considered here is open, and it is then necessary to accept the dilution method as an approximation: one assumes that the specific activity is *approximately* the same throughout the exchangeable potassuim pool. There is no obvious reason to believe in such an approximation (*2*) and—this point is crucial—there has been no way to estimate the degree of approximation (*3*). To test the dilution method by killing animals and analyzing the ash is wrong in principle because the analysis gives total rather than exchangeable potassium. The occasional close agreement between results obtained by the dilution method and by ash analysis merely suggests that the former produces overestimates, in agreement with what theory indicates (*4*); this view is supported by work on sodium and potassium in man (*5, 6*).

Although specific activity in an open system everywhere approaches zero with time, and in that respect ultimately becomes everywhere equal, this fact does not justify the dilution method. The method requires both that the difference between specific activities of two arbitrary parts of the system should be zero, and that the ratio between the two specific activities should equal unity. This is more precisely explained later: it suffices here to note that it is

this necessary condition of unit ratio that is the essential problem of isotope dilution.

How can one get around this problem and still use tracer for determining the exchangeable mass of potassium? The following equation was recently derived, steady state being assumed (*7*):

$$b^o = \zeta^o_{se}\,\theta^o \qquad (1)$$

where we consider an *arbitrary* compartment C (that is, no particular homogeneity is assumed), b^o being the amount of mother substance (in this instance, natural potassium) in C; ζ^o_{se}, total absorbed influx (daily intake) of mother substance from the environment into the system (organism); and θ^o, mean time of sojourn in C (*8*). (Superscript ^{o} denotes that the symbol is independent of time and refers to mother substance; steady state means that all characteristics of mother substance are independent of time.) The answer to the question is then given by the following: If there is an instantaneous, *equivalent* supply of tracer to the system (*9*) at time $t = 0$, then according to (*7*)

$$\theta^o = \int_0^\infty \frac{b(t)}{b_s(0)}\,dt \qquad (2)$$

where $b(t)$ is amount of tracer ($^{42}K+$) in C at time t, and $b_s(0)$ is amount of tracer in the whole system at time zero (that is, the total amount of tracer supplied). Thus, if x^o denotes an entity of mother substance, $x(t)$ denotes the corresponding tracer entity.

To see the significance of these two equations we should first note that they hold for any compartment (domain) of the organism; the compartment may be chosen at will. Let us consider the following two compartments: (i) a small, fixed-volume element in a blood vessel, and (ii) the whole body. Then, if $a(t) \equiv b(t)/b^o$ is the specific activity in the first compartment, Eqs. 1 and 2 imply that

$$b^o_s = \int_0^\infty b_s(t)\,dt \Big/ \int_0^\infty a(t)dt \qquad (3)$$

where b^o_s is the amount of mother substance in the whole body (system), and $b_s(t)$ is the amount of tracer in the whole body (system) at time t. While the given interpretation of $b_s(t)$ is correct, it is incorrect for b^o_s because this quantity does not equal the body's total potassium content but rather a smaller amount representing that part of the total-body potassium that is reflected in the data; that is, b^o_s is the total exchangeable mass. The specific activity of blood is observable, and $b_s(t)$ can be estimated by whole-body counting techniques. Consequently Eq. 3 gives the exchangeable mass in observable quantities.

The method here outlined is theoretically exact and may therefore serve to define the otherwise vague concept of exchangeable mass. However, a practical trouble to note is the requirement that the tracer supply should be equivalent in the sense I employ (*9*); specific experiments on that point are needed. The following equation (from Eqs. 1 and 2) may serve to check the procedure:

$$\int_0^\infty a(t)dt = b_s(0)/\zeta^o_{se} \qquad (4)$$

provided that the daily intake (or output) of potassium can be determined independently; because we always assume steady state in mother substance, intake equals output.

In order to see the basic difference between the old dilution method and the method I present, let us first consider the fundamental requirement of the former: For every $\epsilon > 0$ there exists a time t_ϵ such that with

$$\frac{b(t)}{b^o} = \frac{b_s(t)}{b^o_s}\left[1 + h(t)\right] \qquad (5)$$

one has $|h(t)| < \epsilon$ for $t > t_\epsilon$.

In other words, the assumption of the dilution method is that one can make the ratio between the two specific activities $b(t)/b^o$ and $b_s(t)/b^o_s$ arbitrarily close to unity [that is, $|h(t)|$ can be made arbitrarily small] simply by waiting long enough. That this requirement is stronger than the condition that the difference between the two specific activities should approach zero is made clear by rewriting Eq. 5:

$$\frac{b(t)}{b^o} - \frac{b_s(t)}{b^o_s} = \frac{b_s(t)}{b^o_s}\,h(t)$$

The right-hand member of this equation approaches zero; so does the difference to the left, as soon as $b_s(t)$ approaches zero, independently of what happens to $h(t)$ [we have only to assume that $h(t)$ is finite]. Hence, as I stated initially, even though the specific activity in an open system everywhere approaches zero with time, and in that respect becomes ultimately equal everywhere, this fact does not justify the dilution method.

In the dilution method one must make the far-from-trivial and seemingly (*1–3*) unrealistic assumption that $h(t)$ is negligible and that consequently one has at the time of observation t_o

$$\frac{b(t_o)}{b^o} = \frac{b_s(t_o)}{b^o_s}$$

No such assumption is required for the new method; on the other hand, Eq. 3 can be written:

$$\int_0^\infty \frac{b(t)}{b^o}\,dt = \int_0^\infty \frac{b_s(t)}{b^o_s}\,dt \qquad (7)$$

and comparison of Eqs. 6 and 7 shows that, whereas the dilution method takes into account only a single point of the tracer process (measurements at one instant), the new method considers the whole process and therefore requires a series of measurements. One may say that the theoretical difficulties of the dilution method have been transformed into an experimental procedure that in the new method is more involved (there is the further requirement of equivalent tracer supply). But the increased experimental complexity has some benefits: because of the more rigorous theory, more precise information can be extracted from the data. The new approach may be valuable as a research tool and as a standard for the estimation of errors by the experimentally simpler dilution method. Comparison of results by the two methods may give insight into certain diseases, for example, certain forms of muscular atrophy, in which both the exchangeable mass of potassium and the distribution of that mass over the system are likely to change; the dilution method may be expected to be sensitive to changes in the distribution of mother substance even when the exchangeable mass is constant.

As far as I know, no experimental work along the lines indicated by Eq. 3 has been published. An equation somewhat similar to Eq. 5 has been suggested by Nosslin (*10*), but in his equation the left-hand member seems to refer to a homogeneous plasma (blood) compartment. By considering compartment C to be the whole system one gets the classic Stewart-Hamilton volume equation (applied in studies of blood circulation, but here generalized to an

arbitrary tracer system). An equation similar to Eq. 1 has been applied in the study of iodine metabolism (*11*), but ζ^{o}_{se} is replaced by the influx into the specific compartment (organ), and θ^{o} is interpreted as "the biological half-life for iodine in the thyroid gland"; essentially, the equation is used to define that entity.

The practical example I have chosen is perhaps not very appropriate: the short half-life of ^{42}K may introduce serious difficulties regarding observations during the later part of the tracer process, which are necessary for estimation of the integrals; the possible use of other potassium isotopes (such as ^{40}K) should be investigated. Moreover, if excretion is mainly in feces, the lag may distort the whole-body curve $b_s(t)$, especially if the considered element has a high relative turnover—that is, if ζ^{o}_{se}/b^{o}_{s} is large. This distortion could be a problem in the determination of the exchangeable mass of sodium, but whole-body counter data on retention of $^{22}Na^{+}$ look promising (*12*). The exchangeable mass of certain elements may prove impossible to determine.

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Frog Retina: Detection of Movement

Abstract. *The response of class 2 ganglion cells in the frog retina is dependent on the angular velocity of a black visual stimulus whose size (1.2°) and contrast against a background are held constant. The relation between neuronal discharge rate and the angular velocity of the stimulus may be expressed as a power function.*

Microelectrode recordings from retinal ganglion cells indicate that the retina of the frog performs several distinct types of operations on the visual world (*1*). One class of ganglion cells, called convex-edge detectors or class 2 neurons, is especially sensitive to the movement of objects which are smaller than the excitatory receptive field (ERF) (*1, 2*). Previous studies have shown that the neuronal discharge rate elicited by the traverse of a stimulus through the ERF increases with increasing angular velocity of the stimulus; however, this relation was not examined quantitatively. In our investigation we studied quantitative characteristics of the neural integrative process which determines the class 2 operation. We found that the relation of the angular velocity of the stimulus to ganglion-cell activation could be expressed as a simple mathematical function.

Metal-filled micropipettes were used to record the discharges of single, afferent, optic-nerve fibers in the superficial layer of the optic tectum of the European water frog, *Rana esculenta*. The frog was curarized and fixed before a specially constructed hemispherical perimeter with a radius of 25 cm. The stimulation apparatus has been described in detail (*3*). The stimulus, a black round spot on a white background, was carried by a motor-driven stage behind a window cut in the back of the hemisphere. The motor was geared to permit movement of the stimulus at nine specific angular velocities, between 0.05° per second and 24° per second; higher angular velocities were possible by manual movement of the stage. The traverse of the stimulus was along a straight line, tangential to the hemisphere. The luminance of the white stimulus background was 64 millilamberts, and that of the black spot was 1.9 millilamberts.

Twenty-five class 2 neurons were tested with at least five of the nine possible angular velocities; the sequence of the velocities was varied during the course of the experiments. Each stimulus traverse was followed by a 75-second "rest period" (15 seconds

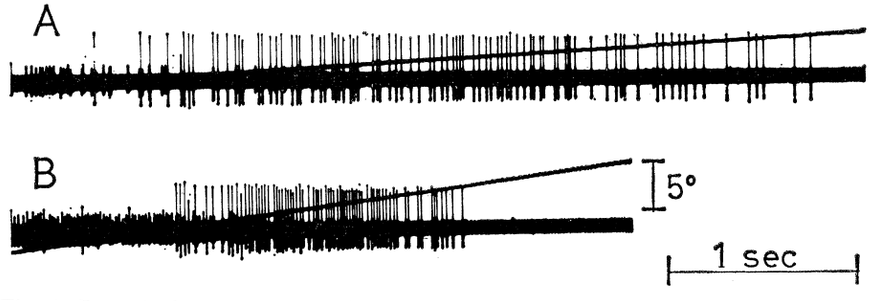

Fig. 1. Record of responses of a class 2 neuron to a 1.2°-black spot on a white background moved at two different angular velocities. The diagonal trace represents the stimulus movement. (*A*) Stimulus angular velocity is 0.95° per second; total discharge number per stimulus traverse of the ERF is 86; average discharge rate per traverse is 24 per second. (*B*) Stimulus angular velocity is 2.4° per second; total discharge number is 71; average discharge rate is 48 per second.