Norman Kroll, Tsung Dao Lee and Zumino (construction of a Lagrangian in which the neutral-vector mesons are the source of the electromagnetic field) permits a consistent theory of meson dominance of the currents to be formulated. Thus the *canonical* commutation relations of meson fields, the so-called field algebra, provides also a current algebra that is, however, more restrictive than that of Gell-Mann and can therefore give additional consequences. Zumino discussed the nontrivial problem of extending chiral SU(2) × SU(2) to chiral SU(3) × SU(3). In a quark model this extension would be equivalent to introducing the strange quark. The point is that in nature chiral SU(2) × SU(2) is a "bad" symmetry, which breaks down to the "good" SU(2) or isospin symmetry. On the other hand since SU(3) is almost as "bad" a symmetry as the unbroken chiral SU(3) × SU(3), there is more ambiguity in deciding how the breaking should occur. In the breaking process the fields that transformed nonlinearly under the group are supposed to turn into linear representations of the smaller group, and this general problem has been understood by Sidney Coleman, Wess and Zumino and was reported by the last author.

Herman Munczek (Northwestern) presented a related, though different, phenomenological Lagrangian based on the meson dominance of currents. Munczek and I have produced essentially a theory of mixing of the pion and the A_1 meson, as suggested by the partially conserved axial-vector current hypothesis, that uses the rho dominance of the vector current and, using parameters fixed by the rho and A_1 meson decay widths, achieves a finite mass difference of the charged and neutral pions that agrees with experiment.

Kinematic analyses. Two of the results reported dealt with work that was, in the broadest sense, kinematical; no specific model was involved for the interaction. The first was Pais and Trieman's analysis, presented by Abraham Pais (Rockefeller), of the Kl_4 decays, from which they conclude that pion–pion phase shifts can be unambiguously inferred from the experimental data when sufficient data become available. The second was Feldman and Matthews's work on covariant angular-momentum analysis, useful for Regge-pole theory, presented by Paul Matthews (University of London). The latter work uses the helicity projection of the Bargmann–Wigner angular-momentum tensor, which simplifies the work to such a degree that they have named this quantity "felicity." The analog of the helicity-flip amplitude, according to Gordon Feldman, they intend to call "felicity slip."

Louis Michel (Inst. des Hautes Études Scientifique) addressed himself to the group-theoretical characterization of the Cabibbo theory of weak interactions, a problem also briefly touched upon by Nicola Cabibbo (University of Rome). Behram Kursunoglu (University of Miami) proposed a theory of leptonic multiplets that predicts some new leptons not yet observed. On the experimental side Melvin Schwartz (Stanford) reviewed the charge-asymmetric decays of K_2^0; William Willis (Yale) summarized the decays of strange particles and W. Galbraith (University of Sheffield) spoke on the decay of K_L^0 to two neutral pions.

Finally a new theory of CP violation in weak interactions was proposed by Kazuhiko Nishijima (University of Tokyo). In this theory the *fundamental* hadronic weak interaction is odd under CP and has a surprisingly large dimensionless coupling constant of the order 10^{-3}. The ordinary hadronic weak interaction is then supposed to be of second order (with coupling constant 10^{-6}), conserving CP, and the two-pion decay of the long-lived K meson is supposed to be of third order, accounting for its CP-odd character and its reduced rate.

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The conference was organized, at the Center for Theoretical Studies of the University of Miami, by Behram Kursunoglu. The proceedings will be published by Benjamin.

This year's conference was the last in a series of five; next year a new series will begin, entitled "Fundamental Interactions at High Energy."

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Radiation Effects in Semiconductors

In 1947 observations at both Purdue and the Oak Ridge National Laboratory showed that germanium and silicon suffer profound modifications of their electronic behavior when exposed to 10-MeV deuterons or radiation in a nuclear reactor. A flourishing research field is now devoted to radiation effects in semiconductors.

The Santa Fe Conference (October 1967) might be taken symbolically at least as marking the 20th anniversary of the subject. In those 20 years many roadblocks had to be circumvented before progress could be made.

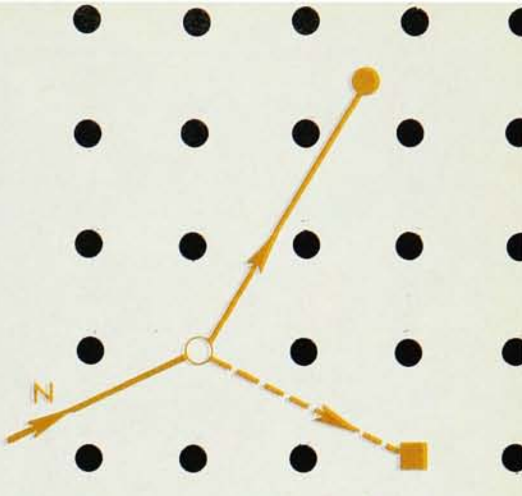
One example of an obstacle that took about 14 years to conquer is the false assumption that the lattice defects responsible for the large-scale changes in electrical behavior observed after room-temperature bombardment were predominantly simple lattice vacancies and interstitials. Because of this erroneous view, there was little progress in identifying the defects responsible for the large number of electronic levels introduced by irradiation. Indeed, one was bound by the false assumption to attribute all such states to either a vacancy or an interstitial.

The gross inadequacy of this view of radiation damage in the diamond-structure semiconductors was uncovered principally by careful explorations of the electron paramagnetic resonance of lattice imperfections in electron-irradiated silicon by George Watkins and associates. They found that the defects that are stable at room temperature are either divacancies, interstitial impurity atoms or vacancies bound to impurity atoms. Studies of the thermal stability of defects revealed that interstitial silicon atoms are highly mobile at temperatures as low as 4°K and lattice vacancies keep their mobility well below 200°K. This new insight resulted in a drastic reëvaluation of ideas concerning defect energy states not only in silicon but in germanium as well, since recent infrared absorption measurements on electron-irradiated oxygen-doped material have shown that germanium vacancies are also mobile in electron-irradiated germanium below 200°K.

More tools needed. The consequences of this revised point of view are still being worked out, as the emphasis of the conference demonstrates. Watkins pointed out how sparse is our knowledge about the nature of these composite imperfections and how much more work needs to be done to correlate energy-level structures and the defects responsible for them. He also discussed the need for additional experimental tools to study the structure of composite defects, as electron paramagnetic resonance, which has been so valuable in studies of irradiated silicon, is not applicable to diamagnetic defects and has not been particularly fruitful in germanium. Two potentially valuable techniques, the influence of uniaxial stress on both optical absorption and photoconductivity, were considered in contributed papers by Lin Cheng, A. H. Kalma and John Corelli. Dale Compton and R. J. Spry discussed another method for defect-structure determination, namely, recombination luminescence at radiation defects. In all of these optical processes the shift and splitting of levels by application of uniaxial stress gives information on the symmetry of the center in question. Nevertheless, as Watkins points out, utilization of this experimental information can be improved by better theoretical understanding of the Jahn–Teller distortions of the defect states.

Another consequence of the discovery of thermal instability of simple defects is the problem of accounting for high interstitial mobility and reconciling the very low activation energy for vacancy motion in irradiated material with the much larger value expected from self-diffusion experiments. On this point Max Swanson stressed that because of complex formation between migrating vacancies and impurity atoms the state of combination of the vacancy must be taken into account in any assessment of the self-diffusion activation energy and its significance for the motion energy of a free vacancy. Alfred Seeger and associates, on the other hand, were concerned with the mechanism of self-diffusion and atomic configurations around the diffusing species. Several interesting concepts resulted from these theoretical examinations of the problem, but the paradox of vacancy-motion energies appears to be far from resolved.

Defect states. Now that it has been freed from the unrealistic restriction that the simple defect-energy levels should correspond to those observed experimentally, the theory of defect states also appears to be making renewed progress. H. Y. Fan reviewed the status of the theory of electronic states of defects, and the inhibiting effect of the early unexamined premise was clearly evident. Recent work on the divacancy in silicon was reported by J. Callaway and A. J. Hughes. They extended a method they had developed earlier for the single vacancy to the two-center system. This approach, which involved the expansion of wave functions and potentials in terms of Wannier functions, yielded two bound states of the divacancy; it appears that transitions between these states may be responsible for the 1.8-micron infrared absorption band that has been attributed to the divacancy. Alan Lidiard pointed out that a natural starting point for theoretical calculations of defect levels is diamond itself; not only are the calculations somewhat simpler, but there are recent experimental data available against which to check calculations. Lidiard summarized recent work by himself and A. M. Stoneham and by M. Lannoo, G. Leman and J. Friedel and demonstrated that much progress was indeed being made. Calculations suggest that the prominent optical-absorption band in the orange that is observed in irradiated diamond is due to transitions involving a lattice vacancy. Renewed interest in the theory of defect states and recent successes (particularly in regard to vacancies in diamond) is most encouraging and indicates that a greater contribution from theory can be expected.



INTERSTITIAL-VACANCY PAIR made by neutron bombardment. The neutron may produce an impurity (square).

Low temperature. There is also extensive interest in the configuration of defects introduced at low temperature by electron irradiation and low-temperature annealing processes. For a number of years defect-annihilation processes that occurred at 35°K and at 65°K in electron-irradiated germanium during isochronal annealing have been investigated; they had been attributed to the annihilation of close interstitial-vacancy pairs. However, John MacKay and Everett Klontz considered the possibility that one of these stages is caused by the release of an interstitial germanium atom trapped at an impurity atom. Similar processes in silicon have been clarified by investigations of the dependence of defect

yield on the energy of incident electrons and on the temperature of irradiation. For example, Fred Vook and Herman Stein report two classes of defects, one whose yield is exponentially dependent on temperature and one whose yield is independent of temperature but increases with increasing energy of the bombarding particle. The first type of defect is apparently the result of the thermally active separation of a close interstitial–vacancy pair after its creation, and the temperature dependence is associated with the energy barrier that must be overcome so that the interstitial escapes the vacancy. The class of defects whose yield is temperature independent is considered to be a more complex type of damage (namely, clusters of defects) that is produced by a high-energy transfer collision.

Advances in technique. One of the outstanding advances in technique that were reported uses the principle of channeling of ions to locate implanted ions. John Davies, J. Denhartog, L. Eriksson and Jim Mayer showed that the back-scattering intensity of energetic protons incident on the surface of an oriented single crystal is associated with the proportion of implanted ions that block open crystallographic directions (channels) and hence are in interstitial sites. Other remarkable achievements pertain to precision determination of lattice structure. Bob Buschert described an x-ray diffraction method involving a reference crystal with which fractional changes in lattice parameters as small as 2×10^{-8} can be detected. Such high precision enables much to be learned about the lattice distortions produced by irradiation. John Parsons reported an equally sensitive electron-microscope technique whereby individual lattice planes and, in favorable circumstances, even individual atomic sites can be resolved in germanium crystals. He has used this development in determining the extent of lattice disturbances produced by bombardment.

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The conference was sponsored jointly by the Sandia Laboratory and the US Atomic Energy Commission; Fred Vook was chairman of the conference and of its organizing committee. The proceedings will be published by Plenum Press.

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