

though the present book constitutes a good introduction to the short-range problems, it gives me the impression the long-range problems, for the time being at least, are almost a monopoly of the science-fiction writers.

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L. Marton is an electron physicist with the National Bureau of Standards. He is engaged in the international relations aspects of science.

Nature of the physical world

THE CHANGELESS ORDER: THE PHYSICS OF SPACE, TIME AND MOTION. Arnold Koslow, ed. 328 pp. George Braziller, New York, 1967. \$7.50

by EUGENIE V. MIELCZAREK

The changeless order, the nature of the physical world, has fascinated Man since his emergence from a lower form. Central to the development from fascination into physical science has been Man's attempt to define and relate the concepts of space, time and motion. In this book Arnold Koslow, a member of the philosophy faculty at Brooklyn College, traces the development of ideas central to mechanics, electromagnetism, quantum theory and the more general problem of the development of conservation laws. The contents are organized into two parts: Space, Time and Motion, and Conservation. The reader progresses from the Greek investigations, through the observations of Galileo and Issac Newton, to Mach's innovations, to our present understanding and its limitations as represented by Albert Einstein, Eugene Wigner and others.

Part I commences with selections from Plato on space and Aristotle's discussion of motion and time. Excerpts from Galileo and Newton and Koslow's introductions focus the reader's attention on the concept of inertia. Gottfried Wilhelm Leibniz, Immanuel Kant and Leonhard Euler are also included. Ernst Mach's rebuttal of Newton's discussion of absolute rotation is followed by excerpts from Einstein and Sciamia. The coherence of this first part is excellent and the reader's understanding is heightened by prefaces by Koslow, who ably demonstrates his knowledge and enjoyment of physics. Part II, Conservation, includes James Joule, on the mechanical equivalent of heat; Michael Faraday, on conservation of

charge, and Einstein, on conservation of mass. The concept of inertia reappears in a discussion by Von Laue on the inertia of energy. The climax of the book comes with two articles by Gerald Feinberg and Maurice Goldhaber, and Wigner on current attempts to formulate symmetry laws.

The book is good. Certainly, educated men will find it profitable and fascinating reading. It might also provide a basis for an undergraduate course on the history and philosophy of physics. However, the nonphysicist will probably be disappointed if he is unable to fully comprehend the last

group of articles on current attempts to formulate symmetry laws. A phrase such as "four vector momenta" and a nonfootnoted figure in Wigner's article are not meaningful to the uninitiated.

The obvious solution is that we should do a more thorough job of explaining physics to nonphysicists; however, this is a task incumbent upon us and not upon those like Koslow who record and appreciate.

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The reviewer is an associate professor of physics at the George Mason College of the University of Virginia.

Planetary physics and our long-neglected satellite

AN INTRODUCTION TO THE STUDY OF THE MOON. By Zdeněk Kopal. 450 pp. Gordon and Breach, New York, 1966. \$27.50

by S. FRED SINGER

The study of the moon has become a major national goal supported by multi-billion-dollar budgets; a great many people, including some scientists, are now beginning to pay attention to

our long-neglected satellite. This volume represents an excellent approach to the study of the moon. Although the title is misleading; the book is much more than an introduction. Furthermore much of the material is oriented towards planetary bodies generally, with the moon merely as an example. By emphasizing basic methods and not just phenomena and facts, the author



GOCLENIUS CRATER. An unusual feature of this crater is the prominent rille that crosses its rim. This 40-mile-diameter crater is located at 10°S latitude and 45°E longitude. The three clustered craters, upper left, are Magelhaens, Magelhaenes A and Colombo A. This photograph was taken during the Apollo 8 flight.

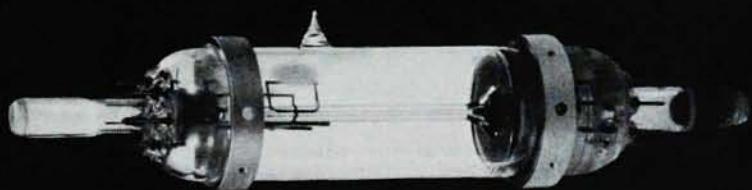


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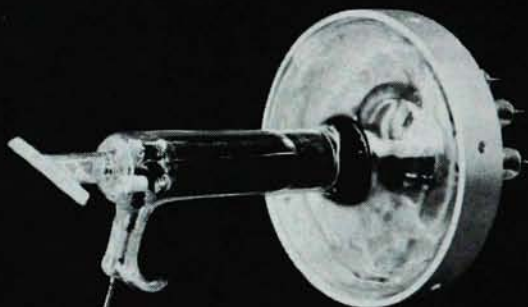


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has managed to provide a treatise especially valuable for someone with little background in planetary physics. But his emphasis is mainly on classical physics, with a perhaps understandable lack of chemistry and geology. Kopal, who holds a chair at the University of Manchester, is widely known for his contributions to theoretical astronomy and to applied mathematics as well as for his editorial activities. He also heads an observational program of lunar studies at the Pic du Midi.

The book is beautifully written, with a literary style that one seldom finds in a scientific volume. Derivations are exceptionally clear and done in great detail; there are valuable and well-written bibliographic notes in addition to the primary references. There is no subject index, but there is an index of persons. Proofreading appears to have been done rather casually. Appended to the volume is a very readable map of the moon, produced in Prague.

The four parts of the book each have six chapters. Part 1 deals with the motion of the moon and the dynamics of the Earth-moon system; part 2 treats the internal constitution; part 3 covers topography and lunar surface features and part 4 considers lunar radiation and detailed surface structure.

Chapter 1 introduces accurate methods of determining the mass of the moon. Often overlooked is that the center of mass of the Earth-moon system moves in an elliptic orbit around the Sun, not around Earth itself. Earth wobbles about this center of mass with a period of one month, and it is the geocentric amplitude of this "lunar inequality" that makes the moon-Earth mass ratio 1/81.3. This value is well confirmed by direct measurements of the perturbations of the Mariner and Ranger space probes. It is well to note the uniqueness of the moon in the solar system. Although there are other satellites, for example Io or Titan, which have about lunar mass or more, the moon has by far the highest mass with respect to its parent planet; it is no ordinary satellite.

The motion of the moon in space is only lightly covered in this volume. First, there are extensive treatises on the subject elsewhere and, second, the motion of the moon in space is virtually independent of any physical properties of the moon itself. To quote: "On account of the smallness of its mass, the moon has virtually no say about its motion through space, being com-



SEA OF TRANQUILITY. The Cauchy crater lies between the Cauchy scarp, lower linear feature, and the Cauchy rille, upper linear feature. This oblique photograph looks generally northwest from the Apollo 8 spacecraft.

pletely at the mercy of outside forces which it cannot influence; and it has to suffer the ignominy of being treated as a nondescript mass particle without any individuality of its own." This sort of language is typical of Kopal's book. Some readers may not like it; I do.

The rotation of the moon, the famous laws of Cassini and the three types of optical librations are well explained. The optical libration in longitude arises from the eccentric orbit of the moon. The optical libration in latitude arises because the axis of rotation is not perpendicular to the orbital plane. The diurnal libration appears because we are observing the moon from the surface of Earth rather than from the center. Thus the optical librations should really be called geometric librations.

The physical librations of the moon are something else again. They are small, minutes of arc, though the optical librations are typically degrees of arc. Discovery of the physical librations came long after their prediction; observations of any value were per-

formed only during the past 100 years. The free oscillations would have a period of about 150 years; forced librations have a period of 2 yrs. 10 mos. Forced librations are still very poorly measured and the information they give us about the fractional differences of the moon's three moments of inertia is not very precise: typically, the accuracy is one part in a hundred.

The chapter on lunar phases and eclipses is characteristic of much of the book, with careful, clear discussion and a great deal of historical background. There is a delightful section on the role of lunar eclipses in history.

The chapter on the dynamics of the Earth-moon system is weak. The formalism of the restricted three-body problem with an elliptical rather than a circular orbit is developed, and it is shown that the Jacobi integral does not, strictly speaking, exist. The zero-velocity surfaces will surely pulsate with a period of one year, but the consequences of this effect on the orbit of the moon are not developed.

In the discussion of particles ejected

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from the moon there are two errors. If the particle does not hit Earth but escapes from the Earth-moon system, then it will still be recaptured by the Earth-moon system — after many years. The statement is made, on page 57, that a particle ejected from the lunar surface with velocity between 1.68 and 2 km/sec will orbit the moon; the particle will, of course, describe only a portion of an elliptic trajectory and immediately hit the lunar surface.

The evolution of the lunar orbit through tidal effects is discussed uncritically. Kopal favors a capture origin of the moon, but for what I believe are the wrong reasons. The calculations of Gerstenkorn are accepted in spite of MacDonald's criticisms: Gerstenkorn's theory would have the moon captured from an initial retrograde orbit but, in the process, the energy dissipated in the interior of Earth would be sufficient to vaporize it. MacDonald's proposition, that the moon formed in the vicinity of Earth, is not even mentioned; nor is Opik's earlier work on a similar theory of origin. Another instance of uncritical acceptance is the possible breakup of the moon as it moves inside the Roche limit during capture. Kopal asks: "How gruesome would be this experience." He accepts Alfvén's proposition that the fragments produced in the breakup would fall down onto Earth. Actually they should continue along roughly the same orbit as the moon and coalesce when outside the influence of Earth's tidal force. In this way the moon, unlike Humpty Dumpty, could put itself back together again.

The discussion of the moon's interior is approached with the assumption of hydrostatic equilibrium and homogeneity. It now becomes possible to calculate the moments of inertia either on the assumption of rotation or of a tide-generating potential, or both; Kopal shows that the second assumption yields a three-times-greater result. However, the calculated moments of inertia do not agree with the observed values; the fractional differences are ten or more times larger than the calculated values. The disagreement hints at a departure from hydrostatic equilibrium or possibly from homogeneity, but this approach is not followed further. The moon's mass is beyond the critical limit under which, after a sufficient length of time, even a "solid" body (which may be nonspherical to begin with) can establish hydrostatic equilibrium. Calculations of the lunar

surface form show that the departure from sphericity caused by rotation would amount to only 16 meters between equatorial and polar semi-axes; the tides would correspond to a difference of 47 meters between two equatorial semi-axes. The observations are not good enough to establish these deformations.

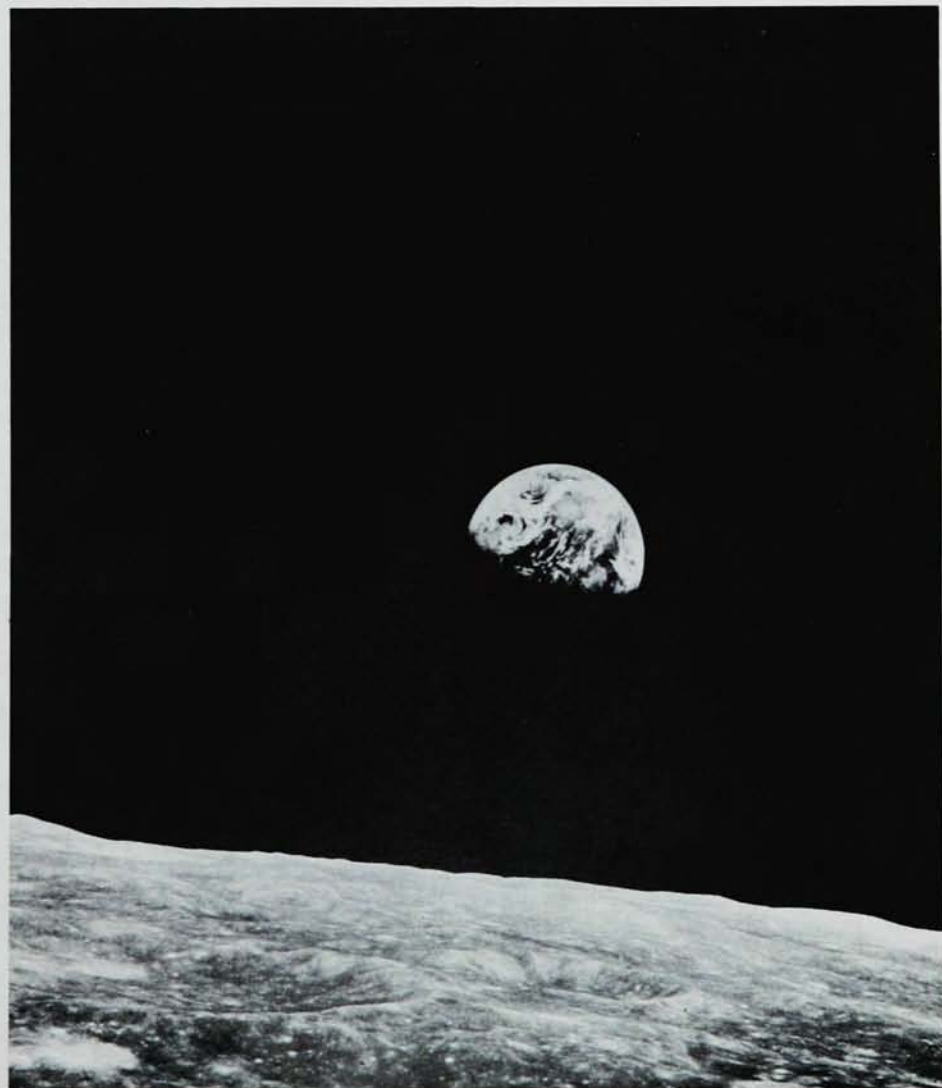
The thermal history of the moon is discussed in a classical manner, assuming only radioactive heating as well as the physical processes of conduction and radiation in the interior of the moon. The moon is assumed to be rigid, that is, nonconvective. External heating from the sun contributes very little. The reader should be warned that our knowledge of the radioactivity of the moon is insufficient to even establish whether or not it should have melted during its history. Furthermore if the moon has ever been close to Earth, and certainly if it has been captured, then tidal friction would have produced a much more rapid heating than radioactivity and would have assured some melting in the moon's interior.

The stress history of the moon is again discussed in a very complete and classical manner. Stresses are ascribed entirely to expansion caused by internal heating. Also considered are the problems of compression of the moon by self-gravitation and the thermal expansion of the moon from illumination by the sun. The author discusses the free oscillations of the moon that might be caused by internal moonquakes or external impacts by a meteorite. Typical periods are of the order of a few minutes, about three times shorter than for Earth.

The possible convection in the lunar interior is an important but vexing problem. The local temperature gradient must be superadiabatic, and the time scale must be long in comparison with the Maxwellian relaxation time (given by the product of the viscosity and isothermal-compression coefficients). This time is of the order of 10^3 years if we assume the same viscosity for the moon as for the crust of the Earth, 10^{22} gms/cm sec.

The last two chapters in this part are rather sketchy. The chemical com-

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position of the moon is dealt with in a very cursory way, and the atmosphere of the moon, or rather, its exosphere, is discussed much too briefly. The problem is quite complicated but of real importance as it bears on whether or not the moon could ever have had an atmosphere or hydrosphere. Kopal categorically denies that any visible features of the moon could ever have been modified by running water, or by freezing or melting water. Unfortunately the evidence from the Orbiter pictures suggests the opposite. (From theory I would conclude that it is indeed possible for the moon to have had an atmosphere and hydrosphere for a short period of time. The problem would have been to create an atmosphere and hydrosphere rapidly enough to preclude equally rapid escape. This problem is still under detailed investigation.) The next chapters deal with the lunar surface. On the basis of quite difficult observations, Kopal concludes that the lunar globe is deformed by about 2 to 3 km, but not along the line of a principal moment of inertia. This forces the conclusion that the moon is not homogeneous; yet the position of the principal axes is unaffected! Next there is a description of mapping, a descriptive survey of lunar surface features and a discussion of the origin of the lunar surface features. Kopal points out that the evidence favors both external impacts and internal processes.

The fourth and concluding portion of the volume is devoted to radiations from the lunar surface and, therefore, necessarily to the microstructure of the surface. The photometry of the moon is discussed first. It becomes clear that the photometric properties are determined by the shadow phenomena produced by surface irregularities, and that the microrelief is more important than the exact form of the diffuse-reflection law. Thermal emission from the lunar surface is discussed in a classical manner. The surface of the moon cannot be solid rock but must be covered by loosely-packed dust, in order to give the correct value of the parameter. $(\text{Heat conductivity} \times \text{density} \times \text{heat capacity})^{1/2}$. At what point below the surface of the moon does the temperature become constant during the course of a lunation (one month)? The answer turns out to be about 30 cms and the temperature is 240 ± 6 K. In the text, it is claimed that the results from numerical integrations of equation 20.9 and 20.10 are shown, however, I was un-

able to discover the corresponding figure.

The origin of the maria is still beset by uncertainties. Kopal takes a strong stand against the dust reservoir explanation; he also presents arguments against an origin by impacts of large planetesimals and suggests that the maria may be the scars of a disruption that occurred when the moon came within the Roche limit of Earth during the capture phase. On the other hand Kopal denies that the moon might have melted at some time between its formation and the present. His contention might be true if only radioactive heating were the cause; however, if the moon is captured, then certainly the frictional heating of the tidal forces

will be sufficient to induce melting.

Perhaps this inconsistency will be removed in a forthcoming new edition; perhaps new observations will suggest a different solution. Keeping up with an explosively expanding subject certainly presents a problem; nevertheless this book contains so much basic subject matter that will stand the test of time that the volume can be strongly recommended to beginning graduate students as well as to the active researcher.

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The reviewer has recently been concerned with the dynamics and evolution of the Earth-moon system. He is the Deputy Assistant Secretary for Scientific Programs with the Department of the Interior.

Statistics kept simple

EQUILIBRIUM STATISTICAL MECHANICS. By E. Atlee Jackson. 241 pp. Prentice-Hall, Englewood Cliffs, N. J., 1968 \$7.75

by GARRISON SPOSITO

This book offers a concise and simple introduction to statistical physics; the book's eminently teachable structure reflects the fact that the author has based it upon his course at the University of Illinois. There are four chapters; three, of modest length, are on probability, the concept of energy and the foundations of statistical mechanics, and the fourth is a lengthy chapter on applications. The first three chapters are embellished by a summary page entitled "Essential Points" and all four feature their important equations in boxes. The language is at all times simple, both mathematically and physically, and presumes only an acquaintance with integral calculus, elementary mechanics and thermodynamics.

The chapter on probability is worth more than a passing comment, as it very successfully conveys its subject in a context of set theory without being mathematically pedantic and, therefore, pedagogically unpleasant. The last section of this chapter is especially successful in creating Boltzmann's H out of a most plausible argument founded in applied information theory.

The discussion, in the third chapter, of the foundations of statistical mechanics does not fare so well as its predecessors. The problem is largely one of clarity and logical precision. For example the idea that one does not

prescribe the classical state variables, position and velocity, any more definitely than to restrict them to infinitesimal ranges is stressed. Yet, the "Basic Assumption of Statistical Mechanics" resides gloriously and unverifiably in its box throne in the form, "All microstates of a system that have the same energy are assumed to be equally probable" — as if one could know the energy precisely even though the state variables upon which it depends are known but imprecisely. Again, in the discussion of the canonical ensemble, one is told that the probability distribution function cannot be simply proportional to the energy because the normalization integral would then cease to exist. The immediate reply that the astute student will fire back is that the infinity catastrophe is obliterated if one does not impose the rather unphysical infinite upper and lower limits upon the velocity integral. Because of this difficulty and the antediluvian manner of presenting the canonical distribution (equivalent to Gibbs's original method but without its straightforward character), the whole discussion of the canonical ensemble comes off rather weakly.

Equilibrium Statistical Mechanics is suggested by its author as a textbook for upper-level undergraduates. This it can be, although one might suggest it as well for an alternative to F. Reif's *Statistical Physics* in the lower-division sequence of introductory physics courses. If it were to be used in a curriculum at the level of the Berkeley