research laboratories of a manufacturer of commercial sterilization equipment. Plastic bags containing red cells and plasma processed through the various afore-described bowls were shipped from Boston to Erie, Pennsylvania, by air express. Shipments were made twice weekly during an 8-month period and comprised 81 samples: 39 bags of red cells, 41 bags of plasma, and one bag of whole blood reconstituted after processing. Upon arrival in the collaborating laboratory, all samples were cultured and studied, utilizing techniques that followed closely those outlined in the 14th revision of *U.S. Pharmacopoeia.*

The results of this study, comprising 1040 cultures on 39 samples of red cells, 41 samples of plasma, and one sample of whole blood, were negative for bacterial growth with the single exception of the cultures from one bag of plasma that had ruptured during aerial shipment. Since completion of this study, the adequacy of the seal has been further corroborated by the routine processing of more than 500 samples of blood products which subsequently have undergone culture or direct *in vivo* use.

Concurrently with the bacteriologic testing, 43 routine samples of red cells, plasma, and platelets were also tested in animals for pyrogenicity. Rabbit testing was carried out at the Commonwealth of Massachusetts, Division of Biologic Laboratories according to *U.S. Pharmacopoeia,* revision 14. The tests showed a uniform absence of pyrogens. The same 500 samples of blood that have corroborated the sterility data also have shown freedom from pyrogens. The satisfactory performance of the equipment in this regard is believed to be due to the simplicity of the bowl assembly. Each of the three bowls can be disassembled into a conical-shaped upper and lower half (similar for all types of assembly) plus any one of the three central bowl inserts (Fig. 6). These latter are varied according to the type of centrifugation desired.

General Equipment

The three bowl principles outlined here and the complete seal unit have been incorporated into a single dual-unit drive mechanism (Fig. 7). This equipment has recently become available commercially (*17*) for research use. It contains complete refrigeration equipment for prompt cooling to +4°C with maintenance at temperatures between 0° and +10°C throughout the period of experimentation. It is mobile and can be operated from standard electric circuits of 25-ampere, 115-volt, 60-cycle single phase. Its dual-drive control permits two completely different experiments or types of centrifugation to be carried on simultaneously. The activation and braking mechanisms permit sensitive control, so that the speed of centrifugation can be varied without turbulence.

Visualization of the separation process is not possible until after the initial overflow of plasma. This occurs at about 7 minutes following institution of a standard red cell-plasma separation. For volume measurement, one can compute the measured overflow content (volumetrically in a bottle, gravimetrically in a bag) and add to the fixed volume of the bowl. For standard operations in which accurate volume measurement is not required, simple timing of flow rate has proved satisfactory. For example, in standard blood separation directly from a donor, the flow is interrupted after 10 minutes on the presumption that approximately 1 pint of blood has been collected.

References and Notes

1. J. L. Tullis, *Blood Cells and Plasma Proteins* (Academic Press, New York, 1953), p. x.

2. Grateful appreciation is expressed for many years of financial support to this project by the National Institutes of Health, Rockefeller Foundation, National Foundation for Infantile Paralysis, Harvard University, Protein Foundation, and industry. We also wish to acknowledge the suggestion of George R. Ryan, Abbott Laboratories, North Chicago, Ill., for a divided bowl to allow interchangeable parts, and the kind assistance and voluntary cooperation of John J. Perkins, American Sterilizer Company, Erie, Pa., during a 1-year project on sterility testing of the centrifuge products.

3. Type-III bowl: falling film.
4. J. G. Gibson II, *In Vivo Survival Studies on Packed Red Cells Separated in the Cohn Fractionator, Conference on the Plasma Proteins and Cellular Elements of the Blood* (Protein Foundation, Inc., and Commission on Plasma Fractionation, Cambridge, Mass., 15 Nov. 1954), p. 12.
5. J. A. Griffols-Lucas, *Plasmoferese no Homen. Noticia de Primeira de Casos* (Congresso Internacional de Transfusao de Sangue, July 1951, Lisbon, Portugal), p. 41.
6. J. Stokes, Jr., and J. Smolens, *Adaptation of Biomechanical Equipment for Immunophoresis, Conferences on Implications of New Knowledge about Proteins, Protein Enzymes and Cells* (Commission on Plasma Fractionation and Related Processes of Protein Foundation, Inc., Cambridge, Mass., and University Laboratory of Physical Chemistry Related to Medicine and Public Health, Harvard University, Boston, Mass., 15 Jan. 1953), p. 27.
7. J. Stokes, Jr., and J. Smolens, *Proc. Soc. Exptl. Biol. Med.* 91, 611 (1956).
8. S. Chapman, in preparation.
9. P. L. Mollison and H. A. Sloviter, *Lancet* 2, 862 (1951); I. W. Brown, Jr., and H. F. Hardin, *Am. Med. Assoc. Arch. Surg.* 66, 267 (1953).
10. H. Chaplin, Jr., and P. L. Mollison, *Lancet* 1, 215 (1953); P. L. Mollison and H. A. Sloviter, *Lancet* 2, 501 (1952).
11. M. Karnovsky and A. F. Brumm, *J. Biol. Chem.* 216, 689 (1955).
12. M. M. Ketchel *et al.*, in preparation.
13. J. L. Tullis *et al.*, in preparation.
14. For simplification, a spontaneous red cell sedimentation for 16 hours at 4°C can be substituted for the red cell removal in type-I bowl with subsequent passage of the supernatant platelet-containing plasma directly into type-III bowl. Platelets so isolated appear less satisfactory than those subject to prompt concentration as outined here.
15. If greater recovery is desired, the effluent plasma may be recycled a second or third time through the same bowl.
16. J. L. Tullis, *Am. J. Med. Sci.* 226, 191 (1953); J. L. Tullis and J. J. McHugh, *Proc. Intern. Congr. Blood Transfusion* (1954), p. 815.
17. Cohn-ADL Centrifuge. Available through Arthur D. Little, Inc., Cambridge, Mass.

Solar Furnace in High-Temperature Research

Tibor S. Laszlo

The large amount of solar energy that reaches the surface of the earth and is freely available to everyone is a great challenge to energy-conscious scientists and technicians. The world-wide interest in this problem was strikingly demonstrated at the first World Symposium on Applied Solar Energy held in Phoenix, Arizona, in November 1955 (*1*).

Solar energy is already used in experimental installations to drive engines, to heat and cool houses, to distill water, to cook food, and to generate electricity. Wherever conventional fuels are in short supply, wherever energy requirements are small and sunshine is abundant, solar energy may find limited application. But in all these uses it remains a substitute in the true meaning of the word. It must compete economically and in convenience with other forms of energy. Accordingly, whenever conventional forms of energy, including nuclear energy, become readily available, the use of solar energy loses its economic or technical justification.

There is, however, one application in which solar energy is superior to any

The author is director of the high-temperature laboratory of the department of chemistry at Fordham University.

other form of energy presently available, namely in the field of high-temperature research.

Conventional High-Temperature Furnaces

Conventional furnaces used in high-temperature research have a number of serious shortcomings. The first of these is the relatively low temperature ceiling that is obtainable. With gas-fired furnaces, the temperature maximum is about 1800°C. Electric resistance furnaces may reach higher temperatures, in special arrangements up to 2800°C, but heavy penalties must be payed in the reduced convenience and flexibility of operation. In such furnaces an inert gas atmosphere has to be maintained, and this has many inherent complications.

The theoretical temperature limit of the induction furnace is the melting point of the magnetic susceptor material in which the high-frequency alternating current generates heat by induction. In practice, however, temperatures seldom exceed 2700°C, since even above 2000°C radiation from the susceptor becomes very intense. Insulators and reflectors have to be used to keep energy losses low and to prevent failure of the copper reduction coil. In many cases, a water cooling jacket is used between the work coil and susceptor. As a consequence, the induction coil and susceptor are placed farther apart; hence, the coupling is poor and the maximum obtainable temperature is lowered.

Another restriction on induction furnaces is that only magnetically susceptible materials may be directly heated in it. If the sample is not a susceptor, an auxiliary susceptor has to be used, and the sample is heated by radiation. It is very difficult to find a satisfactory auxiliary susceptor, because it must have a higher melting point than the desired reaction temperature, and it should not react with the sample, the parts of the furnace, or the atmosphere in the furnace. Carbon is frequently used as an auxiliary susceptor, but the reduction of oxides and the formation of carbides constitute a serious limitation.

Carbon-arc furnaces are used for higher temperatures, but the reduction of oxides and the formation of carbides are even more restrictive here. In addition, the hot zone is very small, uniform temperatures are difficult to obtain, and close temperature control or gradual change of temperature is impossible.

Whether they use gas or electricity, all these furnaces have one disadvantage in common, the need for a container to hold the sample being heated. The container should exhibit good mechanical and

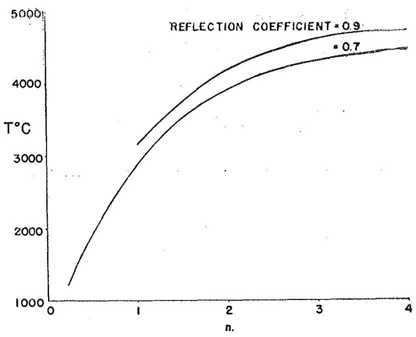

Fig. 1. Correlation of reflector dimensions and maximum obtainable temperature of paraboloidal concentrators of solar radiation; n = diameter/focal length.

chemical stability at the operating temperature, and it should not react with the sample or any other matter in the furnace. In many cases, it is also desirable that the sample should not become an electric conductor or magnetic susceptor even at high temperatures. It is very difficult to meet these requirements. Frequently, before an investigation at high temperature is undertaken, an auxiliary research project has to be carried out to develop a suitable container material. This secondary project may require more time and effort than the investigation of the main problem, and sometimes no satisfactory container material can be found.

Advantages of the Solar Furnace

The use of solar radiation to generate high temperatures offers an elegant solution to these problems (*2*). The temperature limit is thereby extended beyond the previously mentioned values. With a 60-inch-diameter solar furnace, 3500°C has been reached at Fordham University, and it is possible to build furnaces to reach temperatures of more than 4500°C. Figure 1 shows the correlation of reflector dimensions and maximum obtainable temperature. The upper curve (coefficient of reflection = 0.9) represents values for highly polished silver or aluminum reflectors. Metals of better corrosion resistance, such as stainless steel and stellite, would yield temperatures along the lower curve (0.7). All these values refer to geometrically perfect paraboloidal reflectors.

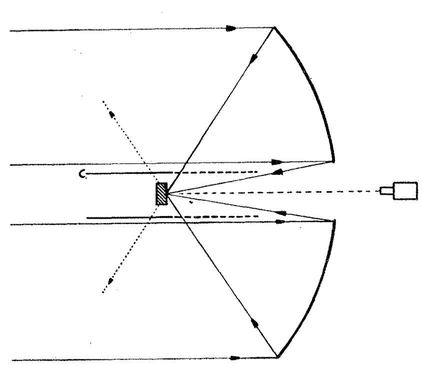

Fig. 2. Schematic diagram of solar furnace for high-temperature research.

Just as important as the high temperature is the ideal experimental condition that exists in a solar furnace. Radiation energy is a very pure heat source. No combustion products and no vapors of refractories or resistance elements are present as contaminants. Since the material to be heated acts as its own crucible, reactions between sample and container are eliminated. Also eliminated are reactions between the sample and other parts of the furnace, since the parts of the furnace remain virtually at atmospheric temperature during the entire heating process.

Since it is possible to raise the temperature to 3500°C within a few seconds, the cycle of heating is very short. The cooling period also is very short, since the sample is not surrounded by a large mass of hot refractory material. Thus, effective quenching, so important in phase studies, can be performed conveniently. If, however, slow heating or slow cooling is required, these too are possible, since the temperature can be controlled closely even at the top range. Furthermore, it is possible to perform the heating in air, in any desired atmosphere, and at low or moderate pressure.

Heating the sample under experimental conditions is only one part of high-temperature research. It has to be combined with observation and measurement during heating. These too can be accomplished far better in the solar furnace. Since only part of the sample is heated, and since the entire surroundings remain at atmospheric temperature, the observation and measuring instruments may be placed quite close to the sample. There is no electromagnetic field to interfere with the measurement of electric properties. It is possible to repeat a test within a few seconds by moving, with the aid of a servomechanism, an unreacted portion of the sample into the focal point.

Operating Principle

Figure 2 shows the operating principle of the solar furnace. Solar radiation is concentrated by a paraboloidal reflector on the sample placed in the focal zone. Since the reflected radiation forms a double cone (dotted line) with the apex at the focal zone, the size of the heated area may be increased by moving the sample along the axis of the cones in either direction. As the heated surface increases, the energy density—that is, the temperature—decreases. Another method of decreasing the maximum temperature consists of moving a reflecting cylinder C into the position indicated by the broken line, thus preventing part of the reflected radiation from reaching the sample. By making the movement of both sample and cylinder continuous, good, gapless temperature control may be achieved.

The solar energy reaching the atmosphere of the earth is 2 calories per minute, per square centimeter. Because of atmospheric absorption and dispersion, this value is reduced to approximately 1.6 calories per minute, per square centimeter by the time the energy reaches the surface of the earth. Accordingly, under ideal weather conditions each square centimeter of the reflector receives approximately 1.6 calories of heat every minute and reflects it into the small focal area, thus producing a very high concentration of energy. Since the reflector cannot be a geometrically perfect paraboloid and cannot have a reflection coefficient of unity, some energy losses are unavoidable.

The cause of a further decrease in energy density at the focal zone is illustrated in Fig. 3, in which the real path of solar radiation in a large-aperture reflector is illustrated. The image of the sun is defined by an angle of 32 minutes at any point of the reflector. The image recreated at the focal zone naturally is defined by the same angle. At a point close to the rotational axis F of the reflector, image 2 is reflected, forming cone 2_1. The intersection of the sample with cone 2_1 forms the base of the cone, which is approximately a circle of d_2 diameter. The axis of cone 2_1 is L_2. A point farther away from F reflects cone 1_1. The base of this cone is an ellipse with a major

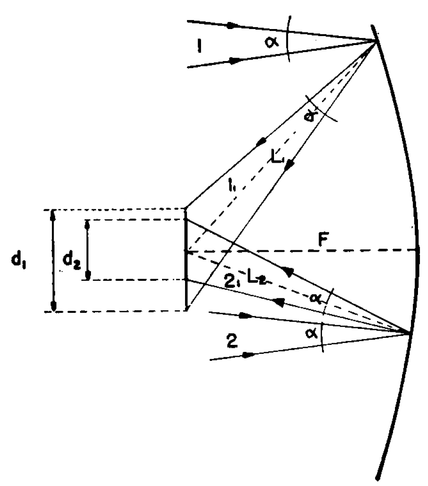

Fig. 3. Formation of the reflected image of the sun; α represents 32 minutes.

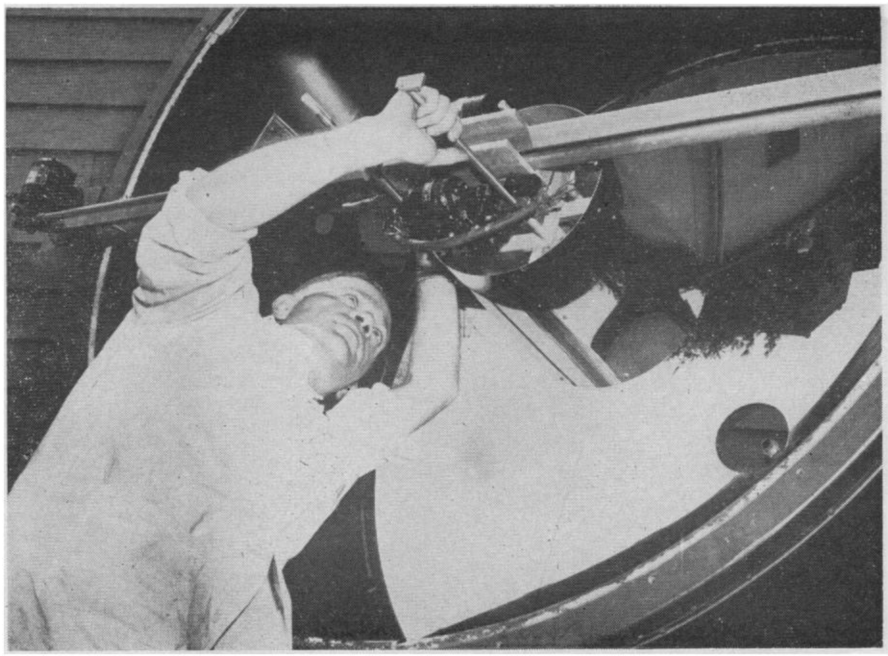
Fig. 4. Front view of the solar furnace at Fordham University.

axis of d_1. Since L_1 (the axis of cone l_1) is larger than L_2, the area of ellipse d_1 is greater than the area of circle d_2. The total energy content of both cones is equal; therefore, the energy density is greater in circle d_2 than in ellipse d_1.

A further temperature gradient results from the fact that the central part of the focal zone receives energy from all points of the reflector, whereas the outer part of the zone is heated only by reflection from the peripheral portions. Accordingly, the peripheral parts of the reflector make no considerable contribution to the highest temperature zone. This explains why no further rise in temperature can be obtained by increasing the aperture n above 4 (Fig. 1).

Since the central parts of the reflector contribute greatly to the high energy density, it is very unfortunate that exactly this valuable portion is shaded by the sample and the temperature-control mechanism. The completely shaded center part of the reflector is cut out, since it would not participate in the concentration of energy anyway. The opening thus obtained is used for the mounting of observation and measuring instruments.

Fordham Solar Furnace

The solar furnace at Fordham University was constructed from a 60-inch searchlight. Figure 4 is a front view of the furnace. The highly polished paraboloid mirror at the back of the furnace reflects the inverted image of buildings and trees. The observation hole with an optical pyrometer mounted in measuring position is seen at the center of the mirror. An I-beam runs across the front of the furnace. Mounted on the I-beam is a carriage that can be moved sideways with the aid of a servomotor shown at the far left side. The carriage contains the sample holder and positioning mechanism, which is activated by three servomotors. One of these motors is at the center of the photograph. Surrounding the carriage is a highly polished aluminum cylinder. This cylinder can be lowered or raised mechanically, thus decreasing or increasing the amount of radiation reaching the sample, as is explained in the discussion of Fig. 2.

The back of the furnace can be seen in Fig. 5. The optical pyrometer in the observer's hand is used for temperature measurements. The switchboard on the right side controls the operation of the servomotors. Thus the observer, without

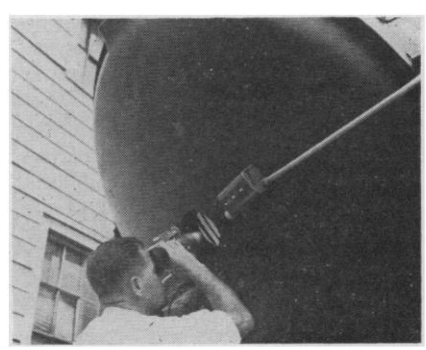
Fig. 5. Rear view of solar furnace at Fordham University, showing mounted optical pyrometer and control switches.

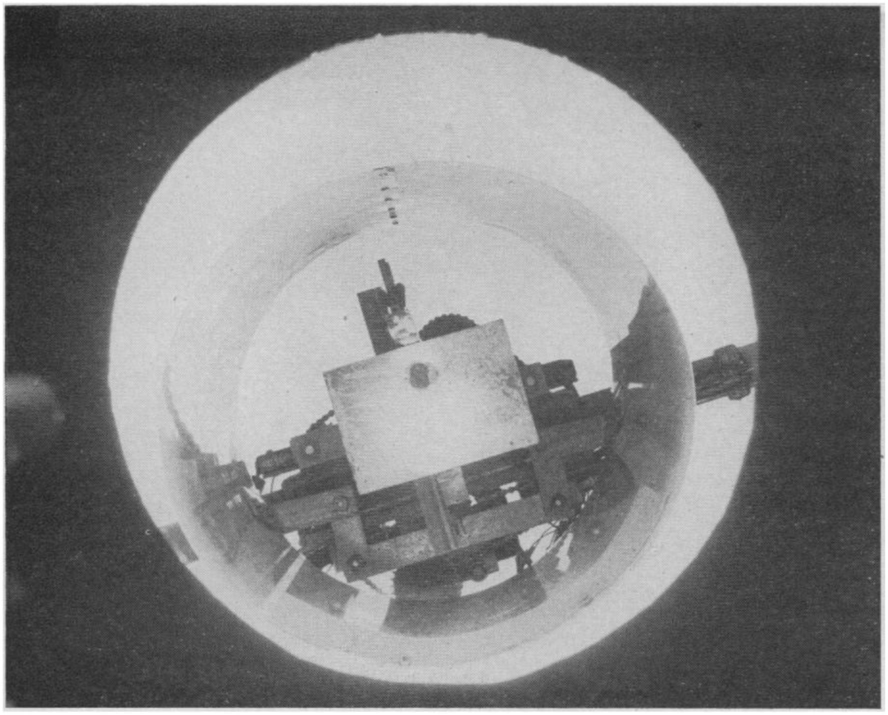

Fig. 6. Mullite sample being heated in the solar furnace.

leaving his post, can change the position of the sample in every direction, move a fresh part of it into the focal zone, and control the temperature of the focal zone. Finally, Fig. 6 is a view through the observation opening during the heating of a sample of mullite. The construction of the sample holder is visible in detail, together with the chain-sprocket system of the positioning mechanism. The bright circle on the mullite block is the heated area, and the dark spot is a cavity that was melted into the sample during a previous run.

Although the maximum temperature may be reached within a few seconds, it may be necessary for certain measurements to maintain uniform temperature at the same spot for a longer period of time. Therefore, an automatic system was developed to guide the mirror so that in its rotation it will follow the apparent motion of the sun (*3*). Solar furnaces constructed especially for this purpose are mounted on a polar axis and need only a synchronous motor for the proper rotation of the reflector.

Solar furnaces will become important tools of fundamental high-temperature research. At present, the determination at temperatures above 2000°C of the simplest physical constants—for example, melting point, boiling point, vapor pressure, and so forth—presents great difficulties in equipment and instrumentation. Measurements of specific heat and reaction rates are limited to even lower temperature regions. Studies of crystalline properties and phase changes are particularly hindered by the container problem at elevated temperatures.

The pure experimental conditions and high temperature range of the solar furnace offer a much needed relief. Some work already has been reported in this direction (*4*). Studies of electric and optical properties require single crystals of extremely high purity. If the material to be studied has a high melting point, the growing of single crystals is impossible without introducing a variable amount of impurity from the environment of conventional furnaces. Single crystals were grown in the solar furnace of Fordham University from highly refractory oxides, such as ZrO_2, without allowing them to come in contact with any material other than air. It may be worth while to mention that the solar furnace, besides being a research tool, is used at the high-temperature laboratory of Fordham University to make the hot junction bead on thermocouples. Eliminated, by this method, is the possibility of carbon contamination, which is always present during the conventional carbon-arc melting method.

No one experimental setup is available for research on solar furnaces. The investigator first has to determine the condition he wishes to maintain and then design his heating and measuring equipment accordingly. The lack of reports on experiments already completed forces every investigator to start afresh. Some consolation for this lack of interchange of information may be found in the fact that this situation is likely to produce several independent approaches to similar problems.

The importance of increasing our knowledge of the high-temperature properties of matter is not academic alone. In many fields of technology, great advances can be expected once we cross this "temperature barrier" in knowledge. Two examples will illustrate this statement. At present the temperature in the combustion chambers of jet engines is about 750°C. If this value could be increased to 1300°C, the fuel consumption of the engine would decrease to half of its present value. No engine material, however, is available to withstand such a high operating temperature. The development of a satisfactory material or combination of materials would have great military and economic importance.

A second example is found in the development of atomic power plants. The operating temperature of atomic piles is limited by the refractory properties of the construction and shielding materials. Whenever better refractory materials become available, the thermal efficiency of atomic power plants will increase greatly. In the search for better materials for the combustion chambers of jet engines, better refractories for atomic reactors, as well as much other high-temperature research work, the solar furnace may be used to great advantage.

Only a few solar furnaces are used at present for research, but considerable interest has been shown recently in this unique tool. The great potentialities of the solar furnace and the favorable reaction it has created in science and industry justify the hope that a large number of the furnaces will be constructed and used for high-temperature research.

References and Notes

1. G. Benveniste and M. L. Kastens, *Science* 123, 826 (1956).

2. I wish to express my appreciation for the financial support received from the National Science Foundation for research work on solar furnaces.

3. T. S. Laszlo, W. deDufour, J. Erdell, "A guiding system for solar furnaces," Conf. on Solar Energy: the Scientific Basis, Tucson, Ariz. (1955).
4. W. M. Conn, *Ceram. Bull.* 33, 69 (1954); F. Trombe and M. Foex, *Rev. mét.* 47, No. 5, 359 (1951).