organic phosphate, the inorganic phosphate signal also decreases because the inorganic phosphate in the cell is diluted by the phosphate whose signal has been destroyed. This decrease can be measured and used to calculate the rate of the reaction. The rate of the reverse reaction can also be determined. Here the signal of inorganic phosphate is destroyed and the change in the signal from the third phosphate of ATP is monitored.

Another advantage of ^{31}P NMR is that it can be used to determine the *p*H's in two distinct cellular compartments. According to Sheila Cohen, Shulman, and their colleagues at Bell, the phosphate peak in spectra from isolated rat liver cells shows a shoulder on the side of the higher *p*H position. These spectra suggested to the investigators that they were seeing the results of a difference in *p*H between the mitochondria and the cell fluid (cytoplasm), with the main phosphate peak indicative of the cytoplasmic *p*H and the shoulder representing the mitochondrial value. This *p*H difference, incidentally, is predicted by the hypothesis put forward by Peter Mitchell of Glyn Research Laboratories in England to explain how mitochondria synthesize ATP. He proposed that the mitochondrial reactions result in the ejection of protons from the mitochondria, thus elevating the mitochondrial *p*H relative to that of the cytoplasm, and that this *p*H difference is the driving force for ATP production.

In any event, Cohen, Shulman, and their colleagues found that a compound known to enhance the *p*H gradient across the mitochondrial membrane causes the resolution of the peak shoulder into a separate phosphate peak, a result consistent with their suggestion that the shoulder is caused by the higher *p*H within the mitochondria. In contrast, treatment of the liver cells with a material that destroys the *p*H difference and also blocks ATP synthesis, produces a ^{31}P NMR spectrum with only a single phosphate peak. Thus, the Bell laboratory results provide direct support for the Mitchell hypothesis.

In addition to their studies of ^{31}P NMR, Shulman and his colleagues are also investigating the use of ^{13}C NMR to follow the passage of materials such as glucose through complex reaction pathways in living cells. Unlike ^{31}P, which is the naturally abundant isotope of phosphorus, ^{13}C constitutes only a small fraction of naturally occurring carbon atoms. Compounds labeled with additional ^{13}C atoms are readily, although somewhat expensively, available from commercial sources, however. The Bell workers have fed glucose labeled at carbon 1 with ^{13}C to *E. coli* and followed the results with NMR. Shulman says that the distribution of the ^{13}C among the various compounds formed from the labeled glucose can be readily followed and the relative rates of competing pathways evaluated. As he puts it, "the whole pathway unrolls before your eyes."

This article has described only a sampling of research in what is becoming a burgeoning new area of NMR investigation. Other work under way includes studies of liver biochemistry and the control of hemoglobin oxygenation in intact red blood cells. Moreover, the investigators doing the work are enthusiastic not just because of the biochemical information they are acquiring but also because they think their research, in combination with that on NMR imaging techniques, will lead to new noninvasive methods for medical diagnosis.

—JEAN L. MARX

The 1978 Nobel Prize in Physics

One-half of the 1978 Nobel Prize in Physics is to be awarded to Peter L. Kapitsa, director of the Institute for Physical Problems, U.S.S.R. Academy of Sciences, Moscow, for his basic inventions and discoveries in the area of low-temperature physics. A review of the record shows Kapitsa to be not only a very competent scientist, but also a talented engineer and a successful technical manager. As his career has, on occasion, become embroiled in Russian politics and the continuing struggle between the individual and the state in the Soviet Union, he enjoys considerable world renown beyond the narrow confines of the physics community. In the popular press, in fact, he has come to be somewhat lionized as a leading scientist who defied Stalin and yet survived to continue as an important scientific contributor. Kapitsa endured harrowing experiences in arriving at the condition of octogenarian in his Mother Russia, but he was also given many honors by successive regimes therein. With all these facts taken together, Kapitsa is a figure who looms large on the world stage, and it is presumably with this combination in mind that the Nobel Committee made its selection, 40 years after his most significant contributions to low-temperature physics.

P. L. Kapitsa, the son of a general of engineers, was born in Kronstadt in 1894, raised in Tsaritsyn, and educated in Petrograd. After graduating in 1918 from the Electro-Mechanical Faculty of the Polytechnic Institute in Petrograd he became a lecturer in the institute and carried out research under A. F. Ioffe. With the beginning of the Red Terror, Kapitsa fled to England and commenced a long association with the Cavendish Laboratory of Cambridge University. From 1921 to 1924 he worked under Sir Ernest Rutherford, in 1924 he was appointed assistant director for magnetic research, and from 1930 to 1934 he served as director of the Royal Society Mond Laboratory.

There is an aura of magic about Kapitsa's career, not least over his sojourn in Cambridge where, after 8 years and a fairly modest publication record, he not only was elected Fellow of the Royal Society but was the first foreigner to be accorded that honor in 200 years. Readers familiar with the British scene cannot fail to be impressed by the election of anyone under those career circumstances and doubly so by its uniqueness (*1*). Those not so familiar will perhaps take more notice of the fact that the Royal Society, in 1930, named him Messel research professor and then built the Mond Laboratory for him.

During these Cambridge years, Kapitsa traveled to Russia each summer to visit his mother. There government officials began urging him to return to Russia, offering working conditions similar to those he enjoyed in England. As these pressures built up, Kapitsa suspected that his freedom to go and come would not last forever, and he discussed these misgivings freely with his Cambridge colleagues. Nevertheless he was given guarantees of safe return (*2*), but when he attended a scientific conference in Moscow in 1934 he was detained on orders from Stalin. Although he had clearly foreseen this eventuality, Kapitsa, it is reported, refused to work for almost a year. He was then made director of the Institute for Physical Problems of the Academy of Sciences, a capacity in which he served until 1946. In addition, the Soviet government purchased all his equipment from Cambridge University

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and installed it in Moscow. In 1939 he was elected a full member of the Academy of Sciences.

Until 1945 Kapitsa was allowed to continue the work he had begun in England, but with the development of the atomic bomb in the United States he was forced to work on a "commission for the study of strategic uses of cosmic radiation." His passive resistance was described by government officials as "premeditated sabotage of national defense"; he was removed as director of the Institute for Physical Problems, imprisoned for some time, and later sent to work in a center for nuclear research in the Urals (*3*). After Stalin's death in 1953 he was reappointed as director of the Institute, and he has held that post to the present. It is reported that he directed laboratories and projects for the development of nuclear weapons (*3*) and that he was in charge of the early stages of the Sputnik satellite program (*4*). In June 1958 he visited the United States to attend a Gordon Conference on polymers, and he has also attended Pugwash Conferences in North America; in 1969 he came to Columbia University to accept an honorary degree. His son, Sergei, recently commented that even today, at 84 years of age, he "works like a student" and spends 8 hours a day at the Institute. A revealing facet of a scientist's quality is often the colleagues he gathers around him, and in Kapitsa's case the names Landau, Khalatnikov, Lifshitz, and Peshkov are eloquent on this score.

Kapitsa's technical career has been varied, including such areas as nuclear physics, electrical engineering, the solid state, liquid helium, hydrodynamics, and gas liquefaction. It is interesting to note that most of his publications are without coauthors; although this must be evidence of his working style, it is remarkable considering the complex nature of some of his undertakings. His first 3 years at the Cavendish were devoted to studies of the tracks of alpha and beta particles, in the furtherance of which he next started to look into the production of high-intensity magnetic fields. These were pulsed fields 10 milliseconds in duration, and in their production and utilization Kapitsa demonstrated great engineering skill and ingenuity. In 1928 he replaced his battery supply by a specially designed single-phase a-c generator of the turbo-alternator type, using one half-cycle to pump some 55 kilowatts into a small copper coil. In this manner he was able to generate transient fields of several decateslas (hundreds of kilogauss), and he employed them first in further studies of alpha particle tracks and later in measurements of the magnetoresistance of most of the readily available metallic elements, at both room and liquid-air temperatures. In 1931 Kapitsa reported a novel spring balance that permitted measurement of magnetic susceptibility in time intervals of the order of 10 milliseconds, and then in a five-part publication in the *Proceedings of the Royal Society of London* he described properties of matter in intense magnetic fields with particular emphasis on the phenomenon of magnetostriction.

In 1934 Kapitsa published an account of the best-known product of his engineering ingenuity, a helium liquefier that employed a combination of expansion engine and Joule-Thomson stage and required precooling only with liquid nitrogen, rather than with liquid hydrogen as had been the case before then. His work on gas liquefaction continued at intervals thereafter and publications on new installations (in Russia), design optimization, and so on appeared in the 1960's. The basic Kapitsa design was improved by S. C. Collins after World War II and brought to commercial status by Collins and the Arthur D. Little Company, a development that notably accelerated research in cryophysics worldwide in the postwar years.

The Superfluid Helium Story

While Kapitsa was getting established in Moscow, research at Cambridge and elsewhere (most notably, Toronto, Leiden, Oxford, and Kharkov) into the astonishing properties of He II—the phase of liquid ^{4}He that exists at temperatures below 2.17 K, the lambda point—was growing apace. W. H. Keesom, in Leiden, had discovered superfluidity in the liquid in 1922 but did not correctly identify the phenomenon, describing it as a "distillation." An extraordinarily low viscosity was determined by E. F. Burton (Toronto, 1935), and the mobile or creeping film was described by B. V. Rollin (Oxford, 1936). Enormous heat conductivity had been effectively observed as long ago as 1908 by H. Kamerlingh Onnes and many specific measurements were undertaken in the 1930's. In 1938 J. F. Allen and H. Jones demonstrated the "fountain effect," the most visually exciting manifestation of the properties of a superfluid. Numerous authors interested in He II have drawn attention to that most remarkable volume of *Nature*, volume 141, published in 1938. The lead articles of the second (8 January) issue are essentially identical reports on improved measurements of the viscosity of He II by Kapitsa and by Allen and A. D. Misener, identifying an upper limit of 10^{-10} Pa-s (10^{-9} poise). Kapitsa said, "The present limit is perhaps sufficient to suggest, by analogy with supraconductors, that the helium below the λ-point enters a special state which might be called a 'superfluid.' " In classical cases a low viscosity implies a high Reynolds number, and Kapitsa went on to discuss the anomalously high heat transport effects in terms of turbulence, an explanation that was rejected by A. K. Kikoin and B. G. Lasarew in the April issue of the same journal.

Kapitsa's last cryophysics papers appeared in 1942. In the first of these he described numerous simple, ingenious experiments designed to elucidate the transport properties of He II, especially the anomalously high transport of heat through liquid-filled capillaries. He developed a picture of "free helium" flowing along the axis of the tube in the direction of (net) heat flow, with a countercurrent of a thin layer (of a lower specific enthalpy) of helium along the inner wall. "The results," he stated, "establish a dynamic picture of the heat transfer in helium II and confirm our original view. The picture at which we arrive, though not so simple as we first thought, leads us to the conclusion that the mechanism of heat transfer can be explained by the property of *suprafluidity* of helium II." In the follow-up paper Kapitsa reported on measurements of the flow of the liquid through a very narrow slit that could be adjusted in width down to about 10^{-5} cm, on the reversibility of hydrothermic processes occurring within the slit, and on the critical velocity. He abandoned the earlier picture of superflow only along the channel wall, found a new value of 10^{-11} poise for an upper limit for the viscosity, and concluded from his observations that liquid helium that passes readily through extremely narrow slits is in a state of zero entropy. This latter conclusion supported the theoretical speculations of L. Tisza and H. London (1938 and 1939) and a quantum mechanical theory for He II by L. D. Landau that appeared in the following article. The latter, 20 years later, earned a Nobel Prize for its author.

With these three papers on He II, Kapitsa did much to substantiate the essential features of superfluid helium. Whether he continued to work in this field is not, I believe, known. There is no evidence, at least, from publications. From 1941 to 1946 there seem to be no publications at all. The Franklin Institute (of Philadelphia) awarded him its Franklin Medal for 1944 and the Institute's journal includes a "notice" by Kapitsa repeating his 1941 suggestion that it might be possible to exploit the zero entropy property to produce refrigeration to very low temperatures. His papers published between 1947 and 1967 deal with the hydrodynamics of fluids in thin layers, the nature of ball lightning, solutions of problems in classical electrodynamics, design criteria for expansion liquefiers, and high-power microwave electronics.

To complete the story of the career of this eminent scientist it would be most interesting to have a detailed account of his managerial and directorial services to the state, which must have been most noteworthy. His honors include the State Prize for Physics, 1941 and 1943; the Order of Lenin, 1943, 1944, 1945, 1964, 1971, and 1974; the Moscow Defence Medal, 1944; Hero of Socialist Labor, 1945 and 1974; Order of the Red Banner of Labor, 1954; Lomonosov Gold Medal, U.S.S.R. Academy of Sciences, 1959; and the Great Gold Medal, Exhibition of Economic Achievements U.S.S.R., 1962. In addition, he has received high awards from many other governments, plus numerous honorary degrees and institutional medals from around the world.

Kapitsa has not hesitated to give vigorous support to a colleague who has fallen victim to injustice. Part of the saga is the story of how the young head of the theoretical section at the Institute for Physical Problems, L. D. Landau, was arrested in 1938 as a German spy and released only after the personal intervention of Kapitsa. This achievement alone deserves the greatest admiration and gratitude of the community of physicists. Kapitsa has continued to capitalize on his high stature within the Soviet Union to oppose the excesses of giant and oppressive government. In 1970 he was among 20 signers of an open letter protesting the detention of biologist Z. Medvedev.

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1. Testimony, apparently, to the influence of the ebullient young Kapitsa on Rutherford and of the latter on the Establishment. See E. Larsen, *The Cavendish Laboratory* (Franklin Watts, New York, 1962), pp. 61-62.
2. The details of Kapitsa's post-Cambridge career are not completely known. Material for this article has been collected from numerous works of reference and other sources, and accounts of various events found therein differ somewhat.
3. *Biographic Directory of the U.S.S.R.* (Scarecrow Press, New York, 1958). Other accounts cover the period 1946 to 1953 with the short statement "was placed under house arrest for seven years."
4. K. Klose, Washington *Post*, 18 October 1978, p. A19.

Sharing the 1978 Nobel Prize in Physics with the Soviet physicist Peter L. Kapitsa are Arno A. Penzias and Robert W. Wilson of Bell Laboratories. Penzias and Wilson were cited for their discovery, in 1965, of the 3 K cosmic background radiation.

Grand and simple discoveries are not frequent in science. Penzias's and Wilson's discovery was one. In astronomy the next but last such discovery was made in 1929, when Hubble found, after a careful study of the red shift in the light from distant galaxies, that the magnitude of the shift was proportional to distance. Since the red shift is also proportional to the relative velocity between the radiation source and the observer, the result means that the more distant the galaxy, the more rapidly it is moving away from the earth. This led theorists to conclude that our universe is in a state of continual expansion. It led Einstein to regret that he had introduced into his theory of general relativity a term, the cosmological constant, that made the theory consistent with the then fashionable idea of a static universe. It led Gold, Bondi, and Hoyle to propose the continuous creation of matter in order that the universe might remain unchanging despite the red shift. It led some, notably Gamow, to propose that our universe began with a big bang, in which the matter we now see so widely dispersed had its origin under conditions of intense heat and pressure.

Hubble's red shift measurements changed our concept of the universe, but did not settle its history. Indeed, as pointed out by Steven Weinberg (*1*), speculation concerning the origin of the universe was not quite respectable without an experimental basis on which to decide among ingenious theories. Penzias and Wilson provided such a basis by finding an isotropic microwave radiation that comes not from the sun, not from our galaxy, not from any identifiable individual source, but from the depths of space. They measured the radiation at a wavelength of 7.5 centimeters and found that its intensity corresponded to that of blackbody radiation with a temperature of about 3.5 K (*2*). Measurements, direct and indirect, of the intensity of radiation at other wavelengths have confirmed that this radiation does indeed have a spectral distribution corresponding to that of electromagnetic radiation in equilibrium with a blackbody at a temperature around 3 K (*3*).

The universe expanded and cooled after its origin. After the first million years the temperature of the primary form of matter, ionized hydrogen, which was initially in equilibrium with electromagnetic radiation, fell to 3000 K. At this temperature the ions and electrons formed neutral hydrogen, which did not interact appreciably with radiation. Matter continued to evolve as stars were formed and other elements were created. The radiation that filled all space persisted, but not quite unchanged. As a consequence of adiabatic expansion of radiation in an expanding universe, the temperature of the radiation fell from 3000 to 3 K over a period that can be computed from Hubble's relation to be about 18 billion years. Thus, an experiment had given us detailed knowledge of the universe in its infancy. Study of the origin of the universe became respectable, and theoreticians now boldly push their theories back to the first few minutes of the history of everything.

New Technology for New Ends

Penzias and Wilson made their momentous discovery while working at Bell Telephone Laboratories. In this and in some other aspects their work strikingly parallels that of Karl G. Jansky, who discovered galactic radio waves in 1931. In both cases, new technology was used to new ends. Jansky had an excellent low-noise receiver with which to explore noise in a new frequency range. Penzias and Wilson had a unique 20-foot horn reflector antenna made by A. B. Crawford as part of the East Coast receiving terminal for the Echo communication satellite. This antenna was mechanically stable. When it was pointed at the sky, it picked up almost no radiation from the hot earth. Signals from the antenna were amplified by a traveling wave ruby maser made by H. E. D. Scovil and others. In principle, this receiving system could be calibrated so as to make absolute rather than relative measurements of the microwave radiation flux.

Indeed, the receiving system had already been evaluated in 1960. Through calculation and measurement, the equivalent blackbody temperature of the noise in their system was predicted to be 19 ± 3 K. The measured system temperature, which varied somewhat from day to day, was found to have a minimum of 21 ± 1 K. There is room here for cosmic background, but none was expected and none inferred.

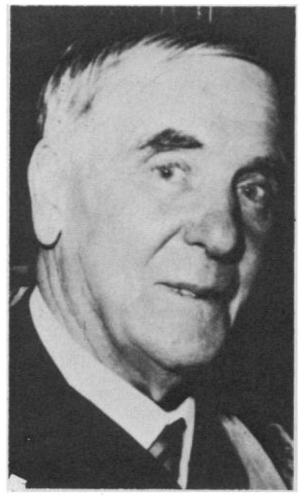
Penzias and Wilson went beyond this early evaluation. They installed a cryogenic reference noise source to compare with noise from the sky. They persistently found more noise than they could account for through known sources in the receiving system, the atmosphere, or the sky. They evicted a pair of pigeons from the antenna throat and cleaned out the evidence of their visits. They cleaned the interior of the horn and covered the joints with metallic tape. The noise was reduced only slightly. Wherever and whenever they pointed the antenna, about 3.5 K remained unaccounted for (*1*). The noise was really there, and it proved to be a vestige of creation.

Like Jansky, Penzias and Wilson were making a careful study of noise when they made their discovery. But here the parallel ends. Jansky announced his results and the world of astronomy was little interested. That was the day of bigger telescopes and astounding new data from optical astronomy—the data through which Hubble found his red shift relation. The radar technology of World War II had not yet alerted physicists and astronomers to the power of radio observations. Jansky was primarily an engineer, and having made his observations, he turned to other engineering studies.

Both Penzias and Wilson were trained as radio astronomers. When they found the unexpected phenomenon, they were puzzled and alerted by what they found, and they inquired around. In Penzias's words, "I mentioned our problem to Bernard Burke during a casual telephone conversation. He replied that a preprint from Princeton had come across his desk shortly before, predicting a ten-degree background at 3 cm. I called Professor Dicke, who sent me a copy of the paper in question. It was written by P. J. E. Peebles and predicted, using certain assumptions, a thermal background radiation as a residuum of the hot, highly condensed early state of the evolution of the universe."

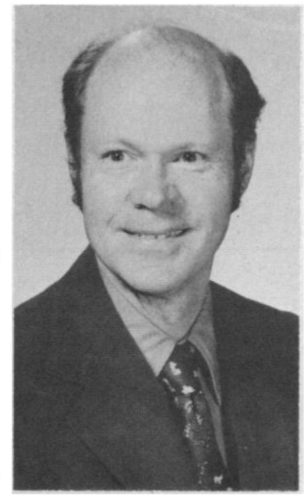
Indeed, P. G. Roll and D. T. Wilkinson of Dicke's group had been working toward the measurement of any cosmic background radiation when Dicke heard of the measurement by Penzias and Wilson. Dicke and his co-workers published a companion theoretical paper to that of Penzias and Wilson in the same issue of the *Astrophysical Journal* (*4*). Later all found that Gamow, in coming to the idea of a primeval fireball in 1946, had predicted such radiation. R. A. Alpher and R. C. Herman had later calculated a value of 5 K. Gamow himself made an estimate of 7 K in 1953. But somehow, over the years, the idea of cosmic background radiation and its critical importance had passed almost unnoticed.

To discover cosmic background radiation took equipment beyond string and sealing wax. It took an environment in which careful work was valued, and it took care, alertness, and insight. While Penzias and Wilson share these qualities, they differ in the strengths each brought to the task. Of the qualities necessary for their discovery and its evaluation, Penzias has more aggressiveness, Wilson greater technique and care. They differ in background also. Although each is married and has three children, Wilson's father was a chemical engineer, whereas Penzias's father had a small leather business in Germany and was a carpenter in this country.



Peter L. Kapitsa

Arno A. Penzias



Robert W. Wilson

Wilson was born in Houston in 1936. He transferred from electrical engineering to physics as an undergraduate at Rice University, where he received a B.A. with honors in physics in 1957. He received his Ph.D. from the California Institute of Technology in 1962. His thesis was on "Observations of the galactic plane at 960 Mc/s," a subject on which he had already published with his adviser, J. G. Bolton. He had published other work in radio astronomy before the discovery of the background radiation.

After spending a year as a postdoctoral fellow at Caltech's Owens Valley Radio Observatory, Wilson went to Bell Laboratories, attracted by a unique antenna that could really be calibrated. He is now head of the Radio Physics Research Department, most of whose 14 members work on things other than radio astronomy—microwave solid-state devices and integrated circuits. Wilson describes himself as something of an engineer, but his heart is in astrophysics. He is particularly interested in the investigation of dark clouds in the galaxy through measurements on a number of molecules.

Penzias was born in Munich in 1933. His father brought him to this country in 1938, fleeing Hitler's Germany. This transplantation was not without ingenuity because Penzias's family had to find a way to overcome the fact that the quota was full. Penzias attended Brooklyn Technical High School. In 1954, he graduated in the top 10 percent of his class at the City College of New York. After 2 years as a radar officer in the Signal Corps, he went to Columbia University for graduate study. His adviser was Charles Townes, and his thesis (in 1962) was "A tunable maser radiometer and the measurement of 21 cm line emission from free hydrogen in the Pegasus I cluster of galaxies." He came to Bell Laboratories in 1961, attracted in part by the facilities available for radio astronomy. He is now director of the Radio Research Laboratory, a group of almost 60 people.

Penzias has a continuing involvement with astrophysics, as a large number of publications show. He is particularly interested in the origin of the elements and sees a need for further radio astronomical data on the abundance of the elements and isotopes, particularly deuterium. Penzias has supervised the theses of four students at Princeton and says that being a teacher helps him to understand things, but he prefers to combine radio astronomy with research that has immediate applications and enjoys being a director at Bell Labs.

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