Nobel Awards–Physics and Chemistry

The Swedish Academy of Sciences announced last week that Lev Davidovich Landau, a Soviet scientist, has been awarded the Nobel Prize in physics for his studies of the low-temperature characteristics of helium. It was simultaneously announced that the prize in chemistry has been awarded to two Britons, John Cowdery Kendrew and Max Ferdinand Perutz, of Cavendish Laboratory, Cambridge, for their studies of protein structure.

Physics

Academician Lev Davidovich Landau has made brilliant contributions in many areas of theoretical physics. The award to him of the 1962 Nobel Prize in physics was for his work on condensed states of matter.

Landau has made a specialty of extending the principles of quantum mechanics to many-particle situations and has been eminently successful in both predicting and explaining the aggregate behavior of such systems. The best examples of Landau's approach to extended systems of particles has probably been his attack on the problem of liquid helium. At temperatures below 2.2°K, this strange liquid was known to acquire weird properties, and it had constituted a scientific enigma, evidencing spectacular characteristics that included superfluidity and the ability to crawl over walls of containing vessels. This liquid helium II provided an excellent challenge to Landau's intellectual agility.

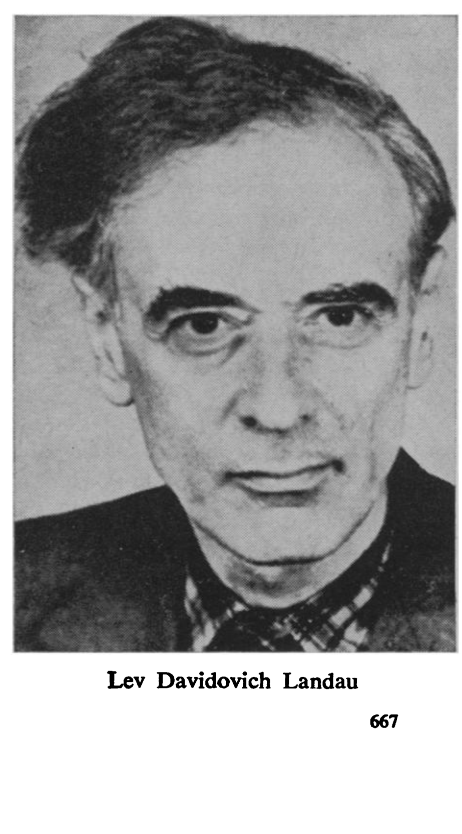
Besides explaining superfluidity or frictionless flow within liquid helium II, Landau extended the understanding of aggregate quantum mechanical systems by predicting a new form of wave motion, which he named "second sound." For liquid helium II the phenomenon, constituting essentially an undamped temperature wave, was first verified experimentally by another Russian physicist, Peshkov, during World War II, although it had been predicted independently by a Hungarian-American physicist, Tisza. The ultimate behavior of second sound propagation toward the temperature limit of absolute zero established Landau's approach as the correct one.

Landau's explanation of liquid helium II hinged largely on the concept of the "roton," introduced as a higher-order energy form of elementary excitation superseding the usual "phonons." Representing effectively a dip, or trough, in the energy-versus-momentum spectrum for phonons, the resultant rotons exist as stable excitons possessing a minimum energy, and thus separated from the quantum mechanical ground state by an energy gap. Basic to the concept of superfluidity, the roton spectrum has been mapped out experimentally in recent years by means of neutron diffraction measurements in full confirmation of Landau's earlier predictions.

Not content with his successes in cracking the liquid helium II problem, Landau moved on during the late 1950's to the properties of the rare-isotopic form, helium-3. Representing an odd number of elementary particles per atom (rather than the even number of ordinary helium-4), the statistical properties of liquid helium-3 had provided a distinct physical contrast. Liquid helium-3 did not condense (in momentum space) into a Bose-Einstein ground state or superfluid; instead, the Fermi nature of the substance seemed to preclude any phase change or onset of "superproperties," such as frictionless flow.

Recently Landau has published a series of powerful articles demonstrating theoretically that, at low enough temperatures, liquid helium-3 should also acquire special properties. In this connection Landau has predicted a form of wave propagation for liquid heium-3 called "zero sound," endowed with a distinctive array of special characteristics. Although resembling in nature ordinary first sound more than second sound, the zero sound wave clearly constitutes an oddball in the society of wave propagations. For one thing, it will probably prove easier to excite zero sound waves at extremely high frequencies than at low frequencies. More unusual, the wave motion will posses special modal forms of propagation related to the nature of the phenomenon rather than to environmental geometry. Although all but the "axially privileged" modes will evidently attenuate rapidly, the galaxy of weird propagation possibilities posed by zero sound provide a staggering challenge to the experimentalist.

But this is not all. Landau, along with other theoreticians, has predicted even a phase change for liquid helium-3, analogous to the sudden acquisition at 2.2 degrees Kelvin of superproperties by liquid helium-4. Such transition has been forecast by Landau as the result of a "Bose-branch" on the normal Fermi spectrum for liquid helium-3. Reasoning by analogy to the reality of superconductivity in electronic systems within metals, Landau concludes that an analogous pseudo-particle pairing of helium-3 atoms can occur, resulting effectively in a similar condensed state of ostensibly Fermi particles (as in superconductors). As soon as the feasibility of obtaining such condensed states was recognized, all the exciting possibilities provided in the past by superfluidity of liquid helium II (for helium-4) re-emerged, and more possibilities emerged, too! For, in addition to superfluidity and the associated



Lev Davidovich Landau

by-products, such as another second-sound type propagation, there should exist a whole new array of properties heretofore never encountered. For one thing, the helium-3 atom possesses a nuclear magnetic moment; thus, magnetic domains might develop spontaneously in the liquid, in analogy to ferromagnetic domains, or (more spectacularly) rotational domains corresponding to nothing ever before observed may develop. For example, a small suspended containing-vessel might jump suddenly into rotation, but in a direction that remains anybody's guess.

The preceding discussion demonstrates the remarkable present impact of Landau's recent thinking and predictions on experimental low-temperature physics. In low-temperature laboratories throughout the world, there is intense activity both to detect zero sound and to produce the phase transition predicted for liquid helium-3. Another area receiving Landau's attention has been that of superconductivity, in particular the theory of the intermediate state, and here, too, his work has greatly stimulated experimentation.

There is tragedy in the fact that during all the present acclaim and present experimental activity sparked throughout the world by his efforts, Landau has only now begun to recover from a near-fatal automobile accident of nearly a year ago. Ironically, he considered driving unsafe and would ride only as a passenger!

My wife and I had the pleasure of meeting Landau only a few months before his accident and found him to be a charming and extraordinary person. A distinct extrovert, Lev Davidovich keeps any company in a state of hilarity with an endless fund of entertaining conversation. He likes children and insisted upon making a series of weird and unbelievable faces before our movie camera to entertain ours (they were impressed and delighted). He has an endless supply of humorous stories of graded degrees of risquéness. Somehow my wife managed to hear a lot more of the really choice ones than I did!

In summary, the Nobel award to Academician Landau is a most deserved recognition, and scientists everywhere look forward to his rapid and complete recovery.

John R. Pellam
1340 East California Boulevard, Pasadena, California

Chemistry

John C. Kendrew and Max F. Perutz of the Medical Council Research Unit of Cambridge University, England, have been jointly awarded the Nobel prize in chemistry for work which led to a knowledge of the atomic arrangement in two very important proteins, myoglobin and hemoglobin. It is extremely gratifying to those of us who work in the field of structural analysis by the method of x-ray diffraction that this great honor was bestowed on these two outstanding members of our fraternity.

The atomic architecture of protein molecules must be known if we are to understand the chemistry of life processes, since all known enzymes—the catalysts which control the intricate systems of chemical reactions which take place in living systems—are proteins. Proteins are also important constituents of most living matter; in particular, the properties of hair, skin, tendon, and muscle of animals derive their valuable qualities from their high protein content.

It has been known for more than half a century that proteins are substances of large molecular weight formed by joining certain alpha-amino-carboxylic acids together into long chains with the loss of one water molecule for the formation of each joint. Such molecules are called polypeptides. The chemical structure of such a chain can be easily written down; it consists of amide groups joined by carbon atoms each linked to one hydrogen atom and one other simple chemical radical (R-group). The R-groups found in proteins are only about 20 in number but range from acidic, through hydrophobic, to basic.

It is thus possible for a protein chain to exhibit a tremendous variety of chemical properties—just the variety needed to provide the vast number of different qualities found among the various components of living systems. Knowledge of this chemical structure had not, as it turned out, provided an explanation of the properties that proteins actually display. Something more was needed: knowledge of the geometrical relationships between the atoms making up these chains.

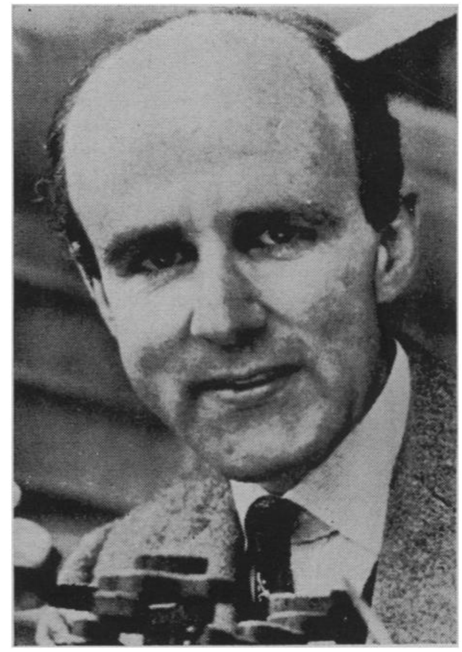
The atomic geometry of thousands of simpler substances has been discovered by applying the methods of x-ray diffraction to crystals. Whenever a substance can be crystallized, it is possible, in principle, to find out exactly how the atoms in it are related. Beginning with Max von Laue's discovery of x-ray diffraction in 1912, and its immediate application by W. H. and W. L. Bragg to the structures of salts and minerals in the years immediately following, the theoretical and experimental methods of x-ray crystallography had developed by about 1940 to a point where it was possible to foresee the elucidation of a molecular structure consisting of thousands of atoms, provided that this was a molecule of a substance that could be crystallized.

Simple structures can be worked out by a trial-and-error process: an atomic arrangement is proposed, its diffraction pattern is computed, and this is compared with the pattern found experimentally. Such methods are hopelessly inadequate for attacking a structure composed of even a hundred atoms per molecule, let alone that of a protein molecule containing at least several hundred, and usually several thousand, atoms.

New and more objective ways of finding structures were discovered during the 1930's and 1940's; these involved using relationships among the intensities of the various x-ray beams diffracted by a crystal, or finding the position of a very heavy atom in the structure and using this knowledge, together with the known intensities, to find the positions of the lighter atoms. Both these methods had been fairly successful, but they had only been applied to centrosymmetric crystals, in which half of the structure is a reflection, through a point, of the other half. It was not known how to use these methods on optically active substances, which, by their nature, cannot crystallize in this way. Yet almost all biologically important substances, including protein, are optically active!

In the late 1940's, Perutz started to study the x-ray diffraction patterns produced by crystalline hemoglobin, which is the oxygen carrier in blood. He was working in the Cavendish Laboratory of Cambridge University with the active cooperation and encouragement of Sir W. L. Bragg, then Cavendish professor of physics. Soon Kendrew joined the same laboratory and began to make similar studies on myoglobin. It is fair to say that none of

John Cowdery Kendrew



Max Ferdinand Perutz

them knew at that time just how to discover the positions of the atoms in these complex structures.

Hemoglobin has a molecular weight of about 65,000, and each molecule contains about 6000 atoms effective in scattering x-rays (hydrogen atoms do not scatter x-rays efficiently enough to be considered); myoglobin, the protein which stores oxygen in muscle, with a molecular weight of about 17,000, contains about 1200 effective atoms.

Kendrew and Perutz set about the task of recording on photographic film the x-ray diffraction patterns of these proteins and also worked on the problem of using these patterns to find the respective structures. Perutz soon discovered that heavy atoms could be introduced into protein crystals without affecting the atomic arrangements in the protein molecules. Then came the break: the way to use the heavy-atom positions in finding the structures of crystals without centers of inversion was discovered by Bokhoven, Schoone, and Bijboet at the University of Utrecht in the Netherlands.

Now came the hard work—the collection of x-ray intensity data from many crystals, each with a different arrangement of heavy atoms. Both workers decided to try at first to obtain a "low resolution" image of their structures. Even so, it was necessary to make many thousands of measurements and perform much ingenious computation with high-speed data-processing machinery. At last, in 1958, Kendrew announced an image, at 6-angstrom resolution, of the structure of the myoglobin molecule. It was a twisted, wormlike object of such a character as to suggest that the alpha helix arrangement of the polypeptide chain of the protein, proposed in 1951 by Pauling, Corey, and Branson of the California Institute of Technology, might be the guiding structural principle. This alpha helix is a spiral arrangement of the protein chain in which each peptide link (amide group) is connected by hydrogen bonds with two other ones, three joints removed along the chain in each direction.

Kendrew at once set out to do the laborious work of finding the structure of myoglobin at a resolution of 2 angstroms. At the same time Perutz continued to work for a 6-angstrom resolution image of the larger, and therefore less tractable, molecule of hemoglobin. The successful conclusion of both these programs was announced in 1960.

A remarkable phenomenon immediately emerged: the molecule of hemoglobin is composed of four subunits each of which is very similar in structure to a single molecule of myoglobin. Another spectacular result was the bringing to light of the true alpha helix structure; this showed up clearly in the 2-angstrom-resolution image of myoglobin, in which the atomic arrangement of the helix occurred in several places. In addition, by using the "anomalous dispersion" effect of the iron atoms in these proteins, it was definitely proved that the alpha helix is a right-handed screw composed of the L type of amino acid residues. All the results obtained for myoglobin are described in a beautifully written and illustrated article by Kendrew in the *Scientific American* for December 1961 (pp. 96 to 110).

This work is continuing at Cambridge. Kendrew is working toward obtaining an image of the myoglobin molecule at a resolution of 1.5 angstroms, in which it is expected that most of the atoms heavier than hydrogen will appear clearly enough to be located. This will make possible a complete statement of the atomic arrangement in a protein—the goal toward which the research was directed some 15 years ago! Perutz is making a similar but more laborious effort; he is working toward obtaining an image of hemoglobin at a resolution of 2 angstroms.

During all this long period these two men and their younger colleagues worked closely together in the small quarters of the Medical Council Research Unit at Cambridge. They talked together about their results daily and received frequent encouragement and cooperation from Sir Lawrence Bragg.

One of the results of this prolonged research effort has been the appearance of a group of enthusiastic younger workers in protein structure. They are now spreading across the world to take up research positions in various laboratories. We can therefore expect to see, during the next few years, the appearance of a number of detailed descriptions of the structures of proteins, and this will go far toward providing us all with the basic knowledge required for understanding the processes of life. For this expected benefit, as well as for the determined work which resulted in such beautifully defined knowledge of the structure of proteins, we must all be grateful to Kendrew and Perutz and rejoice wholeheartedly in the honor they have achieved.

DAVID HARKER
Biophysics Department,
Roswell Memorial Institute,
Buffalo, New York