University of Michigan. Bailey Donnely (Lake Forest, Ill.) discussed the role played by electron alignment in the ejection of electrons from metal surfaces by metastable helium, and P. S. Farago (University of Edinburgh) described the potential use of the polarization of resonance radiation produced by electron impact as a possible way to perform spin analysis.

**Atoms.** With regard to polarized atoms (the other workshop topic) Hans Kleinpoppen (University of Stirling) described the relations of scattering amplitudes to observables in alkali excitations. I then described recent experiments at New York University involving scattering of polarized potassium atoms by unpolarized electrons, with spin analysis performed on the scattered atoms.[7] The emphasis was on the recent measurements of the ratio of spin flip to full differential cross sections, for the $4^2S_{1/2}$–$4^2P_{1/2,3/2}$ transitions in potassium, measured over a range of scattering angles and energies above threshold. The ratio can be expressed in terms of direct and exchange scattering amplitudes, which in turn can be written in terms of elements of the *R* matrix. These elements have been calculated in a three-state close-coupling approximation by E. M. Karule (and by Philip Burke for lithium). A very close connection can thereby be effected between theory and experiment, which is characteristic of any scattering experiment involving spin analysis.

Burke (Queen's University, Belfast) discussed the usefulness of density-matrix formalism in describing collisions involving polarized beams, and Aaron Temkin (Goddard Space Center, NASA, Greenbelt, Md.) reviewed the polarized-orbital method (not to be confused with polarized beams!) for both spinless (for example, rare gas) and spin-dependent (for example, alkali) collisions. He made a very illuminating comparison between this approximation technique, which is based to a large extent upon physical intuition, and the more formal and systematic close-coupling approximation.

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*As with all meetings held at JILA, the authoritative, competent and altogether delightful management by Mrs Robert J. (Modie) Low contributed immensely to the workshop's success. I acknowledge support by the US Air Force Office of Scientific Research, the Army Research Office, Durham, and the National Science Foundation in connection with polarized beam work at New York University. I also thank Steven Smith and Wilhelm Raith for their help in preparing this report.*

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## Particle Physicists Exchange Facts, Models and Speculations

The present state of particle physics is characterized by a steady accumulation of experimental facts, by slow progress at their interpretation in terms of phenomenological models of limited validity and by forays into the realm of speculative ideas. Among the models is Reggeon exchange in hadron dynamics, for which the concept of duality may be useful if adequately defined. Baryon resonances, elegantly defined by theorists, are not easily analyzed by experimenters; some progress can be made, however, with Argand-diagram representations plus imagination. Limited success, so far, attends efforts to enlarge our knowledge of CP violating processes; so far the answers are contradictory.

These topics, with some speculations of uncertain relevance, were the subject of a combination summer school and conference on elementary particles, held 18–29 August at the University of Hawaii. Together the sessions comprised the Third Hawaiian Topical Conference on Particle Physics, latest of a series of meetings held biannually since 1965.

The organization of the meeting had much to recommend it; in the mornings we were able to obtain a broad picture of the status of large areas of elementary-particle physics, and in the afternoons we heard about some of the latest developments. The sessions were well balanced between theoretical ideas and experimental results. The principal lecturers were Leon Van Hove (CERN), Murray Gell-Mann (Cal Tech), Robert Tripp (Berkeley) and Mel Schwartz (Stanford).

**Hadron dynamics.** Van Hove concentrated on topics concerning the dynamics of hadrons, the strongly interacting particles. The main features of many two-body reactions at medium and high energies can be accounted for by assuming that the Regge poles, or "Reggeons," are exchanged in the reactions. An exchanged Reggeon behaves like a virtual particle whose quantum numbers are fixed, except that its spin is a continuous variable with a value depending on the square of the four-momentum transferred in the reaction.

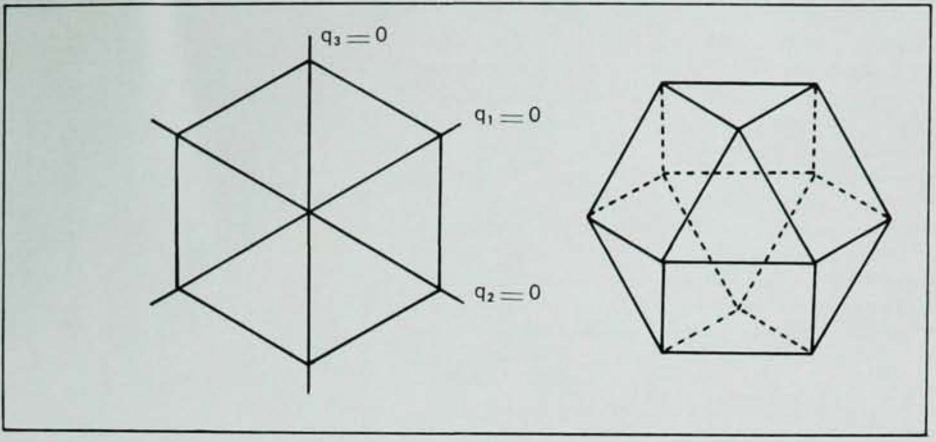
He stressed that in elastic scattering, and certain other reactions, we usually assume that a Reggeon with the quantum numbers of the vacuum, the so-called "Pomeron," is exchanged. (This Reggeon is also called the "Pomeranchon" or "Pomeranchukon," but perhaps the shortest name is to be preferred even though it obscures the etymology.) However, the Pomeron behaves differently from all other Reggeons in many respects. In fact, assuming its existence may be just a way of describing high-energy diffraction scattering within the framework of the Regge-pole model. Van Hove pointed out other difficulties with the simple Regge picture, such as its failure to predict any polarization in pion–nucleon charge-exchange scattering.

This defect can be overcome, but only at the expense of making the model considerably more complicated and thereby less attractive.

The concept of duality in high-energy physics was discussed by Van Hove in considerable detail. Since the original work by Richard Dolen, David Horn and Christopher Schmid, the term "duality" has been defined in as many ways, and as imprecisely, as the word "dualism" by philosophers. But Van Hove was not dismayed by all the definitions. Rather he felt that physicists were groping their way towards an idea that may turn out to be useful in describing nature. Briefly, and of

course loosely, duality is a concept that implies that the scattering of two particles, exclusive of diffraction scattering, can be approximately described either by a sum of resonances between them or by a sum of Reggeon exchanges. The experimental evidence lends some support to the idea of duality, at least in pion-nucleon scattering, but it is by no means conclusive.

Finally, Van Hove discussed many-body final states that can be produced in collisions of two hadrons. The kinematic description of such processes is quite complicated, because many variables are necessary. At high energy we can make a considerable simplification, because the transverse momenta of the final-state particles are on the average much smaller than their longitudinal momenta. The latter are constrained by the fact that their sum is zero and by conservation of energy. If we plot three longitudinal momenta of a three-particle state using axes making 60 deg with each other, they must lie within a regular hexagon (actually rounded at the edges). If the longitudinal momenta of a four-particle final state are appropriately plotted, they lie within a cuboctahedron (the three-dimensional polyhedron formed by the intersection of a cube and octahedron). Figure 1 shows these figures. The mind boggles at the multidimensional figures that are obtained when the number of particles becomes really large. Perhaps more appropriate under such circumstances are the very high-energy models introduced recently by Richard Feynman and by C. N. Yang and his coworkers, but these were not discussed.



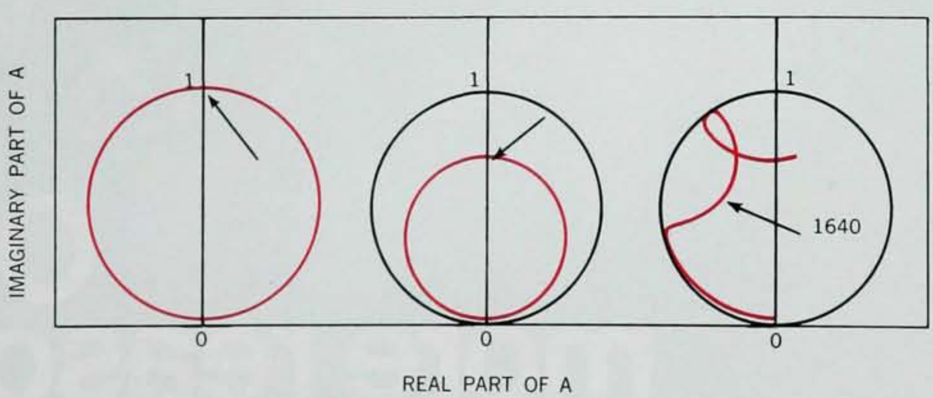

**LONGITUDINAL MOMENTA of final-state particles produced in high-energy collisions, plotted according to the method described by Van Hove. On the left is a hexagon for three-body states, and on the right a cuboctahedron (the intersection of a cube and an octahedron) for four-body states. —FIG. 1**

**Baryon resonances,** or excited states, were Tripp's main concern, but at the outset he was faced with the problem of just what a resonance is. A theorist's definition is that a resonance is a pole of the S-matrix on the second sheet of the complex energy plane. As elegant as this definition sounds, it is not of much use to the experimentalist who measures scattering cross sections only for real values of the energy. If a narrow, isolated peak is observed in a cross section, and it has a Breit-Wigner shape as a function of energy, there is of course no problem. Unfortunately, however, this is not the usual case encountered in high-energy physics. Typically the peaks are low and broad, and there can be considerable interference between resonant and background amplitudes. Furthermore there is no reason to exclude the possibility of overlapping resonances. Out of all this complication, it is no easy task to extract from experiment the mass, width and elasticity (or fraction of decay into the elastic channel) of a resonance.

An important tool in analyzing the data is the Argand diagram, which shows how a partial-wave scattering amplitude moves in the complex plane as a function of energy. A resonance appears as a circle of diameter less than or equal to unity, the maximal size occurring when only elastic scattering is possible. Because of the presence of background, the usual Argand diagram is anything but a circle, and it often takes a considerable amount of staring at a diagram, plus a healthy imagination, to discover a resonance. Typical idealized and actual resonances appear in figure 2.

After pointing out the many reasons for caution, Tripp went on to discuss families of baryon resonances within the framework of unitary symmetry. Of special interest is the question: Do the so-called "exotic" resonances, which are not predicted by a simple quark model, exist? Tripp summarized the present experimental evidence in favor of exotic baryon resonances and found it lacking in force. This area is currently under active investigation.

**CP invariance.** In Schwartz's opinion, the most exciting event in particle physics in the last five years was the discovery by James Christenson, James Cronin, Val Fitch and Rene Turlay in 1964 that CP invariance (CP is the product of charge conjugation and parity) does not hold in the decays of the long-lived neutral K



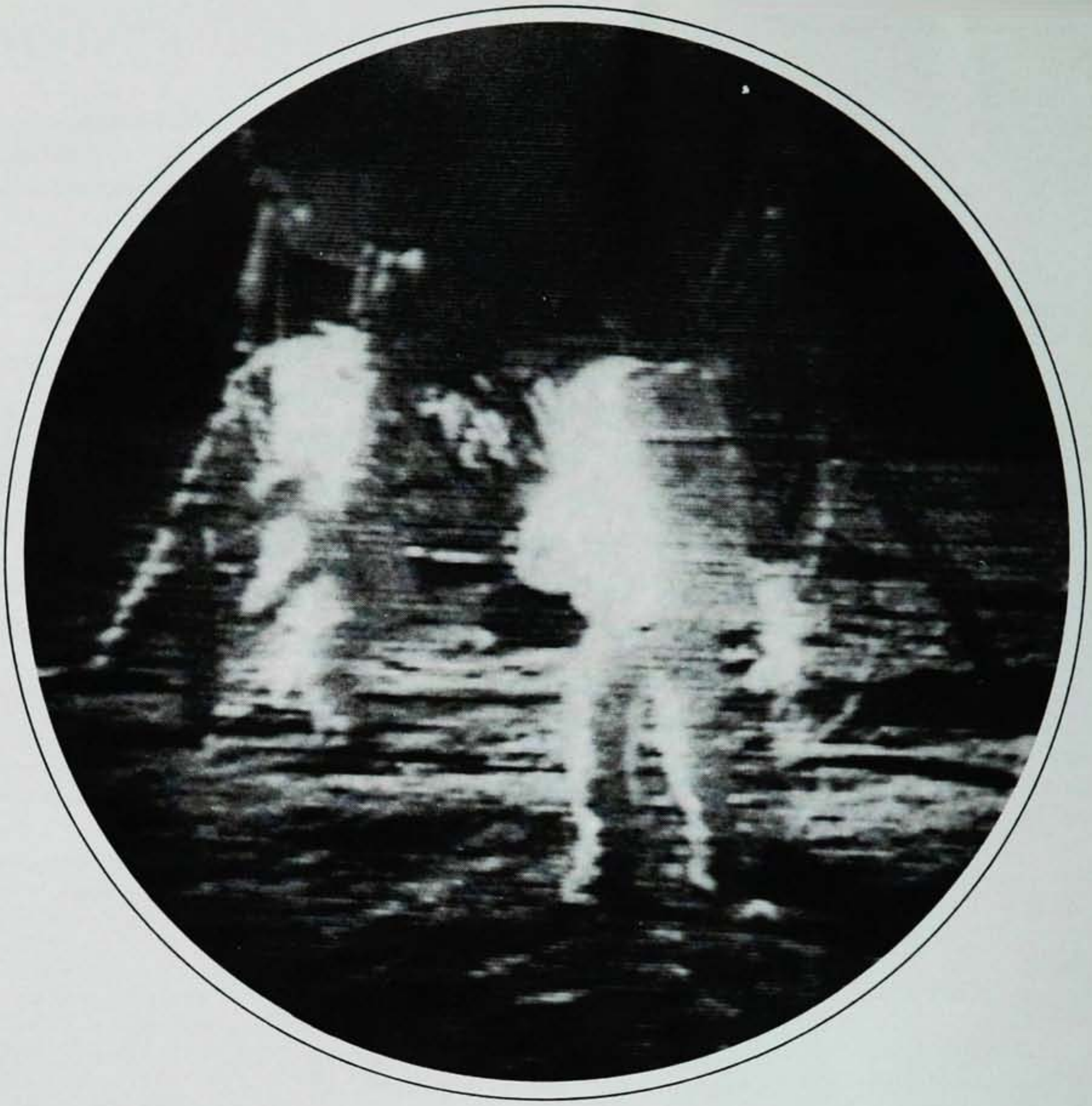

**RESONANCES, IDEALIZED AND ACTUAL. These are Argand diagrams that show the motion of a partial-wave scattering amplitude A in the complex plane as the energy changes. Left and center correspond to elastic and inelastic idealized resonances respectively. On the right is an actual case that has been interpreted by one group (using considerable imagination) as evidence for a pion–nucleon resonance. Arrow shows approximate position of the resonance, the number its energy in MeV. —FIG. 2**

meson. Since then physicists have spent considerable effort to find out further information about CP-violating processes, with only limited success. Schwartz began the subject with a beautiful phenomenological description of the long- and short-lived K mesons ($K_L$ and $K_S$) within the framework of quantum mechanics. He then discussed in detail a number of experiments that have been carried out to measure the parameters of the $K_L - K_S$ system. The most difficult experiments done so far have been measurements of the ratio of the decay rates of $K_L$ and $K_S$ into two neutral pions. Unfortunately several seemingly careful experiments give contradictory answers, but Schwartz held out hope that the correct ratio would be known before too long.

Thus far the experiments have not ruled out Lincoln Wolfenstein's "superweak" theory of CP violation. Many physicists are hoping that this theory is wrong, because it has as a consequence that the amount of CP violation, in other than $K_L$ and $K_S$ decays, is too small to be observed with present techniques. We shall have to wait to see whether nature has contrived to frustrate the efforts of physicists working in this field.

**Speculation.** Gell-Mann's talks were in marked contrast with those of the other lecturers. Whereas Van Hove, Tripp and Schwartz each gave a series of conservative, well organized talks summarizing the current status of their respective topics, Gell-Mann took flight into a number of speculations, some of which appear to have uncertain relevance to physics–as he admitted himself.

Gell-Mann began conventionally enough by reviewing the algebra of currents, which he proposed some years ago and which, as far as is known, holds very well in nature. He then discussed schemes of chiral symmetry breaking by pseudoscalar mesons. Still more speculative was his discussion of attempts, principally by Robert Oakes and by Nicola Cabibbo and L. Maiani, to find a connection between three small quantities–the fine structure constant, the square of the Cabibbo angle (a parameter that measures the relative rate of strangeness-violating and strangeness-conserving weak decays), and the square of the ratio of the pion to K-meson mass. Although the tentative steps taken by



Oakes and Cabibbo do not seem at all convincing, it is a healthy sign that physicists are willing to grapple with such questions. In connection with this topic, Gell-Mann suggested the possibility that the neutron-proton mass difference might not be entirely electromagnetic in origin. So long as no one can calculate the neutron–proton mass difference, the possibility can not be ruled out.

Lastly Gell-Mann discussed the possible relevance to physics of the group of scale transformations and of the conformal group. His treatment of the latter appeared largely formal, but his treatment of scale transformations was quite exciting. Among the various schemes he suggested was that of a spontaneous breaking of scale invariance by a scalar meson that would occur in addition to an SU (3) nonet. He suggested that a possible two-pion resonance at an energy of about 700 MeV might be this particle. The question of broken scale in variance is of current interest because at very high energy the mass of a particle, which breaks scale invariance can be neglected.

Many of the afternoon talks complemented the morning lectures. For example three seminars further explored some theoretical and experimental aspects of duality. Another talk described a careful measurement of one of the parameters that describe CP violation in K decay, thereby providing a new clue to the understanding of this mysterious phenomenon.

Among other topics discussed were the results of the recent high-energy electron–proton inelastic scattering experiments at Stanford. Many more electrons than expected were scattered at large angles, which suggests the interpretation that the proton is made of charged, point-like constituents of matter. Feynman's hypothetical "partons" are one possibility; quarks are another.

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*The conference was directed by San Fu Tuan of the University of Hawaii. He and his colleagues helped provide a very pleasant immediate atmosphere, over and above the beauty of the environment. Proceedings, which will include only the morning lectures, are to be published by Western Periodicals, Los Angeles. One-page summaries of the afternoon seminars are to be collected and duplicated by the members of the University of Hawaii.*

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