PROBLEMS OF MODERN PHYSICS*

By PROF. J. FRENKEL

THE War has shown up sharply the value of physics, and its achievements in the practical and in particular the military sphere. It is not in vain that from the moment the treacherous attack upon the U.S.S.R. began, the physics institutes of the U.S.S.R. (as of all combatant countries) were switched over, almost completely, to the solution of defence problems.

Although these problems are also basic problems of present-day physics, I shall not touch upon them at all here. My task is in brief to survey the 'normal' problems of modern physics, that is, those problems which physics sought to solve in peace-time, and to which it will return after the end of the War.

These problems can be divided into three groups:

(1) *Problems of theoretical physics.* These comprise, in the main, the explanation of phenomena which were discovered and studied experimentally some time ago. In a series of cases, however, theory has preceded experiment and predicted phenomena or laws which had been previously unknown. The most striking achievements of theoretical physics are among this type of prediction. It must be noted, however, that these predictions were in almost every case the outcome of a theory which aimed not at forecasting new, but at explaining old, phenomena. Outstanding theoretical workers have been able by this re-examination of old data to see in it features other than those which were thought to be known and understood.

A characteristic feature of any new theory, which does not try to fit new facts to an already established representation, but attempts a broader representation of the old as well as the new facts, is its irrationality from the point of view of previous ideas. This irrationality disappears only after these old ideas have been radically reconstructed. Striking examples of such 'revolutionary' theories in physics are Newton's theory of gravitation, Maxwell's electromagnetic theory of light (which predicted the existence of wireless waves), and the quantum theory of Planck, Einstein and Bohr.

(2) *Problems of experimental physics.* Here, as in the domain of theoretical physics, it is possible to distinguish two types, namely, the discovery of new things and phenomena (for example, X-rays, radioactivity, the neutron, the positron, etc.) and the detailed study of phenomena of which the general features only are already known. At first sight it would appear that we can discuss problems of the second kind only, because no one can know beforehand anything about phenomena which are still undiscovered. However, the conception of novelty allows a series of gradations, and if we have in view not only radically new phenomena, but also those which are in principle similar to ones observed previously, the search for such new phenomena can be included in a plan of scientific investigation.

(3) *Problems of technical physics.* Experimental physics is closely connected with theoretical physics on one hand and with technical physics on the other. In both cases this connexion has a two-sided character; that is, the respective parts of physics mutually condition and stimulate each other's

development. In the realm of technical physics, we are concerned, generally speaking, with questions of utilizing the achievements of experimental physics for technical and, in particular, for industrial ends. In a number of cases, however, progress by technicians leads to the creation of new apparatus and methods of investigation, which open up new lines of development for experimental physics. Thus, for example, the development of radio-technics, which was the result of success in the study of electromagnetic and electronic phenomena, led in its turn to the creation of apparatus (electron counters, the electron microscope, the automatically operated Wilson chamber, the cyclotron) to which we are indebted for new knowledge in nuclear physics.

Physics of Material Bodies

A discussion of the problems of modern physics could be based on the classification introduced above. It is more convenient, however, to make a division into two groups of a different kind: problems of a macroscopic character connected with the properties of material bodies; and problems of a microscopic character, dealing with elementary processes and elementary particles of matter, and the nature of matter itself. The tasks and methods of theoretical, experimental and technical physics can be rigidly separated into the two groups under consideration.

The physics of the nineteenth century studied successfully the external side of phenomena, which was directly accessible to experiment and observation. The physics of the twentieth century successfully concentrated its attention on the internal mechanism of these macroscopic phenomena, that is, on their microscopic essence. In this way it had succeeded by the beginning of the 'thirties in explaining all phenomena in terms of the movement and mutual interaction of unchangeable elementary particles of two kinds, electrons and protons, in agreement with the general principles of quantum mechanics on one hand, and of electrodynamics on the other. As a result, it was possible either to establish theoretically and verify experimentally or to establish experimentally and explain theoretically, the structure and properties of those ninety-two kinds of atoms from which all material bodies known to us are constructed.

By the structure of atoms I have in mind the number, arrangement and movement of electrons around their respective nuclei, which for the majority of physico-chemical questions can be treated as positively charged point particles. Within the framework of this scheme, the structure of the atom was studied experimentally and theoretically with as much thoroughness as, for example, the structure of our planetary system.

New problems are connected with the deep study of the structure and properties of the atomic nucleus, and also with the process of its transformation—the alchemists' dream of artificial 'transmutation of atoms', now accomplished although only under laboratory conditions. From the other side these new problems are connected with the more detailed study of the system which depicts atoms in their combinations one with another—as molecules, crystals and amorphous bodies.

The development of atomic physics in each of these two directions has a completely distinctive character. In studying molecules and material bodies, physics is dealing with phenomena which have been studied experimentally, and in part theoretically, for many

* Translated by E. B. Holmberg from *Vestnik Acad. Sci., U.S.S.R.*, 4-5 (1943), made available by courtesy of the Science Section of the Society for Cultural Relations with the U.S.S.R.

years, although from a more or less macroscopic and therefore inadequate point of view. The problems of modern physics in this domain consist principally of the theoretical explanation of accumulated facts, from a microscopic point of view, that is from the point of view of the modern picture of the structure of atoms and the behaviour of their constituent electrons and nuclei.

The application to these questions of quantum mechanics and electrodynamics had already led, if not to a quantitative then, in a large measure, to a qualitative explanation of the various phenomena. Modern physics has succeeded in laying the basis of quantum chemistry, and in determining the structure and properties not only of simple but also occasionally of complicated organic molecules and crystals. Here, in the majority of cases, physics has only confirmed or completed those ideas which were worked out earlier by chemists, at times just by feel, on the basis of indirect evidence.

It must not be thought, however, that all this progress was achieved in the realm of theoretical physics. X-rays and cathode rays (electrons) are powerful tools for experimental investigation into the structure of molecules and material bodies. But all the basic problems concerning the structure of systems more complicated than atoms, that is, consisting of several or many atoms, have a theoretical rather than an experimental character.

The modern theory of the structure of molecules and crystals is still very far from the stage of exactness which is achieved in the description of the structure of separate atoms. At the moment, there lies before physics the very wide (although perhaps not very profound) problem of the more quantitative development and clarification of our knowledge. Besides these structural problems, there lie beyond still further unsolved problems connected with the study of the processes which take place in molecules and material bodies under the influence of various factors, such as mechanical action, heat and cold, electric and magnetic fields, light, etc.

Problems of this kind by no means always need for their solution a detailed application of the ideas and methods of atomic investigation. In particular, this is true of problems concerned with the mechanical properties of solids and liquids (or more precisely of crystalline and amorphous bodies). Here can be observed a marked lagging of theory behind experiment and technical practice. It is sufficient to say that, until the present time, we have had no satisfactory theory of such well-known and practical phenomena as the friction of solid bodies; no quantitative theory of the plastic properties of crystals, that is, of their 'flow' under the action of sufficiently strong tension. Our ideas about the mechanical properties of solids and liquids have remained until the present time extremely simple and schematic.

Liquid bodies possess the properties of elasticity of volume, and viscosity under change of form. In recent times it has become apparent that liquids, besides having volume elasticity, also possess elasticity of form similar to a solid body; that is, besides plasticity, they possess rigidity, the latter being masked usually by the former. Further, a series of bodies has been studied which possess unusual properties, and which cannot be put into either of the traditional categories of liquids and solids. An example of these is resin, and other 'resinous' substances with a high elasticity which disappears at low temperatures, and also jelly-like liquids which

have a wide application in the technics of to-day and possess completely individual elastic and plastic properties of structural origin.

The whole question of the 'unusual' mechanical properties of these substances, which are fortunately in most cases connected with their unusual electrical properties, is proof enough that a study of them from a theoretical as much as from an experimental point of view represents one of the tasks awaiting modern physics.

At temperatures near absolute zero, liquid helium occupies a certain peculiar position among these unusual substances. The striking experiments of Kapitza have shown that near the absolute zero of temperature helium completely loses the viscosity characteristic of normal liquids. As an explanation of Kapitza's experimental results, Landau has published an extremely interesting quantum treatment of the hydrodynamics of helium, based on the postulate that there exist two phases in liquid helium, a 'dead' non-viscous phase and a 'live' one possessing finite viscosity.

Landau's theory is in certain respects as unusual and 'irrational' as the experimental result it explains. But this is not sufficient to condemn it as a failure, because, as explained above, every new theory appears at first to be more or less irrational. However, the irrationality of a theory is not enough in itself to confirm its correctness. This can only be done by extending it to cover other phenomena, and then verifying its predictions experimentally (for example, in the case of liquid helium the proof of the theory is connected with the existence of two different velocities of sound in helium).

The absence of viscosity in liquid helium near the absolute zero of temperature is a mechanical analogue of the phenomenon of superconductivity, that is, the disappearance of electrical resistance, in a number of metallic bodies, at very low temperatures. Although this phenomenon has been known for some time, there is still to-day no satisfactory theoretical explanation of it, if we exclude certain attempted explanations of the fact that it occurs in two stages. The discovery of this explanation remains one of the real problems of modern physics, and in all probability it will need a basic alteration of our ideas concerning the normal conductivity of metals, along the lines of a more correct consideration of the mutual interaction between 'free' electrons, which condition this conductivity.

At the present time there is still great urgency about problems connected with the electrical, optical, photo-electric and thermo-electric properties of semiconductors of electricity, in spite of the great progress achieved in this sphere in recent years, particularly by Soviet workers such as A. F. Joffe and his school. These substances occupy an intermediate position between metals and dielectrics, just as liquids are intermediate between solids and gas-like bodies. As a rule, they become more like insulators at low temperatures and like metals at high temperatures. The effect of temperature is to produce ionization; that is, it tears off the bound electrons, which can then move freely throughout the whole crystal and thus conduct an electric current. Radiation also serves as an ionizing agent, not only in the visible but also in the infra-red region. Under the influence of unequal illumination or heating, appreciable photo-electric and thermo-electromotive forces arise in semiconductors.

At the present time, physics has to a large degree

learned how to manage the various properties of semiconductors principally by the method of adding to them a mixture of atoms which either easily give up their own electrons or quickly capture foreign ones. The development of this new domain of physics has already produced results of enormous industrial and technical value, although the future promises still more important technical applications. Perhaps it will be semiconductors which will help mankind to solve a basic technical problem in the not distant future when the deposits of accessible fuel coal and oil are exhausted. I have in mind the problem of utilizing directly the sun's energy by converting it into electrical energy by means of photo- or thermo-elements. The preliminary results obtained before the War by A. F. Joffe and his fellow-workers show that this idea is not Utopian, because the efficiency of rationally constructed photo- and thermo-elements is very high (this efficiency is appreciably greater in the case of semiconductors than in that of metals).

But from the purely scientific point of view, the study of semiconductors is still far from complete, and there are a number of very interesting problems connected with the subject which are as much theoretical as experimental. Among these must be mentioned that of 'localized' but free electrons in a crystal lattice, undistorted except for these electrons. Connected with this is the question of the motion of slow electrons and the existence of 'excitons,' that is, freely movable centres of electron excitation. This last question has particular importance for the understanding of the mechanism of certain photochemical processes in crystalline dielectrics. It acquires special interest in connexion with a new method of testing insulators electrically, which was put forward recently by B. I. Davidov. According to this method of testing gases, ionization takes place in stages, that is, the ionized atoms are first excited (just as in excitation, the ionization is caused by collisions of atoms with electrons which were freed as a result of a previous ionization). This hypothesis seems very plausible to me, although it cannot be accepted without further quantitative experimental verification. In particular, however much the gas test resembles the test for solid dielectrics, Davidov's hypothesis postulates the existence of free electrons (that is, excited atoms) in these solid dielectrics.

The intermediate role of semiconductors is analogous to that played in magnetism by the so-called meta-magnetic bodies such as magnetite and also a large number of chemical compounds of magnetic with non-magnetic elements. At moderate temperatures these bodies behave like ordinary ferromagnetics, but they lose their magnetic properties not only at high temperatures like ordinary ferromagnetics but also at low temperatures. This as yet little studied phenomenon of 'meta-magnetism' has probably an important practical application besides its great scientific interest. In particular, there is great practical value in the further study of the problem of obtaining ferro-magnetic, or rather meta-magnetic, alloys from non-magnetic elements. At the present time, only a few such alloys are known, and they possess very interesting magnetic properties. It is interesting to note in this connexion that there is an analogy with superconductivity. We now know of a series of superconductors (at low temperatures) which are alloys of elements not themselves superconductors.

The study of meta-magnetic phenomena requires the use of very low temperatures, although not so

low as for the study of superconductivity, and the analogous problem of the disappearance of viscosity. These very low temperatures are also required for investigations into the optical properties of crystals, in particular for spectral analysis, and a large number of other properties of solid bodies which only become important in exceptional cases. Therefore one of the necessary subsidiary tasks of physics is to equip institutes with cryological laboratories and to improve further the methods of low-temperature work. (At the present time it is possible by magnetic methods to achieve temperatures of the order of one thousandth of a degree absolute.)

It must not be thought that interesting and little-known properties of solid bodies can only be demonstrated by means of super-low temperatures. In recent years there has accumulated a wealth of experimental material relating to transformations observed in crystalline bodies at medium and high temperatures. In contrast to ordinary allotropic or polymorphic transformations connected with changes in crystal structure and the emission or absorption of heat, 'transformations of the second kind' about which I am thinking only make themselves apparent by anomalous changes, over a fairly narrow interval, in specific heat, coefficient of expansion and a series of mechanical, electrical, magnetic and optical properties.

Similar transformations were first established by observations in the case of ferromagnetic bodies near the so-called Curie point, above which their ferromagnetism disappears. This is a phenomenon similar in character to the disappearance of superconductivity at low temperature, that is, the restoration of normal electrical conductivity, and to the transition of liquid helium from its anomalous modification II having no viscosity to the normal phase, helium I, with a finite viscosity.

Analogous transformations of the second kind were recently brought to light in certain metallic alloys. As was first shown by Bragg and Williamson, these transformations occur when the regularity of the relative positions of the different kinds of atoms breaks down. Thus, for example, in an alloy of zinc and copper in equal proportions, the atoms are arranged in a chessboard pattern at low temperatures, but at a transformation at a certain temperature analogous to the Curie temperature in ferromagnetics this alternating arrangement completely disappears.

Further, a series of crystalline substances is known, for example, compounds of halogens with hydrogen, methane and other paraffins, in which these second order transformations can be traced—wholly or in part—to disordering of the particles (or as Pauling thinks, in certain cases to the molecules changing over from oscillatory motion about regularly distributed equilibrium positions to free motion as in gases). These analogies do not, however, cover all the observed phenomena. Thus, for example, in the case of hydrogen chloride, one Curie point is observed which can be attributed to the molecules becoming disordered (or according to Pauling, to the transition to free motion); but in the case of hydrogen bromide, there are three such transformations.

Thus we can see that the experimental and theoretical study of second order transformations in crystalline bodies represents for modern physics a wide and as yet far from exhausted problem.

The formulation of a theory of the liquid state is a wide and urgent problem for theoretical physics.

Early attempts at a solution of this problem used the kinetic theory of gases and treated liquids as highly compressed gases. In more recent times the tendency has been to liken liquids more to solid bodies, lacking the greater orderliness in the arrangement of their particles, but still possessing that close packing which characterizes the crystalline type of structure. Since the liquid state is intermediate between the solid and gaseous states, it is natural to expect that the similarity between liquids and compressed gases becomes more or less exact at high temperatures (close to the critical temperature) and that at temperatures near crystallization liquids resemble solids. This kind of description, borrowing from the kinetic theory of gases on one hand and from the kinetic theory of crystals on the other, is, however, only an interpolation, having a limited value. There are sceptics who think that, in view of the great complexity of the problem, physics is only handicapping itself in explaining the structure and properties of liquids by such interpolations. Personally, I consider, however, that this scepticism is unjustified, and that further work towards perfecting the kinetic theory of liquids is one of the real tasks of physics in our time.

It must be mentioned that the performance of this task leads immediately to the necessity of radically altering our traditional ideas about the fluid state of bodies, first of all with the aim of removing the contradiction between the concept of plasticity and rigidity. As already explained above, the first of these does not exclude the second but only masks it. It is necessary, moreover, to bear in mind that the division of bodies, or rather aggregate states of substances, into solids and liquids does not accord with reality, which provides an extremely complex profusion of such states. Besides the liquid-crystalline (or mesomorphic) state which has already been studied thoroughly from the experimental side, modern physics knows of states which it is impossible to fit into the 'solid and liquid' scheme; for example, the resinous state, which as shown by very recent investigations can be encountered in such simple substances as sulphur and phosphorus. To phenomena such as these must be added the various jelly-like states which have hitherto scarcely been studied. But among those to whom the study of jelly-like systems (gels) presents enormous interest are the biologists, for recently physics has begun to penetrate into their sphere through the peculiar intermediate science of biophysics. So we see that one of the fundamental problems of modern physics is the experimental study of complex aggregate states and the construction of a molecular-kinetic theory for them.

The development of all natural sciences is closely bound up with the improvement of the apparatus with which natural phenomena are observed and which produces phenomena not encountered under natural conditions. In this respect physics differs from other sciences, for it creates new apparatus in connexion with new methods, not only for other sciences but also and in the first place for itself.

We have already mentioned above the remarkable phenomena of superconductivity and the disappearance of viscosity, which were discovered through working out methods of achieving very low temperatures. In this direction—the approach to absolute zero—physics has still, apparently, not reached finality; a number of properties of material bodies connected with the magnetic moments of nuclei need for their experimental observation and study

still lower temperatures—of the order of one ten-thousandth part of a degree and lower. Physics has the means with which to do this (by using the magnetic moments of atoms and nuclei) but has still to use them fully. This is work for the near future.

In the region of high temperatures, modern physics has still not progressed very far. The maximum temperature achieved in the laboratory is somewhere around 20,000°, although as yet it has not been possible to observe the properties of any bodies at this temperature. In this respect more interesting results have been produced by astrophysics.

In recent times extremely important results have been obtained in high-pressure work. A few years ago, Bridgman succeeded in producing pressures up to 50,000 atmospheres, and further was able to study their effect on a series of properties of solids. More recently still, it has been possible to raise this limit to around 100,000 atmospheres, that is, approaching the order of pressures (about one million atmospheres) which prevail at the centre of the earth. One of the urgent tasks of experimental physics is to study further the properties of matter at these extreme pressures.

Besides these achievements in the realm of super-high pressures and super-low temperatures, physics has in recent years much increased the power of its observations by creating and applying the electron-microscope. Ordinary microscopes give a magnification not exceeding five to six thousand times. With the help of the electron-microscope it has been possible to increase this limit a thousand-fold, that is, to reach a linear magnification of the order of one million. The application of the electron-microscope has already produced a number of remarkable results in physics, metallography, colloidal chemistry and in particular in biology, for it has made possible the observation of individual 'molecules' of certain pathogenic viruses; apparently these molecules are able to grow and multiply, and represent forms intermediate between ordinary crystals and living organisms. The study of the new 'ultra-microscopic world' discovered by the electron-microscope will in the near future be one of the most important and fruitful tasks of so-called higher science. At every stage it brings forth new discoveries and sheds light on phenomena which were known before only incompletely. In this the electron-microscope will play as great a part as did the ordinary microscope in its time. A whole series of objects ranging from those of microscopic size of linear dimensions of the order 10^{-4} cm. down to particles not much larger than molecules now becomes accessible to direct observation and investigation. This is the domain which is of immediate interest for the sciences both of living and dead material.

Finally, there is still one more branch of physics which seems likely to make noteworthy progress. I am referring to the increases in frequency of artificially produced electrical and mechanical vibrations (ultra-short radio waves and ultra-sonic waves). Modern radio technics has succeeded in producing frequencies of the order of 10^9 per second, which correspond to electromagnetic waves with a wavelength of less than 1 cm. However, between these radio waves and those of infra-red heat, there still remains the practically unexplored interval of wavelengths ranging from some millimetres to a tenth part of a millimetre. But it is just this interval which is so interesting for the study of the electrical properties

of liquid and solid dielectrics (for example, absorption and dispersion should be very large). This interval of frequencies also presents great interest for the study of the mechanical properties of solids and more particularly liquids. This can be done by investigating the propagation through them of artificially produced ultra-sonic or hyper-sonic vibrations the frequency of which approaches that of their heat movements. The process of transforming electrical into mechanical vibrations has already been worked out; what remains is to increase further the frequency of radio-waves. During the last three or four years there has opened up a new way of attacking this interesting and important work by the use of klystrons and other electronic apparatus.

Summarizing, we see that the most interesting problems in physics are those connected either with limiting or with intermediate properties of material bodies. This conclusion holds also for other sciences besides physics, and further, the most topical problems are concerned not with those phenomena which are studied by definite specialized sciences, but with those borderline phenomena which fall between them. It is thus perfectly natural that these problems, besides being the most complicated, are also the least studied. A particular example of this is biophysics, the problems of which have been intensively studied by physicists for some time. In recent years, physics has attracted biologists to help in the solution of these biophysical problems, but physicists have not themselves shown much interest (if we except the physiological aspects of optics and acoustics). I am inclined to think that in the very near future this position must undergo a definite change, and that this part of the science front must conduct an extensive battle for new knowledge. I shall not attempt to enumerate the problems of biophysics because they are innumerable. Besides problems about the properties of gels mentioned above, there are those concerning photosynthesis, nervous and mental activity and electro-physiology (in particular, electrical vibrations in the brain). Finally, not the least interesting problem is that of the mechanics of living organisms (for example, the locomotion of animals and insects).

Not long ago, physical chemistry occupied the intermediate position which is now occupied by biophysics. At the present time, the formerly borderline phenomena have been completely assimilated into physics.

In its impetuous rush of growth, physics has of course been unable to prevent itself encroaching on the region long considered the province of chemistry. In distinction from chemistry, which is a science of materials and their transformations, physics, like sciences of other phenomena connected with matter, has lost this sense, by 'going behind' chemistry in discovering the structure of the chemical atoms, elements and showing how to cause their artificial transmutation. In this way, chemistry has become a branch of physics, though it is true one of the largest, most interesting and practically the most important branch. In an exposition of the problems of modern physics, it would therefore be quite appropriate to include also the basic problems of chemistry. I shall, however, leave those problems which belong to chemistry in its narrow sense and pass on to those of the modern 'alchemy' which concern the atomic nucleus.

(To be continued.)

OBITUARIES

Dr. W. A. K. Christie

His numerous friends will receive with the greatest regret the news of the unexpected death of Dr. William Alexander Kynoch Christie, which took place in London on June 16, after a very short illness.

Christie was the youngest son of Charles Robert Christie and Margaret Catherine Paterson, both of Edinburgh, where he was born on October 2, 1882. He was educated at Daniel Stewart's College and Heriot's, Edinburgh, and then in succession at the Universities of Edinburgh and Zurich, where he took the degrees of B.Sc. "with special distinction in chemistry", and Ph.D. respectively.

After acting as Prof. Crum Brown's private assistant, Christie went to the Mond Nickel Co. in South Wales, until he was appointed to the staff of the Geological Survey of India to fill the newly created post of chemist to the Department. He took up his appointment in Calcutta on November 17, 1906. This he held until his retirement from the service on October 10, 1932, after a service of nearly twenty-six years, of which slightly more than five years was spent away from the Department. Of this, nearly two and a half years was during the War of 1914-18 in the Indian Army Reserve of Officers, from which Christie was drafted to the Special Reserve of the Royal Engineers in France, where his chemical knowledge was used in the service of his country.

With other officers of the Geological Survey who had gone to the War he was recalled in 1917, owing to the growing realization of the need of geologists and chemists to help in the production of war minerals. In April 1918 Dr. Christie's services were placed at the disposal of the Government of India in the Finance Department, whereon he was posted to His Majesty's Mint, Calcutta, as deputy assay master, later acting as assay master. He reverted to his post in the Geological Survey at the end of 1920.

In 1936, after a few years in retirement in England, Dr. Christie was again employed by the Government of India, this time as civilian technical officer in the Principal Supply Officer's Committee (India) under the Defence Department, India. He was in England on deputation at the outbreak of war in 1939 and was retained at the India Office, where he was still described as a civilian technical officer, a post he held until his death. In 1930 Christie married Miss Winifred Davidson, who survives him.

Christie's scientific activities were not confined to his official appointments, as is shown by the fact that he was a fellow of the Royal Institute of Chemistry, a member of the Institution of Mining and Metallurgy, a fellow and, in 1927, president of the Asiatic Society of Bengal.

Christie was one of those specially useful men of science who are qualified in two sciences, in his case chemistry and geology. While his chemical knowledge took priority and justified his various employments outside the Department, his wide knowledge of geology and mineralogy made him a valuable member of the Geological Survey of India, as he was often able to offer sound advice both to individual officers and to his director on problems involving both chemical and geological knowledge. With this scientific versatility Christie combined a proficient knowledge of French and German, both spoken and written, and an interest in the literature of both countries.

An additional facet of this versatility was Christie's