Moreover, scattered reference is made to papers that appeared later in 1962 as well as to some published in 1963, but a thorough coverage of the later period is not attempted.

In several parts of the book, facts are given and statements made without the supporting reference. With this exception, the book is well written, and it contains all the essential information about carbene chemistry.

EFTHIMIOS CHINOPOROS
Children's Cancer Research Foundation, Boston, Massachusetts

S-Matrix Theory

Mandelstam Theory and Regge Poles. An introduction for experimentalists. R. Omnès and M. Froissart. Benjamin, New York, 1963. xii + 123 pp. Illus. Paper, $3.95; cloth, $7.50.

Regge Poles and S-Matrix Theory. Steven C. Frautschi. Benjamin, New York, 1963. viii + 200 pp. Illus. Paper, $3.95; cloth, $7.50.

Complex Angular Momenta and Particle Physics. A lecture note and reprint volume. Euan J. Squires. Benjamin, New York, 1963. xii + 161 pp. Illus. Paper, $5.95; cloth, $9.

In 1942 Werner Heisenberg put forward the idea of a new kind of theory of elementary particles, which was based solely on the so-called scattering matrix (S matrix). Heisenberg reasoned that physical theory, in the final instance, should be formulated in terms of the observable quantities only. Ordinary quantum mechanics has already eliminated, for example, the concept of well-defined trajectories of particles because these are not exactly observable in principle. The scattering matrix connects the measured properties of particles in the final state of a scattering experiment with those in the initial state; its elements are essentially the transition probability amplitudes between these states. Quantum principles, the conservation of total probability, and invariance principles (such as relativistic invariance) can be formulated directly in terms of the S matrix. It turns out that the S matrix contains not only information about the cross sections of scattering processes but about the stationary, or bound states (composite particles), and lifetimes of unstable particles as well, if some of the variables, like the total energy of the scattered particles (the S matrix is a function of the energy, momenta, spin, and other quantum numbers of the particles), are allowed to take unphysical, even complex, values. Therefore, a knowledge of the S matrix is sufficient to answer all questions with respect to the interactions of particles regardless of whether they are elementary or composite. However, the quantum and invariance principles are essentially of a kinematical nature and do not suffice to determine the S matrix uniquely.

For this reason Heisenberg's ideas remained dormant for more than a decade until some new "dynamical" properties of the S matrix, properties which are based on perturbation theory, were discovered in quantum field theory. These are the analytical properties of the S-matrix elements. It was recognized that by analytic continuation of, say, the energy variable, the amplitude of a certain process describes other related physical processes as well and, to some order in perturbation theory, it is, with the exception of some required singularities, an analytic function. These singularities, moreover, have definite physical meanings: bound states, unstable particles, thresholds of new energetically possible channels, and the like. If one now assumes these analytical properties from the beginning, in addition to the properties mentioned above, one can approximately determine the S matrix, because analytic functions satisfy very stringent additional restrictions, such as the Cauchy relations (dispersion relations).

Since 1959, largely as a result of its successes in the theory of strong interactions where perturbation theory had so-far failed, this fact has given rise to a very extensive development of a new line of physical theory, the S-matrix theory, based on the assumption of analyticity. In general, some difficulties of the field theory are eliminated, and some simplification of the conceptual framework is obtained; but other more serious difficulties—that is, how to deal with a large number of interacting particles—still remain.

The three overlapping monographs under review resulted from the rapid developments that have occurred during the past 5 years, and all are expanded lecture notes, not really textbooks. The analyticity of the scattering amplitude can be studied in the energy and momentum transfer variables (Mandelstam representation) or in the energy and angular momentum variables (Regge representation). These and other representations of the scattering amplitude are advantageous, depending on the situation. The first two monographs deal with both representations, whereas the third monograph, Squire's *Complex Angular Momenta and Particle Physics*, is devoted exclusively to the latter representation.

Now let us discuss the works separately. The monograph by Omnès and Froissart is a very clear introduction to the subject, with a large number of illustrations. As a matter of fact, it is written for experimentalists, but even theorists who are learning the subject can greatly benefit from the monograph. A little less than half of the book is devoted to the analytical properties of the scattering amplitude in nonrelativistic Schrödinger potential theory. This model, which neglects in the unitarity all states with more than two particles, has been very useful in guessing and interpreting relativistic results. Frautschi's monograph is very similar in content and organization to the first one. Again, about half of the space is devoted to nonrelativistic models, the other half to relativistic considerations—that is, half to Mandelstam and half to Regge representation. There is a little more about approximation methods and examples (N/D method, polology, strip approximation) in the second monograph.

In his monograph Squires provides a more detailed and comprehensive review of the properties of the scattering amplitude as a function of complex energy and complex angular momentum, in both relativistic and nonrelativistic cases. The book also contains reprints of eight related articles that complement the text. In the relativistic theory, the study of the analytical properties of the scattering amplitudes becomes very complicated and confused, in general, because statements are made on the basis of certain graphs or certain terms among infinitely many other graphs or terms. Squires is careful to state what has been proved and what is based on conjecture or is assumed. His monograph gives a complete picture of the theoretical problems, many of which are still unsolved, and of practical applications, many of which are still inconclusive.

A. O. BARUT
Department of Physics, University of Colorado