To Hal with kindest regards
1976-XI-17-♀ Karel Hujer

The Purkinje Effect in the Evolution of Scientific Thought

KAREL HUJER

When Newton announced the principles of color vision in his classical work, *Opticks*, 1704,[1] and by means of a prism decomposed sunlight into seven rainbow colors, he only reaffirmed that the source of our knowledge rests exclusively outside the observer and his senses. The legend of the "falling apple" that was to guide the youthful natural philosopher to the discovery of the universal law of gravitation is epistemologically similar to Newton's observation of the prism decomposing sunlight. It indicates that the structure of light is an entirely external phenomenon which takes place outside of man's mind. Newton's views and his theory of knowledge, corroborated over the years by a series of triumphs, are epitomized in the scientific method which still guides much of our civilization. Certain phenomena in modern physics, however, ever more urgently indicate that Newton's world view no longer reigns without question. We shall investigate aspects of some new ideas as they now appear in optics through the Purkinje phenomenon.

According to Newton's theory of knowledge, there is the world external to our senses, and we learn about its reality by means of our perception. With the help of various tools such as telescopes, microscopes, spectroscopes, photometers, etc., it is possible to extend, amplify and increase the efficiency of our senses and thus augment the precision of our measurement. Therefore, according to Newtonian concepts, the complete externalization and objectification of color indicates that, as every physicist knows, each color from red to violet is associated either with a specific wavelength or a specific number of vibrations per second, called frequency. Thus, the yellow spectrum line D of sodium, for example, in the solar spectrum has a wavelength equivalent to 5896 angstrom units, i.e., 0.000,05896 cm, and appears yellow to anyone, anywhere in the universe. This is a reality whether or not such an organ as the human eye exists.

[1] Sir Isaac Newton, "A New Theory About Light and Colours", *Philosophical Transactions*, Vol. I (February, 1672). Also in *Treatise on Opticks* (London, 1704).

Because of Newton's long-unquestioned authority, this view has continued to dominate related thought to the present day.

In the realm of pure philosophy, as will be shown later, there were divergent opinions concerning the nature of reality, and experimental science, in its dominance, has relegated these ideas to the background. In 1819, however, a young physiologist, J. E. Purkyně, or Purkinje, published a paper in Prague entitled *Beiträge zur Kenntnis des Sehens in subjektiver Hinsicht*.[2] Purkinje's first paper was followed by a second on a similar subject, *Beobachtungen und Versuche zur Physiologie der Sinne. Neue Beiträge zur Kenntnis des Sehens in subjektiver Hinsicht* (Berlin, 1825).[3] The latter contained the idea of the Purkinje effect. These were the only works in which he happened to approach the field of physics. As often happens, the discoverer was little aware of the far-reaching significance of the phenomenon he described, particularly in relation to the theory of knowledge.

What is the Purkinje effect? By this phenomenon is usually meant the curious fact that blue and, especially, green colors look abnormally bright when illumination is diminished, and yellow and, especially, red colors look abnormally dull. When formulated in the language of mathematical physics, the Purkinje effect means that the change in the intensity of light is accompanied by a relative change in color or, according to the subjective experience, the perception of a definite color is not attached to the same numerically stated wavelength, but vacillates with the intensity of illumination. In the quantitative expression of a physicist, objective measurement shows that under the conditions of good illumination, the human retina is most sensitive to the radiant flux of wavelength 5550 angstroem units but when illumination is reduced, the highest sensitivity of the human eye is displaced toward shorter wavelengths. This shift in sensitivity of the retina toward a shorter wavelength, or a radiation of higher energy when illumination is dim, is the most characteristic feature of the Purkinje effect. Or, to state it differently, when the light is weak, the retina requires a higher energy impulse, i.e., shorter wavelengths, to register on our mind the perception of the same color. By 1891, Ladd-Franklin, followed by Ebbinghaus in 1892, the Purkinje effect was extended to color combinations which make colorless mixtures. Examined under various intensities of illumination, these reveal an even more startling aspect of the Purkinje phenomenon. The Purkinje effect evi-

[2] J. E. Purkyně, *Beiträge zur Kenntnis des Sehens in subjectiver Hinsicht* (Prague, 1819).

[3] J. E. Purkyně, *Beobachtungen und Versuche zur Physiologie der Sinne. Neue Beiträge zur Kenntnis des Sehens in subjektiver Hinsicht* (Berlin, 1825).

dently indicates that man's subjective experience in relation to the perception of colors does not accord with Newton's theory of colors. A given wavelength does not always produce an impression of the very same color.

It is particularly interesting to note that among those first to react most sympathetically to Purkinje's publication was Goethe, who wrote to his friend, J. P. Eckerman:[4] "I read the publication with great joy...", and further wrote that Purkinje's paper so well expounds his own theory of colors that he was suprised that the name, Goethe, is not quoted. It is little known that the Weimar poet dedicated the last forty years of his life to ardent study of the theory of colors and centered his philosophy and his Weltanschauung on the notion that, as with colors, all aspects of the external world have no reality outside man's sensory perception. Goethe set forth these ideas in such voluminous works as *Farbenlehre* and *Geschichte der Farbenlehre*, which, despite Goethe's literary fame, have remained relatively obscure.

It is indeed very startling to consider the obstinacy with which this literary giant, conceivably ill versed in mathematics, opposed Newton's scientific authority and his mechanistically based theory of colors which assign the production of colors outside of man's mind, i.e., into the behavior of light waves in the external world. Goethe, on the other hand, describes his method as empirical idealism, and maintains that the sense-perceptible world-picture, including color vision, is the sum total of constantly changing percepts *without any underlying matter*. This, of course, appears fantastic. Not even the fame of the great poet could uphold this radical view against the firmly established Newtonian tradition, and Goethe's concept is still considered a curious vagary of the prolific but occasionally erratic poet. Yet Goethe was so involved in these speculations that he valued his hard-won theory of colors above even his famous literary achievements. He was, therefore, eager to enlist any possible support for his ideas on optics; Purkinje's publication was the basis for the establishment of a continuing friendship between the two.

Goethe's interest in Purkinje's work apparently inspired the young physiologist's visit to the poet in Weimar on December 11-13, 1822; in 1823, Purkinje was appointed to this professorship at Breslau University, thanks partly to the influence of Goethe as well as Alexander von Humboldt. Purkinje dedicated his second paper,[5] previously mentioned, to

[4] O. V. Hykeš – D. E. Hykešová, "Goethe a Purkyně", *Goethův sborník. Památce 100. výročí básníkovy smrti vydali čeští germanisté* (Praha, Státní nakladatelství, 1932), p. 14.

[5] *Op. cit.*, pp. 26-29.

Goethe and expressed his appreciation for the inspiration he derived from the poet's theory of colors. This was rather precarious ground, because Goethe's scientific works were almost generally rejected by contemporary physicists, but his great literary fame outweighed the hostile opinions, and Purkinje did not hesitate to express his feelings openly in the "Habilitation" thesis for his Breslau University appointment.

In dealing with the problem of color vision, guided by Goethe's idea that color is inside, not outside, man's sensory perception, Purkinje turned toward the study of the structure of the human eye. That has since proved to be sound procedure. According to Goethe, the eye does not determine the color, but is the cause of its manifestation. Thus, any theory of color must start with the investigation of the eye. Goethe, in his procedure, thus places the physiological theory of color at the very beginning. Consequently, Purkinje followed the method called heautognosic, according to Gruithuisen's idea. Heautognosy is the preliminary conditioning of senses which are to be used for further scientific investigation. In other words, the researcher must first investigate himself, the value and the state of his senses of perception. The English astrophysicist, Sir James Jeans, gives an excellent example of heautognosy when he considers a physiologist examining the brain of a patient:[6]

> Most people's opinion is that he sees the brain of the patient, but the philosopher insists that actually it is the brain of the physiologist himself.

For many years Jeans was the secretary of the Royal Society of London, and Goethe would surely have been pleased to hear such views from the twentieth-century successor to Isaac Newton in that learned society which bestowed its fellowship upon his friend, Purkinje.

The Purkinje phenomenon, however, points the way to iconoclastic consequences unforeseen either by Purkinje or almost any physicist, even to the present time. The Purkinje effect specifically indicates such subjective conditions of human cognition as were outlined by earlier philosophers, particularly in the Berkeleyan school, then by Schopenhauer and Kant, and most recently by Poincaré and Bergson, intuitive philosophy. The most important aspect of the Purkinje phenomenon is its empirical justification of this idea which extends from Berkeley to Bergson, challenging the questionable supremacy of quantity and space in scientific thought. Quantity and space dominate and motivate our interpretation of the nature of the world, reducing the quality and wealth of life to purposeless insignificance.

[6] Sir James Jeans, *Physics and Philosophy* (Cambridge, University Press, 1953), p. 87.

Most knowledge, both classical and contemporary, is based upon and ostensibly justified by the assumption that the world and everything we perceive in it has an existence independent of our cognizance, with all cosmic phenomena occurring in space and time quite apart from man, the only cosmic reality. It is misleading to take this erroneous assumption as the starting point in the investigation of cosmic phenomena. The fact that there is no absolute number associated with the sensation of a definite color consequently reveals evidence that each individual and his inner world are the only reality. In a similar trend Berkeley describes his ideas of space:[7]

> I am disposed to think that whenever we speak of the extension as an idea common to visual and tactile senses, it is by tacit supposition that we can detach the extension from all other tangible and visual properties and create an abstract idea, an idea that would be common at the same time to both senses of touch and sight.

The French physicist, P. Chambadal, maintains:[8]

> It is to Berkeley that belongs the merit of having demonstrated the independence of our visual and tactile sensations as far as concerns the property of space and geometry. It was reserved to Henri Poincaré to complete this doctrine and to demonstrate that the properties which we attribute to space and which are studied by geometry themselves depend upon our visual and tactile sensations.

Furthermore, Berkeley's eighteenth-century statement has a consequential relationship to that of the late astrophysicist, Sir Arthur Eddington, who remarks:[9]

> The beautiful hues which flood our consciousness under the stimulation of the waves have no relevance to the objective reality.

In other words, whatever we observe as seemingly independent and self-contained in the physical world is actually a form of sense nature. Kant called it an a priori form of sensuousness. Consequently, the properties of the physical extension depend directly on the structure of our sense organs; the properties of mathematical space and all the phenomena it transmits,

[7] George Berkeley, *Essay Towards a New Theory of Vision* (London, 1707). Quoted from *La physique moderne et son interprétation* (Paris, Librairie Armand Colin, 1956), p. 46.

[8] P. Chambadal, *La physique moderne et son interprétation* (Paris, 1956), p. 47.

[9] Sir Arthur Eddington, *The Nature of the Physical World* (Cambridge, University Press, 1929), p. 94.

such as colors, are only an abstract and schematized expression produced by our senses. Whatever may be the individual divergences of the various philosphical concepts we have thus far considered, particularly those of Kant, Schopenhauer, Poincaré or Bergson, their researches on the genesis of geometry arrive at the same result – the physiological relativity and consequently the ideality of space.

As we observe the world about us on the macrophysical scale, it may appear absurd indeed to speak of its non-reality. Yet, the history of man's ideas about the structure of the universe records only a constant struggle between what man has called reality and what the evolution of ideas has always proved to be an illusion. At present, for example, the relativistic aspect of the physical world, which moved the concept of reality even farther away from our direct experience, is extremely elusive on the ordinary scale and at the customary velocities, and its proofs are only possible in the realm of most refined measuring technique. Likewise, in our affirmation of the unreality of an objective world, we must proceed to the very boundary of the physical world and consider the state of our knowledge of such ultimate particles of physics as electron or quantum, and only indirectly examine their reality through a series of intricate experiments.

Although the determination of the charge and mass of an electron secured Nobel prizes for both Millikan and J. J. Thomson, indicating official recognition of the "reality" of such a particle, Eddington, after speaking confidently about the electron existing in the objective world, nevertheless in the next breath tells us that the electron is "something unknown ... doing we don't know what". The electron is entirely invisible, yet what makes the word, electron, such a driving reality in our technology but our own thoughts? If the existence of electrons were established in a seemingly irrefutable manner, it would bring along grave problems: What is the dimension of an electron? Were the electron not dimensionless, its own existence would be self-inconsistent. Being thus utterly unstable, it would instantly explode, thanks to the fantastic forces of repulsion operating within the microcosmic region of its finite dimension. On the other hand, were the electron a dimensionless, geometrical point, we would have to attribute to it an infinite electrical energy which is inconceivable. Therefore, both the suggested and the merely feasible structures are mutually exclusive, because this particle is always associated with a definite electrical charge – the famous physical constant. Yet, our dilemma would not disappear were it possible to admit some finite extension of this corpuscle. We would still face another inscrutable

mystery as to why this particle remains stable in its charge and mass during the frantic course of its fantastic activity. Were the electron strictly a geometrical point without dimensions, it could not enter into contact with another electron without being confounded with it. Were there no contact because of lack of dimension, how could electrons exert mutual interaction? Whatever form of answer or suggestion we may propose as to the mechanism of this ultimate particle, which evidently must represent some universal building material of our physical world, we always end in a blind alley. What then is the reality? Categorically, our question at this point is no different from that raised against an electromagnetic wave such as that which produced our sensation of color.

If the Purkinje phenomenon throws doubt on the reality of color or wavelength, our picture of the electron throws wide open to the fullest extent the mystery of the world about us. Does or does not the electron possess an extension? Why do we insist on one or the other affirmation? P. Chambadal maintains:[10]

> The initial error that brought us to this impasse consisted precisely in the fact that we attributed to this ultimate particle an absolute existence which implies geometrical properties clearly defined. It is sufficient to renounce this "realistic" concept of the world and admit that it exists only in our representation and our antinomy, as many other inextricable problems produced by realistic illusion, and the initial error will reach its true solution. This solution can be expressed as follows: The ultimate particle, electron, is neither a dimensionless point, nor does it possess an extension, it simply does not have an objective existence.

So it appears that Purkinje's idea of tracing the origin of colors in the physiological field, in the study of the human eye, was sound. Evidently he was nearer the goal of the search for reality than Newton, who examined the sunlight with the prism. Nevertheless, not even Purkinje reached the goal; he only replaced Newton's tool – the prism – by another tool, the human eye. The actual distance between the prism and the human eye is not very great. The door of the human mind that receives the message of the physical, external world is somewhere much farther and deeper inside the mystery of being. Eddington says that in the realm of our physical plane we can trace the vestiges of these physical influences up to the door of the mind, where these influences ring the bell and vanish. In this respect, the behavior of the external world, its phenomena, may be described as not producing facts of some reality, but being merely symbols

[10] P. Chambadal, *op. cit.*, pp. 154-5.

of a picture of reality. Then, as H. Poincaré insisted, it is our arbitrary decision to create any convenient picture of reality. In this train of ideas, he maintained that since the earth's rotation is not a fact because we do not and cannot perceive the earth's motion, it is a matter of convenience to affirm that the earth rotates. Similarly, we can have direct experience of neither the atom nor the electron, but, as the physicist, C. F. von Weizsäcker, says, we force the atom or electron through experiment to tell us its properties in an inadequate language – and much to our hidden presumptions. And, Weizsäcker adds, the experiment is a violation of nature in which even more readily we force nature to play our game.

To sum up our subject, the Purkinje effect plays a most significant role in what one of the great scholars of Purkinje, A. Tschermak-Seysenegg, described as the foundation of exact subjectivism. It means even more. It adds another milestone to advancing man's understanding of the nature of the physical world in relation to which our present scientific method will have to make some revision in Galilean science. If such outstanding philosophers as J. Maritain, M. Buber, N. Berdyaev, and others, each in his own way, speak of the tragedy of "objectification", their voices, though little heard in the tumult of our triumphant dehumanized technology, are significant warnings that everything is not right with our objective scientific thought.

A last, though not least important fact, is that only recently Masaryk's University in Brno, Czechoslovakia, was renamed the J. E. Purkyně University. How strange that Masaryk, the realist philosopher, has been replaced by Purkinje, whose discovery, glorified as scientific, actually points the way toward an unfathomable change in the tide of ideas, from materialism of the objectified world and space and from dehumanized purposelessness, toward qualitative wealth of subjective life and the dignity of man.

LITERATURE

J. W. von Goethe, *Zur Farbenlehre* (1810).
Henri Poincaré, *La science et l'hypothèse* (Paris, 1906).
——, *Dernières Pensées* (Paris, 1913).
Henri Bergson, *L'évolution créatrice* (Paris, 1925).
Armin Tschermak-Seysenegg, *Goethe's Farbenlehre in ihrer Bedeutung für die physiologische Optik der Gegenwart* (Prague, 1932).
R. H. Kahn, *Goethe's Augen. Deren Beschaffenheit und Sehvermögen* (Prague, Physiological Institute, 1932).
Christine Ladd-Franklin, *Colour and Colour Theories* (London, 1932).
A. Tschermak-Seysenegg, *J. E. Purkyně als ein Begründer des exakten Subjektivismus* (Prague, 1937).

F. K. Studnička, "Kterak docházejí uznání objevy J. E. Purkyně", *Časopis lékařů českých*, č. 6 (Praha, 1947).

C. F. von Weizsäcker, *The World View of Physics* (Chicago, University of Chicago Press, 1952).

B. Němec – Otakar Matoušek, *Jan Evangelista Purkyně* (Praha, 1955).

M. H. Wilson and R. W. Brocklebank, "Complementary Hues of After Images", *Optical Journal of America*, Vol. 45 (1955).

Karel Hujer, "On the History and Philosophy of Purkinje Effect", *Actes du* VIII. *Congrès International d'Histoire des Sciences, Firenze, Italy, 1956.*

Herbert Dingle, *The Sources of Eddington's Philosophy* (Cambridge, 1954).

C. C. L. Gregory and Anita Kohsen, *Physical and Psychical Research* (Reigate, Surrey, The Omega Press, 1954).

Eva Rozsívalová, *Život a dílo J. E. Purkyně* (Praha, 1956).

C. W. Churchman and Ph. Ratoosh, *Measurement: Definitions and Theories* (New York, N.Y., 1959).

Milič Čapek, *Philosophical Impact of Contemporary Physics* (Princeton, N. J., Van Nostrand, 1961).