Atomic and Nuclear Disciplines Combine in Health Physics

"Health Physics is a profession devoted to the protection of man and his environment from unwarranted radiation exposure." This definition given by the Health Physics Society, which was organized in 1956, indicates the broad scope of interests and varying background of a health physicist. As a physical scientist his primary interests may be in radiation physics, chemistry, particle penetration in matter, neutron diffusion, photon and electron interactions, or nuclear instrumentation. As a life scientist he may study the somatic and genetic effects of radiation on organisms, conduct ecological investigations or evaluate data on human exposures. As an engineer he may be concerned with practical methods of radioactive-waste disposal or with the design and location of nuclear facilities. As an administrator a health physicist often has to establish safe radiation-protection standards, procedures and practices.

Of special interest to physicists at the 13th annual meeting of the Health Physics Society, held in Denver last June, was a one-day symposium on radiation interactions with polyatomic molecules. Also included in the meeting were sessions on charged-particle, neutron and photon penetration in matter, on human exposure to external radiation, and on problems associated with uranium mining.

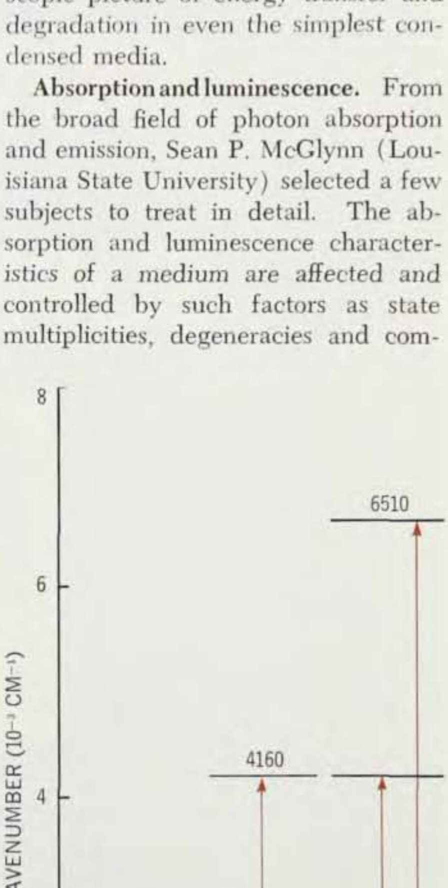
Polyatomic molecules. The symposium, with Robert D. Birkhoff (Oak Ridge National Laboratory) as chairman, consisted of five invited papers followed by a summary of the day's discussions.

Investigations of the interaction of electromagnetic radiation with matter are often directed toward single-photon, single-molecule processes. In the opening talk of this symposium, Michael Kasha (Florida State University) discussed a variety of multiple-excitation events that can occur in condensed systems irradiated at high intensity. These frequently involve a number of molecules at once and include molecular exciton reactions, charge-transfer excitations, molecular excimer formation, triplet–triplet annihilation, nonlinear (biphotonic) absorption and simultaneous excitations. Some of these events may perhaps appear a little strange. In simultaneous excitations, for example, a single photon is shared by two molecules. Thus in the absorption spectrum of an irradiated mixture of hydrogen and carbon dioxide, lines appear not only at wavelengths corresponding to the energies of the first excited states of these molecules but also at a wavelength corresponding to the sum of these energies (see figure). Single-photon sharing is greater at high gas pressures and can be observed at low pressures as an emission process.

Kasha also gave special attention to the physics of excited singlet oxygen in *single-* and *simultaneous-transition* processes. He emphasized the metastable character of this molecular species and that its lifetime (seconds in the gas phase, milliseconds in appropriate condensed phases), abundance and reactivity may have implications for other areas of interest, such as biology and air pollution. The simultaneous transition in a pair of singlet oxygen molecules gives a quantum doubling, in one case producing ultraviolet energies from an infrared electronic state. Kasha suggested that singlet oxygen will soon be found in irradiated systems.

John L. Magee (Notre Dame) described patterns of energy deposition by energetic charged particles in condensed molecular media. Of great interest in radiation physics, chemistry and biology is the chain of events that accompanies the transfer of energy from a swift charged particle to, ultimately, either thermal or chemical energy. Over certain energy ranges we have a detailed understanding of the *initial* events that transfer energy from the particle to a medium. The cornerstone of this knowledge rests on Hans Bethe's theory of stopping power, (which is the mean linear rate at which an energetic charged particle loses energy by electronic interactions.) At low energies the situation is far from being well understood. Magee emphasized the role of transient negative-ion states as efficient intermediates for transferring energy from slow electrons to a medium. Experimental techniques are available for identifying transient species that occur nanoseconds or longer after an initial energy-depositing event, and it appears possible that picosecond investigations may become feasible. However, a great deal of work is required before we have a complete microscopic picture of energy transfer and degradation in even the simplest condensed media.

Absorption and luminescence. From the broad field of photon absorption and emission, Sean P. McGlynn (Louisiana State University) selected a few subjects to treat in detail. The absorption and luminescence characteristics of a medium are affected and controlled by such factors as state multiplicities, degeneracies and com-



SIMULTANEOUS EXCITATION in a mixture of hydrogen and carbon dioxide. The absorption spectrum of the irradiated mixture contains lines corresponding not only to energies of the first excited states but also at a wavelength corresponding to the sum of these two energies.

peting nonradiative events involving single and multiple excitations. McGlynn discussed, in particular, luminescence from organic crystals, excimer luminescence, the effects of ion-pair formation (for example, NO_2^- and Pb^{++}) on the light emitted from salts, and the effects of charge transfer on absorption and luminescence characteristics.

McGlynn pointed out that fluorescence from states above the first excited singlet is very improbable. The lifetime of these states is less than 10^{-12} sec and is of the order of the vibrational time period. Radiationless decay occurs via coupling to the higher vibrational states of the first excited state. In contrast, internal conversion to the ground state may be replaced by fluorescence. Far fewer vibrational and rotational states are available in the ground state; thus decay by emission of a photon can occur with lifetimes approaching 10^{-9} sec. McGlynn also discussed the phenomenon of delayed fluorescence in mixed organic-molecule systems, which may result from two separated solute molecules excited to triplet states. Energy may be transferred from one of the excited triplets to the host and then to the second excited triplet. Sufficient energy is thereby provided to further excite this molecule into a higher singlet manifold from which fluorescence occurs.

Edwin N. Lassettre (Carnegie-Mellon University) reviewed the development of electron-impact spectroscopy, particularly with helium, and contrasted it with ultraviolet-absorption spectroscopy. The probability that an incident particle will excite a gas molecule to a given state n is governed by the generalized oscillator strength

$$f_n = \frac{\Delta E}{2} \frac{p_1}{p_2} (\Delta \mathbf{p})^2 \sigma_n$$

Here p_1 and p_2 are the magnitudes of the particle momentum before and after collision, $\Delta \mathbf{p}$ and ΔE are the momentum and energy lost by the particle in the collision and σ_n is the total cross section for excitation to the state n. All these quantities are experimentally measurable; therefore the generalized oscillator strength can, in principle, be determined by means of high-resolution electron-impact experiments. When the f_n are plotted as a function of $(\Delta \mathbf{p})^2$ one obtains the optical oscillator strength as the intercept of this curve on the f_n axis. Lassettre showed slides of his recent unpublished work in which very low vibrational energy losses are exhibited in the data for carbon dioxide and other molecules. Considerable decrease of the background current in his experiments has enabled him to observe energy-loss transitions from the ground electronic state of O_2 ($^3\Sigma_g^-$) to extremely low-energy electronic states (such as $^1\Delta_g$).

Threshold excitation. Robert N. Compton (Oak Ridge National Laboratory) reviewed recent experimental work on the excitation of polyatomic molecules by electron impact and on the formation of negative ions. Electron-impact excitation at threshold is a sensitive way to detect optically forbidden transitions, especially triplet states. Threshold excitation studies for water vapor and benzene were compared with energy-loss measurements, such as those of Lassettre for high-energy electrons. An energy-loss process beginning at 4.5 eV in water vapor (possibly the first triplet state) appeared in the threshold spectra. Recent low-energy measurements by Lassettre, presented at this conference, corroborated these results. Discussion of transient negative-ion states in polyatomic molecules included reference to the temporary negative-ion state of benzene and the effects of various atomic substitutions onto and into the ring. Recent measurements of negative-ion lifetimes of some long-lived temporary ions were related to existing theory. An approximately linear dependence of the logarithm of the lifetime on the number of degrees of freedom found for nine fluorocarbon molecules was qualitatively accounted for by a model describing nondissociative electron attachment. Finally, Compton surveyed the existing knowledge of dissociative electron capture, including both theoretical and experimental cross sections, energy dependence and isotope effects.

In his summary of the symposium Kasha commented that no new quantum-mechanical laws are invoked to describe new properties that appear when going from atoms to molecules to higher degrees of polyatomicity. (Certain processes that are absolutely forbidden in diatomic molecules become prevalent in more complicated polyatomic systems.) Kasha related characteristic properties to symmetry, geometry and polyatomicity. More-

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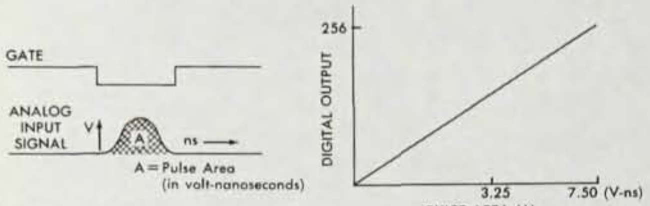
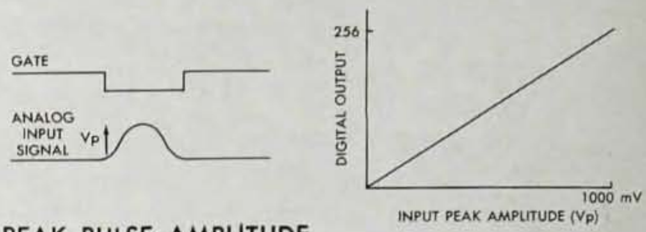
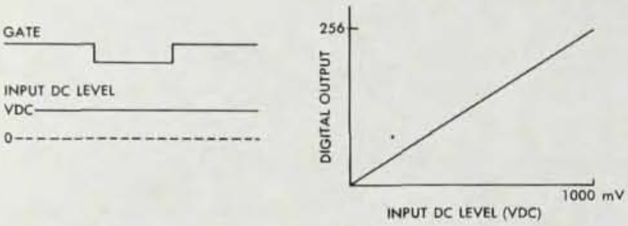


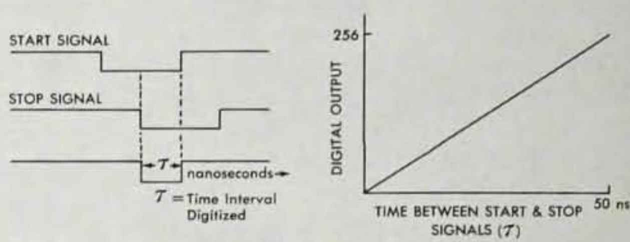
PULSE AREA



PEAK PULSE AMPLITUDE



SLOW PULSE OR DC AMPLITUDE



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over he emphasized that differences between the properties of large and small *polyatomic* molecules may pave the way to an understanding of the complex polyatomic molecule. With sufficient polyatomicity there are virtually no restrictions on the kinds of events that can occur—radiationless transitions, for example, become very probable events. With even greater complexity we should expect to encounter typically polymeric properties, as opposed to typically polyatomic, and so on. Kasha called attention to the fact that radiation physics today complements traditional spectroscopy. One of the most striking things brought into focus at the symposium was the richness of new data that is now becoming available from electron-impact studies.

Penetration in matter. In addition to the symposium there were many sessions of contributed papers. A group of talks on radiation physics dealt with some aspects of charged-particle, neutron and photon penetration in matter. Papers were presented on atomic mean excitation energies, production of delta rays in tissue by 2-GeV protons, bremsstrahlung from high-atomic-number thick-target x-ray devices up to 20 MeV, neutron energy-loss distributions in spherical cavities, and backscatter and neutron–gamma correction factors in the monitoring of personnel for neutrons. High-energy radiation dosimetry has emerged as a relatively new activity among health physicists. The subject has become important with the operation of high-energy particle accelerators, both in the US and abroad, and with the reality of manned space flight. Special sessions of contributed papers included many other topics, such as thermoluminescence dosimetry, instrumentation, radiation biology, ecology, tritium-exposure control, dose from radionuclides in the body, and reactor siting.

Medical irradiation. Other sessions were devoted to subjects of more general interest. A series of invited papers on human exposure to external radiation discussed dose-effect information as obtained from the atom-bomb casualties, from infrequent accidental exposures and from medical irradiations. These data are often plagued by uncertain dose estimates and confounding illnesses. Nevertheless, a growing body of information is

establishing within well defined limits of uncertainty the relationship between radiation dose and several physiological and hematological changes. Chromosome aberrations, for example, known for many years to be produced by exposure to radiation, may now be utilized to estimate dose. The relative percentage of different forms of aberrations can even provide information on the type of radiation, for example, gamma rays and neutrons.

Some sessions dealt with subjects that have had recent national attention. Approximately 45% of the average population dose in the US is received from medical sources, chiefly diagnostic x rays. A panel of invited speakers discussed this subject, and was followed by open discussion from the floor. Although the benefits from medical exposure are not questioned, doses from such exposures can be reduced by continuing the incorporation of improved radiological techniques. Another panel considered health-physics problems associated with uranium mining. They included a general history of the subject, a consideration of the exceedingly complex problem of lung dosimetry and a discussion of the epidemiology of lung cancer among uranium miners. This session, the final one of the formal Health Physics annual meeting, also served as the opening session of a special workshop on uranium mining cosponsored by the Health Physics Society and its Rocky Mountain chapter; this workshop discussed the latest developments in mine-atmosphere control and radiation instrumentation.

As can be seen from this report, the field of health physics encompasses many specialities and employs the talents of many disciplines. Perhaps because of the different backgrounds of its members, the annual meeting provides not only an opportunity for presentation of basic and applied research but also a forum for discussion of society's concern for problems related to radiation exposure.

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We are grateful to the invited speakers, particularly Michael Kasha, for their assistance in the preparation of this report.

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