the specialized topics into which he chooses to go. Although it is not a comprehensive treatise, it is very suitable as one of the main references for a graduate course on cosmology. Indeed, the publisher suggests that it can be used "as a guide to current points of debate in a rapidly changing field." I agree with that.

We are fortunate that two active cosmologists of the stature of Peebles and Sciama have put their thoughts down at this time. The books they have created are, each in its own way, very useful. Fortunately for everyone concerned, they complement each other nicely.

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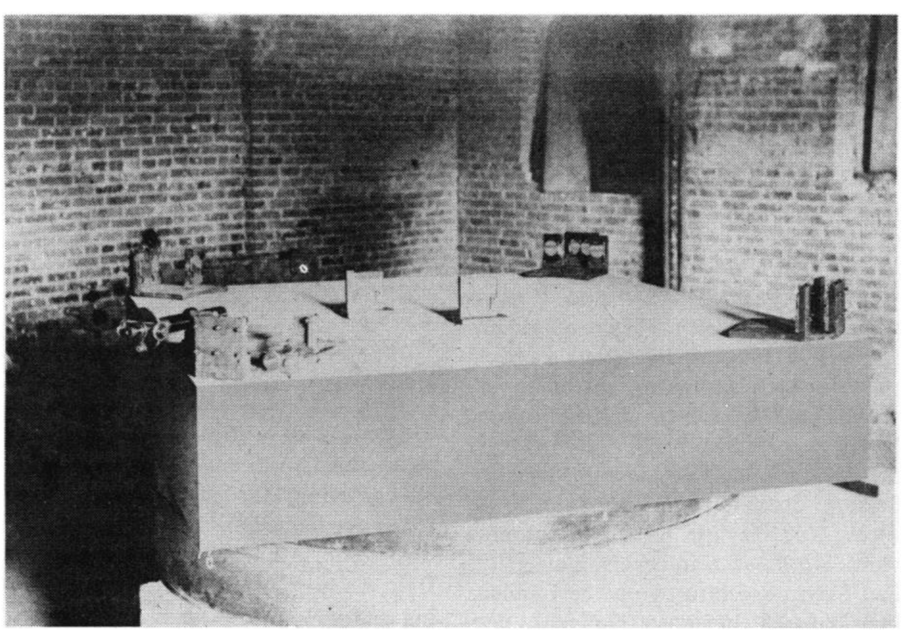
Experiments Touching on Relativity

The Ethereal Aether. A History of the Michelson-Morley-Miller Aether-Drift Experiments, 1880–1930. LOYD S. SWENSON, JR. University of Texas Press, Austin, 1972. xxii, 362 pp. + plates. $10.

Today the long involvement of scientists with the ether problem may seem strange, especially to younger scientists, but Swenson's detailed account of the quest that began with Arago and Fresnel in the early 19th century and only subsided at last when Joos was able to bring to bear on the problem the full technical expertise of the Zeiss Company at Jena is still of considerable interest. Swenson's book is the culmination of ten year's study and research, beginning with his Ph.D. thesis. He has been indefatigable in his search for historical facts and letters and papers, both published and unpublished, bearing on the century-long search for the ether, and he has written with remarkable objectivity. The book deals in greatest detail with the interferometer experiments of Michelson and Morley and Miller, which held the chief interest for both experimental and theoretical developments throughout the greatest part of the period. Other significant experiments by Maxwell and by Lord Rayleigh, the Trouton-Noble experiment suggested by Fitzgerald, Zeeman's work urged by Lorentz, and the results of Ives and Stilwell, of Essen, and of Townes are all discussed, but they are not Swenson's central concern. Neither are the astronomical tests of general relativity of prime interest, although Einstein himself always considered the Michelson-Morley experiment important for his progress from the special theory to the general theory of relativity and gravitation (*1*).



The Michelson-Morley interferometer used for ether-drift experiments in 1886–1887. The only known photograph of the apparatus, this picture was discovered in Michelson's laboratory notebook in the archives of the Mount Wilson Observatory by D. T. McAllister, curator of the Michelson Museum, Naval Weapons Center, China Lake, California. [Reproduced in *The Ethereal Aether*, courtesy of the Hale Observatories]

It is scarcely surprising that the many theoretical developments that continued throughout the century (1830–1930) are not treated in this book. It would have been valuable, however, to have some details of this continuous evolution, starting with Fresnel's contributions and continuing with those of Maxwell, Fitzgerald, Lorentz, Poincaré, Larmor, and Einstein, because of the stimulation and constraint which the century-long succession of experiments exerted on advances in theory; certainly for most of these theories the ether-drift experiment had a special significance.

Perhaps the most outstanding aspect of the history of the theories of relativity was the amazing public interest aroused in 1919 when Eddington's solar eclipse expeditions in West Africa and Brazil confirmed the prediction of the deflection of starlight passing the edge of the sun as given by the general theory of relativity. Prior to that time interest in the theories of relativity had been steadily growing among professional physicists and astronomers but the theories were practically unknown to the general public. Coming soon after the end of World War I, Eddington's spectacular achievement had a tremendous impact on both scientists and the public which to this day is a matter of amazement, considering the small connection between the general theory and everyday life. In 1919 this reviewer heard a lecture on relativity in his parents' living room attended by a group of adults who certainly could not have understood the details of the theory yet who, in common with innumerable similar groups throughout the world, were fascinated by the new concepts of space and time that had entered scientific thought. Popular excitement was probably greatest in Germany, where an educated public had for many years been nurtured on the philosophy of Immanuel Kant with its emphasis on absolute space and time, which in fact carried these concepts much further than had ever been the intent of Newton.

One important reaction to this great uproar touched the Michelson-Morley experiment, which had been performed in Cleveland in 1886–1887 and refined and extended there in 1902–1904 by Morley and Miller. By 1919 Morley had retired and Michelson, by then at the University of Chicago, had long been concerned with spectroscopy and the ruling of optical diffraction gratings, rather than with his results of 1887, for which he always showed less than marked enthusiasm. Upon the urging and encouragement of many leading physicists and astronomers, "who were reluctant to allow the aether concept to die," especially Morley, and George Ellery Hale, director of the Mount Wilson Observatory, Dayton C. Miller of the Case School of Applied Science (later Case Institute of Technology) undertook to repeat these experiments, which in fact, contrary to the textbooks, had never yielded definitively null results. Miller's primary interest was to repeat the experiment at intervals throughout a year, as originally planned (but never completed) by Michelson and Morley, and also to conduct the trials on a mountain top, where presumably the "ether" would be less "entrained" than in the laboratory rooms with heavy walls where the original trials had been made. To carry out these objectives, Miller rebuilt the Morley-Miller interferometer used in 1902–1904, improved its optics, and had it transported to the Mount Wilson Observatory, where from 1921 to 1926 he carried out extensive trials of the experiment. From the first he found small periodic shifts in the fringe positions as the interferometer rotated. These shifts were both a puzzle and an annoyance to much of the scientific world. In spite of great effort in the analysis of his data, Miller had not found a solution to his results that was generally acceptable at the time of his death in 1941. Had Miller's small positive effect been consistent with the azimuth orientations of his interferometer with respect to the north-south line at Mount Wilson, they would undoubtedly have been taken more seriously. Miller himself always emphasized the discrepancy in azimuth but, unlike certain physicists who repeated the experiment at this time, he was not content to announce a result in agreement with the requirements of relativity theory, even though his fringe displacements were less than 10 percent of those predicted by the ether theory.

This reviewer inherited Miller's extensive data and also his suggestion that I might care to do something to clarify the situation if it was felt desirable. For many years this was not possible; but finally, after serious inquiries about Miller's work had been received from a number of distinguished physicists, four of us at Case decided to reanalyze his data (*2*). This new study showed that Miller's small periodic fringe displacements could not be dismissed as being due to statistical fluctuations in very difficult observations. Unsupported statements that they might be so had annoyed Miller considerably, and those who knew him well were completely confident that as an experimenter he was one of the most skillful and was also highly conscientious in reporting his findings.

Having ruled out statistical fluctuations as the explanation of Miller's results, we then examined the question of magnetostriction in the steel base of the interferometer. This effect, though present, was too small to account for the observations. Next, a detailed analysis was made of possible strains and vibrations that might produce the observed effects, but these also were shown to be negligible owing to the structural properties of the interferometer. Finally, our attention was turned to the temperature conditions existing in Miller's lightweight interferometer house on Mount Wilson. Miller was fully aware that temperature variations and temperature gradients across the interferometer would cause shifts in the fringes like those predicted for an ether drift. However, he had made extensive preliminary tests in the physics building at Case to shield his interferometer from thermal effects, and in the last of these trials he had obtained almost perfect null results (*2*). He was confident that by shielding the interferometer with heavy glass and cork he had reduced the temperature effects to a negligible level. This he almost accomplished. But it gradually became clear to us that under the more severe temperature conditions existing at Mount Wilson the shielding that had proved effective in the Case laboratory was not entirely adequate. Our study showed that Miller's results were closely correlated with the temperature gradients existing across his interferometer. (With his thoroughness in experimental detail Miller had recorded the temperatures with a group of thermometers throughout the course of his observations.) The progress of our analysis was discussed several times with Einstein in Princeton (*1*), who showed genuine interest and emphasized that no uncertainty should be allowed to exist in any experiment touching relativity theory. It is unlikely that the considerable effort that went into the reanalysis would have been made except for his interest and encouragement.

The most relevant experimental phenomena in electronics and nuclear physics that today require special relativity for their analysis were not known to the generation of Michelson, Morley, and Miller, and present-day physicists may be puzzled at the great interest the experiments of these men maintained for so long a period. But the central purpose of Swenson's book is to explain their work against the background of their own times, and it is an account that should be of interest to all those concerned with the history and development of physics. Physicists who remember the excitement (and passion!) of the years when this work was in progress will have great interest in Swenson's book, and younger physicists should find it instructive to see how long and complex are the routes that have led us to our present position.

The original papers of Michelson (1881) and of Michelson and Morley (1886; 1887) are reprinted as appendices, and a photograph (reproduced here) of the original apparatus used in Cleveland in 1886–1887 is printed in the book for the first time.

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Planes, Solids, and Nolids

Color and Symmetry. ARTHUR L. LOEB. Wiley-Interscience, New York, 1971. xvi, 180 pp. + plates. $14.95. Wiley Monographs in Crystallography.

Shapes, Space, and Symmetry. ALAN HOLDEN. Photographs by Doug Kendall. Columbia University Press, New York, 1971. viii, 200 pp. $11.

Polyhedron Models. MAGNUS J. WENNINGER. Cambridge University Press, New York, 1971. xii, 208 pp., illus. $14.50.

These three books deal with various aspects of symmetry, in descending order of abstraction:

Color and Symmetry, by A. L. Loeb, presents a beautiful mathematical development of the symmetries possible in a plane. The symmetry operations