Low Temperature and Some of Its Effects Upon the Behavior of Matter

S. C. Collins

Department of Mechanical Engineering,
Massachusetts Institute of Technology

SINCE THE END OF WORLD WAR II the scientific effort directed toward the properties of matter at very low temperatures has increased at a striking rate. More than a dozen laboratories in the United States are now actively engaged in researches which extend into the liquid helium range. There were only two prior to 1946.

The initial interest in very low temperatures was created chiefly by the desire to liquefy the so-called permanent gases, nitrogen, oxygen, hydrogen, helium, etc. Helium, the last to yield, was reduced to the liquid state in 1908 by Onnes. As the temperature range available for experimentation was extended to lower and lower values, it was natural to examine the physical properties of solids as well as those of the low-boiling liquids at the lower temperatures.

Properties of substances which were known to vary with the temperature were the first to receive careful study at low temperatures. Among such properties are electrical resistance, magnetic susceptibility, and specific heat. Onnes, deHaas, and others have found electrical resistance to decrease as the temperature decreases until very low temperatures are reached. At that point the resistance may assume a low constant value, the magnitude of which seems to depend upon the amount of impurity present in the specimen; it may drop abruptly to zero, in which case the substance is said to be superconducting; or it may rise sharply as the absolute zero is approached.

The magnetic properties of matter at low temperatures have been studied extensively by Gorter, Kurti, Simon, and many others. Some substances, normally paramagnetic, exhibit ferromagnetism at extremely low temperatures. Many magnetic anomalies have been observed.

Thermal agitation of molecules is sufficiently reduced at low temperatures as to make possible the observation of characteristic phenomena which are effectively masked at higher temperatures. Broad bands in the absorption spectra of some substances at room temperature appear as a number of fine lines at low temperature. The determination of crystal forms and the identification of certain groups of atoms in the molecule are sometimes possible.

With the development of the quantum theory and Nernst's heat theorem it became important to determine specific heats of solids down to the lowest possible temperature. Nernst's theorem, or the third law of thermodynamics, as it is sometimes called, may be stated as follows:

> For any reversible isothermal process which may take place in a condensed system, the change of entropy, ΔS, approaches zero as the temperature approaches zero.

Assuming Nernst's postulate to be correct, it would only be necessary to measure specific heats and latent heats of the reactants and products of a given reaction over the temperature range $T = 0$ to T in order to calculate the entropy change for the same change of state at temperature T. From the entropy change and the heat of the reaction, the equilibrium constant can be evaluated. This is of practical value, but the implication that, for all states of a system in thermal equilibrium, the entropy approaches zero as the temperature approaches zero is of the greatest theoretical importance.

Debye (*10*), recognizing the value of quantum methods for such applications, developed a theory of specific heats which is in good accord with experimental results over a very wide range of temperature. Certain marked deviations, however, have been observed, especially at very low temperatures. Investigation of the causes of such anomalies has led to significant advances in the theory of the solid state.

Giauque and his collaborators have measured the specific heat of many substances down to very low temperatures. By means of Debye's formula, the specific heat-temperature curve can be extrapolated to the absolute zero. From such measurements and calculations a value of the entropy of a substance at a chosen temperature can be determined and compared with that of the same substance determined from known equilibrium constants or by spectroscopic data. The results have helped to establish the validity of Nernst's theorem.

The preparation of suitable temperature-measuring devices for use at low temperatures has been, and still is, a time-consuming operation. The constant-volume helium gas thermometer, to which corrections are applied to secure conformity to the ideal gas scale, is acceptable all the way down to 1° K. Using this as a fundamental standard, more convenient working thermometers are usually prepared. Vapor pressure thermometers are used wherever possible. The range over which they are useful is about as follows: oxygen, 90–65° K; hydrogen, 21–10° K; and helium, 4.2–1° K. Resistance thermometers of platinum, phosphor-bronze, or other metal and thermocouples are also much used.

For temperatures below 1° K reliance upon measurements of the magnetic susceptibility of paramagnetic salts is general. It is assumed that for these substances Curie's law is valid. This is $\chi = \frac{C}{T}$, where χ is the susceptibility and C is a constant. It is possible to correct this arbitrary scale to the thermodynamic scale of temperature when sufficient magnetic and heat capacity data are available.

Recent developments by Frankl (*14*) and Collins (*5*) have made practical the production of industrial oxygen by plants which require air pressures of 5–10 atm instead of 40–80 atm, which is common to older types. Frankl introduced cold accumulators and Collins a new type of reversing exchanger for the dual role of conserving refrigeration and mechanical purification of the air. Oxygen of higher purity is possible with the latter equipment.

MEANS FOR PRODUCTION AND MAINTENANCE OF LOW TEMPERATURES

Methods and apparatus for securing refrigeration at very low temperatures have received a large fraction of the scientific effort expended in this field up to the present time. Consequently, an account of the results of low-temperature researches of the past should describe, briefly at least, the evolution of modern techniques in low-level refrigeration.

The important physical principles used in the production of low temperatures are three in number: (1) the dependence of the internal energy of a system upon its volume as well as upon its temperature; (2) performance of external work during an expansion, when the system exerts pressure upon a moving boundary; and (3) performance of external work during demagnetization, when the system returns energy to the magnetizing agent. Nearly all actual refrigerative processes utilize a combination of principles 1 and 2.

When a body of gas is compressed adiabatically—that is, without exchange of heat with the surroundings—it becomes hot, mostly because of the work expended upon it, but also by virtue of the fact that generally the specific internal energy of a dense gas is less than that of the same gas in expanded form. If, during the compression, heat is removed so that the initial and final temperatures are equal, the amount of heat removed is the sum of the work of compression and the change in internal energy. If the gas condenses to form a liquid, the decrease in the internal energy is large in comparison to the work of compression; otherwise, it is small.

When a flask of compressed air is opened to the atmosphere and the pressure allowed to equalize, the air remaining in the flask will be quite cold, principally because of the external work performed in pushing back the atmosphere and in accelerating the fraction of the air which was ejected. This experiment was performed in 1819 by Clement and Desormes, and the cooling effect was noted. In this manner oxygen was first liquefied in 1877 by Cailletet. A cylinder of highly compressed oxygen was cooled to the lowest temperature available and then vented to the atmosphere. A mist of oxygen droplets was observed. As a means of liquefying oxygen (b.p. = 90.1° K) the method is quite ineffective. The thermal capacity of the heavy-walled cylinder is so great compared to that of the charge of gas that nearly all of the refrigerative effect is wasted. Half a century later, however, Simon (*32*), capitalizing upon the fact that at very low temperatures the specific heat of almost all metals is extremely small, revived the free expansion process for supplying both liquid hydrogen (b.p. = 20.4° K) and liquid helium (b.p. = 4.2° K). The amount of liquid which can be produced conveniently per cycle is not very large. Because of the simplicity and adaptability of the method, however, it has been extremely fruitful of low-temperature data.

To supply refrigeration continuously, a cyclic process must be substituted for the intermittent charge and discharge of the free-expansion method of cooling. The compressor then operates continuously at ambient temperatures. The compressed gas is cooled by air or water to remove the heat of compression and to effect the appropriate change in internal energy. Continuous adiabatic expansion is accomplished in one of two radically different ways. The simplest manner is to use a throttling valve in which the amount of external work consists solely of the change in the pressure-volume product of the gas. The change in temperature is relatively small. The second method consists of allowing the gas to expand against the piston of an engine in such a manner as to perform the maximum amount of external work. The maximum temperature drop for a given expansion ratio will then be secured.

Joule and Thompson first observed the change in temperature across a throttling valve in 1852. For nearly all gases the temperature falls with decreasing pressure; for hydrogen and helium at ordinary temperatures the temperature rises. At very low temperatures, however, these gases, too, produce a cooling effect by expansion.

The Joule-Thompson effect is so small that the simple expansion alone is worthless as a refrigerative process, but, used in combination with the counterflow heat exchanger developed by Sir William Siemens about 1860, it has played a very significant role both in low-temperature research and in the production of industrial oxygen. The compressed gas, precooled to a temperature sufficiently low to insure a drop in temperature at the expansion valve, flows along one channel of the heat exchanger toward the valve and gives up heat to the slightly colder expanded gas flowing in the opposite direction along a second channel which makes good thermal contact with the first. The compressed gas arriving at the valve becomes progressively colder until the liquid phase appears. Air was liquefied in quantity by this method in 1895. Hydrogen and helium were first liquefied in this manner—hydrogen, in 1898 by Dewar, and helium, in 1908 by Onnes.

The second and more efficient type of adiabatic expansion, in which the maximum amount of external work is performed by the gas in driving an engine, was first used by Gorrie (*17*) about 1846 in the production of artificial ice. The temperature drop across such an engine can be a large fraction of the absolute temperature at the inlet, but the process is greatly improved by the addition of a counterflow heat exchanger so that the engine may be served with gas which is already quite cold. Lubrication of moving parts at very low temperatures presents a problem. Claude (*4*) produced the first successful nonlubricated expansion engine, and this had immediate commercial application in the liquefaction of air for the manufacture of industrial oxygen. The piston was sealed in the cylinder by means of a leather cup similar to that used in a tire pump. Nonlubricated expansion engines operating on compressed hydrogen at temperatures below the liquid air level were first employed about 1926 in industry for purifying hydrogen. Kapitza (*20*), in 1934, described a helium liquefier which contained, as an important element, an expansion engine in which helium was the working fluid. The compressed helium is precooled to 65° K by liquid nitrogen boiling under reduced pressure and further cooled in the heat exchanger to 20° K. A large fraction of the stream is then expanded in the engine. The cold exhaust at 10° K is used to cool further the remainder of the stream for treatment in the usual Joule-Thompson process.

Collins (*6*), supported by the Aero Medical Laboratory of the Army Air Forces, in 1946 completed a helium cryostat in which the entire interval between room temperature and 4° K is spanned without the aid of liquid nitrogen or other refrigerants. Helium is the working fluid, and the expansion ratio is relatively small (14 atm down to 1). A cold chamber in which experiments may be performed at temperatures as low as 2° K is provided. Any gas can be liquefied and transferred to external receivers. The heat exchanger and the engine are suspended in a helium atmosphere rather than in the insulating vacuum so that minor leaks can be tolerated. Twelve of these machines are now in operation in various laboratories in the United States.

The third refrigerative principle mentioned above as the decrease of the internal energy and, hence, temperature of a system during an adiabatic decrease in the magnetization of the system was suggested independently by Giauque (*15*) and Debye (*11*) in 1926. Since external work is done upon a substance when it is magnetized, there should be a rise of temperature when the process is carried out adiabatically, and a corresponding fall in temperature on demagnetization. Ordinarily the effect is very small. In the case of paramagnetic substances at very low temperatures, however, the effect is considerable, and since the specific heat of most solids is extremely small at temperatures below 2° K, a substantial drop of temperature may be expected when the magnetizing field is destroyed. In 1933 Giauque and MacDougall (*16*) attained an estimated temperature of 0.25° K upon adiabatic demagnetization of a sample of gadolinium sulfate which had been cooled to 1.5° K in a magnetic field of 8,000 gauss. Two years later deHaas and Wiersma (*19*) reached an estimated temperature of 0.0044° K. In this connection it should be noted that temperatures below 1° K are difficult to produce by the simple expedient of evaporating liquid helium at reduced pressure. The vapor pressure of helium is only 0.12 mm at 1° K, and pumps of great capacity are required to furnish appreciable refrigeration at this level.

Cooling by adiabatic demagnetization has thus opened up a temperature range not attainable by older methods. The chief deficiency of the method is the fact that the low temperature reached is a transient condition. The cold salt begins to grow warmer immediately. Serious efforts are being made to develop a method based on adiabatic demagnetization which will provide continuous refrigeration at temperatures of the order of 0.01° K.

STRANGE PHENOMENA AT THE TEMPERATURE OF LIQUID HELIUM

Superconductivity. The electrical resistance of a large number of metallic elements and alloys falls to zero at very low temperatures. The transition from the state of normal resistivity to the superconducting state occurs within a narrow range of temperature (less than 0.001° in the case of a single crystal of high purity). Transition temperatures for various substances range from 14.5° K for columbium nitride to 0.34° K for hafnium. An electric current, once started in a superconducting circuit, continues to flow without help from an electric cell or other source of potential.

Such permanent currents are usually started in a ring of the superconducting material by electromagnetic induction. If the temperature of the ring is allowed to rise above the transition point, the current dies out quickly because of the finite resistance.

The behavior of substances in the superconducting state is fairly complex. If a magnetic field is applied parallel to a superconducting wire, the resistance of the wire is suddenly restored at a definite field strength. The lower the temperature, the greater the field strength required to restore the resistance. The magnitude of the maximum critical field is of the order of 100–1,000 gauss. An electric current flowing through the superconducting wire will restore its resistance if the magnetic field produced by the current itself exceeds the critical value appropriate to the existing temperature. If the superconducting specimen is impure, inhomogeneous, or irregular in shape, the transition from the state of infinite conductivity to normal is not abrupt. The field strength required to produce the first trace of resistance may be a small fraction of that necessary to restore it fully.

When a superconducting cylinder of metal is placed in a magnetic field of less than the critical value, the field does not penetrate the cylinder as it would if the latter were in a normal state. This result could easily be explained on the basis of induced permanent currents set up in a thin layer on the surface of the cylinder. But if the field is established in the cylinder before it is rendered superconducting by cooling, no disturbance of the field would be expected. Meissner and Ochsenfeld (*27*) tried such an experiment and found that the lines of force had been completely expelled from the cylinder. This and subsequent experiments led to the conclusion that in a pure superconductor the magnetic induction, B, is equal to zero as long as the external magnetic field is less than the critical field strength. This condition of zero magnetic induction or perfect diamagnetism seems to be the most fundamental property of superconductors.

Currents flowing in a superconductor are generally confined to a thin surface layer. The thickness of this layer is also the depth to which an applied magnetic field penetrates into the superconductor. The penetration of the magnetic field can be expressed in terms of the number of superconducting electrons per unit volume. Different methods are available which yield some information about this quantity. Pippard (*30*) has used a radiofrequency method which measures effectively the difference between the penetration depth, λ, in the superconducting state and the skin depth, δ_n, of ordinary eddy currents when the superconducting state has been destroyed by a magnetic field. This method is applicable when δ_n does not vary with the temperature. Casimir (*3*) and Laurmann and Shoenberg (*25*) have measured the mutual inductance between two coils wound upon a superconducting core. The mutual inductance decreases slightly as the temperature is lowered because of the decrease in λ. The results have given interesting evidence of anisotropy of penetration depth in single crystals. Desirant and Shoenberg (*12*) have measured $\Delta\lambda$ from the temperature variations of susceptibility in thin cylinders. Their results indicate a value of the penetration depth at the absolute zero of 7.6×10^{-6} cm. A method similar to that of Pippard has been used by Slater and co-workers at the Massachusetts Institute of Technology, employing higher frequencies (24,000 megacycles/sec) and modern radar techniques. Their results are to be published soon.

If a small magnetic field is applied to a long superconducting cylinder in a direction perpendicular to the axis, the field strength will be doubled at the equator because of the zero-permeability of the cylinder. If the strength of the applied field exceeds one-half the value of the critical field of the specimen, then at the equator the local field strength exceeds the critical value, and superconductivity begins to disappear. The cylinder is said to pass into the intermediate state, a state of inhomogeneity in which superconducting regions and normal areas are interspersed with each other. The actual minimum field required to produce the intermediate state has been shown by Misener (*28*) and others to be approximately 0.58 H_c rather than 0.50 H_c. Landau (*22*) has explained the discrepancy on the basis of surface energy requirements at the boundaries between the normal and superconducting phases. Desirant and Shoenberg (*13*) have recently measured the magnetization of tin and mercury cylinders in transverse magnetic fields at a variety of temperatures. Their results show a sharp change in magnetization at the onset of the intermediate state and make possible an estimate of the surface energy at the boundary between normal and superconducting phases.

Impurities and irregularities in shape make the behavior of superconductors more complex. The transition temperature interval (the temperature at which resistance begins to fall rapidly minus the temperature at which the resistance completely disappears) is widened, and considerable penetration of both current and magnetic field may occur.

The most significant change in the properties of a substance during the transition from normal to superconducting state, other than the decrease in resistivity, is an anomaly in the specific heat. There is a discontinuous change in the specific heat amounting to several per cent.

When the transition occurs in zero magnetic field, there is no latent heat; but, if the change in state takes place at a lower temperature in the presence of a magnetic field, it is accompanied by the evolution of heat. Conversely, if the superconducting state is destroyed by increasing the field at constant temperature, heat will be absorbed. If the increase in the field strength occurs adiabatically, the temperature will fall. The transition between the normal and superconducting states is thus seen to be reversible and amenable to thermodynamic treatment. Rutgers (*31*) and Gorter and Casimir (*18*) have regarded the transition as a change in phase quite analogous to that of a vapor-liquid system and have put forward a convincing thermodynamic analysis. The transition temperature depends upon the field strength instead of on the pressure as in liquid-vapor phase equilibrium. The well-known Clausius-Claypeyron relation takes the form $\frac{dH_c}{dT} = \frac{-4\pi (S_n - S_s)}{VH_c}$ where H_c is the critical field strength and S_n, S_s denote the entropies in the normal and superconducting phases, respectively.

A satisfactory complete theory of superconductivity has not yet been advanced.

Liquid helium. The critical temperature of helium is 5.20° K, and the liquid-vapor equilibrium extends from 5.20° K to the absolute zero. Solid helium exists only under considerable pressure, 25 atm at the lowest temperatures to 5,400 atm at 42° K. There are two forms of liquid helium, helium I and helium II. The transition temperature is 2.19° K under saturation conditions and is known as the lambda point of liquid helium.

The only unusual feature of helium I is the fact that its viscosity decreases as the temperature decreases. In that respect it behaves as a gas rather than a liquid. Helium II, however, has many strange properties. Onnes observed in 1922 that, when an open Dewar vessel containing liquid helium II is surrounded by a larger Dewar vessel, the liquid quickly distributes itself between the two vessels, establishing the same level in both. If the liquid is then splashed from the inside vessel to the outside in order to make the level higher on the outside, the level outside can be seen to fall while that on the inside rises until again they are in the same plane. The liquid seemed able to flow over the retaining wall as if by a siphon.

Rollin found that the rate of evaporation of a body of helium is greatly increased when the temperature is lowered below the lambda point. He suggested that a thin layer of helium II creeps up the walls of the apparatus and is evaporated when it reaches a warmer zone. Daunt and Mendelssohn (*7*), in further experiments, were able to show that the amount of liquid transported was the same for a copper surface as for glass and was proportional to the perimeter of the surface cutting the liquid.

The thermal conductivity of helium II is phenomenally high, rising to a maximum at a point just below 2° and dropping thereafter as the temperature falls. The maximum value attained is some 200 times that of copper at ordinary temperature, 3×10^6 times that of liquid helium I. The apparent thermal conductivity strangely depends upon the temperature gradient and upon the cross-section and length of the column of liquid.

Various attempts to measure the viscosity of helium II gave rather baffling results. Wilhelm, Misener, and Clark (*35*) in 1935 obtained a value which was about one-tenth the viscosity of helium I. Allen and Misener, Kapitza, and others, using fine capillaries and flow between parallel plates, obtained widely different results. They discovered that the quantity of helium II flowing was almost independent of the pressure drop.

Allen and Jones (*1*) were the first to observe the effect upon the flow of helium II in narrow tubes of a temperature gradient in the tube. Fountains of helium rising to a height of several centimeters could be induced by allowing the light from a pocket torch to fall upon a tube packed with fine emery and partially submerged in helium II. The tube is open at both ends and equipped with a nozzle at the upper end. The flow of liquid is generally in a direction opposite to the flow of heat.

The fountain effect has been shown to be reversible. If the helium is caused to flow by mechanical means through a capillary or a tube packed with powder, a temperature gradient is set up.

To account for the extraordinary properties of helium II a number of theories have been proposed, notably by London, Tisza, and Landau. London (*26*) suggested that the transition of liquid helium might be the result of the condensation phenomenon of Bose-Einstein statistics, the condensed phase being dispersed throughout the normal phase in ordinary space but separated from it in momentum space. The atoms of the condensed phase are in the lowest energy state. The atoms of the excited phase exhibit a distribution over higher energy states as in a gas. Above the lambda point (He I) all atoms are excited. At lower temperatures (He II) the proportion of excited atoms decreases as the temperature decreases. At the absolute zero all atoms are condensed.

Accepting these ideas, Tisza (*33, 34*) has developed a theory, somewhat phenomenological in character, which has been very successful in accounting for the behavior of helium II. He pointed out that the condensation in momentum space means that helium II has a heterogeneous nature implying the existence of separate velocity fields for the two phases. This results in an "internal convection" carrying energy and entropy, but not associated with any net transfer of matter. This complex hydrodynamics allowed the correlation of phenomena which appeared paradoxical from the point of view of ordinary hydrodynamics. The nature of the two flows is rather different.

The normal phase (excited atoms) possesses a gas-like viscosity. The viscosity of the other phase is zero—hence the name superfluid. Because of the difference in viscosity, a fine capillary becomes a semipermeable membrane. Differences in concentration of superfluid can be created by temperature differences. If one of two vessels containing helium II and connected by a capillary is slightly warmer than the other, the concentration of superfluid within it is lower. Superfluid would flow from the second vessel into the first until a head of pressure sufficient to oppose the flow is generated. This process is analogous to osmosis in ordinary solutions. By the flow of superfluid, the fluid remaining in the colder vessel becomes warmer, while that in the warmer vessel becomes colder with admixture of the zero-point energy superfluid. The creation of a difference in temperature by causing flow through a capillary by mechanical means was predicted by Tisza (*33*) and observed by Daunt and Mendelssohn (*8*).

Assuming that the superfluid wets all surfaces to which it has access, the properties of the helium film can be qualitatively understood. The siphon effect exhibits the transport of quantities of liquid through a very thin film by virtue of the vanishingly small viscosity.

The abnormally high thermal conductivity is the result of the transport of superfluid in a direction opposite to that of the flow of heat, the superfluid being raised to the excited state, entailing the absorption of a quantity of heat which is large in relation to the quantity which might have been transferred by normal conduction or convection.

The analogy between two-phase helium and ordinary solutions is not perfect. In the case of solutions, differences in concentration are attended by diffusion, a very slow process. In the case of helium II, Tisza predicted that a concentration gradient would give rise to a current which would propagate according to a "wave equation" rather than the usual "parabolic equation" of heat conduction. The velocity of these waves was computed as a function of temperature. Later, the existence of these waves was demonstrated experimentally by Peshkov (*29*) and by Lane and his collaborators (*24*). This phenomenon, which has come to be known as "second" sound, is produced by periodic heating of helium II.

Finally, Landau's (*21*) theory should be discussed. Landau developed a complex microscopic hydrodynamics closely resembling that of Tisza. He rejects, however, the idea of any connection between helium and Bose-Einstein liquid and explains the heterogeneous nature of helium II on the basis of quantum hydrodynamics. He replaces the Bose-Einstein gas with a gas of "phonons" and "rotons."

The measurements of the velocity of "second" sound as a function of temperature by Peshkov and Lane bear out Tisza's prediction and are not in accord with Landau's equation.

Nevertheless, Tisza (*34*) has recently shown that the above-mentioned results can be obtained without any detailed molecular assumptions. Thus, the question of Bose-Einstein versus "rotons" gas theory is still open. The decision can be expected from the properties of the He^3 isotope, which obeys Fermi-Dirac statistics. These properties should show whether Bose-Einstein statistics is of fundamental importance for the phenomenon of superfluidity. Preliminary results seem to indicate that He^3 is not superfluid. Daunt, Probst, and Johnston (*9*) and Lane and Fairbank (*23*) have described new methods for the concentration of the isotope He^3. Both methods depends for their efficacy upon the isotope's failure to act as a superfluid.

The method of Daunt and collaborators consists of the transport of helium II from one reservoir to another through a thin surface film. Superfluid passes along the film easily, and normal atoms are stopped. Lane and Fairbank made use of a capillary containing helium II with a thermal gradient along the capillary. Superfluid passes from the cold end toward the warmer; normal helium, from the warmer end to the colder. In both cases substantial concentrations of He^3 were effected.

The heterogeneous nature of helium II has been demonstrated experimentally by Andronikasvilli (*2*), who measured the moment of inertia of a rotating vessel containing helium at various temperatures. The moment of inertia decreased rapidly as the temperature fell below the lambda point. The superfluid component of helium II does not take part in the rotary motion but glides through the interpenetrating atmosphere of normal helium atoms without friction—an effect first predicted by Landau.

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Loyalty Clearance Procedures in Research Laboratories

Committee on Secrecy and Clearance,
Federation of American Scientists

THE POSSIBLE MILITARY APPLICATIONS of scientific research have raised several serious problems for scientists in the past few years. Of these, the problem of clearance procedures and loyalty determination has proven one of the most vexing. It has involved not only scientists working in government laboratories but also those in university, industrial, and other private laboratories.

In the belief that sufficient information on present clearance procedures has not been readily available to most scientists, this Committee was formed to survey and report on the current situation in various types of research laboratories.

Sources of Information

In November 1947 a questionnaire was sent to the directors of 140 research laboratories throughout the United States. The Committee went over lists of research laboratories operated by universities, industries, and the Federal Government and selected at random a representative number from each group. The larger laboratories in the fields of physics, chemistry, and biological sciences were favored in our selection. A letter was enclosed which described the purpose of the survey and stated that the results would be published.

Replies were received from 57 laboratories, as listed in Table 1.

Although a number of the replies were incomplete or evasive, the questionnaire yielded considerable useful information.

The committee has collected many documents, articles, and newspaper clippings pertaining to clearance procedures. A number of selected references are listed at the end of this report.

In addition, members of the Committee have corresponded or had conversations with government and laboratory officials, with about 15 scientists who have been denied clearance, and with other informed persons. We wish to thank all those whose cooperation has enabled us to collect and present this information.

TABLE 1

Type of laboratory	Questionnaires sent	Replies received	Percentage replying
Atomic Energy Commission	9	3	33
Armed Forces	25	4	16
Other government laboratories	19	10	53
Industrial and private	39	14	36
Universities	48	26	54
Total	140	57	41

This report does not attempt a complete presentation of all the data collected, but will merely summarize the salient points. The Committee hopes to publish additional detailed information in further articles. The results of the survey will be reported under the five headings named in the above table.

Atomic Energy Commission

According to the Atomic Energy Act of 1946 (*5*), no individual may be employed by the Atomic Energy Commission or have access to restricted data "until the Federal Bureau of Investigation shall have made