proved by positive feedback which brings about increased air flow by the act of starting to pass air. If the feedback factor is made high enough so that the loop gain in this system is greater than or equal to unity, then the system will become bistable (*3*)—that is, a small suck will bring about a self-perpetuating air flow that will persist until back pressure builds up. No effort is involved in breathing in the intermediate condition. Limited positive feedback makes breathing easier, but the use of hysteresis or bistability requires further experiment to determine whether, due to nonlinearity in muscle response, it may not take more work to start and stop a self-perpetuating flow than to produce a steady vacuum in the usual fashion. However, human muscles do seem to be able to give a short intense effort more readily than a weaker prolonged one. Methods of producing the bistability (feeding air or not feeding air) include constructing the diaphragm in the fashion of an oil-can bottom, spring-loading the linkage as in a toggle switch, shaping the valve seat so that opening gives an increasing area to produce an increased opening force, or the use of a Venturi tube in which air flow reduces the pressure applied to the diaphragm, thus sucking it in. By analogy with the generation of a nerve impulse, or the action of monostable multivibrator, one can visualize another type of unit in which a bistable regulator is returned after a short interval to its original off state by some auxiliary process such as a slow leak into the main chamber from the high pressure region.

Breathing can be made easier by eliminating impedance to flow through the inclusion of the hoses in the feedback loop. For any such configuration two essentially isolated chambers are involved. For example, sucking, via one hose, could cause the diaphragm to move in and feed air into and from the second hose until the pressure backs up through both. One exhales into and from the chamber containing the diaphragm through the first hose.

One problem of deep diving might be touched upon. It is necessary that the partial pressure of oxygen at all depths be roughly within a factor of ten above normal at the surface in order to avoid either oxygen deficiency or poisoning. In discussion, M. Bradner suggested storing oxygen in a hemoglobin-like material which would always then maintain the surrounding partial pressure constant at the equilibrium value. The extra pressure, to match that in the surroundings, would be supplied through a regulator by a high-pressure cylinder of helium or nitrogen which would have to supply gas only during descent, and thus could be small. Alternatively, a mixed-gas apparatus could either receive oxygen from a pressure-insensitive, constant-flow-rate device, or else an oxygen-detecting element could be used to control the flow. For a detector, for example, one might employ the output voltage of a fuel cell (*4*). H. Bradner has suggested that oxygen content might be controlled by the mechanical changes in size of certain chelates or else by the output voltage of any oxygen-depolarized battery. Alternatively, one could control oxygen flow by monitoring the generation of carbon dioxide.

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References and Notes

1. This work was supported in part by a grant from the Schussler Fund. The weight-compensated regulator was previously described in *Seafarer* [1, No. 2, 3 (1954)].
2. R. S. Mackay, *Am. J. Phys.* 16, 186 (1948).
3. ———, *ibid.* 26, 60 (1958); *J. Appl. Phys.* 25, 424 (1954).
4. *Chem. and Eng. News* 35, No. 38, 25 (1957).

15 September 1958

Preservation of Whole Blood in Frozen State for Transfusion

Abstract. Addition of sugars to whole citrated human blood permits freezing and thawing with recovery of a large percentage of erythrocytes. Survival of erythrocytes thus frozen, transfused without further modification after thawing, has been satisfactory after 6 months of storage at −93°C.

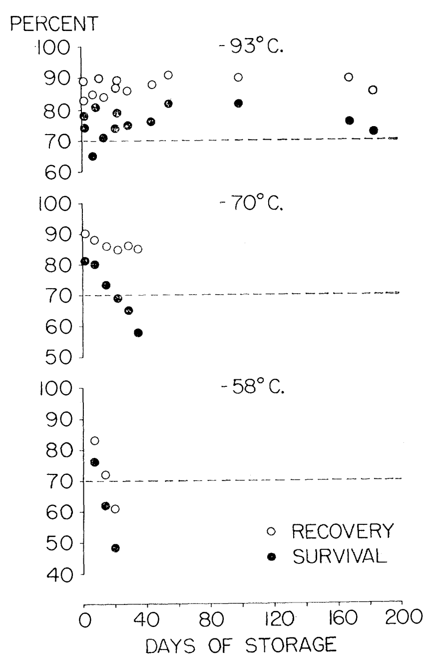

Fig. 1. Effect of temperature of storage on recovery and survival of frozen human erythrocytes. Each solid circle represents a transfusion.

Hemolysis due to freezing of erythrocytes at temperatures below −3°C (*1*), followed by thawing, may be avoided to a considerable extent by ultra rapid freezing (*2*) or by modification of freezing with the addition of glycerol (*3*).

In the study described in this report (*4*) modification of erythrocytes to prevent hemolysis has been obtained with varying concentrations of dextrose and lactose, alone or in combination. Modification consists in mixing equal parts of acid-citrated blood with the sugar solution to obtain a $0.2M$ concentration of lactose, a $0.7M$ concentration of dextrose, or an additive molarity of 0.6 with both sugars. The length of modification is not critical, and periods of 5 to 270 minutes have given similar results.

Modified blood is frozen in flat containers made of thin aluminum or tin-plated copper, measuring inside 3 mm in thickness, by immersion, in CO_2–ethanol mixture at −60 to −78°C. Thawing is obtained by immersion in a water bath at 37°C. Optimally the time of cooling and freezing, from −3° to −40°C, and the time of thawing must not exceed 10 seconds.

The results of freezing and thawing of erythrocytes will be expressed as "recovery" and "survival." By "recovery" is meant the number of intact red cells remaining after freezing and thawing; "survival" indicates the amount of radioactivity of frozen, stored, thawed, and transfused red cells remaining in circulation in the recipient 24 hours after transfusion, as determined with the Cr^{51} tagging technique. The values reported as survival include all losses occurring in vitro and in vivo. Blood has been transfused within 1 hour of thawing, without any further preparation.

Without use of sugars the recovery of human erythrocytes frozen and thawed with the technique described averages 29.3 percent. With the modification of freezing obtained with sugars the average recovery rate is optimally about 95 percent. The 24-hour survival of erythrocytes in five transfusions of human whole blood frozen and thawed without appreciable period of storage is only 2 percent below the optimal established for fresh, autotransfused erythrocytes; the curve of disappearance of erythrocytes after the first 24 hours parallels that of fresh cells.

The recovery and posttransfusion survival of erythrocytes of whole blood frozen as described and stored in the frozen state depend on the temperature of storage. With storage at −58°C, both rate of recovery and rate of survival deteriorate rapidly, as shown in four transfusions (see Fig. 1). At −70°C, the rate of recovery is fairly well maintained for about 40 days, but the survival in six transfusions deteriorates progressively and at 3 weeks is already below 70 percent. At $-93° \pm 2°C$ a satisfactory recovery and survival are maintained for periods of at least 6 months, as shown in 13 transfusions.

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References and Notes

1. M. M. Strumia, *Science* 110, 398 (1949).
2. B. J. Luyet, *Biodynamica* 6, 217 (1949).
3. C. Polge, A. V. Smith, A. S. Parkes, *Nature* 164, 666 (1949); A. V. Smith, *Lancet* 2, 910 (1950).

4. This work was carried out with funds from the Army Medical Research and Development Board and with the aid of a grant from the National Advisory Heart Council of the National Institutes of Health. We acknowledge the technical aid of Jean Bentz.

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Ionium-Thorium Chronology in Deep-Sea Sediments of the Pacific

Abstract. The ratio of ionium to thorium varies exponentially with depths in deepsea sediments of the Pacific Ocean and gives rates of accumulation of the order of millimeters per thousand of years. Surface values of the ratio were not constant over the eastern Pacific Ocean. This observation may result from differences in thorium isotope concentrations in near bottom waters which furnish these isotopes to the sediments.

The method of ionium-thorium chronology (*1*) of deep-sea sediments is based on the simultaneous removal of ionium (Th^{230}, $t_{1/2} = 80{,}000$ years, a member of the U^{238} radioactive series) and thorium (Th^{232}, $t_{1/2} = 1.4 \times 10^{10}$ years) from the water to one or more of the mineral components of the deposits. The critical assumptions for the application of the method follow. (i) The Io/Th ratio has remained constant in the waters adjacent to the sediments over the time intervals involved. (ii) The chemical species of Io and Th in the sea water are the same, and these isotopes have identical distributions among them. (iii) The analyzed materials do not contain detrital materials, of continental or volcanic origin, with significant contributions of Io or Th. This method appears preferable to the previous method of radium chronology (*2*) inasmuch as the observed diffusion of radium from the decay site of its parent ionium can invalidate any age determinations (*3*).

Table 1. Ionium-thorium ratios in three cores from the Eastern Pacific Ocean (Capricorn 50BG—latitude 14° 55′N, longitude 124° 12′W, 4270 m; Chinook 11—latitude 49° 39.5′N, longitude 177° 39′W, 4850 m; Downwind 49HG—latitude 42° 02′S, longitude 98° 01′W, 4350 m). The ratios are given in terms of disintegrations of Io per disintegration of Th per unit time.

Depth interval in core (cm)	Io/Th ratios		
	Capricorn 50BG	Chinook 11	Downwind 49HG
0–4	30	16	35
4–8	23	18	26
8–12	16	11	19
12–16	9.0	10	5
16–20	8.4	7.0	2
20–24	6.1	6.2	
24–28	5.3	4.4	

The isotopes of Th were isolated from sediment samples by previously described methods (*4*) and subsequently plated on a 1-in. platinum disc. Preferential solution of the nondetrital matter was accomplished with hot, concentrated hydrochloric acid. The principal detrital minerals, quartz and feldspars, were insoluble and were discarded following centrifugation. The recovery of the Th isotopes from the samples was determined with UX_1 (Th^{234}), and yields varied between 50 and 98 percent. The plated Io and Th were readily differentiated and quantitatively assayed with an alpha-ray spectrometer, a Frisch screen-grid ion chamber being used as a detector. The dominant alpha energies of Io and Th are 4.6–4.7 and 3.98, respectively (*5*).

Preliminary analyses (*6*) of a number of Eastern Pacific deep-sea cores have emphasized three significant results. First of all, exponential decreases in the ratio with depth have been observed in 10 of the 12 cores analyzed. Two South Pacific cores had values of the ratio that were both low and essentially invariant with depth. Whether such results indicate a lack of deposition over the last few hundred thousand years or a loss or disturbance of the upper section of the core during the handling has as yet not been determined. Table 1 gives typical analyses on three cores collected by expeditions of the Scripps Institution of Oceanography.

Secondly, determinations of the recent rates of accumulation of these Eastern Pacific clays, made on the basis of these data and of the half-life of ionium, are remarkably uniform, with values for the Capricorn, Chinook, and Downwind cores of 1, 2, and 1 mm per 1000 years, respectively, in the upper 10 cm. A dramatic drop in the Io/Th ratio, corresponding to nearly 2 half-lives of ionium over a few centimeters' distance, is observed in the Downwind core. Such a change has been observed in but one other core, also from these southerly latitudes.

Finally, *the surface ratios* fall into two distinct groups: a set in the region between the Aleutian Islands and Hawaii with values averaging about 15 and a second group, in the region between longitude 120° and 140°W and latitude 40°N and 40°S, with a ratio varying around 35. The cores given in Table 1 are representative of such groups. The isotopes of lead show a similar distribution pattern (*7*).

These results can be interpreted on the basis of the assumption that the deep-oceanic water masses, which are in contact with the sediment surfaces, furnish these isotopes to the sediments. Hence, these two regions should have circulating, overlying water masses which possess values for the Io/Th ratio which are similar to those found in the surface layers of the sediment deposits. The distinctive isotopic composition of thorium in a given water mass probably reflects the weathering processes responsible for the introduction of thorium and uranium into the water mass and the inorganic and biochemical processes in the ocean that cause their removal.

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References and Notes

1. E. Picciotto and S. Wilgain, *Nature* 173, 632 (1954).
2. C. S. Piggot and W. D. Urry, *Am. J. Sci.* 239, 81 (1941).
3. G. Arrhenius and E. D. Goldberg, *Tellus* 7, 226 (1955); F. F. Koczy, *Nature* 178, 585 (1956).
4. E. D. Goldberg and E. Picciotto, *Science* 121, 613 (1955).
5. A description of the plating techniques and instrumentation is in preparation.

6. This report is a contribution from the Scripps Institution of Oceanography. This study was sponsored by the Office of Naval Research under contract with the University of California.

7. T. Chow and C. Patterson, personal communication.

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Radio Control of Ventricular Contraction in Experimental Heart Block

Abstract. This report describes a method for the stimulation of the ventricular myocardium by transmitting the stimulus over a radio-frequency carrier which is demodulated by a radio receiver enclosed within the animal's chest. The method can be applied in conjunction with experimental heart block.

Experimental heart block combined with electrical stimulation of the myocardium is a valuable technique in the study of the physiology and the pathology of the circulatory system.