names for future drugs, thus neatly avoiding a tedious and formerly unsystematic task.

The Revised Standard Version of the Bible obviously requires a new concordance, and it was the happy thought of Reverend John W. Ellison that this be made with the aid of UNIVAC (*26*). Every word of the new Bible was entered, with its context, onto four reels of magnetic tape. By proper programming, the machine eliminated 132 frequently used short words (thus reducing the number of entries from 800,000 to 350,000) and then rearranged the words alphabetically. The output included the context and book, chapter, and verse.

The foregoing four examples have had outputs that would correspond to preparing compilations of scientific data and thus illustrate only that part of the process.

A meaningful and pertinent use of data handling for answering questions has recently been described by two chemists from the Dow Chemical Company (*27*). They have attacked an old problem in chemical literature searching: how to select chemicals having parts of structures in common. For instance, it may be required to select from an "inventory" of chemicals, stored on tape, all those containing two nitro groups, or those with three or more rings, or even chemicals having groups in a specified orientation to one another.

Using a specially designed code for chemical structure, and with the aid of a general-purpose, stored-program digital computer, Opler and Norton have been able to program a search on 1000 compounds that takes only a few seconds to complete. A manual on this program has appeared (*28*). The code for this experiment is of interest because it is derived from more general topological solutions, which have a bearing in searching circuit diagrams, maps, and the like (*29*).

It may also be of interest to record here that a mathematical model for integrated data systems has been proposed (*10*, p. 275).

Summary

This brief survey of integrated and electronic data processing has touched on such matters as the origin of the concepts, their use in business, machines that are available, indexing problems, and, finally, some scientific uses that surely foreshadow further development. The purpose of this has been to present for the consideration of scientists a point of view and some techniques which have had a phenomenal growth in the business world and to suggest that these are worth consideration in scientific data-handling problems (*30*).

To close, let me quote from William Bamert on the experience of the C. and O. Railroad once more (*8*, p. 121): "Frankly, we have been asked whether we weren't planning for Utopia—the implication being that everyone except starry-eyed visionaries knows that Utopia is unattainable. Our answer is that of course we are! Has anyone yet discovered a better way to *begin* program planning of this nature? Our feeling is that compromise comes early enough in the normal order of things."

References and Notes

1. I wish to thank Earl L. Green for his help in discussing this paper, but the errors, whether of omission or commission, are my own. The views expressed here are not necessarily those of the Chemical Abstracts Service or of the American Chemical Society.
2. H. F. Klingman, Ed., *Electronics in Business* (Controllership Foundation, New York, 1955).
3. E. Marting, Ed., *A New Approach to Office Mechanization: Integrated Data Processing through Common Language Machines* (American Management Assoc., New York, 1954).
4. Haskins and Sells, *Data Processing by Electronics* (Haskins and Sells, New York 1955).
5. R. G. Canning, *Electronic Data Processing for Business and Industry* (Wiley, New York, 1956).
6. Moore Business Forms, Inc., *Automated Data Processing* (Niagara Falls, N.Y., undated).
7. Standard Register Co., *Paperwork Simplification*, No. 36 (4th quarter, 1954).
8. M. J. Dooher, Ed., *Electronic Data Processing in Industry* (American Management Assoc., New York, 1955).
9. R. H. Brown, *Office Automation/Integrated and Electronic Data Processing* (Automation Consultants, Inc., New York, 1955).
10. G. Kozmetsky and P. Kircher, *Electronic Computers and Management Control* (McGraw-Hill, New York, 1956).
11. M. P. Doss, Ed., *Information Processing Equipment* (Reinhold, New York, 1955), later chapters.
12. A product of Commercial Controls Corp., Rochester, N.Y.
13. Stanford Research Institute, *Research for Industry* 7, No. 9 (Oct. 1955).
14. British Pat. Specification 708,780, assigned to Compagnie des Machines BULL.
15. A product of International Business Machines Corp., New York, N.Y.
16. A product of Sperry Rand Corp., New York, N.Y.
17. L. N. Ridenour *et al.*, *Bibliography in an Age of Science* (University of Illinois Press, Urbana, 1951), pp. 55–56.
18. E. C. Berkeley, *Computers and Automation* 5, Nos. 3, 9 (Mar. 1956).
19. M. Taube *et al.*, *Studies in Coordinate Indexing* (Documentation, Inc., Washington, 1953–); vols. I–III have appeared.
20. J. W. Perry, A. Kent, M. M. Berry, *Machine Literature Searching* (Western Reserve Press; Interscience, New York, 1956), annotated bibliography.
21. Current work is often reported on in journals such as *Am. Documentation*, *J. Documentation*, and *Special Libraries*.
22. Anon., *Ind. Laboratories* 7, No. 9, 48 (Sept. 1956).
23. Rand Corp., *A Million Random Digits, with 100,000 Normal Deviates* (Free Press, Glencoe, Ill., 1955).
24. H. P. Luhn, *Self-Demarcating Code Words* (International Business Machines Corp., New York, ed. 2, 1956).
25. Anon., *Chem. Eng. News* 34, 774 (1956).
26. W. R. McCulley, *Systems Magazine* 20, No. 2, 22 (Mar.–Apr. 1956).
27. A. Opler and T. R. Norton, *Chem. Eng. News* 34, 2812 (1956).
28. ———, *A Manual for Programming Computers for Use with a Mechanized System for Searching Organic Compounds* (Dow Chemical Co., Pittsburg, Calif., 1956).
29. A. Opler, *A Topological Application of Computing Machines*, presented at the Western Joint Computer Conference, San Francisco, 8 Feb. 1956.
30. After this article was set in type, the following new book appeared: R. N. Anthony, Ed., *Proceedings Automatic Data Processing Conference* (Harvard Univ. Press, Boston, 1956).

Cryogenic Instrumentation

J. G. Daunt

Progress in low-temperature technology has been associated with the development of methods of producing lower and lower temperatures. Milestones in this progress have been the successive achievements of the large-scale liquefaction of the so-called "permanent" gases, in particular air, hydrogen, and helium. It is now well over half a century that liquid air, as well as its important components liquid oxygen and liquid nitrogen, has been available. In this time the technology of liquid air temperatures has formed the basis for a multipurpose large-scale industry. Many plants operate today to produce liquid oxygen at rates of 120 tons per day (*1*), and the commercial needs for these low-temperature products continue to increase.

Production and Transportation of Low-Temperature Refrigerants

The development of the production of liquid hydrogen and liquid helium on a commercial basis, however, is relatively

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recent, and consequently the technology and instrumentation associated with these lower temperatures are today rapidly expanding. It is of interest to note that in September 1956 the second national Cryogenic Engineering Conference was held at the National Bureau of Standards Laboratories in Boulder, Colorado, and that this conference devoted a major fraction of its program to instrumentation for temperatures of liquid hydrogen and below.

The NBS Boulder Laboratories operate a large-scale hydrogen liquefaction plant capable of producing more than 300 liters per hour. A brief description of this equipment was published in October 1953 (*2*). The same liquefier when run with helium gas (although only at two-thirds capacity) produced 120 liters of liquid helium per hour (*3*). Collins now has a helium and/or hydrogen liquefier in operation in his laboratory at Massachusetts Institute of Technology which produces either 50 liters per hour of liquid hydrogen or about 45 liters per hour of liquid helium (*4*).

The uses to which this increasingly large-scale production of liquid hydrogen and liquid helium are being put are manifold, and consequently transportation of the refrigerants over long distances is becoming increasingly common and necessary. In this regard, one may note that recently a liquid helium service has been established in England by the National Physical Laboratory which provides many universities with this refrigerant on a commercial basis. The institution of a similar service in the U.S.A. is long overdue.

Looking beyond the relatively modest needs of research institutions for a liquid helium service, a study has been made by Scott and his staff at the NBS Boulder Laboratories of the feasibility of transporting helium in large quantities as a liquid rather than as a high-pressure gas, as is now done. They have estimated that a plant producing 400 liters of liquid helium per hour would allow its transportation as a liquid to compete economically with present rates (*3*). A similar conclusion has been arrived at by Collins (*4*), who considers it possible to reduce the cost of liquefying both hydrogen and helium to a figure only slightly greater than the cost of liquefying air.

Some of the newer and developing uses of liquid hydrogen are, for example, the separation of the hydrogen isotopes by distillation, the cooling of very high field electromagnets, and as the working liquid in large bubble chambers. The development of liquid helium bubble chambers is a new aspect of very low temperature instrumentation. A brief outline of these relatively new instrumental developments in cryogenics follows.

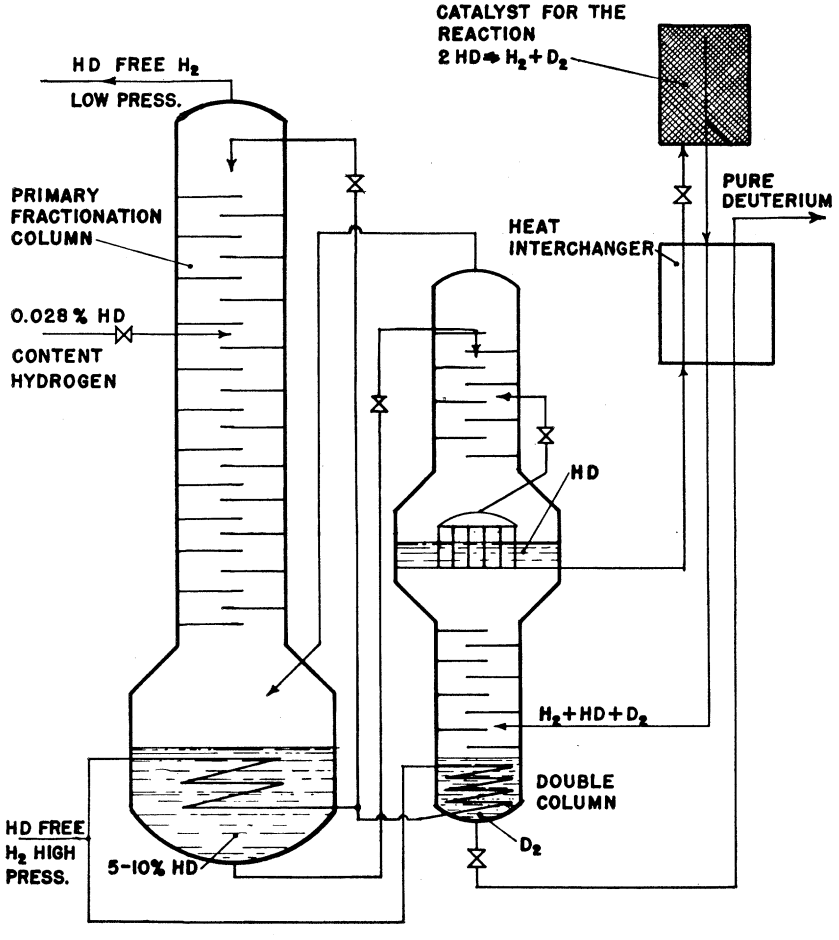

Fig. 1. Schematic diagram of technical arrangement for the extraction of deuterium from natural hydrogen containing 0.028 percent HD, due to Clusius and Starke (*8*).

Separation of Hydrogen Isotopes by Distillation

The pioneer work of Urey, Brickwedde, and Murphy (*5*) on the enrichment of deuterium was by a distillation process. Subsequently small-scale separations by distillation have been carried out by Keesom and coworkers (*6*), Brickwedde and Scott (*7*), and Clusius and Starke (*8*). The latter work was done in 1941–42 but was not published until 1949, at which time the commercial importance of heavy water for power reactors emphasized its significance. Large-scale distillation separation of deuterium is economically significant only if by this technique the price of D_2O can be reduced well below that of other more usual methods of heavy water production (*3, 9*). In fact, the distillation process looks economically very advantageous, as was pointed out by Clusius and Starke (*8*), who computed that D_2O could be produced by this process for 4.8 kilowatt hour per gram as compared with 120 to 150 kilowatt hour per gram by the electrolysis of water (*10*).

The Clusius-Starke process for the large-scale separation of deuterium proposed fractionating natural hydrogen, which has about 0.028 percent HD content, in a primary rectifying column at about 20°K, so that the top of the column would be essentially HD free and the bottom would have 5 to 10 percent HD content. The HD-rich liquid would then pass to the top half of a secondary fractionating column, from the bottom of which nearly pure HD would be extracted. This HD, after passing through heat interchangers, would be converted at room temperature by a catalyst so that the reaction $2HD \rightleftharpoons H_2 + D_2$ would take place. The reacted product, $H_2 + HD + D_2$, would be fed back, by way of the heat exchanger, to the lower half of the secondary fractionating column, from the bottom of which pure deuterium could be drawn off. The flow diagram is given in Fig. 1.

Plants, using processes similar to the one just described, were designed in 1950 by Hydrocarbon Research, Inc. (*11*) in the U.S.A. for liquid hydrogen distillation to produce 34 tons of D_2O per year, and plans have been made by Linde-Gesellschaft in Germany (*12*) for the production by distillation of 6 tons of

D_2O per year and by Le Societe l'Air Liquide (*13*) in Toulouse, France, for 2.5 tons per year. The latter two plants are to be located at large synthetic ammonia plants, so that the raw hydrogen can be "borrowed," stripped of its deuterium, and then returned.

The problems involved in the detailed designs of such plants are peculiar to the unusually low temperatures and to the characteristics of the material being processed, and experimental work on such problems has recently been reported (*14*) by the NBS Cryogenic Engineering Laboratory at Boulder, in particular concerning the efficiency of various types of plates for use in the fractionating columns.

Liquid Hydrogen-Cooled Electromagnets

By cooling the windings of electromagnets with refrigerant liquids, a considerable gain in the power consumption for a given magnetic field times volume product can be achieved. Liquid nitrogen-cooled solenoid magnets have been operated by Collins (*15*) and by Fritz and coworkers (*16*). In the hollow cylindrical core of such a magnet, the core being 2⅛ inches in diameter and 4 inches long, a field of 22 kilogauss could be maintained with a power dissipation of 15.3 kilowatts and a liquid nitrogen consumption of 5.7 liters per minute (*15*).

Liquid hydrogen-cooled solenoids have been developed at the Los Alamos Scientific Laboratory, and a recent report by Laquer (*17*) states that a wire-spaced "jelly roll" type solenoidal magnet, 5 inches long, 2½ inches inside diameter, and 7½ inches outside diameter, maintains a field of 65 kilogauss for a dissipation of 15 kilowatts when it is cooled by "freshly boiling hydrogen." This corresponds to an evaporation of 28.2 liters of liquid hydrogen per minute. Where liquid hydrogen is available in very large quantities, this offers a significant method of attaining intense magnetic fields with minimum power requirements.

Liquid Hydrogen and Liquid Helium Bubble Chambers

The bubble chamber, introduced by Glazer (*18*), like the Wilson cloud chamber, detects tracks of ionizing particles. The chamber is filled with a suitable liquid which is brought into a superheated state by rapid expansion. Ionizing particles passing through the liquid produce centers of nucleation for the boiling of the liquid and produce a "bubble" track. One of the most useful liquids for such bubble chambers is liquid hydrogen, since nuclear events involving protons are of particular significance. As is pointed out by Hildebrand and Nagle (*19*), who first reported the construction of a liquid hydrogen bubble chamber at Chicago University, it provides "a hydrogen target of greater density and purity than can be achieved in a cloud chamber."

For successful operation, the chambers must be maintained at about one-half of the critical pressure of the liquid before the expansion takes place: low boiling point liquids, with their correspondingly low critical pressures, allow small operating pressures to be employed. In liquid hydrogen bubble chambers, pressures of about 5 atmospheres are usually employed; and in the helium bubble chambers, first developed by Fairbank and coworkers at Duke University (*20*), atmospheric pressure is used, which technically is very advantageous. In the hydrogen bubble chamber being developed by the NBS Cryogenic Laboratory and the University of California Radiation Laboratory (*3*), the operating pressure and temperature are 5 atmospheres and 27°K, respectively; that is, the liquid hydrogen is subcooled. The expansion suddenly reduces the pressure to 2 atmospheres and, after a time of approximately 2 milliseconds, the bubble tracks are photographed.

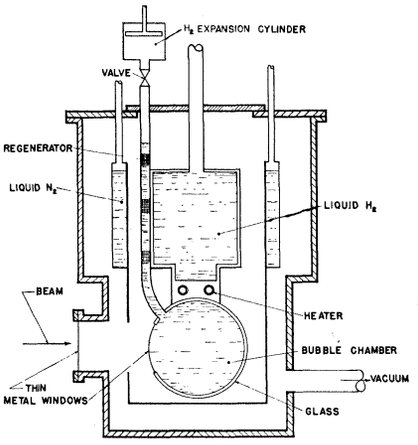

Fig. 2. Schematic diagram of liquid hydrogen bubble chamber, due to R. B. Scott. The expansion is effected by expanding the vapor through the valve into the expansion cylinder. [Drawing from W. Meissner, *Z. Kältetechnik.* **8**, 34 (1956)]

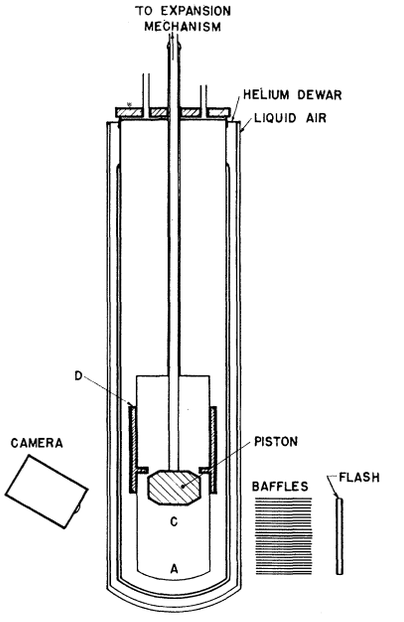

Fig. 3. Diagram of liquid He^4 bubble chamber, due to Harth, Fairbank, Blevins, and Slaughter (*20*). The expansion is effected by an upward movement of the piston, which is in direct contact with the surface of the liquid. The piston is of Teflon and slides in a close-fitting Teflon sleeve.

The expansion of the liquid in the chamber can be achieved either by rapid expansion of the vapor above it, as is shown in the liquid hydrogen design of Fig. 2, or by actual expansion of the liquid itself, as is shown in the liquid helium arrangement of Fig. 3, which is designed to have a 1.01 expansion ratio.

A liquid hydrogen bubble chamber 10 inches in diameter and 6½ inches in depth with an active volume of 8 liters has been put into operation at the University of California Radiation Laboratory (*21*), and it is located in a magnetic field of 12-kilogauss intensity. A still larger one for use with the 6-Bev accelerator, having a glass window 20 by 72 inches and a volume of approximately 500 liters, is being designed by the University of California Radiation Laboratory and the NBS Cryogenic Engineering Laboratory (*3, 22*).

The liquid helium bubble chambers at present being designed are more modest in size; Fairbank *et al.* (*23*) are reporting now on chambers 8 by 5 by 4 inches.

Magnetic Refrigerator

To obtain temperatures below 1°K, the well-established method of magnetic cooling first proposed in 1926 independently by Giauque (*24*) and Debye (*25*) has been in use since 1933. This method makes use of the magneto-caloric effect in paramagnetic substances, which, when they are adiabatically demagnetized, suffer a temperature drop. Starting at initial temperatures of about 1°K, temperatures as low as a few millidegrees can be reached within suitable paramagnetic salts. The paramagnetic cooling substance, together with such experimental arrangements as may be in thermal contact with it, after attaining the low temperature suffers continually thereafter a steady heat influx from its surroundings. The final end temperature of the process

is that of the surrounding liquid helium bath.

Recently a cyclic system of magnetic cooling has been devised by Daunt and Heer (*26*) which can maintain a reservoir *continuously* at temperatures below 1°K. In our first working model of this cyclic system (*27*) temperatures as low as 0.25°K could be continuously maintained (*28, 29*). Its operation can be followed from the diagram of Fig. 4. Here the paramagnetic salt A is the working substance, suspended in a vacuum chamber that is immersed in a liquid helium bath at about 1°K. The working substance is connected thermally, on the one hand, to the bath by way of the thermal valve V_1, which is in the form of a thin lead ribbon soldered to copper supports E, and, on the other hand, by way of a similar thermal valve V_2, to the reservoir R, which is to be continuously refrigerated. The thermal valves, which can be made to allow or almost prevent the flow of heat through them, depend for their action on the fact that pure superconducting substances such as lead, at temperatures well below their transition temperatures, have a thermal conductivity in their super state much smaller than that

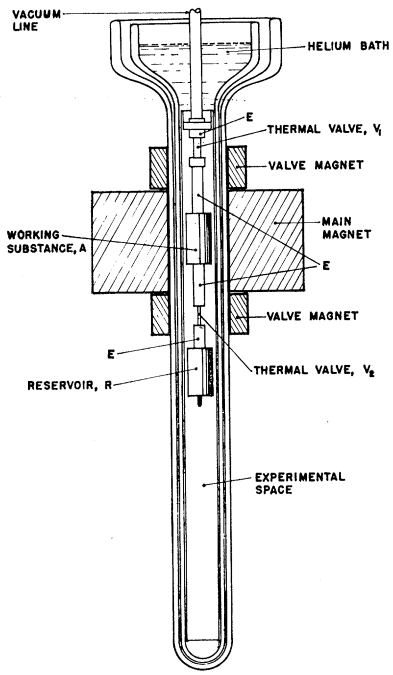

Fig. 4. General arrangement of the low-temperature parts of the magnetic refrigerator (*26, 27, 29*).

in their normal state (*30*). The transition from super to normal state can be made reversible by the application of a small magnetic field (for the lead thermal valves, switching fields of about 800 gauss are used), and hence by application or removal of this magnetic field the lead strip can be made either a thermal conductor or a thermal insulator. The operation of the cyclic refrigerator therefore consists in having valve V_1 "open" and V_2 "closed" when A is being magnetized, and on the demagnetization of A valve V_1 is closed and V_2 opened. During the demagnetization therefore the reservoir R can share in the cooling produced in A. The complete cycle, in which ferric alum as the working substance is magnetized in fields of about 7 kilogauss, is repeated every 2 minutes, the operation being controlled by the switching in correct succession of three magnetic fields, one for the working substance and two for the thermal valves.

Thermal Rectifier

An interesting thermal rectifier for use below 1°K has been reported by Hwang, Fulton, and Fairbank (*31*). In their preliminary experiments they used a 3-percent solution of He^3 in He^4 located in a vertical stainless steel capillary 4 inches long and 0.017 inch inside diameter, the lower end of which was tied thermally to the temperature of a helium bath at about 1°K and the upper end supported a paramagnetic salt for magnetic cooling. They found that when the upper end was warmer than the lower end, heat flowed easily through the tube, whereas when the salt was cold the tube was an effective thermal insulator. This rectifying action, they suggested, was due to the fact that when the upper end was the cooler, internal convection within the He^3 and He^4 solution would carry the He^3 to the top, where it would form a thermally insulating "pocket." On the other hand, when the temperature gradient is reversed there is no gravitational preference for collecting a pocket of He^3 from the convective process. The rectifying action therefore is dependent on the gravitational field. A similar strong dependence of the heat conductivity of He^3 and He^4 solutions on the relative directions of gravitational and thermal field gradients has been noted in work on very dilute solutions by Beenakker, Taconis, Lyndon, Dokoupil, and van Soest (*32*).

References and Notes

1. J. G. Daunt, *Handbuch Physik.* **14**, 1 (1956).
2. *Natl. Bur. Standards U.S. Tech. News Bull.* **37**, 152 (1953).
3. R. B. Scott, *Bull. inst. intern. froid* Annexe 3, 368 (1955), suppl.
4. S. C. Collins, *Natl. Bur. Standards 2nd Cryogenic Eng. Conf. Abstr.* A-2 (1956).
5. H. C. Urey, F. G. Brickwedde, G. M. Murphy, *Phys. Rev.* **39**, 164, 864 (1932).
6. W. H. Keesom, H. von Dijk, J. Haantjes, *Proc. Koninkl. Akad. Wetenschap. Amsterdam* **36**, 248 (1933); *Commun. Kamerlingh Onnes Lab. Univ. Leiden No. 224a.*
7. F. G. Brickwedde and R. B. Scott, *Phys. Rev.* **55**, 672 (1939).
8. K. Clusius and K. Starke, *Z. Naturforsch.* **4a**, 549 (1949).
9. G. M. Murphy, Ed., *Production of Heavy Water* (McGraw-Hill, New York, 1955), National Nuclear Energy Series, Vol. III-4F.
10. These computations were carried out with the help of Dr. Becker of Linde-Gesellschaft.
11. See J. Selak and J. Finke [*Chem. Eng. Progr.* **50**, 221 (1954)] for a brief description of this plan, together with flow diagrams.
12. See W. Meissner [*Z. Kältetechnik* **8**, 34 (1956)], who gives a flow chart for the process.
13. See *Nuclear Power* **1**, 9 (1956). This paper also gives a flow chart.
14. T. M. Flynn *et al., Natl. Bur. Standards 2nd Cryogenic Eng. Conf.* Abstr. A-6 (1956).
15. S. C. Collins, Tech. Rept. No. 1. ONR contract N5ori-78. T.O. XXIII. NRO16-801. Mass. Inst. Technol. July 1950.
16. J. J. Fritz, O. D. Gonzales, H. L. Johnston, Tech. Rept. No. 7. ONR contract N6onr-225. T.O. III. NRO16-407. Ohio State University (1949).
17. H. L. Laquer, *Natl. Bur. Standards Cryogenic Eng. Conf.* Abstr. D-1 (1956).
18. D. A. Glazer, *Phys. Rev.* **87**, 665 (1952) and **91**, 496, 762 (1953); D. A. Glazer and D. C. Rahm, *ibid.* **97**, 474 (1955).
19. R. H. Hildebrand and D. E. Nagle, *Phys. Rev.* **92**, 517 (1953).
20. W. M. Fairbank *et al., ibid.* **100**, 971 (1955); also, *Bull. inst. Intern. froid* Annexe 3, 371 (1955), suppl.
21. R. L. Blumberg, J. D. Gow, A. J. Schwemin, *Natl. Bur. Standards 2nd Cryogenic Eng. Conf.* Abstr. H-1 (1956).
22. D. B. Chelton, D. B. Mann, R. A. Byrns, *ibid.* Abstr. H-2 (1956).
23. W. M. Fairbank *et al., ibid.* Abstr. H-3 (1956).
24. W. F. Giauque, *J. Am. Chem. Soc.* **49**, 1870 (1927).
25. P. Debye, *Ann. Physik* **21**, 1154 (1926).
26. J. G. Daunt and C. V. Heer, *Phys. Rev.* **76**, 985 (1949); also, *Proc. Intern. Conf. on Low Temp. Phys. Mass. Inst. Technol.* (1949), p. 64.
27. C. V. Heer, C. B. Barnes, J. G. Daunt, *Phys. Rev.* **91**, 412 (1953); *Rev. Sci. Instr.* **25**, 1088 (1954).
28. An engineered model of this, called a Magnetic Refrigerator, is now being produced by A. D. Little, Inc. (*29*).
29. J. G. Daunt *et al., Bull. inst. Intern. froid,* Annexe 3, 362 (1955), suppl.
30. Thermal valves based on this effect were devised and first used below 1°K by Heer and Daunt [*Phys. Rev.* **76**, 854 (1949)], and suggestions for such use were also independently put forward at the same time by Gorter [*Les Phenomenes Cryomagnetique* (1948), p. 76], and by Mendelssohn and Olsen [*Proc. Phys. Soc. London* **63**, 1182 (1950)].
31. C. P. Hwang, C. D. Fulton, W. M. Fairbank, *Bull. Am. Phys. Soc.* **1**, 217 (1956); C. D. Fulton *et al., Natl. Bur. Standards 2nd Cryogenic Eng. Conf.* Abstr. F-5 (1956).
32. J. J. M. Beenakker *et al., Commun. Kamerlingh Onnes Lab. Univ. Leiden No. 289a; Physica* **18**, 433 (1952).