

Polarized Beams Show Promise For Atomic Collision Experiments

Since the discovery of electron spin, the problem of preparing an electron beam in a definite state of polarization has intrigued, and even haunted, many a physicist. The related problem of how to employ such beams in collision experiments to good advantage has also occupied the thoughts of experimentalists and theorists over the years.

The early development of the Mott scatterer opened the experimental era of the polarized electron. This device has served nobly, for example in the observation of parity nonconservation in weak interactions and in the $g - 2$ experiments at the University of Michigan.

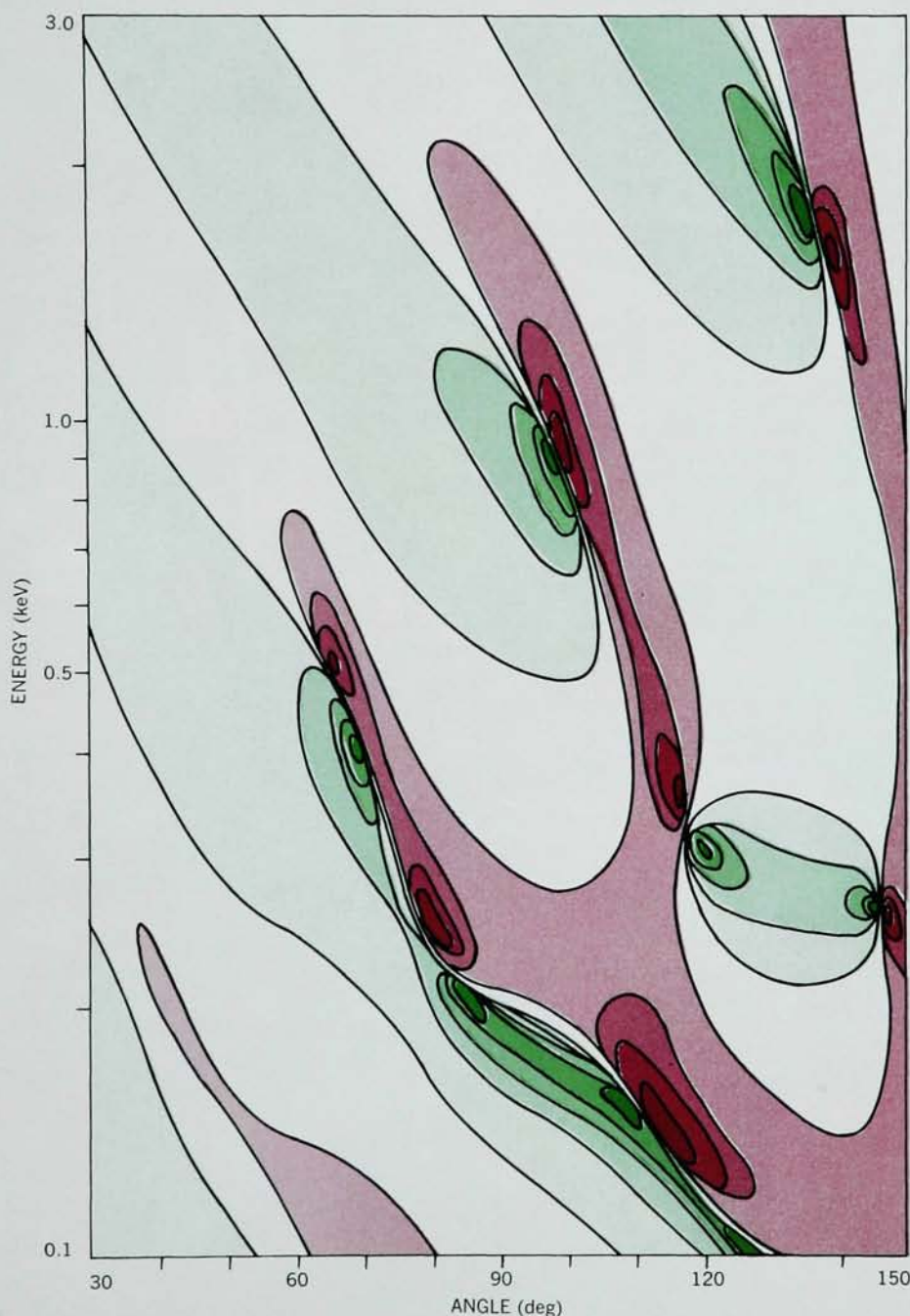
It has been apparent for some time that the day when polarized electrons could be used in more general experiments, particularly those involving atomic and nuclear collisions, was rapidly approaching. A noted increase in activity, particularly with a view toward creating a practical *source* (rather than *analyzer*) of polarized electrons, has occurred recently. At the same time, experiments involving polarized targets (atoms or nuclei) are already being performed and have served to stimulate interest by theorists in spin-dependent interactions in general.

A number of independent, but nevertheless related, developments underlie the rapidly increasing interest in polarized electrons. They are most particularly related to atomic, rather than nuclear interactions (although applications of polarized beams in nuclear and high-energy experiments are obviously of great importance). Among these developments are the production of polarized electrons by elastic scattering of low-energy electrons in mercury and the use of optical pumping to obtain polarized electrons. There is also the very recent experimental confirmation of the existence of a significant spin-orbit interaction in the continuum, which results in polarization of electrons produced by photoionization of alkalis by circularly polarized radiation.¹ At the same time, experiments involving polarized electrons and polarized atoms had been reported, and furthermore,

many experiments involving scattering of polarized electrons by both unpolarized and polarized targets are underway at a number of laboratories.

Workshop. It was within the context of all this recent history that

Steven Smith, a National Bureau of Standards staff member at the Joint Institute for Laboratory Astrophysics (JILA), and Wilhelm Raith of Yale undertook the organization of a "workshop" in polarized electrons and atoms.



POLARIZATION YIELD $S(\theta, E)$ of electrons scattered from mercury, as a function of scattering angle and energy. White to dark red shows the variation in S from zero to -1 , in five steps each of 0.2 . Pale green to dark green shows the variation from zero to $+1$, again in five steps. The boundary between the white and pale green areas is the zero polarization-yield line.

—FIG. 1

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The workshop was held at JILA, on the campus of the University of Colorado in Boulder, 7-9 August, under the management of Smith and Raith. A small but fairly representative number of workers (about 30) attended.

In keeping with the informality of the occasion, there were no abstracts, no titles and, in fact, no prepared program. No transcripts were made and there will be no published proceedings. A number of fairly extensive talks were presented, and everyone present had an opportunity to describe the current status of their programs.

We heard reports on what currently appeared to be the most promising sources of polarized electrons. Specifically, these sources are low-energy elastic scattering from mercury, optically pumped helium afterglow, photoionization of alkalis by circularly polarized light, and field emission and photoemission from ferromagnetic materials.

Low-energy scattering. A recent review article by J. Kessler² describes in satisfying detail the history and current status (to 1968) of both Mott scattering and low-energy elastic scattering, which therefore need not be repeated here. Of particular interest to the workshop were questions concerning the efficiency of low-energy elastic scattering from mercury as a source, detector, or both, of polarized beams. At low energies, polarization results from a combination of interference effects, which produce maxima and minima (that is, wiggles) in the differential cross sections, and a relatively weak spin-orbit interaction; this interaction causes the maxima and minima in the differential cross section to occur at slightly different angles for the two polarization states. Thus one should expect a large polarization effect near those angles where the average differential cross section goes through a minimum, because one of the two spin-dependent cross sections goes identically through zero while the other remains finite.

A remarkable feature of this work has been the extremely satisfactory state of comparison between theory and experiment. In all cases where such a comparison has been made there is quantitative agreement down to energies of the order of 100 eV, even though the theory is based upon a static potential model (no polarization or exchange). Qualitative agree-

ment is obtained at lower energies, although the characteristic low-energy complications caused by polarization and exchange do indeed then come into play. Another (though not as happy) characteristic is that high polarization is obtained at precisely those angles where the differential cross sections are very small: Nature's perversity once again reveals itself!

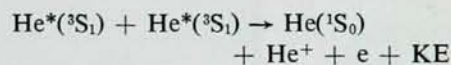
An example of theoretical polarization, calculated over a range of electron energies and angles, for mercury is shown in figure 1. Here the ordinate is energy, the abscissa, scattering angle. The various contours refer to different degrees of polarization yield for unpolarized electrons incident on mercury. This illustration has been supplied by K. Jost of Stanford (on leave from Karlsruhe University), who reviewed recent measurements on low-energy elastic scattering and also described efforts now in progress at Stanford to optimize design parameters and thereby produce a practical polarized electron source (0.2 microamp, 300 eV, polarization $P \approx 20\%$ expected) by this means. From Mainz, Germany, it was reported that H. Deichsel and coworkers have built a source that employs scattering from mercury at 6.75 eV, yielding 2×10^{-8} amps, $P = 27\%$.³

Low-energy scattering from mercury as an analyzer has been used principally by the Mainz group. A particularly intriguing device is being used by Deichsel in a triple-scattering experiment. This analyzer uses mercury vapor, rather than a beam; the overall dimensions are very small, compared with those of conventional Mott detectors. Although the net polarization asymmetry is only 20%, this is such a convenient instrument that it, or variants of it, may possibly be the prototype of a host of future spin analyzers.

Optical pumping. In pursuing the quest for polarized electrons, we would naturally consider optical pumping. This technique can serve as an angular-momentum pump, transferring positive or negative helicity from a circularly polarized light beam to the absorbing target gas. Surely there must be a way, in a further step, to transfer the angular momentum from the target to free electrons, which subsequently can be extracted in their aligned state. Such a two-step process has already been used by H. G. Dehmelt and others, without extrac-

tion from the gaseous environment. They exploited electron elastic-exchange collisions to produce a net polarization of the electrons in a weak alkali discharge and to perform a $g - 2$ resonance experiment on them.

It remained for a group at Rice University, led by G. King Walters, to point the way towards a practical polarized-electron source with optical-pumping techniques. Walters reported on the current status of this work.⁴ A weak helium discharge at low pressure is optically pumped with circularly polarized 1.08-micron radiation, corresponding to the transitions from the metastable triplet state $1s2s^3S_1$ to the multiplet $1s2p^3P_{0,1,2}$. Subsequent radiative decay readily results in pumping of the metastables towards either $m_j = +1$ or $m_j = -1$, depending upon the helicity of the pumping radiation. The two atomic electrons of these magnetic substates are aligned either parallel or antiparallel to an applied longitudinal magnetic field. Metastable-metastable collisions can then result in ionization of one of the collision partners. The excess energy required for this reaction is supplied by the other metastable, which decays to the ground state. Provided that spin is conserved in this reaction, that is, provided the process does not occur via an intermediate long-lived state, the emitted electron will possess the same polarization as the atomic electrons. Symbolically this reaction can be written

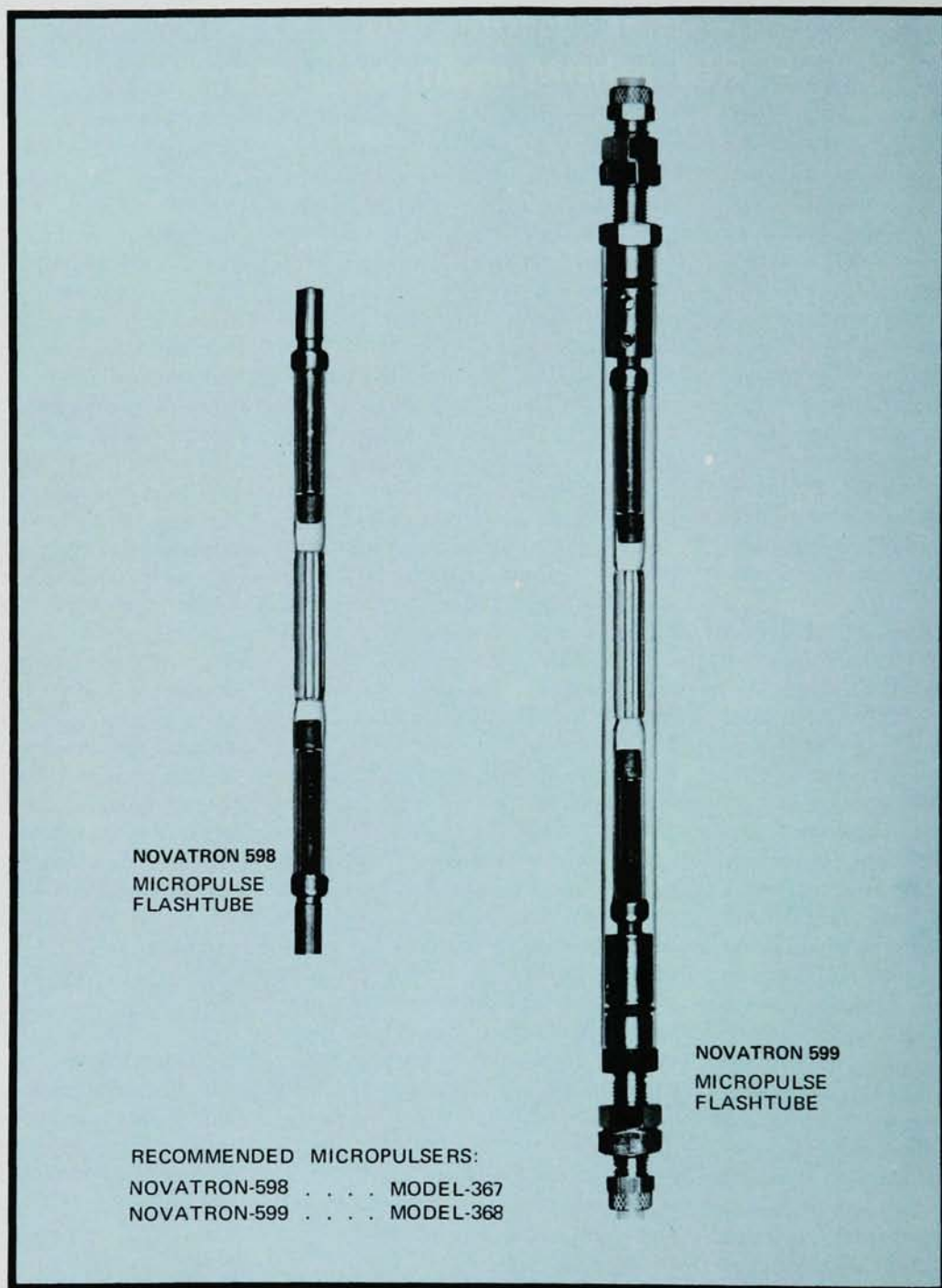


Note that this reaction could not occur were the metastable target completely aligned, because in that case the angular-momentum projection along the B field on the left side of the equation is ± 2 , whereas the right side is ± 1 . Thus the target must be only partly aligned, and the maximal theoretical yield of polarized electrons will be something less than 100%.

In practice best results are obtained in the late afterglow rather than during the active stage of the discharge. There are many competitive sources of free electrons, most of which yield unpolarized electrons, while energy is being supplied to the gas to sustain a discharge. In the late afterglow, after the primary electrons have vanished, the principal and perhaps even the only source of free electrons is the above reaction. As is characteristic of much of the optical-pumping field, the

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experimental setup is almost embarrassingly simple—perhaps to the chagrin of beam-oriented experimentalists. It seems almost sinful that copious amounts of polarized electrons, as reported by Walters, can be obtained by such simple means—although I should add that both the reported degree of polarization (up to 16%) and the energy spread (at least several eV) are not as good as is obtained by direct methods.

Photoionization. M. S. Lubell, G. Baum and Raith of Yale reviewed the recent developments relating to photoionization of alkali beams. They reported on the Yale experiment that has confirmed Ugo Fano's prediction¹ that circularly polarized radiation will produce polarized photoelectrons.⁵ Fano's idea was based upon Michael Seaton's earlier theoretical analysis of the dependence of the photoionization cross section in the heavy alkalis upon photon energy. Seaton postulated the existence of a significant spin-orbit interaction in the continuum. The emitted electron remains near the ionized atom long enough for this interaction to take hold.

The Yale group have performed a variant of Fano's proposed experiment,

finding it more convenient to employ both polarized atoms and circularly polarized light, and observing the dependence of ion current upon the relative orientations of polarizations. (The difference between the two experiments is illustrated in figure 2.) There was then no need to perform a Mott analysis of the polarization of the photoelectron, thereby vastly improving the experimental statistics. The Yale experiment can be shown to be equivalent to Fano's. Meanwhile, back at Karlsruhe, Kessler has reported the observation of electron polarization in an experiment corresponding to the upper part of figure 2.

Ferromagnetics. Finally, Gustav Obermair reviewed efforts to obtain polarized electrons from ferromagnetic materials.⁶ As Obermair stated the case, everyone knows there are polarized electrons inside ferromagnets, so why can't we just get them out? The problem really is that in ferromagnetic metals, the conduction band from which most emitted electrons are likely to come turns out to be not significantly polarized, despite the large exchange forces that produce an anisotropy in the spin-density distribution function of the conduction band. This turns out to be effectively counteracted by an antiferromagnetic perturbation

between the 3d ferromagnetic band and the 4s conduction band. For ferromagnetic semiconductors, on the other hand, the situation is far more promising because of the weakness of this perturbation interaction there. Obermair described some recent experiments, by G. Regenfus, in which field-emitted electrons from fine whiskers of gadolinium in a strong magnetic field were up to 8% polarized. This is certainly a promising technique for some applications, because very large pulsed circuits can be obtained.

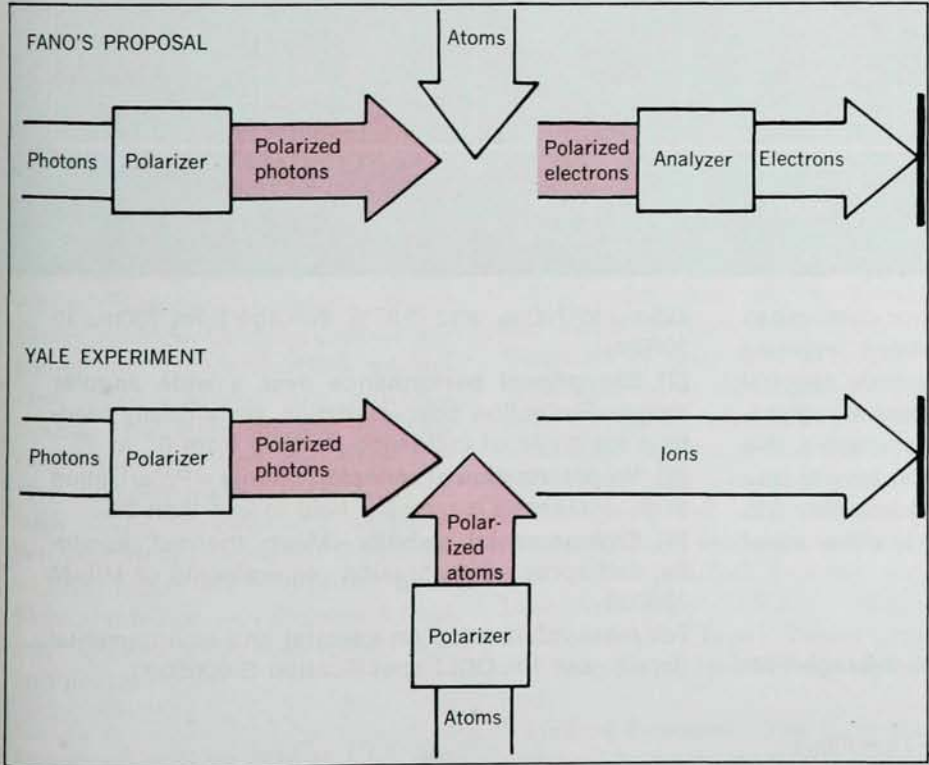
One of the principal difficulties in this experiment—that of growing tiny crystal whiskers—was apparently overcome by a Jesuit priest working in Regenfus's laboratory. The question of whether there was a theological inference to be drawn from this special talent was raised by several observers.

Similar experiments, equally successful, have been performed by H. C. Siegmann and coworkers in Zurich, using photoemission. Again, with electron polarization one can measure exchange splitting in various ferromagnets directly; such work, by R. E. Collins, is in progress in Australia.

The utility of this phenomenon as a polarized-electron source is open to some question, particularly for atomic-physics experiments. The chief difficulty is the very high magnetic field (usually pulsed) required for alignment; such a field always causes trouble when dealing with low-energy electrons.

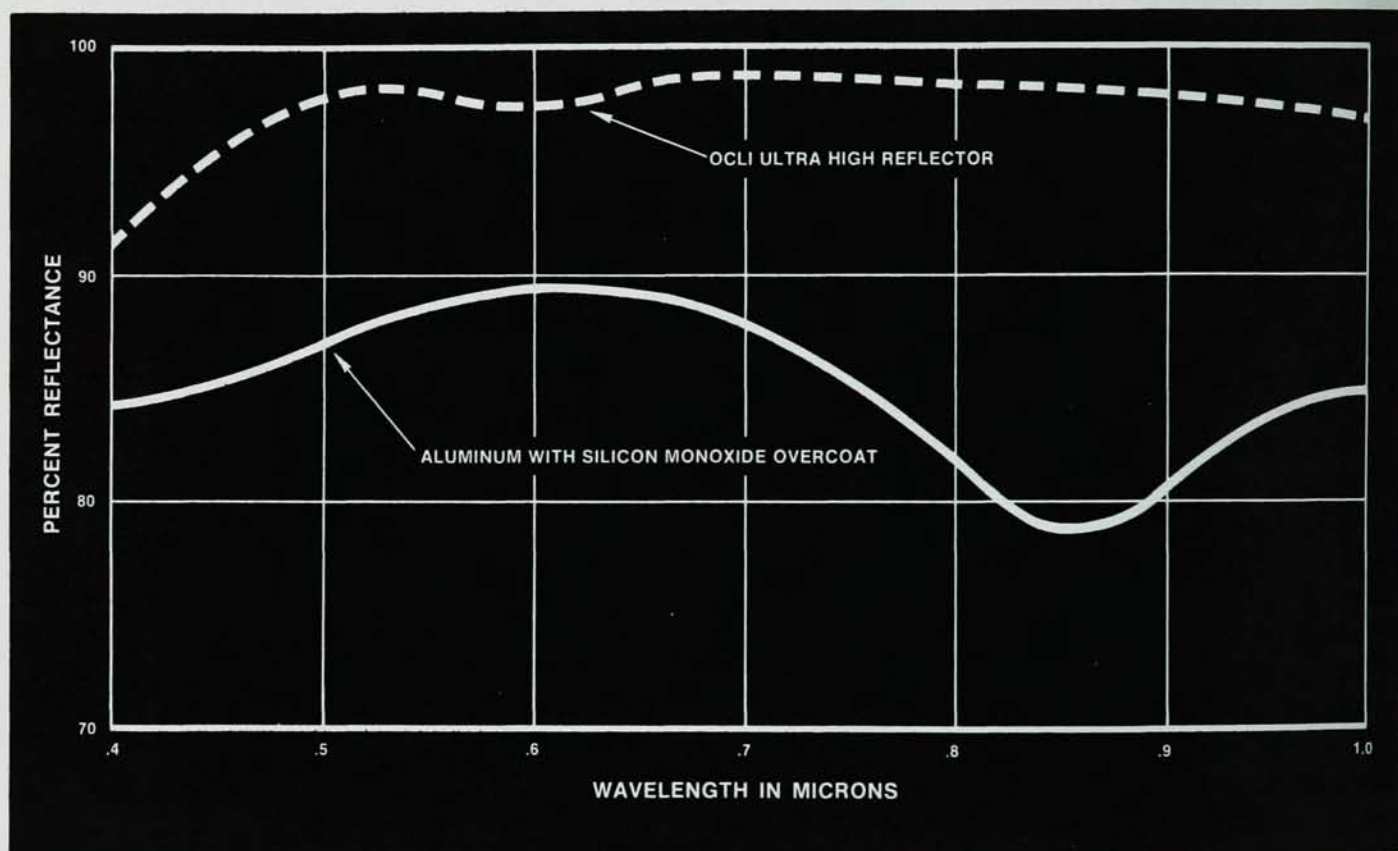
Merits. Of course a good deal of time was devoted to discussion of beam technology, design considerations and to the question of relative merits of various devices for production and detection. I can safely state that no firm conclusions were reached. At the moment there is no single clear winner in this game, but some methods (in particular, at least in my opinion, those discussed above) are more promising than others. I should emphasize that current experiments employing polarized electrons are primarily exploratory in nature. Quantitative measurements await further improvements of source technology.

Other speakers referred to specific areas where electron spin plays a significant role. Wolfgang Franzen (Boston University) reviewed the role played by spin-orbit interactions in resonance scattering. Arthur Rich reviewed recent $g - 2$ experiments for both electrons and positrons at the



POLARIZATION BY PHOTOIONIZATION. At top is Ugo Fano's suggested experiment, and below it is the experiment as performed at Yale. The two approaches can be shown to be equivalent. —FIG. 2

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University of Michigan. Bailey Donnelly (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 $4^2S_{1/2} \rightarrow 4^2P_{1/2,3/2}$ 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.

* * *

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

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BENJAMIN BEDERSON
New York University

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