models in which the cosmological constant, a cosmic self-repulsion of the vacuum first invented and then rejected by Einstein, plays a major role in the expansion of the universe. Lemaître emphasized the cosmological constant because it could reconcile the geological age of the earth with the much younger age predicted by the expansion rate of the universe as first measured by Hubble. Additionally, a suitably chosen value of the cosmological constant provides an epoch of stagnation, when the universe expands very slowly and fluctuations that would eventually become galaxies can rapidly grow in amplitude. Though no cosmologists today believe in a stagnation phase, most are willing to consider that a cosmological constant may be important. The cosmological constant remains a fundamental outstanding problem of particle physics and cosmology today, and it is a shame that this volume does not contain any contributions addressing modern considerations of the subject.

Modern cosmological theories have progressed to the point of specifying candidate particles to have emerged from the primeval atom and survived to this day as the "dark matter" in the universe. Sciama summarizes the implications of a universe dominated by massive neutrinos or photinos. These candidate particles are suggested for reasons related to theories of particle physics and demonstrate the exciting influx of new ideas generated by detailed consideration of the very early universe, a subject now wholly in the hands of elementary particle physics theorists. The nucleosynthesis of light elements in the first three minutes of the universe is considered the most remarkable success of the hot big-bang models and is here well reviewed by Audouze. A modern view of galaxy formation is provided by Silk, and Oort reviews observational evidence for large-scale clustering of galaxies. Evidence for spatial homogeneity in the universe is very sparse, and therefore it is of interest to consider spatially inhomogeneous cosmological models. Krasinski and Mashoon discuss such models, which are likely to be wrong but are useful nonetheless.

The section of the proceedings concerned with celestial mechanics is connected to the one concerned with cosmology only in being a reflection of Lemaître's scientific focus late in life. Several of the contributions in this section are quite technical. A detailed pedagogical presentation by Deprit of the dynamics of orbiting dust in the presence of radiation pressure is excellent. Broucke discusses modern aspects of the complex problem of motion of a charged particle in the magnetic field of a dipole, a topic that Lemaître labored on for decades because of its connection to the propagation of cosmic rays. Several of these contributions will be of interest only to specialists, but others, such as a review of the three-body problem in astrophysics by Hut, are of more general interest.

The volume is most interesting to me for its historical aspects; it reminds us how the focus of a problem changes over time, and it puts into perspective the progress that has been made in the 50 years since Lemaître's great innovation. However, because of its eclectic subject matter and incomplete coverage, it is not suitable as an introduction or as a testament of current progress in either cosmology or celestial mechanics.

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Stochastic Mechanics

Quantum Fluctuations. EDWARD NELSON. Princeton University Press, Princeton, N.J., 1985. viii, 146 pp. $32; paper, $12.95. Princeton Series in Physics.

Quantum mechanics, from its inception in 1913, posed many questions concerning the mathematical description of physical measurements and the processes of making such measurements. In quantum mechanics one agrees to identify a "state" of a physical system (a beam of photons impinging upon a grating) with a normalized vector ψ in Hilbert space, a physical observable with a self-adjoint operator O in this space, and the measured value of O on the state ψ with the expectation $(\psi, O\psi)$. In 1936, G. Birkhoff and J. von Neumann initiated a derivation of quantum mechanics from a calculus of propositions more suited to the language of measurement, which, at the same time, made clear the special nature of quantum mechanics. This framework was thoroughly reexamined by the Geneva school of J. Jauch in the 1960's. Others have proposed "hidden variable" theories in which quantum mechanical observables are related to deterministic variables that supplant the uncertainty principle on the basis of the inherent lack of simultaneous measureability for complementary observables. Such hidden variables of one type were shown not to exist by S. Kochen and E. P. Specker in 1967. On the other hand, stochastic mechanics as developed by E. Nelson does succeed in basing quantum mechanics on a classical deterministic theory that is not a hidden variable theory. Nelson takes the point of view that quantum fluctuations, which are usually attributed to the uncertainty principle, might be real and caused by direct physical interactions. This is the background field hypothesis. Quantum phenomena are now described in terms of a stochastic process with "diffusion" as the primary construct rather than in terms of only the wave function ψ. The physics, which is purely classical, appears in the equations for the diffusion process, and quantum fluctuations result from the randomness of this process; that is, they are fluctuations in the customary sense of probability theory. Such a relation between the Schrödinger equation of quantum theory and a diffusion was shown by I. Fényes in 1952 and was rederived by Nelson in 1966 from a stochastic analogue of Newton's force equation. A complete account of these derivations with background material is contained in the first two chapters of Nelson's monograph.

To obtain agreement between stochastic mechanics and quantum mechanics, the stochastic diffusion matrix is $\sigma = \hbar m$, where m is the matrix of masses for the classical stochastic dynamics and $\hbar$ is Planck's constant, which determines the scale size for quantum phenomena. This relation between diffusion and mass fixes the size of the fluctuations for the stochastic process in physical terms and is the mathematical manifestation of the background field hypothesis. Dynamics for the underlying process is provided by a variational principle that is a stochastic analogue of Lagrangian variational principles in classical mechanics. The time evolution of the process is related to a Hamilton-Jacobi equation from which results the Schrödinger equation. Given an initial probability density ρ_0, an initial drift vector b_0, and a suitable potential, the stochastic process is a stationary point for the stochastic variational principle when there exists a wave function ψ satisfying Schrödinger's equation and related to the probability density ρ and drift vector b at later times by $\rho = |\psi|^2$, $b = (\text{Re grad } \psi + \text{Im grad } \psi)/\psi$. In stochastic mechanics, the wave function is a derived quantity, but for all predictions based upon it agreement is obtained with those of quantum mechanics. The point of view, however, is markedly different. The wave function is now described in terms of actual point particle motions that allow the appearance of expressions absent from conventional quantum theory. In chapter 3, Nelson discusses and analyzes the differences for single and double slit diffraction of plane waves, bound states for the hydrogen atom, and the grafting of spin and statistics onto the stochastic theory. A critical confrontation with quantum theory arises when measurement in stochastic mechanics is described. Under the additional requirement that the process is Markovian, the notion of locality within the setting of Bell's theorem for quantum mechanics is shown not to hold for the stochastic theory. This important example is given in chapter 4 for two particles, one a free particle and one a bound harmonic oscillator, which are stochastically correlated by dynamically uncoupled Markovian diffusions. With some agony, this example leads Nelson to abandon Markovian for non-Markovian diffusions as a possible stochastic framework for quantum fluctuations. Where this will lead must be left for the future.

For myself, this volume of lecture notes presents the foreground between stochastic mechanics and quantum mechanics with clarity, economy, and elegance—virtues that I have come to expect from Nelson's writing. The reader will need to have a background in mathematics and physics at the level of first-year graduate courses and some knowledge of tensor calculus on Riemannian manifolds. Otherwise the book is self-contained. There can be little doubt that the mathematics of stochastic mechanics is interesting and worthy of pursuit and that as an area of physics stochastic mechanics might provide a context for the study of classical phenomena in random backgrounds, such as electromagnetic phenomena that result from random sources. Whether one views stochastic mechanics as a possibly correct description of quantum fluctuations, without a flat contradiction between the two, is liable to depend upon whether one views quantum mechanics as a correct description of nature. A conservative view holds quantum mechanics to be only an approximation at the atomic scale of a more fundamental theory valid at subnuclear scales—perhaps quantum field theory or quantum statistical mechanics. These differing views need not be contradictory, but a considerable amount of work will be needed to make a convincing argument for stochastic mechanics as a fundamental physical theory. In this monograph the endeavor is in skillful hands.

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(Continued on page 683)