Horizontal Diffusion

Abstract. The neighbor diffusivity for pairs of diffused particles is determined from observations on drifts of various kinds of materials such as drift bottles in many parts of the ocean and a lake. Its values are expressed as the 4/3 power of separation of particles over a range from 10 to 10^8 cm.

A recent work by Joseph and Sendner on horizontal diffusion in the sea seems to give promise of an eventual resolution of the Fickian versus neighbor diffusivity problem (*1*). Among other things, it has caused us to reexamine our own work on the subject. The purpose of this note is essentially to extend the range in which the 4/3 power law appears to be valid.

It will suffice to consider only the one-dimensional aspect of diffusion. If $\nu(x)$ is the concentration of particles at x, there will be $\nu(x)\mathrm{d}x$ particles between x *and* $x+\mathrm{d}x$. By analogy to classical concentration, the neighbor concentration $q(l)$ is defined as the number $q(l)\mathrm{d}l$ of pairs of particles whose separations are in the range l to $l+\mathrm{d}l$. The Richardson diffusion equation

$$\frac{\partial q}{\partial t} = \frac{\partial}{\partial l}\left[F(l)\,\frac{\partial q}{\partial l}\right] \qquad (1)$$

is analogous to the classical Fickian equation since $F(l)$, the neighbor diffusivity, takes the place of the ordinary diffusivity K. Stommel postulated that the initial separation l_0 is large compared with $l_1 - l_0$, where l_1 is the separation after time T (*2*). With this restriction, he derived the relation

$$F\left[\frac{1}{2}\,\overline{(l_1 + l_0)}\right] = \frac{\overline{(l_1 - l_0)^2}}{2T} \qquad (2)$$

where the bars indicate averages. Stommel checked the validity of this equation by using pieces of parsnip with spacings of the order of 25 to 200 cm (Richardson and Stommel, *3*) and dye spots with spacings 1000 to 10,000 cm and sheets of mimeograph paper with spacings 40 to 1000 cm (Stommel, *2*). These data are shown by crosses in Fig. 1. Later, Olson (*4*) showed that his drift card data (*5*) and Platania's (*6*) drift bottle data also seemed to satisfy Eq. 2 in spite of the severe deviation from the conditions imposed in deriving the equation. This may be seen in Fig. 1 where Platania's data are represented by a square and Olson's data by triangles.

Ichiye treated drift bottle data from Japanese waters in a somewhat similar manner (*7*). Since he was interested at that time in verifying an approximation occurring in one of his derivations, the data were not plotted as they are in our Fig. 1. By plotting these data in this manner, however, we find (see circles) that they are in excellent agreement (*8*). The line shown in Fig. 1 was determined by least squares for the condition that the slope is 4/3. It represents the equation

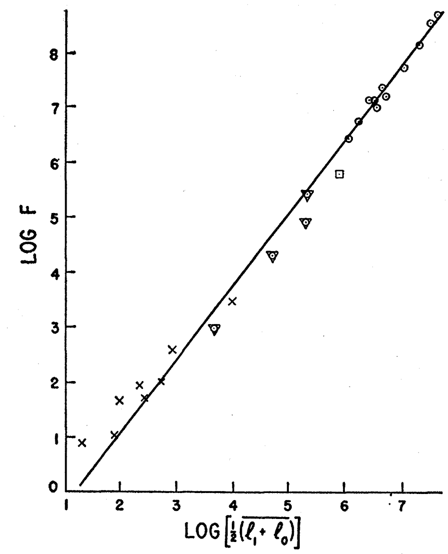

Fig. 1. Composite graph of data from Stommel (crosses), Olson (triangles), Platania (square), and Ichiye (circles). The line is a least-square fit of

$$\log F = \frac{4}{3}\log\left[\frac{1}{2}\,\overline{(l_1 + l_0)}\right] + a,$$

where a was determined to be -1.609.

$$F(l) = 0.0246 l^{4/3} \qquad (3)$$

where $l = \tfrac{1}{2}(l_1 + l_0)$.

For the data as a whole, the correlation coefficient $r = 0.993$. For Ichiye's data alone, $r = 0.992$. A least-squares fit for the data as a whole gives a slope of 1.29; for Ichiye's data, the slope is 1.37.

Figure 1 is remarkable in many respects. Included in it are observations on parsnips, dye spots, sheets of paper, drift cards, and drift bottles. The observations were made in the Atlantic and Pacific oceans, in the Mediterranean Sea, and in Lake Erie. Drift card and drift bottle data are notoriously inaccurate. Most of the points were obtained under conditions which nowhere met the requirements made by Stommel in his derivation of Eq. 2. Yet the correlation over a range from 10 to 10^8 cm is 0.993 (*9*).

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8. Actually l_1 was taken as the distance between recovery points of pairs of drift bottles thrown at the same station and l_0 was put to zero.
9. This report is contribution No. 119, Oceanographic Institute, Florida State University.

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Zinc-65 in Foods

Abstract. Small quantities of Zn^{65} have been found in a wide variety of foods obtained from the local markets serving Cincinnati, Ohio. The highest levels of radioactivity were observed in oysters harvested from Chesapeake Bay; however, none of the samples contained significant quantities of this radionuclide in terms of a potential radiological health hazard. In view of the widespread occurrence of Zn^{65} in foods, it has been postulated that this radionuclide has been dispersed by high-altitude fallout.

Recently Perkins and Nielsen (*1*) have reported the presence of Zn^{65} in produce from farms irrigated with water from the Columbia River and also in animals and people eating this farm produce. They state: ". . . Zn^{65} from nuclear tests has not been ob-

Table 1. Concentration of Zn^{65} in foods.

Sample	Date of sampling	Zn^{65} ($\mu\mu$c/kg)
Oysters (Chesapeake Bay)	Jan. 1959	178
Oysters (Chesapeake Bay)	Mar. 1958	124
Clams, hard-shelled (East Coast)	May 1958	40
Mixed Meats*	Sept. 1958	17
Mixed fresh leafy vegetables (washed)†	Aug. 1958	12
Mixed fresh root vegetables (washed)‡	Aug. 1958	10
Eggs	Aug. 1958	6
Mixed fresh legumes and corn (washed)§	Aug. 1958	4
Milk	Jan. 1959	4
Mixed fresh fruits (washed)‖	Aug. 1958	3

* Equal parts of chicken, lamb, beef, and pork; † equal parts of lettuce, cabbage, spinach, broccoli, celery, and cauliflower; ‡ equal parts of potatoes, sweet potatoes, carrots, beets, radishes, and turnips; § equal parts of shelled peas, string beans, shelled lima beans, and corn; ‖ equal parts of apples, grapes, grapefruit, oranges, peaches, plums, strawberries, and cantaloupe.

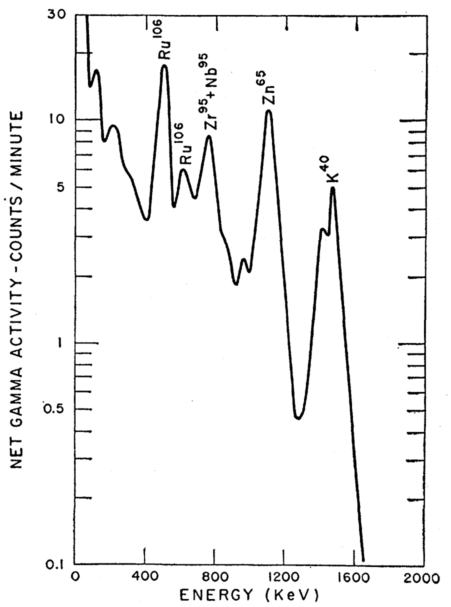

Fig. 1. Gamma spectrum of the ash of an oyster sample harvested from Chesapeake Bay.

served in foods raised in this country." Investigations made in our laboratory have revealed the presence of this radionuclide in a wide variety of foods of different origin, although at levels considerably lower than those observed in the samples collected downstream from the Hanford project.

A number of food samples purchased on the Cincinnati market have been analyzed for a variety of radionuclides, including Zn^{65}, during the past year. The gamma spectra of the ash of large samples of these foods, ranging up to 3 kg, have been determined with a heavily shielded 4- by 4-in. NaI crystal and a 100-channel pulse-height analyzer (*2*). With this instrumentation the efficiency of counting Zn^{65} was approximately 11 percent, and the sensitivity was of the order of 1 $\mu\mu$c in the ash.

The gamma spectrum of the ash of an oyster sample harvested from Chesapeake Bay is shown in Fig. 1; this curve reveals the presence of Zn^{65} in addition to some of the fission products and the naturally occurring K^{40}. The results of Zn^{65} analyses on a number of different food samples are summarized in Table 1, demonstrating the presence of this radionuclide in a wide variety of foods. The higher levels of Zn^{65} in oysters, as compared to other foods, is not unexpected in view of the findings of Chipman *et al.* (3), who demonstrated experimentally the capacity of this organism to concentrate Zn^{65} at levels many times higher than the level in the surrounding water.

The extent of nuclear operations, including the use of isotopes, in the Chesapeake Bay area seems entirely inadequate to account for the presence of the levels of Zn^{65} observed in oysters. Similarly, there are no obvious sources of the Zn^{65} found in the other foods; of these, some were grown in the Cincinnati area, while the rest were obtained from diverse parts of the United States. Therefore, it may be assumed that this radionuclide, which has been found in large amounts in samples taken near the Pacific proving grounds (*4*), must have been deposited on the East Coast and throughout the United States from high-altitude fallout.

The concentrations of Zn^{65} observed in these foods cannot be considered to constitute a radiological health hazard, since the maximum permissible concentration for this radionuclide is 6×10^6 $\mu\mu$c per liter of water or kilogram of food (wet weight) (*5*).

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2 July 1959

Subthreshold Retinal Integration Shown in Low Contrast Flicker Measurements

Abstract. Evidence of facilitation of response has been found in psychometrically determined critical fusion frequencies to flicker at low contrast. Spatial summation is denied by the distribution form of the data. Temporal summation within a determined time limit is supported. This may be mediated through association cells at the bipolar-ganglion synapse.

The use of low-contrast flicker measurement to assess retinal function was proposed in 1958 (*1*). Flicker refers to the perceptual response to a rapidly alternating dark and bright stimulus. In the present study (*2*) we alternated two nearly equally bright foveal stimuli in a circular area 1° in diameter on a 50° surround at 5 percent contrast above and below the 60 cd/m² background. Originally, for experimental convenience, the stimuli were presented in random order in two ranges, from 22 to 34 and from 30 to 46 per second.

The perceptual response fails when the rate increases across a threshold, called the critical flicker frequency. This visual response is analogous and may be identical to the scintillation found in a weakly irradiated phosphor. It is random in nature and may represent a chance distribution of the responses of individual foveal cones. Our results have been expressed in terms of the duration of half of the stimulus cycle, being therefore shorter as the rate of flicker increases. For example, 40 flickers per second equals a half cycle of 12.5 msec. Data are reported for each eye separately for 172 subjects for approximately 112 trials per eye, or a total of 38,324 trials. This volume of data is sufficient for discrimination between various distribution forms (*3*). The data were analyzed as probability functions of perception of the flicker against the temporal duration of the brighter half of the alternation (Fig. 1).

The two ranges show considerable difference in response, although the rates of alternation and all other conditions were the same where the ranges overlap. Attempts to fit these two curves with normal or Gaussian frequencies by the methods of probit analysis and least squares were unsuccessful (*4*). The best fitting normal distributions showed chi-squared equal to 11.23 and 84.75 for the seven centralmost points for the slower and faster ranges respectively. The probabilities of fit are interpreted as 8 percent and less than 0.0001 percent.

An attempt to fit the curves to log-normal functions indicated that the transformation log $(X-A)$ for X would be needed (*5*). The data for the slower range fit a log-normal distribution nicely, where $A = 0$, $\chi^2 = 2.91$, and $p = 82$ percent for the seven centralmost points. In the case of the faster range, the function can be described accurately only when $A = 11$ msec; then χ^2 becomes 1.93 and $p = 92$ percent for the centralmost points. The differential area between the two curves (Fig. 1) is itself a log-normal curve, where $A = 0$ (Fig. 2).

In attempting to establish another relationship between the distributions for the slower and faster ranges, the slower range curve was expressed as a probability power function, such that $p^n = 1 - (1 - p)^n$. This function, shown where $n = 5$ (Fig. 2), fails to approach any chance of congruency with the faster range curve.

In discussing these results, we refer to Polyak's description of the neural structure of the retina (*6*). Polyak describes the cones, the bipolar cells, and the ganglion cells as the primary neural