Goethe's theory of color and scientific intuition*

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A summary of Johann Wolfgang von Goethe's color studies is presented with special attention paid to his "method." It is proposed that the act of accurate qualitative observation creates the capability in the observer for an intuitive understanding of the physical laws underlying the phenomena under observation. The use of such a method as a basis for laboratory instruction is discussed.

Lord Kelvin (1824–1907) gave the following as a description of that with which science is concerned[1]:

> I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of *Science*, whatever the matter may be.

Here we encounter explicitly a central presupposition which has lain at the base of scientific inquiry since Newton; in short, science is *quantitative*. It is usually held that by such quantification of information we can circumvent the subjective nature of human experience. Much concern has been expressed as to the validity of such a view and if valid what are its limitations and implications.[2–4] Little of a positive nature, however, has been done to investigate the question; how far can one go towards the formation of a science based on the exact *qualitative* experiences of man? It is precisely this "qualitative science" that we wish to explore as a complementary and perhaps necessary addition to the more orthodox "quantitative science" taught in high schools and universities today. In Goethe's *Theory of Color*[5] one has, I believe, the elements necessary to form a fruitful alternative to the purely quantitative nature of modern science. In the following pages we hope to set forth an approach fundamentally different from modern science in certain respects and yet true to its underlying aims.[6] This approach is one which stresses the reality of "intuitive" experiences of natural laws as complementary to the more formal mathematical formulation of such laws. Finally, we briefly point to certain pedagogical ramifications in the design of laboratory courses which such an approach might have.

INTRODUCTION

In 1810, Johann Wolfgang von Goethe (1749–1832) published what he considered his most important work, *Zur Farbenlehre* (*On the Theory of Color*). In large part due to his polemic against Newton and his then accepted theory of color (*Opticks*, 1704), Goethe's own theory "sounded like a shot in the mountains," that is to say he was essentially ignored then, as now, by most of the scientific community.[7] However, more recently a reconsideration of Goethe's contributions to science has been undertaken by such contemporary scientists as Walter Heitler[2] and Werner Heisenberg.[8] Unlike the above authors, our purpose is not to evaluate Goethe's *Farbenlehre*; rather, it is to render as clearly as possible Goethe's thought concerning the physical sciences as evidenced through his color studies. By becoming aware not only of the explanations he advanced but also of his *method*, one can be led to experience the insightful and timely aspects of his scientific world view. His is a method which retains an intimacy with nature, and is thereby accused of subjectivity. It establishes as well a relationship to phenomena which retains the element of genuine wonder. The ancient Greeks are often quoted as stating that all knowledge begins in wonder. By approaching the world in a phenomenological fashion, one may still arrive at an understanding of natural phenomena which, we hope to show, can legitimately be called a "theory." Through the immediacy of the experience of beholding the laws of nature in the phenomena themselves, students stand initially in awe of the simplest experiments. Yet this awe leads not to myth but rather to genuine scientific endeavor.

THE EYE: PHYSIOLOGICAL COLORS

Goethe begins his *Farbenlehre* with a consideration of the organ of sight; we shall choose to do so as well. One may perform the following experiment to this end.

A well-illuminated, strongly colored object[9] is placed far enough away so that it takes up no more than 2° of one's field of vision (in order that the image falls on the fovea centralis—pure cone vision). If, after a period of about 30 sec, one either closes one's eyes or diverts them to a neutral surface, gradually a colored afterimage will appear. It will float, as it were, before one's eyes although no external stimulus may be present; the image is produced entirely by the eye. If variously colored objects are used, one discovers that the afterimage hue is complementary to the object hue. (This is not strictly true. For a very interesting presentation of afterimage hue as a function of saturation, see Ref. 10.) The first recorded description of this phenomenon is found in Aristotle's *De Somniis* (*On Dreams*), where he speaks of the colored images of dreams and the imagination as bearing a resemblance to the eye's afterimages. This phenomenon was rediscovered throughout history by figures such as St. Augustine, Alhazan, and Peiresc. One may point out, with Goethe, that the color circle can be built up via afterimage pairs in such a way that pairs are on opposite ends of diameters. He considered the tendency of the eye to create afterimages of extreme significance and indeed generalized it as the "Law of Re-

quired Change" ("Gesetz des geforderten Wechsels"[11]). This law states that as a strong impression is received its complement is produced by the individual, so that when the external stimulus is removed the complementary inner gesture becomes expressed—thus the appearance of an afterimage, tears when joyful, and so on. The eye then is *not* a passive device but rather a creative organ, one which "demands completeness and seeks to complete the color circle in itself."[12]

> You see [said Goethe] that there is nothing without us that is not also within us, and that the eye, like the external world, has its colors.[13]

The reflection of the outer world in the inner, of course, dates back to the ancients and persisted certainly until the seventeenth century as evidenced by the acceptance of a geocentric universe. As we shall see, Goethe's ideas in many ways mirror those earlier views in a way which bears the imprint of a modern genius.

One further experiment which is most instructive and fascinating is the production of colored shadows. Two sources of light are needed (originally sunlight and candlelight were used) of different colors, for example, red and white. These are projected in register on a screen, and a suitable object is placed such that two shadows are cast, one illuminated by red light alone the other by white alone (Fig. 1). However, rather than perceiving a red and "white" shadow, respectively, red and green shadows are seen. This is explained by current color theory according to the theory of "chromatic adaptation," which essentially states that the subjective "white point" of the chromaticity diagram is shifted according to the color (in this instance the white–red mixture) that dominates. Here we are confronted unavoidably with the subjective nature of perception. It is not sufficient to know the spectral energy distribution of the incident radiation and spectral reflectance curves of the object. We must also consider the surroundings into which our object has been set as well as the last impression on the retina.

From experiments such as these Goethe was strongly convinced, unlike Newton, that one must *not* remove man from nature during the process of scientific investigation. Man is a part of nature and therefore, in the observation of nature, nature is observing herself.[14] Such a view has also been sounded by Werner Heisenberg in his *Physicist's Conception of Nature,* where he accurately describes the dilemma of the scientist when he writes:

> . . . the object of research is no longer nature itself but man's investigation of nature.

That is, the traditional distinction between man and nature, observer and observed, is no longer a valid distinction. This is written, of course, with his uncertainty principle as a backdrop. Yet Goethe goes further. Not only should we remember that through observation we enter into and disturb the course of nature, but more importantly the colors, tones, and forms themselves affect us in a way peculiar to each individual perception. This should not be understood in an atomistic sense; rather one should conceive of the colors, tones, and forms as all being fundamentally *creative* in nature. It is often remarked in anthropological circles how well man is adapted to his environment. For example, the eye is most

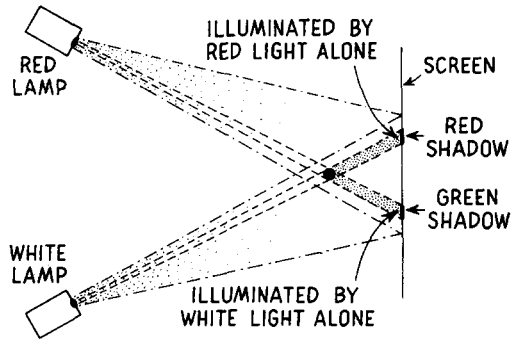

Fig. 1. Setup for the demonstration of colored shadows or chromatic adaptation.

sensitive to that range of frequencies at which the sun primarily emits. In a very real sense Goethe pictured the eye (indeed all of man) as being molded by in-streaming stimuli. So it is that he states[15]:

> The eye owes its existence to the light. Out of indifferent animal organs the light produces an organ to correspond to itself; and so the eye is formed by the light for the light so that the inner light may meet the outer. . . . If the eye were not sunlike, how could we perceive the light?

Here we have come to a very central insight into Goethe's science. Man is a part of nature not to be sundered from it for the cause of objectivity. Nature has created and is creating organs in man through which man may perceive her. Man in turn responds by his own creative actions.

Perception then is a continual dialog between the senses and the sensible. In Empedocles[16] and Plato[17] one encounters a theory of vision of such a nature. The fire without (the sun) acts so as to bring the images of the world to the eye, but then as an answer a comparable image is projected from the retina to the surface of the eye via the action of a pure inner fire which dwells within the eye. In the interaction between these two images arises the perception.

So it is then that we come to a picture of man as a being inseparable from nature, one engaged in a continual dialog, both consciously and unconsciously, with nature. Perhaps most importantly, it is a creative dialog, one which leads to organs fit to perceive that which surrounds man.

PRISMATIC COLORS

Before proceeding further with Goethe's ideas, let us remind ourselves what we mean by "science." As has been frequently pointed out, for example, by Whitehead,[18] the world presents itself to our senses in such a way that, if we are *completely* and *rigorously* deductive, no "laws of nature" can, *a priori,* honestly be put forward. The scientist possesses, however, a usually unspoken faith that causal relationships *are* to be found in nature and that these relationships, contrary to Hume,[19] are not arbitrary. Motivated by such a belief, the scientist endeavors to uncover those relationships which will so order his perceptions that elements of permanence are found in what otherwise appears as unrelated experience. In the words of Einstein[20]:

> The object of all sciences is to coordinate our experiences and to bring them into a logical system.

The nature of science is thus the attempt to reduce a complex of phenomena to certain general and exact laws out of which the individual phenomena may be derived. Thus we think, for example, of one physical law as governing both the path of a dropped stone as well as the orbit of the moon—namely, the law of gravitation. The world then presents us with a multitude of experiences which we order by seeing them as particular manifestations of a certain law or laws of physics. With this in mind, we hope to indicate in just what sense Goethe's color studies form a science, one which concerns itself not with the abstract causal relationships assumed to exist by the modern scientist, but rather with the laws as seen in the phenomena themselves, as the active interplay of polarities. Thus we hope to show in what sense Goethe also hoped to find, "In the flow of ever-changing phenomena . . . that which was permanent. . . ."[21]

We may now posit the question, what are the "laws of color"? It is to be stressed that we are not here concerned with the laws of optics but rather purely with color. (The two are, of course, intimately related; nonetheless, the distinction is a real one.) Optics, as Goethe points out, is certainly a valid domain for a mathematical science; yet this approach he sees as inadequate when searching for the laws of color.[22] History, of course, paid little heed to Goethe's sentiments, and one can legitimately say that modern color theory really began with Newton, whose approach was fundamentally antithetical to Goethe's. Newton's celebrated experiment of the production of the spectrum[23] was taught to Goethe in his youth as it was to us in ours. The story of Goethe's active experimental work begins with a repetition of that experiment.

Goethe had a friend–scientist, Hofrat Büttner, at Göttingen from whom he borrowed enough optical equipment to perform most of the basic experiments of optics. Upon their receipt Goethe placed them in a corner and promptly forgot about them. It was only after reminders and messages that Büttner in effect forced Goethe into his first rudimentary experiment. Goethe reports that he picked up a prism and, placing it to his eye, saw something other than the rainbows he had expected.[24] Indeed, he states that he happened at that moment to have been in a completely white room. Thus he expected that the reflected light of the white walls when passed through the prism would produce many rainbows over its surface. He was, as one might predict, greatly disappointed. Yet from this moment of disillusionment was born the resolution that Newton's notions were in error, which led him to his extensive and accurate research of color phenomena. Goethe then turned from wall to chamber window, thinking that perhaps sunlight contained the essential element. Again he saw not what he had expected, but rather something of an altogether extraordinary character. Where the lattice work of the window frame crossed the window he saw color: blue and violet on one side, red and yellow on the other. It was *here* that the laws of color were to be found, not in light alone but rather in the meeting of light with darkness! At these boundaries the light "interacts" with the darkness, yielding color. Goethe, therefore, begins his study of prismatic colors with what we call today the boundary colors. He considers these as fundamental, whereas

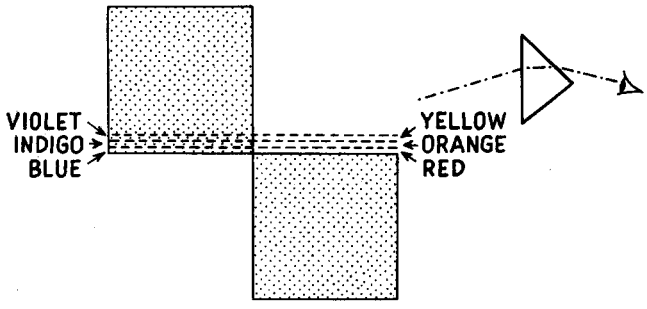

Fig. 2. Demonstration of boundary colors: color as the "deeds and sufferings" of light with darkness.

modern color theory usually deals with them as a composite phenomenon. It is important to realize, however, that one may *legitimately* begin with boundary colors and develop a color theory on that basis.[25]

Let us consider boundary colors more exactly and in a way consistent with Goethe's approach: that is, purely phenomenologically. Figure 2 depicts a first experiment. Regions of black and white are arranged as indicated in the figure and then viewed through the top half of a prism, one of whose edges is held against the nose. Certain colors will appear at the black–white interfaces. Important to note is the fact that there are two sets of colors: the "warm" colors, red, orange, and yellow, and the "cool" colors, blue, indigo, and violet. A number of observations may be made at this point. For example, the cool colors appear over the black region while the warm appear over the white. Also, the color green is absent altogether although present in the Newtonian spectrum. Finally, the figure appears displaced upward.

As noted, the color green is absent from the boundary colors. How then can one produce this color? The following experiments are a vivid and a beautiful demonstration of that process. Place a sheet of white paper beneath two black sheets as shown in Fig. 3(a). Slowly slide the black sheets together while viewing the narrowing white region through a prism. As will be seen, the yellow of the warm colors will come into contact with the blue of the cool colors to give rise to green. From this experiment Goethe concluded that green is produced by the mixing of yellow and blue as is done in painting. (This is, of course, in error since the green produced here is approximately spectral green, that is, pure green, not a

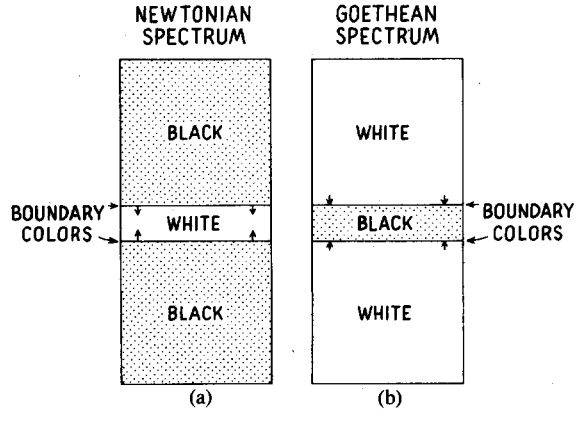

Fig. 3. (a) The generation of green in the Newtonian spectrum. (b) The generation of "purpur" (magenta) in the Goethean spectrum.

mixture.) Goethe then performed an experiment complementary in nature to the above. Whereas before one viewed a slit of light in a field of darkness, now let us view a slit of darkness in a field of light. (Note that this is precisely complementary to Newton's experiment.) The setup is shown in Fig. 3(b). Now the white sheets are pushed together to create a color (when viewed through a prism) that is *not to be found in Newton's spectrum.* Goethe called this color "purpur" (magenta) and spoke of it as arising due to an "intensification" (Steigerung) of the violet and the red as distinct from the mixing of yellow and blue to give green. One can also notice a delicate shift in hue in all the other colors towards the pastel.

Through these two experiments we have produced all the colors of the modern color circle or chromaticity diagram. The lower two-thirds of the diagram's colors arises via Newton's experiment while the upper two-thirds can be seen in the Goethean experiment. (This is *not* to imply that Goethe saw white as the composite of all colors, but only to indicate that for the full range of colors presented in the modern chromaticity diagram Newton's spectral colors are not sufficient.) The duality which is here evident is of an astonishing character. By effecting the transformation of white to black and black to white, one produces a complementary sensory experience in as much as green and magenta are afterimage complementaries. In this concept of duality lies much that is central to Goethe's world view. It is a reflection of the Goethean notion of *polarity,* which will be dealt with further.

Up to this point the approach we have assumed is essentially that of modern science: a careful analysis of the phenomena themselves. Hereafter, however, there is a distinct parting of the ways with modern science following the route of mathematical analysis and "modeling,"[26] while Goethe remains within the phenomenal experience. At this juncture the scientist typically resorts to "secondary" concepts which have no reality outside the mind. For example, the early picture of the atom as a ball with assorted hooks and eyes to explain bonding is, of course, an attempt to explain scientific facts regarding something of an unseen, submicroscopic nature by analogy with what is sense perceptible, namely, hooks and eyes.[27] Although certainly no trained scientist accepts such a naive model as depicting the reality, it is nonetheless often viewed as such by the nonscientific community.

ARCHETYPAL PHENOMENA

The question still remains, how is one to understand the phenomena of color? How is one to proceed if the end point in mind is knowledge, not mere enumeration and classification? It is here that the core of Goethe's method is to be found.

In order to discover the general principles which order the world, the intellect must be brought into play. It seeks for the essential element which may run through a whole series of phenomena. For the Goethean method as well as the modern scientific approach this forms the second partner of the pairs, percept–concept and observation–reasoning. It is only the application of the intellect to the *objects themselves* rather than to the *relationships* between them at which Goethe balks. The rightful domain of activity for man's intellect is in the discovery of relationships. Perceptions, direct or indirect, should not be submitted to abstraction or speculation as to ultimate composition, etc.[28,29] Goethe states[30]:

> He [the investigator of nature] should form to himself a method in accordance with observation, but he should take heed not to reduce observation to mere notion, to substitute words for this notion, and to use and deal with these words as if they were things. . . .

Here we are warned of the danger inherent in straying from the experience itself to "notions" and mere "words" while forgetting that the reality of such depends on ourselves and not on the phenomenon. The method Goethe would have us use refrains from such naming and notions. Rather it has the characteristics of reduction to the most essential and ascension to the most general. He characterized this method when he stated[31]:

> . . . the circumstances which come under our notice in ordinary observation are, for the most part, insulated cases, which, with some attention, admit of being classed under general leading theoretical rubrics which are more comprehensive and through which we become better acquainted with certain indispensable conditions of appearances in detail. From henceforth everything is gradually arranged under higher rules and laws, which, however, are not to be made intelligible by words and hypotheses to the understanding merely, but, at the same time, by real phenomena to the senses. We call these primordial phenomena [Urphänomen], because nothing appreciable by the senses lies beyond them, on the contrary, they are perfectly fit to be considered as a fixed point to which we first ascend, step by step, and from which we may, in like manner, descend to the commonest case of everyday experience. . . .

In our presentation thus far we have followed Goethe's advice in merely presenting and describing the phenomena under study. The present task is then to arrange them into the "higher rules and laws" of which Goethe wrote, rules which do not entirely depart from the sense perceptible, appealing thereby not to the intellect alone but also to the senses.

Returning to the concept of duality, we might expect to find it at play here as well. The major polarity of light and darkness should have their reflections in dual experiments, one of which would yield the warm colors, another the cool colors. These experiments should admit expression of the archetypal phenomenon (Urphänomen) which we seek and from which the rest of the color world may be understood. Goethe pointed to the interaction of light with darkness as fundamental. In more poetic terms he declares color as "the deeds of Light, the deeds and sufferings."[32] What is the nature of this interaction, of these "deeds and sufferings"? Goethe, following Aristotle, Roger Bacon, Leonardo de Vinci, and others, saw colors as produced by the raying of one extreme or pole through the other. More specifically, the warm colors arise from the raying of the light through the darkness. Nature's most prominent and beautiful example of this is to be seen in the sunrise and sunset. As the sun nears the horizon, its light penetrates more and more air (which carries the darkness), giving rise to the sequence of colors yel-

low, orange, and red progressively as it sets. Once again by performing the transformation of light to darkness, darkness to light, we encounter immediately the "complementary" or "dual" experiment which yields the cool colors. That is, by passing darkness through light one experiences the blues and violets. Here one sees instantly the active character which Goethe attributes to darkness. It is *not* seen as the absence of light, but as an active principle in itself! Once more nature provides us with immediate examples in both the sky and ocean. The blue sky (or ocean) is seen as produced by the passing of the darkness of space (or the ocean bottom) through the light-filled medium of the air (or water). So it is that the air acts as the bearer of darkness in producing the warm colors and as the bearer of light for the cool colors. This act of "bearing" is common to entities which in Goethe's terminology are "turbid" (trüb). Out of these two archetypal phenomena the whole of the color world is to be explained. Indeed, one can go far with these thoughts towards an understanding and appreciation of the hues of nature. Indeed, Goethe goes so far as to explain the prismatic colors in terms of these archetypal phenomena.[33] This, then is an example of the ascent to the "Urphänomen" of which Goethe spoke and beyond which one cannot go:

light through darkness → warm colors;

darkness through light → cool colors.

> The highest which man can attain in these matters is astonishment; if the archetypal [Ur] phenomenon causes this, let him be satisfied; more it cannot bring; and he should forebear to seek for anything further behind it: here is the limit. But the sight of a primal phenomenon is generally not enough for people; they think they must go still further; and are thus like children who after peeping into a mirror, turn it round directly to see what is on the other side.[34]

INTUITIVE PERCEPTION

This approach is one which is, in several essentials, fundamentally different from that of orthodox science. The laws of nature, in that more orthodox view, are fathomable only by dint of "rational analysis."[35] They are not a self-evident reality. It is here that Goethe begs to differ. He claims that it is possible to submit a field of experience to a reduction. Out of such a reduction there arises the fundamental perception of the archetypal phenomenon. The archetypal phenomenon *is* a self-evident manifestation of physical law. One attains through it a genuine perceptual encounter with the laws of physics. Here we may have cause to recall the roots of the word "theory," which in the Greek was $\theta\epsilon\omega\rho\epsilon\omega$ ("to behold"). The entire impulse of Goethe's contribution to science rests on this principle—to know is to have seen. Just this thought is found expressed in the Greek

Table I. A sketch of certain important parallels and differences that exist between Goethe's approach and that of modern natural science.

Goethe (1749–1832)	Newton (1642–1727)
Point of Departure	
Eye	*Sunlight*
begins with the organ of sight, the *eye*: afterimages and colored shadows—"subjective" spectrum	begins with the investigation of *light*—"objective" spectrum
Place of Man	
Man as nature	*Man observes nature*
man as observer and nature as observed are inseparable	one must separate the observer from the observed
Explanation	
Polarity	*Many in one*
color is seen as arising from the "deeds and sufferings" of light with darkness	all colors are contained in white light and arise due to their particular "refrangibility"
Theory of Color	
Archetypal phenomenon	*Model*
the phenomena of nature lead man to that phenomenon from which all others may be explained (e.g., "light thru darkness" → reds; "darkness thru light" → blues)	the phenomena of nature lead man to the "laws of nature," models: mathematical or physical (e.g., the wave and corpuscular theories)
Faculty of the Mind	
Intuition	*Intellect*
knowledge through "perception"	knowledge through abstraction
Domain of Application	
Art	*Technology*
sensory–moral aspects of color: painting, therapy, . . . , man's inner concerns	current color science: color television, photography, . . . , man's outward concerns

verb οιδα, which means both "I know" and "I have seen." As Heisenberg points out, the distinction Goethe is making here corresponds to the two types of knowledge possible in Platonic philosophy, *Episteme* and *dianoia*. To quote Heisenberg: "*Episteme* is precisely that immediate awareness at which one can halt and behind which there is no need to seek anything further. *Dianoia* is the ability to analyze in detail, the result of logical deduction."[36] Although Goethe certainly saw his science as radically opposed to Newton's, it is our opinion that a complementary relationship can exist between modern science and Goethean science if both modes of knowledge can be made exact and objective. Thus can man's understanding of nature become balanced and whole: not merely mechanistic nor purely poetic. (See Table I for a further comparison of the Goethean and Newtonian streams.) So it is that the abstract nature of modern scientific thought to which the student is perennially submitted finds in Goethe its counterpoint.

Perhaps it is insufficient to merely augment the formulas of mathematical physics with appropriate demonstrations. Might one not develop, parallel to the mathematical formulation, a phenomenological formulation which leads ultimately to encounters with the archetypal phenomena within each discipline of physics? Herein lies the intelligent schooling of intuition. Unlike the usual laboratory experiments designed to exemplify physical laws, there would be a structured series of experiments designed to lead the student to a *perceptual* encounter with the laws of physics!

It is to be stressed that such perceptions are *not* immediate. Merely showing students the appropriate archetypal phenomenon by no means guarantees the concomitant perception or intuition. How many people saw the cathedral chandelier before Galileo and failed to make his observations concerning pendulum motion? The initial necessary element is the feeling of wonder without which the investigator can make little or no progress, but then, as the perceptual world flows into us in a coarsely differentiated fashion, faculties or abilities gradually arise which lead to a sufficiently refined perception, the result of which is cognition.

Here one can find a striking parallel in Greek thoughts on vision. Cognition arises when, in Greek terms, the inner ειδολα (or image) of the eye encounters the outer ειδολα of nature. Both ειδολα, or images, are elicited by the action of fire, either outer or inner. Inherent in such an approach is an immediate analogy for more current views of the process of cognition. As the percept (outer ειδολα) reaches the eye, the intellect (inner fire) mates it with the appropriate *concept* (inner ειδολα), which results in cognition. As with the eye, so also with more subtle "intuitive" faculties. That is, might it not be possible to develop the capacity to "perceive" a physical law?

If so, how would such an ability be created? Here our study of afterimages and colored shadows may prove of assistance. Through these experiments we saw the dynamic properties of visual perceptions. Indeed, in both cases something was changed in us either physiologically or psychologically by the colors themselves. The very process of attentive perception transforms the observer into harmony with the perception! A trivial example might be the machinist who at a glance can distinguish between a 6-32 or 8-32 machine screw. He certainly doesn't count threads or measure the diameter. Rather, such knowledge is a matter of *perception*. This ability was gained through experience with just these objects. In like manner one can conceive of a finer training of one's perceptual capabilities through a Goethean method. These observations are not meant in any sense as a rigorous proof of Goethe's ideas. That perhaps is best left to the field of psychology. Rather, these comments are meant to clarify and support Goethe in his thought[37]:

> Every new object, well contemplated, opens up a new organ within us.

Once one admits the possibility of such a schooling, the possible pedagogical applications are immediate. One could determine the laws of physics which would be approached in this Goethean way and then set up a sequence of laboratory experiments the purpose of which would be to give the student the opportunity to experience in the "archetypal experiment" (the final experiment) the law of physics under study. The given sequence of experiments would have to be carefully determined and, indeed, might vary somewhat from student to student. Still the experience, the inutition of the law which generally precedes its more formal expression, would be a valid one. Not only would it be of importance for the young physicist but also for the nonscientist whose approach to the world may be quite other than theoretical: for example, the artist.

To carry out the description of Goethe's *Farbenlehre* to its rightful conclusion, it is necessary to point to the ideas contained in the last chapter, entitled "The Sensory–Moral Aspects of color." In that chapter Goethe carries his ideas of color into the artistic. Through his studies he hoped to construct an objective foundation for the artistic use of color. With each color experience Goethe associated an inner human response. These responses he called our experience of the "moral aspect of color," and they are, if you will, the psychological image of color. Once again the understanding of the objective moral aspects of color was to be had through direct perception. By dealing with color in terms of the "deeds and suffering of Light" with darkness, we have a most impressive picture of the wellspring of such moral and aesthetic aspects.

SUMMARY

Hopefully, we have accurately conveyed the basic ideas which Goethe gave in his *Theory of Color* one hundred and fifty years ago. In addition, it is hoped that its value as an important first step towards a science based not on measurement but on keen qualitative observations and schooled intuition has become evident. Through such training the student is brought to the point of perceiving through the archetypal phenomenon the laws of nature. This will, I believe, be of some value in the design and philosophy of laboratory instruction. Perhaps most importantly, through such experiences the student has the opportunity of acquiring a direct experience of what may hitherto have eluded him in the mathematical presentation, the excitement of knowing: οιδα—I have seen.

So it is that we feel with Heisenberg that[38]:

> Even today we can still learn from Goethe that we should not let everything else atrophy in favor of

the one organ of rational analysis; that it is a matter, rather, of seizing upon reality with all the organs that are given to us, and trusting that this reality will then also reflect the essence of things, the "one, the good, and the true." Let us hope that the future will be more successful in this regard than our own day, than my own generation, has found it possible to be.

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[5]J. W. von Goethe, *Zur Farbenlehre,* in *Goethe's Werke, Hamburger Ausgabe,* edited by E. Trunz (Hamburg, 1961), 5th ed., Vol. XIII, or *Theory of Colors,* translated by C. L. Eastlake (MIT Press, Cambridge, MA, 1970).

[6]W. Heitler, Ref. 2, p. 13.

[7]G. Jaki, Am. J. Phys. **37,** 195 (1969).

[8]W. Heisenberg, *Wandlungen in den Grundlagen der Naturwissenschaft* (Hirzel, Leipzig, 1945), or *Philosophic Problems of Nuclear Science,* translated by F. C. Hayes (Faber and Faber, London, 1952), pp. 60–76.

[9]Although any colored object is adequate, from classroom experience Colormatch sheets have proven well suited for this experiment.

[10]M. H. Wilson and R. W. Brocklebank, J. Opt. Soc. Am. **45,** 293 (1955).

[11]In recording a conversation with Goethe on 1 February 1827, Eckermann states: "This led our conversation to a great law which pervades all nature, and on which all life and all joy of life depend. 'This [afterimaging],' said Goethe, 'is the case not only with all our other senses, but also with our higher spiritual nature; and it is because the eye is so eminent a sense, that this law of required change is so striking and so especially clear with respect to colors' " [J. P. Eckermann, *Goethes Gesprache mit Eckermann* (Insel-Verlag, Leipzig, 1929), or *Conversations of Goethe with Eckermann and Soret,* translated by J. Oxenford (Bell, London, 1883), revised ed., pp. 216–217].

[12]Reference 5, *Theory of Colours,* p. 28.

[13]Reference 11, *Conversations of Goethe with Eckermann and Soret,* p. 216, 1 February 1827.

[14]P. J. Bouma, *Physical Aspects of Colour* (St. Martin's, New York, 1971), p. 176.

[15]Reference 5, *Zur Farbenlehre,* in *Goethe's Werke, Hamburger Ausgabe,* Vol. XIII, pp. 323–324. The Eastlake translation is poor.

[16]V. Ronchi, *The Nature of Light* (Harvard U.P., Cambridge, MA, 1970), p. 6.

[17]Plato, *Theaetetus,* 155d–157c [see, for example, F. M. Cornford, *Plato's Theory of Knowledge* (Liberal Arts Press, New York, 1957), p. 45].

[18]A. N. Whitehead, *Science and the Modern World* (Free Press, New York, 1967), Chap. 1.

[19]D. Hume, *Inquiry Concerning Human Understanding* (Clarendon, Oxford, 1962), 2nd ed., Sec. IV, p. 30.

[20]G. Holton and D. Roller, *Foundations of Modern Physical Science* (Addison-Wesley, Reading, MA, 1965), p. 214.

[21]K. Vietor, *Goethe the Thinker* (Harvard U.P., Cambridge, MA, 1950), p. 17.

[22]For example, in writing of the proper and improper applications of mathematics Goethe states: "The theory of colours, in particular has suffered much, and its progress has been incalculably retarded by having been mixed up with optics generally, a science which cannot dispense with mathematics; whereas the theory of colours, in strictness, may be investigated quite independently of optics" [Ref. 5, *Theory of Colours,* p. 287].

[23]The original description by Newton of this experiment is reported to Oldenburg, secretary of the Royal Society, in a most interesting letter [see, for example, Ref. 16, p. 160].

[24]J. W. von Goethe, *Geschichte der Farbenlehre,* in *Goethe's Werke, Hamburger Ausgabe* (Hamburg, 1961), Vol. XIV, pp. 257–261.

[25]Reference 14, pp. 176–177.

[26]Reference 20, Chaps. 13–15, especially p. 223.

[27]W. Heisenberg, *Physics and Beyond,* translated by A. J. Pomerans (Harper and Row, New York, 1971), p. 2.

[28]*Kurschner deutsche National-literatur,* edited by R. Steiner (Spemann, Berlin, 1892–1897), Vol. 35, or *Goethe the Scientist,* translated by O. D. Wannamaker (Anthroposophical, New York, 1950), p. 223.

[29]The same spirit is manifested by P. A. M. Dirac when he states: "The main object of physical science is not the provision of pictures, but the formulation of laws governing phenomena and the application of these laws to the discovery of new phenomena" [P.A.M. Dirac, *The Principles of Quantum Mechanics* (Oxford U.P., Oxford, 1958), p. 10].

[30]Reference 5, *Theory of Colours,* p. 283.

[31]Reference 5, *Theory of Colours,* pp. 71–72.

[32]The Eastlake translation (Ref. 5) is poor here. The German reads: "Die Farben sind Taten des Lichts, Taten und Leiden" [*Hamburger Ausgabe,* Vol. XIII, p. 315]. In the MIT edition this quote is to be found on p. xxxvii in the "Preface to the First Edition of 1810."

[33]Reference 5, *Theory of Colours,* pp. 82–83.

[34]Reference 11, *Conversations of Goethe with Eckerman and Soret,* p. 370, 18 February 1829.

[35]Reference 4, p. 129.

[36]Reference 4, p. 137.

[37]Reference 5, *Hamburger Ausgabe,* Vol. XIII, p. 38.

[38]Reference 4, p. 141.