require a dark sky, but *do* call for a large telescope. Many of these problems have to do with high-resolution stellar spectroscopy, a field that is capable of producing results of fundamental importance. Some recent examples carried out with 100-inch-class telescopes are Doppler imaging of the surfaces of stars,[3] the obtaining of a new constraint on the temperature of the microwave background,[4] detection of cosmologically significant constituents of the interstellar medium,[5] studies of the origin and galactic distribution of the chemical elements,[6] and a search for planetary-sized companions of nearby stars.[7]

Potential future uses of the 100-inch telescope are equally exciting. A program to study systematically the faint stars of our galaxy's halo is already underway. The 100-inch is also an ideal telescope for the emerging field of stellar seismology; studies of oscillations on late-type stars promise to turn the study of stellar interiors into an observational science, and may offer an answer to the nagging solar-neutrino enigma. The recent introduction of ultrasensitive charge-coupled devices has made it possible to contemplate research projects of these kinds on stars that were previously considered hopelessly faint, even for the 100-inch telescope.

The 100-inch is indeed elderly. But Mt. Wilson's telescopes were built well and do not require excessive maintenance. Indeed, dismantling this rugged instrument would be a major undertaking. Any needed modernizations would surely be much less expensive than the construction of a new 100-inch telescope and its associated building, dome, and instrumentation.

If the Carnegie Institution finds itself unable to keep Mt. Wilson open, it would be a shame if other interested parties did not come forward to take over the observatory's operation. What made Mt. Wilson a successful observatory in the past, and what keeps others successful today, was not a dark sky or a state-of-the art telescope, but a staff that depended on, and had a commitment to, operating those telescopes in order to conduct astrophysical research.

Will the 100-inch be the first large telescope to be closed? Will the coming generation of ultra-large telescopes lead to the closure of more and more of the smaller but still scientifically productive instruments? Or does the Hooker telescope have yet more glorious years ahead of it? We suggest that astronomy is neither so rich that it can afford to close Mt. Wilson, nor so poor that it is compelled to do so.

References

1. Nature **310**, 88 (1984); Science News **126**, 5 (1984); PHYSICS TODAY, December 1984, p. 63.
2. K. Horne, H. H. Lanning, R. H. Gomer, Astrophys. J. **252**, 681 (1982).
3. S. S. Vogt, G. D. Penrod, Pub. Astr. Soc. Pacific **95**, 565 (1982).
4. D. M. Meyer, M. Jura, Astrophys. J. (Lett.) **276**, L1 (1984).
5. R. Ferlet, E. S. O. Messenger, No. 30, p. 9 (1983); L. M. Hobbs, Astrophys. J. **286**, 252 (1984).
6. R. E. Luck, H. E. Bond, Astrophys. J. **241**, 218 (1980), Astrophys. J. **244**, 919 (1981), and Astrophys. J. **259**, 792 (1982).
7. G. W. Marcy, private communication (1984).

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9/84

Newton's theory of color

Alan Shapiro's article, "Experiment and mathematics in Newton's theory of color" (September, page 34), was a welcome novelty in PHYSICS TODAY. May a colorimetrist add three comments?

▶ A book published[1] in 1665 records that Francesco Grimaldi recombined with a lens the colors of the Sun's spectrum separated by a prism, and observed that the result was white. Grimaldi concluded that white light is a composite of the colors of the spectrum, that the prism merely separates the colors, and that white light is always composed of them.

Thus, before Newton made the same experiment and observation (in 1666), Grimaldi had discovered and reported the composite nature of white light. Grimaldi's book, published two years after his death and six years prior to Newton's *New Theory*, proposed a wave theory of light: to each color he attributed[2] a specific "undulatio."

In the first sentence of the third book of *Opticks*, Newton mentioned Grimaldi's discovery of diffraction and of the colored fringes that occur around shadows cast by sunlight admitted through a small hole into a darkened room. But Newton did not mention Grimaldi's recombination of the colors to white, or the wave theory that Grimaldi proposed to account for the behavior of the fringes and their colors.

▶ For the past two centuries, students of color vision have wondered whether Newton (or his assistant, who marked the boundaries of the seven colors on the diagrams reproduced on pages 38 and 39 of Shapiro's article) had some strange anomaly of vision that caused him to see such a distinctly different color in the spectrum between violet

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and blue as to justify the separate designation "indigo." If blue is taken, as is usual today—and has been for about 200 years—to appear neither reddish (as does violet) nor greenish, then there is no color between violet and blue that merits a separate name.

Study of Newton's uses of the names "indigo" and "blue" leads me to suggest that by "indigo" Newton meant what we now call "blue," and that by "blue" he referred to the short-wave greenish blues for which workers in color photography and color printing have adopted the name "cyan."[3] If Newton's use of the name "blue" had been retained throughout the subsequent three centuries, we would not have had the long-continued discussion as to whether green paint can or can not be made by mixing yellow and blue pigments. As Newton, his predecessors and many of his successors during the 18th century seem to have used "blue"—to refer to greenish-appearing short-wave hues—that recipe is correct. If the name "blue" had continued to be used in that sense, then the name "indigo" most likely would have continued to be used in Newton's sense—to refer to the hues of short wavelengths that appear neither reddish nor greenish. Thus the phosphor used in color television would be called "indigo," and not "blue."

The 19th-century shift of the meaning of "blue," from Newton's greenish-blue to the colors of green-free short waves, left unnamed a spectral band (about 475–495 nm) that is of key importance in color photography and all of the graphic arts, including painting. That lacuna had to be filled, and was filled by the term "cyan." The extremely difficult and, as yet, mostly futile task of re-educating artists, teachers, and students—to get them to say that "yellow and *cyan* paints make green"—would not have been necessary if Newton's original meaning for the word "blue" had been retained. In that case, his use of the word "indigo"—for blues that do not appear greenish—would constitute no mystery.

▶ Judge as we may Newton's success (or failure) to treat dispersion mathematically, his application of mathematics to Problem II, Proposition VI, in Part II of Book I of *Opticks* was entirely successful. It is the foundation for the technology of color measurement. Problem II, "In a Mixture of Primary Colours, the Quantity and Quality of each being given, to know the colour of the compound," is completely solved by Newton's representation of the colors of the visible spectrum, and of the (additive) compound (mixture) of its red and violet extremities by a closed boundary, and by his identification of the color of every "compound" with the center of gravity of the components that lie on that boundary. Newton's center-of-gravity principle is the most powerful tool of the colorimetrist.[3,4] By use of it we learn that white-appearing light can be compounded of three fixed primaries, which can be selected from the spectrum in a triple infinity of ways. In Experiment 13 of Book I, Part II, Newton compounded white "by using only three prisms, as also by using only two." This proved that three primary colors were sufficient. It also showed that a wide variety of *pairs* of colors (complementaries) could be used to produce many physically different but visually identical white lights.

Newton's center-of-gravity principle, used with modern data, shows that complementary pairs range continuously from 380 nm combined with 567 nm to 492.4 nm combined with 700 nm. The first combination is typical of the pair that produced the white that Newton represented by the point P in figure 10, Book I, Part II. The combination of 492.4 nm with 700 nm is typical of the pair that produced the white light that Newton indicated by point T. In both cases, the first-listed component comes from the lower prism and the second from the upper prism. Points Q, R, S in Newton's figure 10 represent the physically different whites he produced by combination of such complementary pairs as 440 nm with 568 nm, 472 nm with 574 nm, and 487 with 593 nm, respectively (see table 4.1 of reference 4).

Modification of Newton's color circle (figure 11 of Book I, Part II) to the familiar spectrum locus and its closure on the chromaticity diagram, and identification of Newton's "quantity," or "number of rays," to which the center-of-gravity principle applies,[3,4] had to await the development of spectroradiometry and color-matching techniques. But those are mere technological details. Newton's color circuit and his center-of-gravity principle alone brought about the complete fulfillment of his aim "to see y^e science of [colours] become mathematicall." Spectroscopy and dispersion theory are only incidental, whereas Newton's center-of-gravity principle is fundamental.

References

1. F. M. Grimaldi, *Physico-Mathesis de lumine coloribus et iride aliisque adnexis libi duo,* Typographia Heerdis Victorii Benattii, Bononia (1665). Reprinted by Forni, Bologna (1963) and by Dawson, London (1966). See especially pp. 269, 379, 404, 405. Facsimiles and translations of the relevant passages are available from the undersigned.
2. J. Marek, Atti della Fondazione Giorgio Ronchi **35**, 677 (1980); **36**, 559 (1981); D. L.

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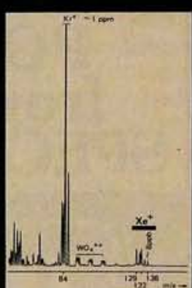

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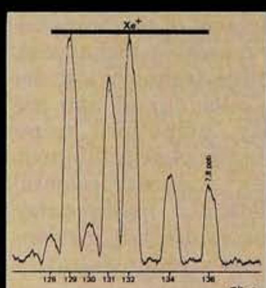

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MacAdam, Color Research and Application 8, 123 (1983).

3. D. L. MacAdam, J. Opt. Soc. Am. **65**, 483 (1975).
4. D. L. MacAdam, *Color Measurement: Theme and Variations*, Springer–Verlag, New York (1981).

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THE AUTHOR COMMENTS: Because only MacAdam's third comment directly relates to the theme of my article, I will confine myself to it. My concern was not in the first place with Newton's color theory, but rather with the historical development of his method and his first attempt to mathematize an entire area of physics. Because Newton attempted to mathematize the science of color by means of spectroscopy and dispersion theory, they were obviously fundamental for him and not at all incidental. The main point, however, is not what is essential or fundamental now, but Newton's bold and imaginative attempt to create a new branch of mathematical physics before the *Principia*, his willingness to recognize his lack of success, and his ability to recast his initial work into an experimental form.

I am aware of the significance of Newton's color circle and have described[1] it elsewhere. Newton, however, did not recognize its true significance as described by MacAdam. It was to take another 150 years before Hermann Grassmann recognized[2] that it could serve as the foundation of colorimetry. MacAdam's account of Newton's color circle is misleading, for it conflates what we today deduce from his color circle with what Newton deduced. To illustrate this I will consider his comments on Newton's Experiment 13. MacAdam states that this experiment proved that three primary colors were sufficient to compound white, and also that a wide variety of pairs of colors (complementaries) could also produce white. However, in Experiment 13 Newton himself says[3] that "rays of every sort," not just three sorts (or colors), were mixed to produce white. Moreover, in describing his color circle Newton explicitly denies[4] that there exists even a single pair of complementaries, let alone a wide variety: "I could never yet by mixing only two primary Colours produce a perfect white."

As late as 1852, Hermann von Helmholtz, with his vastly more sophisticated experimental apparatus, was able to discover[5] only one pair of complementaries. It was only after Grassmann finally recognized the true significance of Newton's color circle and pointed out to Helmholtz that it implied that there must be many complementaries, that Helmholtz succeeded in locating[6] a wide variety. By attributing such a complete understanding of his color circle and its experimental implications to Newton, MacAdam in effect eliminates 150 years of very exciting history. The difference of emphasis between MacAdam and me, of course, depends on our different principal interests, his being colorimetry and mine history.

References

1. A. E. Shapiro, Isis **71**, 211 (1980).
2. H. G. Grassmann, Ann. Phys. Chem., ser. 2, **89**, 69 (1853) [Philos. Mag. ser. 4, **7**, 254 (1854)].
3. I. Newton, *Opticks*, Dover, New York (1952) p. 149.
4. D. L. MacAdam, Color Research and Application **8**, 123 (1983) p. 156.
5. H. von Helmholtz, Ann. Phys. Chem., ser. 2, **87**, 45 (1852) [Philos. Mag. ser. 4, **4**, 519 (1852)].
6. H. von Helmholtz, Ann. Phys. Chem., ser. 2, **94**, 1 (1855).

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Word-processed manuscripts

When I was managing editor of the *Proceedings of the National Academy of Sciences*, I found that many of the manuscripts created by modern word-processing methods have serious defects. Fortunately, these defects are the result of lack of attention rather than flaws inherent in the methods. I am writing this letter to call attention to the problem areas in the hope of decreasing the disadvantages without affecting the advantages.

To set the stage, first I will state the important physical requirements of a manuscript, which derive from the things that happen to the manuscript in the course of its conversion from typescript to printed page. It must be on relatively sturdy paper, because it will be handled by 6 to 12 people. It must be easily readable at high speed, because several workers not familiar with the subject matter or the vocabularly, such as keyboarders and proofreaders, must process it. It must have generous margins and interline spaces, because editors need room for their instructions to the production personnel.

Paper quality is mainly a question of what the paper should not do. It should not wrinkle or tear easily. It should not be so shiny that glare makes reading difficult. It should not be so porous that ink spreads, or so heavily coated that finger pressure deletes editorial

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