

Color vision: history and state of the art

Colour Vision in the Nineteenth Century: The Young-Helmholtz-Maxwell Theory

P. Sherman

233 pp. Hilger, Bristol (US dist. Heyden, Philadelphia), 1981. \$77.00

Color Measurement: Theme and Variations

D. L. MacAdam

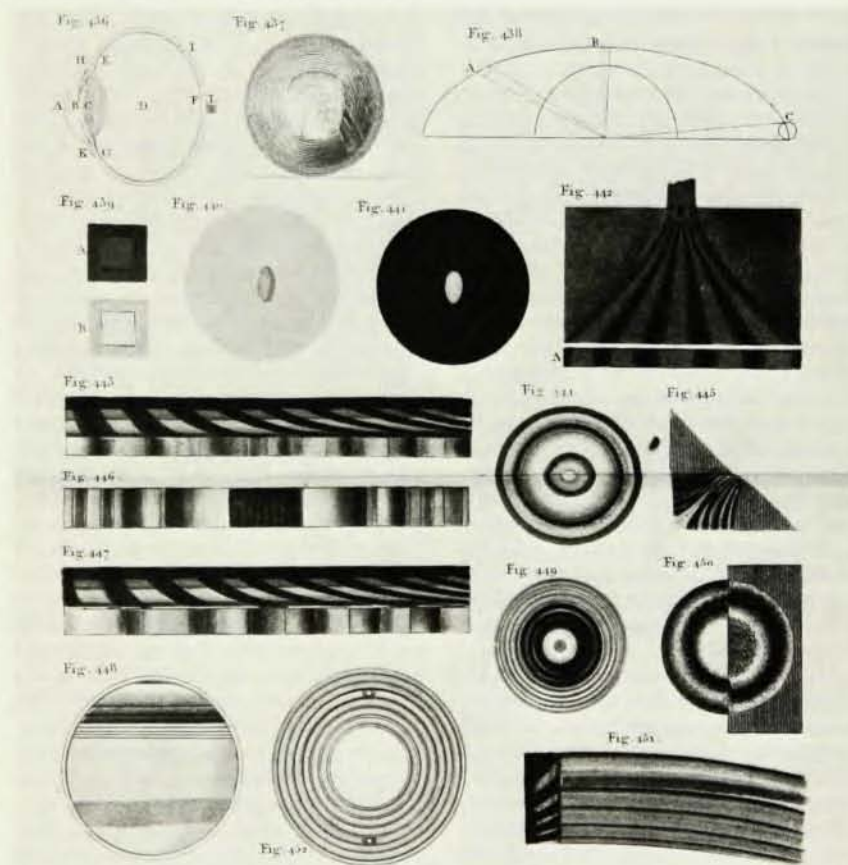
228 pp. Springer, New York, 1981. \$39.50

Reviewed by David G. Stork

In the same 1801 lecture in which he proposed his wave theory of light, Thomas Young put forth the trichromatic theory of color vision—that a color sensation is determined by the relative stimulations within three wavebands (red, yellow and blue). The development and elaboration of this hypothesis is the subject of Paul Sherman's book, a fascinating account and analysis of the brilliant insights and technical innovations as well as the honest mistakes, personal rivalries, misleading experimental results, false analogies, deliberate misrepresentations, and what we can confidently call in retrospect pseudoscience, that surrounded the nascent field of color science.

Like any good theory, Young's raised more questions than it answered: Was the magic number 3 determined by light itself, or was it, so to speak, in the eye of the beholder? Confusion and faulty measurements led David Brewster to state that *all* light, even monochromatic light, was an admixture of three types of fundamental rays, a conclusion that led him to other erroneous "discoveries," such as "spectra white." By carefully performing experiments and taking into consideration physiological effects such as afterimages, Hermann von Helmholtz demolished Brewster's conclusions and thus removed a formidable conceptual obstacle to the development of color theory.

Further, why *three* wavebands? Hermann Grassman resolved this issue with an elegant and unexpected argu-



Images illustrating phenomena of color vision that originally appeared as a color plate in Thomas Young's *A Course of Lectures on Natural Philosophy and the Mechanical Arts*, published in 1845. Images include the eye (436), retina (437), and a rainbow (451).

ment involving degrees of freedom. Moreover, he applied his techniques of vector analysis to color mixing, correctly predicting the existence of spectral complementaries, and laid the foundations of a quantitative theory that was later to be advanced significantly by James Maxwell. What about a mechanism? Young posited three types of "sympathetic fibres of the retina" with different frequency sensitivities, a hypothesis that attained physiological verification some 150 years later.

Any theory of color must account for

cases in which color vision runs amok. Although phrenologists were convinced that color deficiency resulted from a problem with an "organ of colour" in the brain, certain deficiencies fit well into the trichromatic scheme: One needed to assume only that the deficient person lacked one type of "fibre" and hence could not detect light within one of the three wavebands.

Of fundamental importance was the physical nature of color mixing. The difference between additive color mix-

ture (addition of lights) and subtractive mixture (due to absorption, as in filters) was not immediately recognized. It caused confusion until Helmholtz showed that neither technique of mixing could give supporting evidence to the other.

Sherman portrays Maxwell as the overriding genius who unified the field: He clearly understood the difference between the two types of color mixing (and concentrated on the simpler, additive case). He developed his light box and spinning disk of colored papers and used them to determine quantitative laws of color mixture. Further, he employed these devices to test color deficiencies, and he showed that they needed but two colors to match any other color. Finally he employed his basic results to demonstrate the feasibility of color photography.

Sherman is at his best when he reads between the lines of primary reference material (of which he includes an extensive list). He focuses on crucial experiments and concepts and paints a convincing picture of the motivations of the scientists involved. One shortcoming, though, is that he does not treat the other major scientific theory of color of the time, Hering's opponent-colors theory. Most modern theories of color vision reconcile and incorporate both the basic theories, and we can only regret that Sherman didn't extend his treatment to include Hering's idea. Nonetheless, in *Colour Vision* historians of science, the color community, and lay readers will find deep insights into the process of science and the history of color theory, especially those concerning an often unrecognized but vitally important aspect of the work of Maxwell.

Maxwell's pioneering work laid the foundations of modern colorimetry, the science of color measurement. The distinguished colorimetrist David MacAdam describes the current state of affairs in *Color Measurement: Theme and Variations*, a collection of fundamentals and selected topics confined to the physical aspects of color. (There is little or no discussion of color deficiency, color contrast or theories of color vision, for example.) The book's "theme" (Chapter 1-3 and parts of 4 and 5), consisting of a revision and abridgment of the *Handbook of Colorimetry* (1936), treats basic concepts such as lightness, purity, chromaticity coordinates, spectral reflectance curves and complementary colors; techniques such as color matching, spectrophotometry and spectroradiometry; and physical laws such as those of Planck, Beer and Bouguer. The lucid discussion of the CIE chromaticity diagram here is particularly helpful, since the powerful tool is used extensively throughout the rest of the book—the

"variations."

MacAdam goes on to describe color properties of light, such as color temperature and the color rendering index, including the conventions for determining the color temperature of an arbitrary (for example, nonthermal) spectrum. He clearly differentiates between additive mixture and absorptive or subtractive mixture and shows how the chromaticity diagram can be used to predict precisely the result of an additive mixture based on the appearance of the component lights while it cannot be used to predict absorptive mixtures—spectral transmittance curves of the component colors are needed for that.

He deals more thoroughly with topics of his own research interests. This is a mixed blessing. In explaining the determination of a tristimulus value (which involves the sum over wavelength of the product of a source intensity and a particular response function), he lists table after numerical table appropriate for different illuminants and statistical assumptions. Most of this is reference material and can be skipped on first reading. Similarly, his discussion of nonlinear transformations of the chromaticity diagram is somewhat specialized. The familiar three-dimensional color systems of Friedrich Ostwald and A. H. Munsell receive only cursory treatment (a color plate would have helped the uninitiated), whereas MacAdam does a great service in explaining the recent Optical Society uniform-color scale, which he helped devise. This scale is simple, at least in theory: The three-dimensional Euclidean separation between colors corresponds to their judged similarity or difference. All four of the book's color plates are devoted to illustrating this scale, which should find wider use as a result of the treatment here.

Color Measurement contains modern terms, conventions and data useful to physicists and physical chemists concerned with color measurement, photography and lighting. Educators teaching popular courses on light and color will find both books excellent background reading.

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Electromagnetic Fields and Relativistic Particles

E. J. Konopinski

629 pp. McGraw-Hill, New York, 1981.
\$29.95

For many decades, classical electromagnetism has been a part of every

physics student's curriculum in graduate school. The main features of the subject are well established; textbooks differ mainly in organization, details and the selection of applied topics. Emil Konopinski, a physicist at Indiana University, has written a book with a distinctive approach to this subject.

The main body of the text is organized in the standard way. A review of Maxwell's equations and their physical significance is followed by three chapters on static fields and a fifth chapter on the motion of nonrelativistic particles in static fields. Often a simplified argument is followed by a more complete one, with some topics being discussed more than once. For example, when Konopinski calculates the energy required to bring together two static-current loops, he first omits Faraday induction, but then introduces it to show how the additional work done in maintaining the current changes the sign of the interaction energy. A student will probably remember this point and be helped.

The novel feature of the book is that a quarter of it appears in seven supplementary chapters. Included are background mathematics (vector calculus and cylindrical harmonics), as well as everything on polarizable, permeable and finite-conductivity matter. The advantage of the arrangement is that the main text maintains the simplicity that holds when the discussion is restricted to discrete point charges and continuous charge-current distributions creating and responding to electromagnetic fields. This is probably a help to students learning field theory for the first time. (Think of the murky status of the stress-energy tensor in matter.) On the other hand, readers may be tempted to shortchange essential parts of the subject, and some topics that belong together (such as wave guides and attenuation in wave guides) are separated.

The remaining chapters describe time-dependent electromagnetism. In Chapter 6 there is a discussion of potentials and the storage and transport of energy, momentum and angular momentum. This is followed by chapters on plane waves, vector spherical waves and on radiation. The last four chapters treat special relativity, the covariant formulation, the Lagrangian formulation and radiation reaction.

Several topics are notable because they are present: the classical Zeeman effect, for example. Others are notable in their absence: There is no collection in one place of useful vector identities, integral theorems, and operators in curvilinear coordinates. The omission of Čerenkov radiation is unfortunate, especially because students building Čerenkov detectors may find the topic