stopcock is opened to the mercury reservoir, a vacuum is produced by lowering the mercury to the 50-ml mark, and the gases are extracted by gentle shaking for 2 to 3 minutes. The fluid sample is then drawn into the reservoir chamber; following this, mercury is admitted to the reaction chamber from the mercury reservoir. When the mercury level reaches the 0.2-ml mark in the reaction chamber, the upper three-way stopcock is opened to the waste-arm side and the extracted gases are injected into the carrier-gas stream by moving the fluid level to the junction of the waste arm and carrier-gas tubing. After a wait of 5 seconds, the small amount of fluid and mercury can be returned to the reaction chamber; this is closed off from the column gas, and the sample is reextracted to remove any gas that may have redissolved as the vacuum was released following the first extraction. The sample fluid is removed from the Van Slyke chamber, via the same port through which it was admitted, by filling the reaction chamber with mercury from the reservoir.

The sample gases thus placed in the carrier-gas stream are then carried through the chromatograph column and eluted as separate components; the length of time required depends upon the characteristics of the gas and the column material. Each component is detected, and the quantity of the gas present is determined by a thermal conductivity reference and by sensing cells; the signals are amplified and recorded, in time, on the strip chart recorder.

The use of a 4-ft, 5-A molecular sieve column 0.25 in. in diameter allows the oxygen component of a sample of permanent gases to be eluted first from the column; this is followed by nitrogen and carbon monoxide. Carbon dioxide is permanently absorbed. All permanent gases with the exception of argon, which at present cannot be separated from oxygen by known column materials, can be separated and analyzed by means of a molecular sieve column, a silica gel column, or a charcoal and firebrick column (*5*).

The stability of the instrumentation, including the molecular sieve column, was tested by repeated injections, over a 4-hour period, of a constant volume and concentration of oxygen and nitrogen in the gas phase through an injection port placed in the carrier-gas stream. Reproducibility of the extraction technique for oxygen was determined by analyzing the amount of oxygen contained in 1 ml of sterile distilled water which had been equilibrated at 37°C with the oxygen and nitrogen in room air. A syringe tonometer and a constant-temperature water bath were used for the equilibration. Double extraction analyses were performed on each of 35 samples over a 2-day period. The application of the technique to biological fluids was tested in the same way, human blood plasma being substituted for water. The results of these determinations are shown in Table 1.

Table 1. Oxygen tension of water and plasma as determined by gas chromatography. Column, 4-ft. 5A molecular sieve; current, 360 ma; flow pressure, 20 lb/in.^{2}; carrier gas, helium; column temperature, 100°C for water and 70°C for air and plasma. Standard deviations are given in columns 4 and 6.

Type	Sample		Peak height (mm)	O_2 (ml)	P_{O_2} (mm-Hg)
	No.	Size (ml)			
Room air	15	0.03	122 ± 0.17	.0059	140
Water	35	1.0	124 ± 0.23		148 ± 0.28
Plasma	27	1.0	92 ± 1.04	.0044	148 ± 1.68
Plasma (duplicate analysis)	13	1.0	92 ± 0.70	.0044	148 ± 1.13

The accuracy of oxygen analysis has been tested in two ways. First, both water and plasma have been equilibrated with different concentrations of oxygen, and the graphic plots of the resulting peak heights relative to the oxygen contents form a precise straight line through zero. Second, equal amounts of oxygen, whether initially in solution or initially in the gas phase, produce the same peak heights.

The extraction method presents two difficulties. (i) Biological fluids tend to foam and trap gas bubbles with vacuum extraction of gases. It is possible to collapse the bubbles, however, by pulling them through the lower stopcock before the vacuum is released. (ii) The peak heights of the oxygen curve may vary considerably if the rate of injection of the extracted gas into the carrier stream is varied (a very little practice allows one to keep this injection rate steady). However, the area under curves distorted by variable injection rates is constant. Mechanical integration of the strip chart record can remove this variable if it is so desired.

In addition to the exceptionally good stability, linearity, and reproducibility of this method, it is useful because of its accuracy and speed. The time required to introduce the plasma sample in the carrier-gas stream is less than 5 minutes. The time required for elution from the column is less than 2 minutes, and during this time another sample can be extracted.

The remarkable sensitivity of the instrumentation to minute changes in oxygen content in relatively small samples of biological fluids, the excellent stability of the instrumentation, and the accuracy of the method offer opportunity for its widespread use in biological research and clinical medicine. The method makes possible accurate analysis, on small samples, of the concentration of biologically important gases present, or changing in time, in biological solutions. It seems likely that many determinations previously made by means of the Van Slyke, Haldane, Scholander, and Warburg methods can now be made with equal or better accuracy and simplicity and in less time. The oxygen tension of arterial blood can easily be calculated from the oxygen content of plasma as determined in this manner. Such determinations previously required exceptional technical skill and even then were less accurate and more time-consuming than determinations made according to the method described (*6*).

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2. A Beckman GC-2 gas chromatograph was used.
3. The strip chart recorder was secured from Minneapolis-Honeywell, Brown Instruments Division, Philadelphia, Pa.
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5. The three columns are Beckman columns No. 17298, 70019, and 70028, respectively.
6. This work was supported by public Health Service grant No. H-2798.

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Tritium Tracer in Arctic Problems

Abstract. Tritium measurements in the Arctic Ocean confirm a marked near-surface stratification. Sea water at 400 meters' depth, however, is less than 3 years old, suggesting a contribution to this water mass due to sinking along the continental shelf. The top ice layer on the Ward Hunt Island ice field is older than 25 years.

Tritium (H^3; half life, 12.26 years) is ideally suited as a natural tracer in the study of polar mechanisms of exchange and mixing among the various phases of H_2O. A steady state of cosmic-ray produced tritium has probably been achieved. Recently, however, water of relatively high specific activity has been introduced into the atmosphere by thermonuclear weapon tests; this water makes it possible to study short-term mechanisms of mixing in sea water and arctic ice.

As part of a study at T-3, an ice island floating in the arctic sea (*1*), three sea water samples were collected in July 1955 at depths of 10, 80, and 400 m by A. P. Crary and N. Goldstein (Air Force Cambridge Research Center). The first two samples were taken at latitude 83°00′N, longitude 92°00′W and the last at latitude 82°45′N, longitude 93°30′W. The samples were intended to represent the surface water, an intermediate water, and water of Atlantic Ocean origin, respectively.

Table 1. Tritium content of arctic samples.

Date	Lat. °N	Long. °W	Type	Depth of sea samples (m)	Temp.* (°C)	Salinity* (%)	T:H ratio† (× 10^{18})
1 July 1955	83°00′	92°00′	Sea water	10	− 1.72	31.64	6.8 ± 0.7
1 July 1955	83°00′	92°00′	Sea water	80	− 1.43	32.40	0.1 ± 0.1
12 July 1955	82°45′	93°30′	Sea water	400	+ 0.35	34.89	0.9 ± 0.1
July 1955	About as above		Sea ice				4.0 ± 0.4
21 Oct. 1954	Ward Hunt Island Field ice						2.2 ± 0.2
1953	North Atlantic Surface sea water (av.)						1.0 ± 0.2

* Interpolated from Project Icicle data (*5*). † A blank value of (0.3 ± 0.1) × 10^{-18} was subtracted from all values. The values have also been corrected for decay back to time of collection.

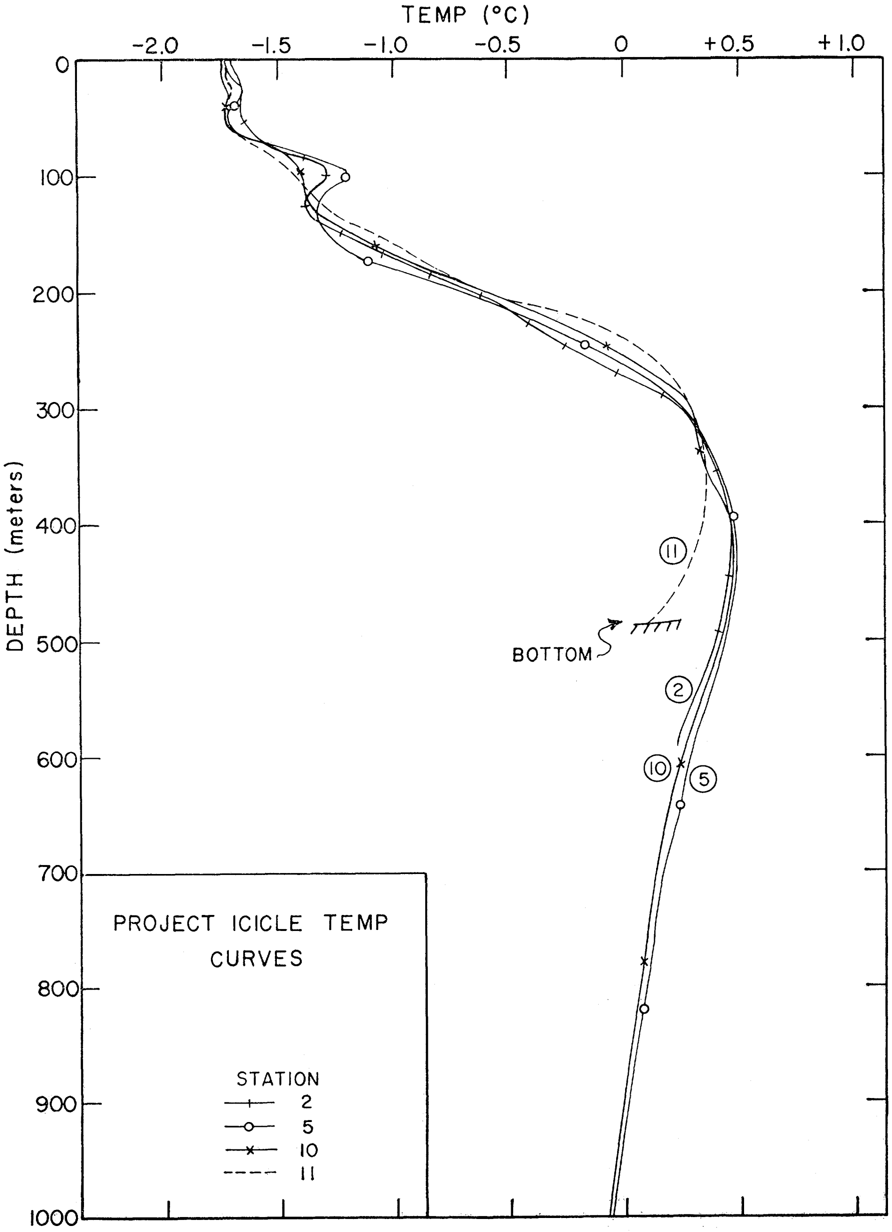

Fig. 1. Project Icicle temperature curves (after Worthington, *6*).

The 1954 atomic tests in the Pacific Ocean (Castle series) increased the tritium content of precipitation markedly in the Northern Hemisphere (*2, 3*). Therefore it would be expected that this low-salinity water would run off T-3 and reside as shallow "pools" near the surface of the sea. The surface sample of North Polar water had a relatively high tritium concentration (Table 1), 6.8±0.7 TU (tritium units = H^3:H × 10^{18}). This sample, plus the two reported by Brown and Grummitt (*4*) (3.0 and 4.2 TU) suggests that the tritium content of the arctic surface water has been significantly increased by man-produced sources. The average pre-bomb North Atlantic surface water had 1.0 TU (*2*), and it is unlikely that the pre-bomb North Polar water was higher in tritium concentration, for tritium is produced largely in the stratosphere and enters the troposphere in the temperate latitudes. By the summer of 1955 North Atlantic surface water had been contaminated to the level of 2.0 to 2.5 TU (*2*). The North Polar water therefore must include melted snow of the previous year.

The sample from 80-m depth represents intermediate water which gives the sharp minor temperature maximum at about 100 m (Fig. 1). This feature was observed over a large area north of Alaska and Canada (*5, 6*). The negligible tritium content, 0.1 ± 0.1 TU (Table 1) is further evidence of the strong near-surface stratification which prevents rapid vertical mixing to 80-m depth.

The sample from 400-m depth was taken as representing Atlantic water. The overall circulation pattern (*7*) consists of inflow at the surface north of Spitsbergen, sinking of this more saline water below the arctic surface water, and counterclockwise flow along the Siberian coast and back around to the east side of Greenland. The sample from 400-m depth was collected in the small clockwise eddy which exists north of Alaska and Canada (*6*). Eighteen hydrographic stations in this general area (*5, 6*) give curves like the solid lines shown in Fig. 1 except for the water near the sample location (one station), where the temperature is considerably lower (dashed line). (The accuracy of these measurements is ± 0.01°C.) It is suggested, therefore, that this water resulted from conditions in the sounds of the Canadian archipelago similar to those in the Weddell (*7*) and Chuckchi seas (*8*) (that is, surface water freezes, adds salt to the water immediately below, which becomes more dense and sinks). In this case the amount of water is small and affects only the bottom 100 m. This sinking water mixes with the normal Atlantic-derived water but, being surface water, has a much higher tritium content. If the sample (0.9 ± 0.1 TU) were largely arctic surface water it could not have flowed down earlier than 1953 and still retain a tritium content of 0.9 TU. A similar age limitation would apply to the sample if it were Atlantic-derived, requiring improbably rapid subsurface flow rates in the arctic sea of about 10 cm/sec (if a path length of 3500 miles and 2 years' travel time are assumed). It is suggested that the water represented by this sample moved down along the continental shelf during 1953–55.

A sample of sea ice was also taken in the vicinity of the sea water samples. The loose snow cover was removed first, and only solid ice was taken. The high value of 4.0 ± 0.4 TU shows that precipitation as well as sea water forms part of the ice. Since surface snow melts in the summer, it is likely that some contamination occurs from seepage through the ice. This means that the dating of sea ice with tritium alone is, at best, a difficult problem.

A sample of ice from the Ward Hunt Island ice field (north of Ellesmere Island) collected in August 1954 had 2.2 ± 0.2 TU. Because of the results obtained from the sample of the sea ice, seepage and contamination are suspected here too. On the basis of a mean of 8 TU for precipitation (*9, 10*) in the prebomb era, it is estimated that the sample is at least 25 years old. If contamination had occurred in the summer of 1954 when precipitation probably had up to 100 TU, 2 percent of this would suffice to give the observed result on old ice containing negligible tritium. For 1953 precipitation (pre-Castle) to produce such an effect 25 percent replacement is required.

From the preceding it is seen that (i) tritium exists in measurable quantities in the ice and sea waters of the arctic; (ii) there is clear evidence of artificially produced tritium in the arctic surface sea water; (iii) the near-surface stratification of the polar sea water is confirmed; (iv) a new source of the deeper water of the Arctic Ocean was found to be in the Canadian archipelago; (v) downward seepage in arctic ice may make the dating of pack ice difficult; (vi) ice from the top of the Ward Hunt Island is at least 25 years old (*11*).

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Comparison of the Effects of Delayed Auditory Feedback on Speech and Key Tapping

Abstract. Delaying the return of a speaker's vocal output to his ears (the auditory feedback) radically changes his speech (*1*). The present report concerns the effect of delayed auditory feedback on simple key-tapping tasks. Evidence is presented which indicates that changes in speech and key tapping under delayed auditory feedback are analogous.

When a delay is instituted in the return of a speaker's vocal output to his ears (*1*), his speech changes in characteristic ways (*2*). The most common changes which occur are an increase in mean vocal intensity, an increase in phonation time, and a tendency to repeat sounds. There is considerable individual variation in the degree to which subjects manifest these changes while speaking under delayed auditory feedback conditions; however, almost all subjects show one or more of the above changes to some degree.

Preliminary studies on the effects of delayed auditory feedback on nonvocal motor tasks (*3*) have indicated that whistling and playing musical instruments are strongly influenced by delayed auditory feedback. Simple hand-clapping behavior is also reported to change under such conditions. A subject was asked to clap his hands six times as regularly as possible each time a click from a metrotome was presented through his earphones. When a delay of 250 msec was introduced in the return of the sounds of his clapping to a subject's earphones, he often clapped seven times instead of six and slowed down his performance.

It is not clear from the above data how closely the quantitative changes in nonvocal motor performances under delayed auditory feedback approximate the characteristic changes in speech under such conditions. Clarification of this issue is the rationale for our investigation (*4*).

Each of 14 young adult subjects was asked to repeat the speech sound "b" as in *book* in groups of three. During the first trial the subject's vocal output was amplified and returned without delay to his earphones. In the second trial a delay of 244 msec was introduced before the amplified speech was returned. Vocal performance was recorded on magnetic tape and later displayed on an oscilloscope and photographed. The resulting oscillograms give a graphic display of the subject's speech with respect to time and amplitude. Analysis of the oscillograms (Fig. 1, *A*) revealed that under delayed auditory feedback, subjects tended to speak louder (12 subjects), prolong sounds (eight subjects), increase pauses between sounds (11 subjects), and repeat the sound four times instead of three (eight subjects). Thirteen of the 14 subjects showed at least one of these changes.

Each of the subjects was then asked to tap on a key, the taps to be in groups of three. Each time a subject tapped the key, the lever hit a strip of spring steel with a strain gage mounted on it. During the first trial the sound produced was amplified and returned without delay to a subject's earphones (*5*). In the second trial a delay of 244 msec was introduced before the amplified sound was returned to his earphones. The amplification of auditory feedback for all conditions of the speech and key-tapping experiments was identical.

Each time a subject tapped the key, the output of the strain gage was amplified and fed into a direct-writing galvanometer to give a continuous record of the time and pressure characteristics of the subject's key tapping. Examination of the graphic records (Fig. 1, *B*) revealed that, under delayed auditory feedback, subjects tended to tap the key harder (12 subjects), hold down the key longer (five subjects), increase the pauses between taps (13 subjects), and tap four times instead of three (two subjects). All subjects showed at least one of the above changes (*6*). Thus, the changes that are observed in vocal performance under delayed auditory feedback are also observed in nonvocal performance under such conditions.

The change in speech and key-tapping performance following alteration in auditory feedback suggests that these two motor systems require auditory feedback for their control. However, the specific way in which the auditory feedback was altered—the delay in time—may be of even greater importance in explaining