tures and Science. Indeed, this has sometimes led to the same scientists being approached about the same matter by television and by such radio services as Home, Overseas, and Third Program, and it has been suggested that, to counter this, there be some form of central coordination. However, different programs, and their producers, may have different approaches to the same subject, and much of our programming strength lies in decentralization and the encouragement of individual journalistic initiative. Moreover, rather than being too busy to be bothered by such multiple approaches, in many cases scientists welcome them, especially if multiple fees are involved.

Other Efforts

Among the other departments of the BBC which undertake science broadcasting the Natural History Unit, based in Bristol, is most notable; it originates at least 90 hours of broadcasting a year, divided between BBC-1 and BBC-2. In addition, science and scientific affairs are reflected in all the BBC's output. The Drama Department produces such series as "R.3" and "Out of the Unknown," which keep scientific speculation within the public gaze. The Current Affairs Department provides topical coverage of space shots, the cost of technology, and medical subjects. The Documentary Department also takes a share of scientific coverage, and our correspondents in the News Division cover an average of about 120 stories related to science every week. In addition, on both television and radio, there are a great many daytime science broadcasts aimed at school and adult-education audiences. It should also be mentioned that our regional competitors on Independent Television produce some science programs.

Our television science programs on BBC-1 now regularly reach 4 to 6 million viewers. The figures for the ultrahigh-frequency channel are of course much smaller, but the potential audience is already 6 million, growing rapidly, and compares favorably with that of radio. In fact, the television channels alone now provide wide coverage of the whole field of science.

Can the impact of all this broadcasting be assessed? Not precisely. The number of people watching any particular program can be gauged, and surveys (as well as the 250,000 letters a year we receive) indicate whether audiences like or dislike a particular program, but such information provides only short-term rules of thumb for program planning. It does not reveal the long-term effects on the public.

In my mind there is no doubt, however, that over the last ten years our output on television has played a part in the growing awareness of the importance of science and its role in the community. The fact that our output has gradually increased (as has the coverage in the press) without any diminution of interest on the part of the public, and indeed, with steady demand for increased coverage, suggests that the main target, the building of a body of critical opinion, stands a chance of being reached.

1966 Nobel Laureate in Chemistry: Robert S. Mulliken

The award of the 1966 Nobel prize in chemistry to Robert S. Mulliken is a recognition of his leadership over the last 40 years in the development of the "molecular-orbital theory" of chemical structure. The award is unusual in that it is given to a man who, for most of his professional life, has been a member not of a chemistry department but of a physics department. And in this case it is given not for any experimental results but for the development of a purely theoretical method of description, anaiysis, and computation.

Yet chemists everywhere will feel that this award to Mulliken helps to restore the balance of recognition between the two rival descriptive theories of chemistry. These two theories, the "valence-bond theory" or "resonance theory" and the "molecular-orbital theory," are only different ways of applying to molecular structure the ideas and equations of quantum mechanics which were developed for atoms and electrons in the 1920's. But the contention between their adherents has divided the chemical world for a generation. The theories are supposed to be formally identical when all higher-order corrections are included, but in practice they are as different as night and day.

The resonance theory treats the molecule as made of interacting atoms, each one keeping its own electrons. This approach is more easily related to the historical structural formulas, and it was expounded in excellent monographs by Pauling and by Wheland in the early 1940's. Pauling was awarded the Nobel prize in chemistry in 1954 largely for his contributions to this theory.

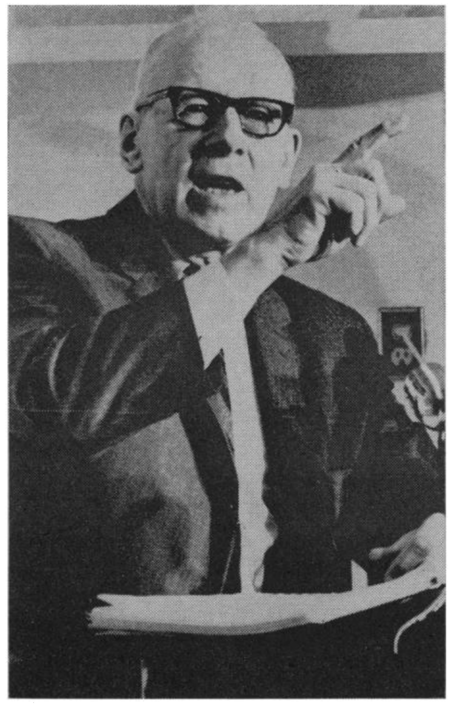
The molecular-orbital theory differs in that it treats the "outer electrons" or "valence electrons" of a molecule not as being localized but as being spread out in electronic wave functions or "orbitals" over the atoms in a chemical bond or even over all the atoms of the molecule. Since these are the electrons that determine the spatial structure, chemical binding energies, ionization potentials, and spectra or light absorption of a molecule, these properties can be predicted if the electronic wave equations can be solved. The equations are so complex that exact solutions are impossible, even with the most advanced computers, but the approximate solutions appear to be getting better every year. The knowledge of the theory is spreading, and for fundamental calculations it is now used far more widely than its rival, and simplified versions of it are being taught to college freshmen and even to high school students. Many scientists contributed to the development of this improved approach—Hund, Hückel, Maria Mayer, Lennard-Jones, Coulson, and others—but it was Mulliken who had the fundamental notion of molecular orbitals and who saw that they were capable of being put into a rigorous mathematical form which could be the basis of a much more accurate theory of chemistry.

Robert Sanderson Mulliken is the Ernest D. Burton Distinguished Service Professor of physics and chemistry at the University of Chicago. He was born in 1896 in Newburyport, Massachusetts, of an old New England family. His father, Samuel Parsons Mulliken, was a professor of organic chemistry at Massachusetts Institute of Technology and was the author of a well-known text on the subject. In high school, Robert Mulliken was already interested in molecular theories, and his graduation oration was entitled, "The electron, what it is and what it does." He graduated from M.I.T. in 1917 and later went on to the University of Chicago to take his Ph.D. in physical chemistry under W. D. Harkins, with a thesis on the partial separation of mercury isotopes by evaporation. Afterward he received a National Research Council fellowship which took him to Harvard for further study.

He was a spare and frugal New Englander then as now, and there is a characteristic story of how he and his friend Samuel Allison, when they went on a walking tour of Italy, always had a debate about stopping in restaurants, with Mulliken arguing that he and Allison could be sustained perfectly well simply on dried figs from his knapsack.

But such summer relaxation was rare. Mulliken was fascinated by trying to analyze the spectra of a series of diatomic molecules, trying to apply to them the new quantum rules that worked for atoms. He once said that he got into theory because he had to wait several months for a diffraction grating to arrive and he just never got back to experiments.

In 1925 he went to Europe again to discuss molecular problems with leading spectroscopists and quantum theorists. Then, after a period at Washington Square College, he came back to the University of Chicago in 1928 as associate professor of physics, and he has remained there ever since. At that time he had already made an international reputation with his interpretation of the spectra of diatomic molecules, and he was soon elected to the National Academy of Sciences, the youngest man to receive that honor for many years. In 1929 he married Mary Helen von Noé, the daughter of a distinguished



Robert S. Mulliken

Austrian emigré who had come to the University of Chicago as professor of geology. Today they have two daughters, one of them the wife of a foreign service officer stationed in Athens.

At Chicago, Mulliken directed the work of a succession of distinguished colleagues and students in experimental spectroscopy, meanwhile extending his "united atom" and his developing molecular-orbital ideas to more complicated diatomic spectra such as that of I_2, and to the description of the electronic bonds between atoms in polyatomic molecules. He and his students also explained the weak absorption spectra of the ketones, and he wrote a famous series of papers on the intensities of spectra of organic compounds. He was assiduous in developing better notation and nomenclature and is credited today not only with the term "orbital" but with the terms "σ-electron" and "π-electron" for the electrons of single and double bonds in organic compounds, and with many other terms well-known to the modern chemist.

It is hard to convey an adequate idea of Mulliken's productivity. Over the years he built up an indexed reprint collection which now contains over 50,000 reprints, and he has always worked a 14-hour day, from 10 a.m. to midnight, which has enabled him to turn out an average of more than 4 papers a year, a rate which statistics indicate has been exceeded by only one man in the American Physical Society. Eminent chemists often publish at a higher rate, but they generally put their names on the thesis publications of their students, a practice which Mulliken and the other members of the physics department at Chicago have never permitted. Wits have said that the *Journal of Chemical Physics* was founded as an American Physical Society journal in 1932 just to have a place for Mulliken's papers; but the fact is that all the molecular theorists needed it, because the great *Journal of the American Chemical Society* did not, until the mid-1950's, publish any papers not containing experimental data.

Mulliken's productivity is particularly striking when one considers his habit of including new considerations and continually revising and rewriting his manuscripts—to the despair of secretaries and editors—right up to the final state of proof. But he also reads and conscientiously criticizes scores of other men's manuscripts that are sent to him as friend or referee. His helpful remarks have turned many a poor paper into a good one, and this steady influence behind the scenes may possibly have done as much for progress in quantum chemistry as the direct influence of his own publications.

Mulliken, like Pauling, has always been guided by excellent chemical intuition, and he always seems to have had the right feeling as to whether a result is chemically reasonable or not. This characteristic, and his perseverance and patience, fit in well with his philosophy of science. He has said, "The scientist must develop enormous tolerance in seeking for ideas which may please nature, and enormous patience, self-restraint, and humility when his ideas over and over again are rejected by nature before he arrives at one to please her. When the scientist does finally find such an idea, there is something very intimate in his feeling of communion with nature."

In 1941, Mulliken was on one of the committees of the National Academy which recommended pursuit of the uranium project, and during World War II he continued at Chicago, serving as director of educational work and information on the plutonium project from 1942 to 1945. In 1944 he helped draft the project's first "Prospectus in Nucleonics" for postwar uses of atomic energy, and in that report it was he who was responsible, together with Eugene Rabinowitch, for the warning of a forthcoming nuclear arms race.

After the war, Mulliken brought

Platt and later Roothaan into the physics department to help build the spectroscopic laboratories back up again. For nearly 20 years the three of us worked fruitfully side by side with our various students and co-workers on our very different molecular interests. Mulliken always found bright young men and support money, first from the ONR and then from other granting agencies, and he made this group, in what came to be called the laboratory of molecular spectra and structure, the largest one of its kind in the world. The succession of brilliant quantum chemists who spent months or years in the group includes Bigeleisen, Cade, Clementi, Gouterman, Huo, Klevens, Kasha, Kolos, J. S. Ham, N. S. Ham, Huzinaga, Lichten, Longuet-Higgins, Matsen, McConnell, Moccia, Nagakura, Orgel, Parr, Person, Price, Ransil, Ruedenberg, Scherr, Shull, Tanaka, Tsubomura, Wahl, Wilkinson, and many others. The red-bound technical reports containing all our reprints were sent out twice a year to a mailing list of hundreds, and today they fill some 2 feet of shelf space.

Since the war, Mulliken's most important papers have undoubtedly been those of the 1950's on the "charge-transfer" interpretation of the binding and spectra of "molecular complexes," the relatively weak associations of two molecules that often give rise to intense spectra. He showed quantum-mechanically how the partial transfer of an electron between the two molecules might explain the observations, as well as many other observations on weak intermolecular forces.

His Fulbright year at Oxford and his year as science attaché in London in 1955 did not diminish his flow of work. More recently, many honors have been coming to him. They include a 1964 Festschrift volume of reminiscences and contributions entitled "Molecular Orbitals in Chemistry, Physics, and Biology," five major awards from the American Chemical Society, and honorary doctorates from Columbia University and the University of Stockholm. And he has been made at last a member of the department of chemistry of the University of Chicago, although he now spends the winter months as professor of chemical physics at Florida State University in Tallahassee.

In his manner, Mulliken has always been calm, courteous, and tolerant. He does not get angry, never swears, never jokes, and never quits, but goes on steadily and good-humoredly to the next item in the mountain of work that seems to be always before him. His lectures are full of intricate details and often run long past the hour. When he is willing to spare the time for it, he is full of interesting anecdotes and is a good host who mixes a good Manhattan; and on his very rare walks in the park he reveals himself to be an amateur botanist who knows the names of more plants and grasses than many professionals. He dresses conservatively and always wears a hat outdoors, but he is indifferent to clothes, and when his office was cold in the Chicago winters he would simply put his overcoat back on and go on working steadily all day. He is a chain-smoker, and the most vivid image of him that most of his colleagues have is the vision of him pinching the last half-inch of his cigarette with his fingertips and continuing to make fine pencil notes on the margin of a manuscript or reprint while listening to a lecture or taking part in a conversation.

Chemists and colleagues everywhere will be glad that this new recognition has now been given to Robert Mulliken and to the molecular-orbital interpretations on which he has worked so diligently and so long.

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1966 Nobel Laureate in Physics: Alfred Kastler

On 3 November, the Swedish Royal Academy of Science announced that the 1966 Nobel prize in physics had been awarded to Alfred Kastler for his work on the energy levels of atoms. Professor Kastler and his co-workers at the Ecole Normale Superscience in Paris have, since 1950, developed many new techniques for studying the fine and hyperfine structure of atoms. These new methods have led to many refinements in atomic spectroscopy and to a better understanding of atomic energy levels and the perturbation of atomic energy levels by their environment.

Shortly before World War II a group at Columbia University under the leadership of I. I. Rabi learned how to use radio-frequency fields to make precise measurements of the energy levels of atoms in their ground state. In general an atom in its ground or lowest energy state has several magnetic substates, and when the atom is placed in a magnetic field these states differ slightly in energy and each state has a characteristic effective magnetic moment. The Columbia group used deflection magnets and slits to prepare an atomic beam such that all of the atoms were in a few magnetic substates and such that only atoms in certain substates could make a complete journey through the apparatus from the source to the detector. They then applied a radio-frequency field of the proper frequency to cause the atoms to make transitions from one magnetic substate to another. When these transitions took place the number of atoms transmitted through the apparatus changed. Thus these workers were able to use the number of transmitted atoms to determine when the radio-frequency field was of the proper frequency to cause the atoms to make transitions from one state to another. From the frequency they could calculate the energy separation of the energy levels. Thus a new method for studying the energy levels of atoms in these ground states was discovered. This method became known as the atomic beam, magnetic resonance technique. For this discovery and other atomic beam work Rabi was awarded the Nobel prize in 1944.

While working on radar development and other government research projects during World War II, physicists developed new techniques for dealing with radio-frequency fields and for detect-