as shown recently by Alan Leeds at the University of California, Los Angeles. The cooled lithosphere is more dense than the mantle and sinks at the trenches to at least 700 km, as shown by seismic data.

Griggs said the real nature of this vast convective system could not become clear until the "flow law" of mantle material is clarified. He reported on the argument of Robert Post [*Science* **181**, 1242 (1973)] that flow in the mantle is non-Newtonian; strain rate is proportional to the third power of stress. This type of behavior is found in dunite in the laboratory and it explains the Fennoscandian postglacial uplift better than Newtonian viscosity. Arrhenius responded that an alternative to this flow theory has been developed by Øyvind Gjevik at the Institute of Geophysics and Planetary Physics at the University of California, San Diego, who suggests that depression under the ice load and rebound subsequent to its removal is due to the olivine-spinel transition at depth, with relaxation being controlled by the advection of heat involved in this transformation.

Press commented that a flow process, rather than compression, would seem to be supported by the indication of partial melting in the asthenosphere. The crucial question remains, is the system convecting because of plate motions or the reverse? One possibility is that the lithosphere grows as the cooled boundary of a convection current. Another is that earlier expressed by Griggs—plates slide downhill away from the oceanic rises. The plates, however, do not move gradually but by jumps. They stick along their margins, and when they come unstuck and slip they produce earthquakes.

Press asked, what happens to the descending slabs? Plate motions have been directly detected and delineated. For instance, in the big Alaska earthquake in 1964, *P* waves arrived in Europe 6 seconds before the United States, presumably because they traveled along a deep-descending cold slab on their way to Europe, but followed the usual path to the United States. Although earthquake epicenters are not observed below 600 or 700 km, descending plates may not disappear at this level.

Outstanding unsolved problems include (i) the mechanism of plate motions, (ii) the location of the olivine-spinel transition in subducted slabs, (iii) the delineation of plate tectonic motions before 200 million years ago, (iv) the mode of aggregation of the earth and the origin of its concentric structure, (v) the time and manner of outgassing of atmosphere and hydrosphere, and (vi) the nature and geochemical consequences of atmospheric, hydrospheric, and biospheric evolution.

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Note

1. Persons attending the conference included P. H. Abelson (Carnegie Institution of Washington, Washington, D.C.), G. Arrhenius (Scripps Institution of Oceanography, La Jolla, California), J. M. Bird (Cornell University, Ithaca, New York), P. Cloud and J. C. Crowell (University of California, Santa Barbara), R. H. Dott, Jr. (University of Wisconsin, Madison), G. Ernst (University of California, Los Angeles), J. Gilluly (U.S. Geological Survey, Denver, Colorado), D. Griggs (UCLA), W. Hamilton (USGS, Denver), S. R. Hart (Carnegie Institution of Washington), H. L. James (USGS, Menlo Park, California), G. Kennedy and L. Knopoff (UCLA), P. D. Lowman, Jr. (Goddard Space Flight Center, Greenbelt, Maryland), J. C. Maxwell (University of Texas, Austin), F. Press (Massachusetts Institute of Technology, Cambridge), W. W. Rubey and J. W. Schopf (UCLA), L. T. Silver (California Institute of Technology, Pasadena), L. B. Slichter (UCLA), J. Sutton (Imperial College of Science and Technology, London), G. Tilton (UCSB), A. C. Waters (University of California, Santa Cruz), and J. T. Wilson (University of Toronto, Toronto, Canada). Bird, Dott, Ernst, and Lowman served as recorders for the conference. Their notes, plus reactions to an early draft from many others, contributed importantly to the preparation of this summary. This conference was sponsored by the Carnegie Institution of Washington and organized by a steering committee consisting of Abelson, Cloud, Crowell, and Ernst.

Radiation Chemistry of Condensed Phases: Report of a Joint Japan–United States Seminar

When high-energy radiation impinges on any system a spectrum of excited states is formed; these immediately decompose and set in train a complicated series of processes, which eventually result in the observed chemical and physical changes. It is the business of radiation chemistry to categorize and describe these processes as they occur in various types of material, so that radiation effects in actual biological and industrial systems can be understood. The processes occurring in gaseous systems are now well understood in principle and have been studied in some detail, but those in liquid and solid systems are more complicated and many aspects are still uncertain. The purpose of this seminar, which was sponsored by the National Science Foundation, was to review and discuss current American and Japanese research bearing on this subject.

The participants included 17 Japanese and 15 American scientists. The meeting was held at the Marine Laboratory of the University of Southern California on Catalina Island on 5 to 9 February 1973. The material systems discussed included water and organic compounds in their crystalline, glassy, and liquid states, and organic polymers.

The spectrum of excited states produced by electron bombardment of simple hydrocarbons has been determined by W. H. Hamill (University of Notre Dame, Notre Dame, Indiana) by looking at the energy losses of electrons scattered out of a beam on passage through a thin film of hydrocarbon deposited at 77°K. The method is a powerful one, but so far only a beginning has been made in characterizing the states and transitions which they undergo. A more detailed characterization of the behavior of the lower excited states is obtained by studying fluorescence of hydrocarbons induced by light in the far-ultraviolet. S. Lipsky (University of Minnesota, Minneapolis) reported on luminescence obtained from saturated as well as aromatic hydrocarbons. The factors that determine whether an excited state should ionize or not were discussed on a theoretical basis by T. Watanabe (University of Tokyo). So far, theoretical treatments are available only for the simplest molecules, such as methane.

When ionization does occur, the fate of the electrons produced depends strongly on the nature of the medium. In polar liquids the electron usually becomes solvated—it forms a shell of molecules that move with it so that its properties resemble those of an ordinary ion. The optical and chemical properties of the solvated electron in various ethers were reported by L. M. Dorfman (Ohio State University, Columbus). Solvated electron states may even exist in saturated hydrocarbons, but their stability may be so low that an equilibrium occurs between the solvated and "quasi-free" state (A. O. Allen, Brookhaven National Laboratory, Upton, New York). The result is that the electron energy and mobility are extremely sensitive to the detailed molecular structure of the hydrocarbons. Y. Hatano (Tokyo Institute of

Technology) reported on reactions with dissolved nitrous oxide of electrons in hydrocarbon solvents. One approach to study of the solvation process is simply to freeze the liquid to a glass in the hope that the electron will be caught in the initial stages of solvation. A detailed study of the spectra and properties of electrons trapped in organic glasses at 4°K was made by T. Higashimura (Kyoto University). In some glasses the electrons at 4°K gave a spectrum extending to much longer wavelengths than the normal solvated electron spectra, which were obtained when the material was warmed to 77°K. Thus, the electrons are trapped initially by arrangements in which the molecules are not fully oriented. In other cases, however, the spectra showed little change between 4° and 77°K, indicating less sensitivity of the energy to the molecular orientations. J. Willard (University of Wisconsin, Madison) presented evidence that electrons trapped at low temperatures can move to more stable states by the process of quantum-mechanical tunneling. How the detailed nature of these trapped electron states can be studied by magnetic double resonance techniques (ELDOR and ENDOR) was shown by L. Kevan (Wayne State University, Detroit, Michigan).

In mixtures, it is important to know how energy taken up from the radiation by one component can be transferred to another component, and especially how far and in what form energy can travel through a system. In a solid, preferential reaction of dissolved molecules must result either from electric charge migration or a transfer of excitation from molecule to molecule. That a good deal of such energy transfer occurs within polymers was shown by S. Siegel (Aerospace Corporation, Los Angeles, California), but it is difficult to establish the predominant mechanism. T. Miyazaki and Z. Kuri (Nagoya University) showed that in solidified mixtures of saturated hydrocarbons considerable energy transfer occurred from molecule to molecule, and in directions which made it very unlikely that charge transfer could play an important role. Transfer of high excitation seemed to be the predominant process and appeared to occur over distances as great as hundreds of angstroms. They found that in crystalline hydrocarbons the nature of free radicals formed by radiation depended on the crystal structure, which suggested that preferred directions of motion of the energy might be fixed by crystal structure. Specificity in radiolysis for more polar crystals was studied by M. Iwasaki (Industrial Research Institute, Nagoya) by the ENDOR technique. He showed that the original anion or cation radicals formed in carboxylic acid crystals donate or accept protons from neighboring molecules along certain specific hydrogen bonds. Demonstration of such highly selective proton transfer in these free radical systems may have a bearing on the mechanism of many enzymatic reactions which are thought to involve free radicals.

Whatever the early processes of excitation and ionization, they result eventually in the formation of neutral free radicals, and it is the behavior of these radicals that leads to the ultimate observed condition of the system. Electron spin resonance studies of the nature of radicals, long used in solid and in nonpolar liquid systems, have now become possible in aqueous solutions, and R. Fessenden (Carnegie-Mellon University, Pittsburgh, Pennsylvania) presented some interesting and somewhat unexpected observations on the nature of radicals formed in aqueous solutions of potassium cyanide and of ascorbic acid. S. Arai (Japan Institute of Physical and Chemical Research, Wako) discussed charged radicals formed from aromatic compounds dissolved in organic solvents. Y. Tabata (University of Tokyo) discussed diffusion of radicals through plastic organic crystals, such as frozen cyclohexane. The radiation chemistry of glycine and glycyl glycine was discussed by W. R. Garrison (Lawrence Berkeley Laboratory, Berkeley, California). The complicated phenomenology of these systems can now be reduced to a gratifyingly simple scheme of free radical reactions, which apply equally to irradiations in solution and in the solid state. Another type of system, also of possible relevance to basic radiobiology, was discussed by J. K. Thomas (University of Notre Dame). Micelles, suspended in water, have nonpolar material inside surrounded by a stabilizing polar shell. It was found that free radicals and solvated electrons readily penetrate into the interior to react with nonpolar molecules dissolved there. Electrons formed in the interior by photoionization appear as solvated electrons in the water phase.

In water radiolysis, the striking change in hydrogen yields with radiation quality (linear energy transfer or LET) has long been described by a quantitative theory involving the competition between interactions of radicals generated in a group ("track" or "spur") and diffusion out of the group. Extensive data on effects of varying radiation quality presented by A. Appleby (Rutgers University, New Brunswick, New Jersey) support the theory. The accepted model implies a rapid disappearance of radicals during the first nanosecond after their formation, and recent developments in ultra-fast pulse radiolysis have shown that this does not occur, according to M. S. Matheson (Argonne National Laboratory, Argonne, Illinois). Some modification of the theory seems required. The effects of extremely high track densities were studied by M. Imamura (Japan Institute of Physical and Chemical Research) by the use of high-energy beams of carbon and nitrogen ions. Interesting effects were observed in organic compounds.

The largest practical use of radiation is in polymerization and polymer modification, including grafting. Cross-linking and grafting depend on the diffusion and interaction of free radical centers in the solid. J. Silverman (University of Maryland, College Park) uses crystalline paraffins ($C_{20}H_{42}$ or $C_{36}H_{72}$) as model systems and grafts polystyrene to them. The odd electrons in these irradiated crystals tend to pair up in triplet configurations. Radiation-induced polymerization can occur by either ionic or free-radical mechanisms. K. Hayashi (Osaka University) finds that cationic polymerization is much slower in isobutyl vinyl ether than in other systems, such as styrene, perhaps because of ion solvation. S. Okamura (Kyoto University) spoke of "channel complexes" of vinyl monomers with urea or thiourea, in which the monomer molecules are lined up along one axis, but surrounded by urea in other directions. On irradiation, rapid ionic polymerization occurs, leading to a product with a very high molecular weight. T. Okada (Osaka Laboratory for Radiation Chemistry) compared gamma-ray and electron-beam polymerization of styrene.

The meeting served not only to point out the areas of radiation science in which basic understanding is lacking, but also to indicate progress in applying radiation chemistry in other fields, notably those involving the reactions of free radicals.

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