motion pictures at a speed of 4000 frames/sec (*3*). These studies show, as described here, that the manner of formation of vapor bubbles is entirely different in each of the three types of boiling.

The purpose of the investigation described here (*4*) was to determine how the sound of boiling depends on the type of boiling.

Methyl alcohol was boiled at atmospheric pressure at 148°F in a glass boiler, approximately 1 gal of liquid being employed. Heat was supplied from a horizontal copper bayonet heater 6 in. long and ⅜ in. in diameter. Saturated steam at various pressures condensed inside this heater tube. The methanol vapors passed overhead, where they were condensed and returned to the boiler. Measurements included the heat-transfer rate from the tube to the methanol and also the over-all temperature difference between the steam and the methanol.

The sound measurements were made through a crystal microphone located 6 in. from the boiler wall at the same elevation as the heating tube. Interposed between the boiler wall and the heater tube was 1 in. of liquid methanol. The microphone was mounted directly on a General Radio Co. sound level meter, Type 759-B. This meter indicated the intensity of the total sound in decibels in the frequency range from 25 to 7500 cy/sec.

Preliminary tests showed that the background noise was severe during ordinary working hours. Therefore the final data were obtained late at night when the background noise was not significant.

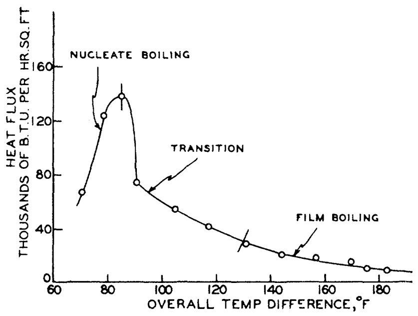

Fig. 1. Boiling curve for methanol.

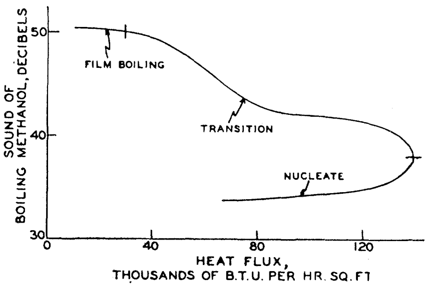

Fig. 2. Effect of heat flux on the sound of boiling methanol.

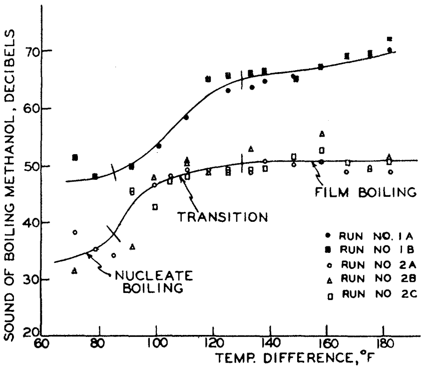

Fig. 3. Effect of temperature driving force on the sound of boiling methanol.

The sound of boiling is indeed a function of the heat-transfer rate during boiling (Fig. 2), but not in the way generally imagined. Contrary to popular opinion, the sound does *not* increase continuously with the heat flux. Inasmuch as the heat-transfer rate is a function of the temperature driving force, the sound is a function also of the temperature difference between the hot solid and the boiling liquid (Fig. 3).

During nucleate boiling any increase in the temperature difference causes an increase in the heat flux and an accompanying increase in the sound intensity. Nucleate boiling—that is, repeated, systematic, bubble formation at specific locations on the hot solid—ceases at a temperature difference of 85°F, and transition boiling exists from this value up to about 130°F. During transition boiling, bubbles form violently and explosively at random locations on the hot tube. The sound increases steadily as the transition region is traversed. However, although the sound increases, the heat flux decreases. Above a temperature difference of 130°F, film boiling occurs and the sound level is rather uniform. During film boiling, the hot solid is blanketed with a film of vapor, and no solid-liquid contact occurs. The heat transfer becomes very poor. A trained listener should be able to distinguish between nucleate boiling and film boiling by ear. He would have difficulty in classifying the transition type of boiling.

Runs 2A, 2B, and 2C (Fig. 3) show that the reproducibility of results, on a single night, was close. A small, but possibly important, difference exists between run 2B and the other two. Run 2B was made with successively increasing values of the temperature difference; runs 2A and 2C were made in the reverse direction. Hysteresis in boiling curves (heat transfer rate versus temperature difference) has been reported by at least one group of observers (*5*). The sound measurements support their observations.

A pertinent fact was discovered by taking data on two different nights. Runs 1A and 1B were taken 5 nights prior to the second series. The relationships are the same qualitatively on the two occasions, but they are different quantitatively. On the second occasion (runs 2A to 2C), great care was taken to make sure that the copper tube was highly polished and that the methanol was well degassed. The sound of boiling is influenced either by the smoothness of the hot solid or by the dissolved gas content of the boiling liquid. Both of these possible causes are suspected. It is known that the heat-transfer rate during boiling is influenced both by the surface texture of the solid (*5*) and by the dissolved gas content of the liquid (*6*). Further tests will be needed to evaluate the individual effects of these two factors.

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References and Notes

1. J. W. Marx and B. I. Davis, *J. Appl. Phys.* **23**, 1354 (1952).
2. K. Goldman, Nuclear Development Associates, White Plains, N.Y., *NDA 10-68*, 1953.
3. J. W. Westwater and J. G. Santangelo, *Ind. Eng. Chem.*, in press.
4. This research was supported by the National Science Foundation.
5. C. Corty and A. S. Foust, annual meeting, Am. Inst. Chem. Engrs., St. Louis, Mo., preprint No. 1 (1953).
6. F. R. Pike, P. D. Miller, Jr., K. O. Beatty, Jr., *ibid.*, preprint No. 2.

20 April 1955

Diffusion of Sodium Ions from Cerebral Tissue in vitro

The diffusion of inorganic ions from pieces of tissue into surrounding stirred aqueous media follows a double exponential time course (Fig. 1), which has been attributed to intracellular-extracellular tissue compartmentation (*1*). This interpretation is brought into question by the present observations (*2*), which afford strong presumptive evidence that, at least in the case of sodium diffusion from pieces of brain tissue *in vitro*, the double exponential curve depends upon other physical factors.

Figure 1 is the semilogarithmic plot of the concentration of radioactive sodium (*3*) remaining in pieces of brain after various times of diffusion. Since each point was established by 10 to 15 experimental determinations, and since each arm of the curve was fixed by several points, there would appear to be little question concerning the double exponential form of the curve. Its significance, nevertheless, is not uniquely determined.

In a general study of the physical laws

governing diffusion of molecules out of a solid into a stirred liquid, March and Weaver (*4*) demonstrated that such curves occur in simple nonorganic physical systems as well as in biological systems. Danckwerts (*5*) similarly demonstrated, on the basis of classical diffusion theory, that diffusion can be described in terms of a series of exponential functions regardless of the shape of the particle from which the diffusion occurs.

The workers cited previously (*1*) have presumed that the first, rapid portion of the curve is related to diffusion from extracellular spaces, while the later, slower part is related to diffusion from intracellular spaces. No such relationship can be inferred from Fig. 1, for only 10 percent of the sodium was present in the rapidly emitted component. The assumption that this sodium is extracellular requires the untenable conclusion that 90 percent of brain sodium is intracellular. (The hypertonicity of the sucrose solution used was not of basic importance because similar percentages of rapidly diffusible sodium were observed with isotonic Ringer's solution as the immersion medium).

Moreover, the percentage of sodium in the rapid component varies with the surface-to-volume ratio, as shown in Table 1, which presents the data from diffusion curves similar to those of Fig. 1; however, the curves were determined with tissue pieces of different surface-to-volume ratios. The percentage diffusing rapidly was found to be directly proportional to surface area. The calculated ratios between surface area and rapid sodium loss (column three of Table 1) were identical within the limits of experimental error; this is further evidence that the rapid fraction of diffusion is directly related to surface area.

Attention is drawn to two physical factors other than intracellular-extracellular tissue compartmentation that may be of greater importance in determining the double exponential form of these diffusion curves. First, as mentioned previously, the general physical laws of diffusion out of solid particles give curves similar to those in Fig. 1. Second, microscopically demonstrable shredding and fracturing of the surface of the tissue incident to excision and handling probably increase the effective diffusion area and therefore cause an initially accelerated rate. This suggestion receives additional support from the observation of macroscopic changes in color and fragility of the superficial fraction of a millimeter of tissue. By either mechanism, the slope of the later, slower part of the curve depends upon the rate of diffusion through tissue in the depths of the block. These considerations will be examined in detail in a later publication.

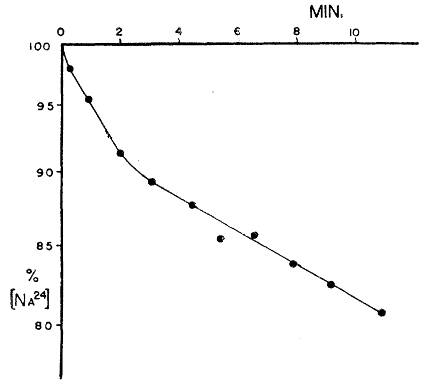

Fig. 1. Semilogarithmic plot of concentration of radiosodium remaining in pieces of hamster brain after various times of diffusion. Medium, 50-percent sucrose in water; average weight of pieces, 230 mg. Each point is the average of 10 to 15 experimental determinations.

Table 1. Effect of surface-to-volume ratio on rapid phase of sodium diffusion in hamster brain.

Approximate surface-to-volume ratio (mm^2/mm^3)	Rapid sodium (%)	Ratio
0.97	8	0.121
1.04	10	0.104
1.83	16	0.114

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References and Notes

1. H. Levi and H. H. Ussing, *Acta Physiol. Scand.* 16, 232 (1948); G. H. Mudge, *Am. J. Physiol.* 173, 511 (1953); L. G. Wesson, Jr., W. E. Cohn, A. M. Brues, *J. Gen. Physiol.* 32, 511 (1949); I. S. Edelman, *Am. J. Physiol.* 171, 279 (1952); A. M. Shanes, *J. Cellular Comp. Physiol.* 43, 87 (1954); E. J. Harris and G. P. Burn, *Trans. Faraday Soc.* 45, 508 (1949).
2. This work was supported by the Cox Fund for Medical Research and the Lucie Stern Fund for Research in Epilepsy. We thank I. S. Edelman for his interest and helpful comments. This paper is from a thesis submitted by B. Garoutte in partial fulfillment of the requirements for the Ph.D. degree, University of California.
3. Radioactive sodium (Na^{24}) for this study was made available through the kindness of Kenneth G. Scott and Ernest L. Dobson.
4. H. W. March and W. Weaver, *Phys. Rev.* 31, 1072 (1928).
5. P. V. Danckwerts, *Trans. Faraday Soc.* 47, 1014 (1951).

20 April 1955

Reference Samples of Isotopic Abundance

At the request of the U.S. Geological Survey, the National Bureau of Standards has undertaken a program for the preparation and distribution of reference samples of isotopic abundance in forms suitable for mass spectrometric analysis. The National Bureau of Standards will serve as a clearinghouse for data on the isotopic abundance ratios as measured by cooperating laboratories and will distribute the accumulated data with each sample requested.

Laboratories throughout the world are engaged in mass spectrometer research on variations in natural isotopic abundance using a variety of techniques. Different laboratories are equipped to measure mass spectra of gases, of compounds evaporated from a furnace, and of ions emitted by a hot filament. Different compounds of the element are required for these different techniques. Table 1 lists reference samples that are now available for distribution or will soon be available. The gaseous samples are

Table 1. Reference samples of isotopic abundance.

Element	Compound	Source
H	H_2O	Steam condensate from Potomac River Water
	H_2	From H_2O
D	D_2O	Commercial – 99.8 atom percent D
	D_2	From D_2O
He		Atmosphere (commercial)
Ne		Atmosphere (commercial)
A		Atmosphere (commercial)
Kr		Atmosphere (commercial)
Xe		Atmosphere (commercial)
Li	Spodumene	King's Mountain, N.C.
	Li_2CO_3	Commercial
K	K_2CO_3	Commercial
Rb	Rb_2CO_3	Commercial
Sr	$SrCO_3$	Commercial
Mg	$Mg(OH)_2$	Commercial
Cl	NaCl	Marine (commercial)
Br	NaBr	Marine (commercial)
S	Mineral	Wharton County, Tex.
	SO_2*	Mineral and air
O	O_2*	Air
N	N_2*	From air
Pb	Galena	Ivigtut, Greenland
	PbI_2	From galena
	$Pb(CH_3)_4$*	From galena
Ag	$AgNO_3$	Commercial
Cd	CdI_2	Commercial
Hg†	Element	National Physical Laboratory
B	BF_3	Commercial
Si	SiF_4	Commercial
Ca, C, O	Limestone	Solenhofen, Bavaria

* Will be available in the near future.
† A small sample that was carefully measured by several mass spectrometer laboratories.