The Aurora

Is It Possible to Explain It by Means of a Copuscular Ray Theory?

By Otto Stuhlmann, Jr., M.A., Ph.D.

WE hear from over seas that the Germans raided London during the aurora display on March 7th; making use of the unusual illumination to guide them that night over the usually stygian darkness enveloping that city. Probably few of the phenomena of nature so entirely charm and interest scientific and non-scientific men alike as the aurora borealis or "Northern Lights" as they are sometimes called. The spectacle seen on the night of the above date was one of unsurpassing interest and beauty.

Just a few minutes before seven-thirty, on the above date, in a latitude just north of Chicago there appeared one of the most beautiful and inspiring displays of "Northern Lights" that has been my good fortune to observe. It began like the dawn of a cold clear wintry morning. Faintly at first like pink mists of twilight it glowed in the northwest, followed by a similar glow toward the south and east. Soon a soft crimson glow tinged the heavens like the blush of dawn creeping over the sky. Rapidly white shafts of light shot across the zenith enveloped in faint phosphorescent patches of deathly green. The colors come and go and change from red to deeper red and shimmer as they wane. The bark of a dog out of the cold distant quiet night calls to my attention the fleeting minutes. The hour is nine. Simultaneously there appear toward the West and East and North three red wings of light like the splash of wet red paint smeared on the sky-line, to show how Nature in her more eccentric moods can outdo her bravest sunsets. And through it all and for half an hour more a death-like stillness reigns. Then suddenly through the haze that has settled on the far horizon, a green-white streak appears, followed rapidly by shafts as sharp and regular as two-edged swords, they leap higher and higher, they reach the zenith and lo and behold, a similar sheath of blades have climbed the vault of the heavens from the other side; they meet and whirl in what appears a maelstrom overhead. The colors flicker, fret and flash like summer lightning through the sky. Through it all the stars shine as if the aurora had added extra luster to their silvery light. Soon all is motionless and calm, the time is ten-fifteen. Some purple reddish clouds fringed with the sheerest gauze-like drapery float across the scene. The shafts of light soon flicker, shrink and fade. A last slowly moving mass of phosphorescent haze fades from the vaulted sky; soon all has sunk into the depths of night.

Such a spectacle cannot fail at all times to be a subject of admiration, even to the least impressionable of men. Hence it is no wonder that the aurora has at all times received a considerable amount of attention at the hands of governments, learned societies and scientific men.

The most recent attention given to the solution of the cause of the aurora has been a paper by Carl Stormer (Kristiania). The conclusions drawn from his experiences and observations on the Aurora Borealis Expedition to Bossekop in the northern part of Norway, was published in the magazine for Terrestrial Magnetism and Atmospheric Electricity in September and March of last year. His mathematical contribution explaining the well known experiments of Birkeland, will no doubt become classic. He made no less than 2,500 observations alone on the altitude the aurora reaches in the heavens. These altitude observations, which measure the height to which auroras ascend, are reproduced here in Fig. 1. From this diagrammatic distribution and subsequent supporting data Stormer draws the conclusions that, "There are two predominant maxima, one at a height of about 101 to 103 Km. and the other at about 105 to 108 Km." That is, on the average the auroral display, as usually seen, takes place in the atmosphere about 65 miles above the earth's surface. The most natural question to ask is, Does the earth's atmosphere extend that far out? The height of the earth's atmosphere is usually conservatively placed at about 40 miles. There is abundant evidence from the phenomena of meteors that the atmosphere extends to a height of 100 miles at least, yet it cannot be asserted positively that it

has a definite upper limit. Even at the height of 65 miles we are evidently dealing with phenomena taking place in a highly rarefied atmosphere, comparable to the pressure used in the electric vacuum lamp.

Some earlier observations taken at the Haldde Observatory, Norway, by L. Vegard and O. Krogness find

penetrate down into our atmosphere. This lower limit is also generally very sharply defined, while upwards the luminosity more gradually fades away into space, and the upper limit is consequently not so definite.

A subsequent series of 2,487 determinations of the height of different aurora included the following types: diffuse arcs, drapery shaped arcs, typical draperies, split bands, rays and diffuse pulsating light areas. On the average the results so far indicate that the forms enumerated are of the same nature. The fact that the rays do not descend so low as arcs and draperies is somewhat striking and contrary to the impression one gets from a direct examination of an auroral display.

As pointed out by Stormer these observations also agree well with his recent results. The existence of maximum altitudes attained by the display, which seem to remain unaltered from one year to another, is a fact of far reaching importance. The immediate conclusions one

Altitude and Situation of Auroras.

Fig. I

the upper altitude limit to vary from 110 Km. to 330 Km. The very low limits were found belonging to the phenomena simulating arcs and draperies. The highest values were always found for the ray forms. To appreciate these observations, one must remember that, whatever is the explanation of the phenomena, the cause

can draw from this is that "a predominant part of the cosmic rays, coming presumably from the Sun and producing the aurora-borealis, is made up of two groups, each of which has its own quite definite penetrating power. The fact that the diffuse arcs, the drapery-shaped arcs, and the draperies all give the same principle maxima affords evidence that these most frequent forms are essentially of the same physical nature and must be produced by the same kind of rays." Of the less frequent forms not sufficient data is on hand to warrant any certain conclusions; though the small differences in the average height of the aurora indicate "that all forms are produced by the same type of rays."

Now what are these "cosmic rays" here referred to? This question has in the past years drawn into this interesting field of research such eminent men as Poincare, Birkeland, Arrhenius, Lenard and others, who have attempted to explain the phenomena both from an experimental as well as mathematical point of view, using some form of electron (corpuscular) theory as a basis.

It appears, however, that the physicist Goldstein¹ was the first to publish the idea that the sun sends out into space electrical rays analogous to cathode rays, and that we may thus explain the mysterious connection between variations in solar activity and the corresponding fluctuations in the magnetic and electrical phenomena on the earth.

Some years later (1894), the Danish meteorologist, Adam Paulsen, was led to the hypothesis that the aurora is due to cathode rays; but instead of assuming that the rays come from the sun he believed that they originated in the upper strata of the atmosphere. In 1896, however, Kr. Birkeland made some far-reaching and remarkable experiments with cathode rays in a magnetic field. Perhaps they were suggested to him through some observations during his Norwegian Aurora Polar Expedition of 1902-1903.² In his journal he remarks that "we had made a very interesting observation of a rare, but very significant, auroral phenomenon. It was ten minutes to six on the evening of the fifth of February, when we were some miles from Hammerfest, the weather clear and the moon shining, when there appeared a sharply defined arc of light from east to west through the zenith. From the first the arc was very intense but very narrow, right above our heads. Notwithstanding the bright moonlight the aurora, which soon began to pass through various phases of development, with draperies and sheaths of rays, was visible up to half past seven when it disappeared . . . It immediately occurred to me that the observation was a confirmation of the hypothesis put forward by me in 1896 regarding the origin of the aurora, namely, that the "Northern Lights" are due to cathode rays or similar rays emitted by the sun, these rays being drawn from space toward the earth by the terrestrial magnetic forces."

On returning from this expedition he attempted to reproduce the aurora effect in the laboratory on the

¹Goldstein. Wiedemann Annalen, vol. XII, p. 266, 1881.

²Published by Longmans, Green & Co.

Fig. II

seems to come from without and drive itself down into the denser regions of the air.

In treating these observations special attention has been paid to an exact determination of the bottom edge of the aurora, so as to find with the greatest possible accuracy the height to which the "cosmic rays" can

Fig. III

hypothesis that cathode rays converge upon the earth's poles from without the atmosphere. With what brilliant success these experiments were performed can be seen from the accompanying photographs (Figs. II, III and IV).

He first found that a magnet had an effect on a beam of parallel moving cathode rays (swiftly moving luminous, negative electric charges that pass through a vacuum when an electric potential is applied to oppositely placed metal terminals). The result was analogous to that of a lens upon a beam of light, the magnet, when used as the terminal upon which the rays were to impinge, forced them to converge toward a point upon its surface. This simple experiment showed him that the aurora borealis might be due to a similar effect, viz., the effect of the earth's magnetic field on the hypothesized rays coming from the sun. In order to test his theory further he exposed a spherical electromagnet to a stream of cathode rays coming from one side of a large vacuum chamber. Fig. II shows this electromagnet in the form of a spherical shell which simulates the earth in the following experiments. This spherical magnet was 36 centimeters in diameter, could be magnetized so as to conform to the magnetic figure of the earth, with magnetic poles at opposite ends

Fig. IV

ored to determine mathematically the trajectories of the electric corpuscles in the magnetic field of the earth, hoping in this way he says, "to confirm not only the details of Birkeland's experiment, but also the principal features of auroras and magnetic storms." With what singular success he achieved this more than ordinarily difficult problem can be appreciated from a survey of some examples of his models here shown in Fig. V.

"If we assume," suggests Stormer, "that the sun sends out into space large quantities of electrical corpuscles the mathematical problem reduces itself to finding the paths of these corpuscles in the field of an elementary magnet." As simplifications he assumes the motions of the earth and sun to be negligible with respect to the

parallel moving stream of electrons could be considered first.

After much difficulty some trajectories were obtained that allowed the corpuscles to come near enough to a magnetized globe, to verify theoretical conclusions as to the shape of the orbits on coming near enough to the magnet. The path described by such a corpuscle is reproduced in Fig. VI, the curves being similar to the well known geodic lines of a cone of revolution, with very small opening. A view of a large group of trajectories of these corpuscles as they approach the earth, shown here as the small dark sphere, is reproduced in the three plates of Fig. V. Certain characteristic features are seen in the three views of this model. First, the large group of

Fig. V

of the diameter of this iron sphere. This was placed into a large glass vacuum chamber of 1,000 liters capacity. Its sides were made of heavy plate glass. In one corner of this huge rectangular vacuum chamber was placed an aluminium cathode, while the metallic parts of the box acted as anode when an electric discharge was passed through it. Imagine yourself standing on the sphere, shown in Fig. II, looking upward, and it becomes apparent at once that it strikingly simulates the aurora rays, striking downward all around, forming the auroral zones of the earth. The arc usually seen overhead is beautifully illustrated, while the shafts of light that apparently strike upward out of the horizon are nothing more or less than the concentration of the discharges as they approach the poles at the upper and lower ends of the sphere. By varying the magnetism of the globe, the radius of the globe, the light zone could be altered at will, within wide limits, diminishing with strong magnetic fields. Fig. III shows something similar, but in this case the globe (earth) itself was made the object upon which the discharge terminated. This phenomenon was even more significant, for in the belt in which the rays from the cathode descended upon the globe, is seen the remarkably beautiful effect of light zones around the earth's magnetic poles. The so-called "aurora-belts" in particular were exceptionally well reproduced. Fig. IV is a fine group showing the same sphere from three positions. In No. 1 the north pole is exposed to view with the evening side of the globe to the left. The remarkable spiral-like effect here seen is often probably visible directly overhead. In No. 2 the photograph of the equatorial belt of the globe shows in a striking manner how the auroral zones confine themselves to the extreme northern and southern latitudes, and why the phenomena is never visible very far toward the equator. No. 3 of this group shows the corresponding south polar region under the same conditions, with the morning side of the sphere to the left.

These experiments gave the first really good support to the cathode ray or corpuscular theory of the aurora.

From a mathematical point of view the corpuscular theory, however, affords a much more difficult and in some respects unsolvable problem. This phase of the problem was attacked by Carl Stormer with unusual success. He became interested in Birkeland's experiments, recalling that the problem of the concentration of cathode rays toward a single pole had been mathematically treated by no less a mathematician than Poincaré. Following up the problem, Stormer endeav-

speed with which such corpuscles travel between the sun and the earth. Since the difficulties of solution, even under these conditions, are extraordinarily complex he further assumes that the corpuscles are not affected by any forces other than the earth's magnetism, and that they follow the laws observed by the motion of cathode rays in stationary magnetic fields. Finally, he supposes for simplification of the computations that the earth's magnetism, in accordance with Gauss's hypothesis, is considered as caused exclusively by magnetic masses in the interior of the earth; further that the earth's magnetic field may be considered as equivalent to that of a uniformly magnetized sphere, or what amounts to the

trajectories turning round the nocturnal (evening and night side), hemisphere of the globe, the trajectories being supposed to come from the sun. In the neighborhood of this group there are seen other trajectories encircling the globe in an undulating fashion. On the morning side we have another series of trajectories bending abruptly away from the globe. Near the early afternoon side is seen a whorl, in the center of which trajectories approach the globe in spirals as illustrated in Fig. VI. The dotted circle corresponds to the luminous rings experimentally shown by the work of Birkeland, to appear under similar conditions.

These whorls and spirals and deflected trajectories were shown by Stormer to account remarkably well for the experimental work with cathode rays, when they were concentrated on a magnetized sphere through the magnetic field generated by such a sphere. If this is true, and if Birkeland's experiments reproduce on a small scale what we actually see when we stand under the arch of the aurora, we are led to the inevitable conclusion that corpuscular rays coming from the sun contribute to the effect or account for it completely.

There remains, however, one serious objection to this hypothesis, viz., the difficulty of conceiving of the enormous velocity these corpuscles (electrons) must possess in traveling from the sun to the earth in order to penetrate to the depths of the atmosphere at which auroras occur, velocities much larger than any heretofore observed in the laboratory.

An hypothesis meeting this objection, and, hence, perhaps more acceptable, is that put forward by A. Paulsen, who assumes that an enormous ionization and electrification takes place in the upper regions of the atmosphere, through the absorption of cathode rays coming from the sun, which daily is renewed, and when intense enough becomes visible through electrical discharge. Convection currents in these layers would account for the observed and difficult to explain curtain auroras, the characteristic feature of which is what appears to be a vertically hanging curtain consisting of densely coordinated parallel rays. Luminous waves may often be seen rushing through the display, the wave appearing to pass through the entire length of the drapery.

The color of the aurora is, more easily accounted for. The spectrum of the visible portion shows a primary line of λ 557 μ , while photographic spectral analysis has shown, during periods of great intensity, lines corresponding to λ 427 and 390 μ ; during periods of less

Fig. VI. The path described by a corpuscle in approaching a magnetic pole

intensity 2440, 433, 421, 407, 399, 394, 379, 374, 369, 357, 353, and 337 μ were observed.

The most prominent line corresponds to krypton, most of the other lines belong to krypton and such rare gases as argon, xenon, and neon.

Due to the great height at which auroae appear one would not expect to find the spectrum lines of nitrogen and oxygen, but only those gases which through their small molecular weight are a large per cent of the composition of the rarefied air in high altitudes, or which,

through their chemical characteristics, are especially susceptible to luminescence.

A complete theory including all the phenomena and meeting all the difficulties raised, is however, still expected to arrive.

The Psychology of Color—II*

Color as a Form of Consciousness

By Leonard Thompson Troland, Harvard University

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ANOTHER unsolved mystery of color vision is that of its evolutionary origin and its biological significance. To the layman it may seem absurd to ask "What is the use of color vision?" because there are so many practically important discriminations in our every-day life which depend upon, or at least are aided by a perception of color. However, the pertinency of the question increases when we consider, first, that nearly all of these practical situations have been created in the course of social development, because color vision already existed; and, second, that even in our complex colorific civilization the color-blind person gets along with very little difficulty, so that he may never become aware of his defect until he is carefully tested in the laboratory.

Some reasons exist for believing that originally color vision was developed as an adjunct of the reproductive function, and should be considered virtually as a "secondary sexual character." Color blindness appears in heredity to be a "sex-linked character," as it occurs some forty times more frequently in the male than in the female. The females of many species are drab, for protection, while the males are highly colored. It is not improbable that this may have been the case with the fur-coated progenitors of the human species, and that color vision is in reality a vestige of by-gone evolutionary conditions, which has now been distorted from its primitive function, the recognition of a mate.

A more plausible view is possibly to be found in the consideration that, although practically every judgment which we make on the basis of color can be made also on a basis of luminosity or shape, color discrimination greatly increases the speed with which such judgments can be delivered. The visual discriminative reactions of the color-blind individual are often slow and hesitant. The function of vision is of such tremendous importance for the welfare of the individual that any feature in its working which could add appreciably to its general efficiency would markedly increase the chances of the individual or species in the struggle for existence. Color perception, also, is more absolute than is the perception of luminosities. The tremendous changes in illumination to which the eye is forced to adapt itself make it practically impossible for the visual mechanism to evaluate luminosities save in relation to other, simultaneously presented, luminosities. On the other hand, although color adaptation occurs, its range is sufficiently small so that our color sense provides us readily with judgments of absolute as well as of relative color.

COLOR AND MENTAL EFFICIENCY

My feeling, to which I have already alluded, that the topic "The Psychology of Color," exhausted the contents of the science of color was somewhat allayed when the committee informed me, in answer to an inquiry concerning their conception of the scope of my paper, that what was desired was a discussion of "the affective value of color." My instinctive reaction to this problem was that nothing was known about it, and that probably there was nothing in it to be found out.

However, it is my good fortune to have at hand an account of the recent investigations of Dr. S. L. Pressey, in the Harvard Laboratory, on "The Influence of Color upon Mental and Motor Efficiency." Dr. Pressey's work, although of necessity limited in its scope, represents—so far as I am aware—the only systematic attempt which has thus far been made to study the relations of color to the higher psychological processes, under well-controlled laboratory conditions. In considering this subject, I shall therefore confine myself to a brief summary of his methods and results.

The problem of the *higher psychology of color* may be subdivided into the problems of color preference, and of the influence of color on mental efficiency. Both of these factors may be supposed to involve the influence of affective tone, *i. e.*, the pleasantness or unpleasantness of the color experience; or the emotional effect. The literature of these topics is fairly extensive, but it is characterized throughout by lack of scientific method and lack of agreement. Practically every color has been preferred

by one group of individuals or another, in one historic period or another. All of the colors have been employed as symbols of happiness, and all as tokens of death. Statistically, the literature makes no statements; one color appears to be almost as good as another for any purpose, except that of actually copying the aspects of nature. There is some agreement that brightness and redness have a "stimulating effect," but even this is very indefinite.

Dr. Pressey's results confirm this conception of the effective neutrality and equivalence of the colors, considered as isolated factors of experience. He made no attempt to deal with color patterns or sequences, such as enter into the chromatic fine arts, but simply studied the effect upon mental performance of single colors spread uniformly over the visual environment of the subject. The colors employed in the principal series of experiments were primary red, green and blue, of about equal saturation. The subjects sat before a table which was covered with a white, unglazed paper, and this was flooded with the colored light from above, the eyes being protected from direct glare. Large gelatine filters were employed, and the brightness of the table top was in all cases about 7 candles per square meter. Pre-exposure of the eyes was given to a "normal" tungsten light, for which the colored light was substituted (without dark interval) during the test period. The exposure periods were timed systematically.

As indices of the possible mental effects of the colors, Dr. Pressey made use of the subjects' performance in a number of fundamental "mental tests," and also measured pulse and breathing rates. Previous work by Stefanescu-Guanga, at Leipsig, had indicated a marked influence of color upon respiration and heart action, but Dr. Pressey's carefully taken records show absolutely no consistent effects of this sort. Nine subjects were tested, over a period of ten to twelve weeks.

In order to test the effect of the colored light upon general muscular facility, the subjects were required to tap at a comfortable rate with the finger during one-minute periods. The five subjects employed showed no influence due to color, although significant increases in the tapping rate were obtained by increasing the *brightness* of the light, proving the test to be sensitive to the general sort of effect which was being studied. Another test of a similar nature, sensitive to changes in general neuro-muscular tone, consisted in requiring the subject to register a definite pressure with the hand upon a postal scale. The results again were negative, both for color and for brightness.

Closer contact with the immediate affective experience of the subject was obtained in a series of experiments made upon the effects of color upon the pleasantness of "touch substances." These touch substances were simply small squares of materials varying in texture. The subject passed his finger tip over them in succession, while exposed to the action of the colored light, and estimated the pleasantness or unpleasantness on a subjective scale of seven "points." Twenty substances were used, but no influence of the color upon the judgments was evident.

A further test, clearly involving mental efficiency, was that of the rate of multiplying under the colored illumination. Great care was taken to allow for practice effects in this work, and although increased brightness increased the rate of work, no specific effect due to color could be detected.

The next test to be tried was that of the so-called "free association experiment." The procedure of this experiment is simply for the experimenter to speak a single word, and for the subject to reply as quickly as possible with the first other word which comes to his mind through association. The time required for him to "think" of this latter word is taken with a stop-watch. The recall of ideas by association is of course one of the most fundamental principles of mental action. Eight subjects were tested over a long period, but no influence either of color or brightness was found. Similarly negative results were obtained with respect to the rate at which the subjects memorized nonsense syllables.

The final test employed by Dr. Pressey in his experiments is what he calls a "continuous choice reaction." In the ordinary choice reaction experiment the subject is required to react in one way if a certain stimulus is presented, but in a different way if a certain other stimulus is presented. In other words his muscular response is specific with reference to the stimulus. In Dr. Pressey's continuous choice reaction, as soon as the subject has completed one reaction he is automatically presented with another stimulus, to which he must react immediately, and so on indefinitely. The number of correct reactions which he can make in a specified time determines his score in the test. This test presents in elementary form the typical situation which we face in all neuro-muscular or mental adjustments, but no appreciable influence of color upon the average performance of six subjects, could be detected; although brightness had a slight effect.

During the experiments, Dr. Pressey often required his subjects to make introspective reports concerning the affective value of the colors, as directly experienced. These reports not only showed very little consistency from individual to individual, but also varied from day to day in the same individual. Red was more often found to be exciting than indifferent, and bright illumination was usually preferred to dim, but in certain subjects the reverse was true.

Dr. Pressey, himself, would not claim that his experiments dispose entirely of the proposition that the use of color in lighting may have a practical influence upon human happiness or efficiency. The tests employed, although representative of fundamental psychological functions, were not exhaustive. It would be desirable to supplement laboratory investigations of this sort by experiments carried out with actual factory operatives working in their usual environment. However, it seems to me that Dr. Pressey's work, being carried out with 26 subjects, over a period of three years, does establish a strong presumption that the higher psychological influence of color in illumination—if it exists—is of very minor importance.

Dr. Pressey's tests were designedly selected so that their results would not depend upon any direct ocular factors, such as for example, visual acuity. Owing to the chromatic aberration of the eye, monochromatic light gives a better defined retinal image than does white light. Moreover, Nutting has shown that the eye is quite accurately corrected for achromatism in the midregion of the spectrum—the region of high visibility—but very poorly corrected in the end regions. Consequently, since in practical lighting we are forced to employ a wide spectral range, the acuity factor would seem to demand the use of yellow green. Considerations of luminous efficiency also obviously make the same demand.

It should be borne in mind that generalizations concerning the psychological effects of color may fail to apply to individual cases. The generalizations are simply averages, in which a multitude of individual differences cancel one another out. The affective values of specific colors in individual mines will depend upon the idiosyncrasies of individual experience. Psychopathic cases are not rare in which the sight of a certain color suffices to induce an hysterical fit or to arouse an emotion of terror which quite paralyzes the mind. Such phenomena, however, are due to associations of ideas based upon past emotional experience, and may occur in connection with stimuli of any sort. Uniformities in the social environment of all human beings may produce some uniformity in these associations, such as that of red with danger—blood, fire and railway signals—but actually these uniformities do not appear to be very marked.

CONCLUSION

Even if the utilization of a homogeneous spread of color in illumination should not recommend itself upon rigidly practical grounds, this would not mean that the illuminating engineer should lose his interest in color. The affective value of color lies essentially in *color combinations*, and the production of color combinations which are pleasing to the eye, although primarily a task for the

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