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The fear of the Lord is the beginning of wisdom. Psalm 111:10

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Science and Human Relations

Achievements in the realm of the physical sciences have encouraged many investigations to employ the same ideology and methodology to the study of inter-human relations. As a consequence much work is being planned and published in this field today and some of it is at variance with traditional Christianity as expressed in American protestanism and the political and social pattern which it has fostered. The following illustrative excerpts are taken from: "Social Responsibility" Chisholm, Science, 109, 27 (1949)

(1) "Only in the last few years has it become clear to the people in all countries who are capable of thinking independently of the hysteria of the media of mass communication that this old method of competitive survival has become synonymous with racial suicide."

(2) "Business men trained to make profits, or old-time diplomats trained in gentlemanly behavior and the classics are also obviously inadequate to the needs of interhuman relations on a world scale."

(3) "Most of us by being civilized too early or too forcibly have been driven to believe that our natural human urges are "bad," "not nice," "wicked," "sinful," or whatever the local equivalent may be. This is the dreadfully damaging concept of "original sin" which really only states that babies are not born civilized according to the local customs of the natives."

(4) "It appears that a system which imposes an early belief in one's own sinfulness, or unacceptability in ones natural state, with its consequent inferiority feelings and anxiety, must be harmful to interhuman relationships and to the ability of the human race to survive in the kind of world this has become."

It seems clear from these statements that current sociological ideology is in conflict with some of our major Christian doctrines. Surely original sin, or any sin is more than our lack of being "civilized according to the local customs of the natives." Likewise when " a system which imposes an early belief in ones own sinfulness" is accused of being harmful to interhuman relationships, we must consider that traditional Christianity, if not being subjected to a frontal assault, is being undermined very rapidly.

It appears that Christians who are students of the sciences dealing with interhuman relationships such as psychology, psychiatry, sociology and anthropology will face an increasingly formidable foe in the future. There can be no doubt that there is a great field of Christian service and study in the subjects mentioned above. American Scientific Affiliation Members would do well to invite into their ranks more earnest Christian scholars who have chosen careers in the sciences of inter-human relationships.

REPORT ON THE 1949 ANNUAL

CONVENTION

Paul DeKoning

The third annual convention of the American Scientific Affiliation was held at Calvin College in Grand Rapids, Michigan, on September 1, 2, and 3.

It was a source of real pleasure and genuine profit for those who attended this year's convo to renew old acquaintances and make new ones among the men and women whose purpose it is to honor the Lord in their scientific achievements. As in the two years past, it was splendid to have fellowship with those of "like precious faith" who are engaged with teaching and research work in various fields of science.

I'm certain that I speak for everyone on the program committee as well as for those of our membership who attended, when I say that we appreciated very much the fine hospitality shown us by the faculty and staff of Calvin College. Every courtesy was extended to us, and we were all made to feel right at home in the splendid dormitory where a number of us stayed during the conference. We extend our thanks to the local arrangements committee, Mr. Mart Karsten, and Dr. Edwin Monsma. Especially do we thank the good wives of these two gentlemen for preparing the fine lunch for us during the evening of our arrival. Thanks must also be extended again to the other members of the College who made our stay so pleasant.

As was the custom at our other conventions, we began our day's activity with a devotional period each morning. The singing of hymns, the brief expositions of the Word, and the fellowship in prayer were all stimulating, and continually reminded us that our first responsibility was to seek the Lord. We can attribute every successful part of our program to the fact that we did seek to serve the Lord in all that we did. One thing that stands out clearly in this year's convention which was also evident in the others, was the spirit of earnestness and keeness in seeking knowledge, not for it's own sake, but for the glory of the Lord. This was especially noticed in the kindly and charitable attitude among us as we carried on our various discussions. This surely must have been the result of much prayer on the part of all the members prior to the convo, and during our time together. For this I am sure everyone was grateful.

Those of us at the conference this year witnessed the successful culmination of several years work in the issuing of the Student handbook, "Modern Science and The Christian Faith." This book was received with favor, and many copies were distributed to members and also to the public during the meetings.

This year we attempted to provide for more complete coverage of the discussions and remarks concerning the various papers presented, by employing a court stenographer. This gentleman took down all remarks with the stenotype machine, making it possible for the first time for us to have an accurate record of all the convention transactions. Thus we can share with those who did not attend the meetings all the interesting things which transpired.

Subject matter of the papers presented was of a varied nature. It was gratifying to see how everyone was vitally concerned with the material given, as was noticed by the lively discussions which followed every paper, and continued even after the various sessions were over. More than this, it was clearly evident that the members of the ASA were earnestly trying to face the scientific problems of the day, and were not merely interested in advocating some pet theory of their own. Considerable disagreement among us on some problems demonstrated this. Again it can be truthfully said that in all of our agreements and apparent disagreements, there was displayed a remarkable Christian spirit, by all in their remarks during and after the meetings.

The two public meetings which were held in the evening as before, were very well attended. The college auditorium was well filled on both evenings. Dr. Allan MacRae presented some very interesting material on Archaeological matters the first night, and at the second public meeting the new film "Voice of the Deep" was shown. In addition to this, our President Mr. Everest spoke briefly along with Dr. Marion Barnes, concerning the work of ASA. It was felt that this was an excellent opportunity to publicize the activities of ASA.

A special feature of our convention this year was the visit made to the Psychopathic Hospital at Cutlerville. Our tour was conducted by Dr. Gelmer Van Noord, chief of staff for the hospital, and proved to be very interesting. We were able to see first hand the fine work being done by this outstanding institution in an effort to help the mentally ill.

In conclusion, I would like to say that it was a pleasure to have been able to work on the details of the program for the 1948 convention. Any success which we may have had can be attributed to the goodness of the Lord in supplying the willing workers who presented the papers, and led the discussions.

Book Review
THE ROAD TO REASON
By
LeComte Du Nouy

"The Road to Reason" represents the matured expression of an eminent biophysicist who has had a prodigious scientific experience. Born and educated in France, Lecomte du Nouy obtained the degrees of LL.B., Ph.B., Sc.B., Ph.D., and Sc.D. He was an associate member of the Rockefeller Institute, Head for ten years of the Bio-Physics division of the Pasteur Institute and the author of some 200 published papers before his untimely death in 1947.

Far from establishing in him a scientific positivism, which he abhored, or an unlimited confidence in the human intelligence to solve all mysteries, the author's total experience raised in his mind serious questions regarding the validity of some generally accepted theories, reasonings and concepts. Lecomte du Nouy states that in the last fifteen years, "...our self-confidence has been somewhat shaken. Everything seems more complicated than we had first thought. We have become more prudent, - less affirmative."

While embracing evolution the author frankly discusses the "fragile basis" of the structure, the ignorance of cause, the improbability of a single protein molecule ever having been formed by chance - not to mention life and progressive evolution. He points out that even such "explanations" as exist can be not more than mathematical formulations which only tend to the illusion of understanding.

Lecomte du Nouy ascribes no moral character to science. He refers to the bankruptcy of the "Goddess of Reason" and adds, "We can not ask science to raise the moral level of humanity. The present state of the world is proof enough of that."

For all these problems the author postulates a directive force, "an 'anti-chance' which it is easier to call God." In "Human Destiny", written seven years later Lecomte du Nouy is more convinced that the inability of chance "inevitably leads to the idea of God."

The book makes most interesting and stimulating reading both from the standpoint of the material presented and the author's vital, lucid style.

H.J.O.

Moody Institute of Science Plans New Picture:

Blindfolded bats avoiding obstacles, fish spawning up on dry sand, the mystery of bird imigration, hearing molecular bombardment of the eardrum in one of the quietest spots on earth are some of the subjects being treated in Moody's latest film, as yet unnamed.

The audience will hear the ultrasonic cries of bats as they operate their locating equipment, the forerunner of modern radar and sonar. The halteres, or balancing organs, of the house fly will be demonstrated; the source of the suggestion for the latest development in gyros, the vibrating gyro.

Did these just happen? Are they parts of a great accident? Did the laws of chance mold them?

The picture is scheduled for September 1st release and it will be shown first in civic auditoriums in the larger cities across the country. All three Moody films released to date, "God of Creation," "God of the Atom," and "Voice of the Deep" bear ASA approval. This means that a committee of ASA scientists has studied the script and the film in detail and that upon their recommendation, the council has passed upon its scientific accuracy. The new film will also be subject to this scrutiny prior to release.

ASA Members of L. A. Area Meet:

On the evening of February 21st, the ASA group of the Los Angeles area met in Prof. Peter Stoner's new home in Altadena. The arrangements for the ASA convention in Los Angeles in August were discussed at some length. After this, critical evaluations of various chapters of Modern Science and Christian Faith were presented. Chapters so treated were those on biology, mathematics, and Christian Interpretation of Science.

The ASA members present were: Earl C. Rex, David M. Spaulding, Edgar B. Van Osdel, Hawley O. Taylor, Walter E. Lammerts, Peter W. Stoner, and F. Alton Everest. Guests were: Lewis H. Humphrey, Carl F. H. Henry, Prof. Spauldings son, and Bernard Ramm.

1949 CONVENTION:

Please note: the time of the 1949 convention has been tentatively set for the week of August 21st. For a consideration of several vital scientific and Christian issues, for a stimulating time of discussion by those who know, for grand Christian fellowship, and for an opportunity of seeing Southern California and points of scientific interest on field trips---MAKE YOUR PLANS NOW TO ATTEND!

24 Feb 49
FAE

A Physicist's Glimpse of God

Prof. Paul Bender, Ph.D.

Goshen College, Goshen, Indiana

There are two sources of human knowledge. The one of these is purely human whereby knowledge is obtained through human observation, experimentation and reasoning by the method commonly called the scientific method. This is the only source commonly considered valid in current intellectual circles, and the entire body of knowledge commonly accepted by the present intellectual world has been accumulated by this process. This knowledge is cumulative and is growing rapidly, perhaps more rapidly at the present time than ever before in human history. When God told Adam and Eve to "replenish the earth and subdue it", I think He had in mind not only that man should dominate the animal life on earth, and that he should exploit the natural resources of the earth, but also that he should accumulate knowledge about the created universe, and should use this knowledge for his own purposes.

The other source of knowledge is Divine revelation. God has spoken to man in order that He might show to man who He is, what is His character, and what is His purpose in creation, as well as His purpose and plan for man himself. This revelation has come to man through God's inspiration of writers of the Holy Scriptures, and also, in its supreme form in the coming of God himself to the earth in the person of Jesus Christ. This is an important source of knowledge, giving to us information that could not have been obtained through the human source. The knowledge thus made available is essential to our present and ultimate well being. It is also necessary for giving proper interpretation to the knowledge obtained through the human source.

From these two sources are obtained bodies of knowledge which, in the final analysis, are in perfect agreement with each other and are supplementary to each other. Knowledge from each source will illuminate and interpret that from the other. This follows from the very nature of truth, because truth must agree with itself from whatever source it comes. Experience has also amply demonstrated that truth revealed in the Bible agrees perfectly with the truth obtained by human reasoning, when that reasoning is correctly done.

On the one hand, God's revelation gives meaning to the universe about which man is attempting to obtain information. The Bible points the way to a correct interpretation of the universe and is a good source for suggestions as to lines of approach for research regarding the ultimate character and history of the universe.

On the other hand, human knowledge also illuminates God's revelation. For example the remarkable harmony found in all creation gives meaning to God's statement concerning His creation that He "saw that it was good." Also, the knowledge modern science has accumulated regarding living organism, particularly to the nature of species and the laws of heredity, gives meaning to the story of creation in which it is specifically stated that all animals were created "after their kind."

An interesting example of the manner in which human knowledge confirms the revelation of God's creation is found in the reasoning of the physicist-philosopher, Sir James Jeans. In an effort to explain the nature of matter, physicists came to the conclusion that a mathematical statement of the nature of matter was the only adequate explanation possible. Since mathematics is the product of pure reasoning, and reasoning is an activity of the mind, Jeans arrives at the conclusion that behind the universe there is a reasoning mind similar to the human mind, which is the ultimate cause of matter. In other words, he concludes that there must be a personal Creator. This, however, is as far as human reasoning can go. It is necessary for us to learn from revelation who the Creator is and what are His characteristics.

The present discussion proposes to point out another line of reasoning, in which some of the findings of physics are used to determine something of the character of the Creator of the universe.

The physicist looks upon the physical universe as being composed of three fundamental quantities: space, mass and time. Each of these quantities is measurable, and the commonly used units of measurement are the centimeter, gram and second, or more recently, the meter, kilogram and second, respectively. All other quantities in the physical universe are derived from these three; for example, veolcity is a combination of space and time, being the time rate of motion in space. The many other quantities used to interpret and describe the physical universe are similarly derived as combinations of two or more of these fundamental quantities.

Space is three-dimensional, having length, breadth and depth. Time is one-dimensional, extending from the past through the present to the future. Intuitively we think of mass as being located within the framework of space and continuing throughout time. We thus isolate the three fundamental quantities, thinking of them as being independent of each other.

We as humans are limited in each of these three quantities. We ordinarily think of being most strictly limited in time. Time marches on inexorably and we are entirely powerless to alter our position in time. We must live in each particular moment as it comes and we are carried forward in the stream of time without the least ability to increase or decrease its pace. We cannot project ourselves into the past nor into the future.

We are also extremely limited in space, although here we feel a certain amount of freedom in that we are at liberty to move about from place to place. For instance, each of us, on his own volition, determined to travel from his home to Grand Rapids. We felt perfectly free to make this decision and to execute the journey. However, it was absolutely necessary in making this journey that we should traverse all the intervening space. We had to cover every foot of the way from home to Grand Rapids. Before starting the journey, we could in our mind imagine ourselves at Grand Rapids, but we were perfectly powerless to realize that imagined fact without first traversing the intervening space.

We are also limited by mass. Each of us, as a human personality, lives within a physical body, and the physical body places very real limitations on our activities. We must live within the framework of space, time and mass with certain definite limitations imposed upon us by each of these quantities.

Another simplifying approach made to the physical universe by physicists is to consider that everything within the framework of space and time can be thought of as composed of two entities, mass and energy. These two entities can never be dealt with entirely independently of each other. That is, mass must always be thought of as having energy associated with it, both in the gross manifestations of mass as well as in the ultimate dynamic nature of matter itself. On the other hand, energy is known and can be studied only as it manifests itself in matter. Radiation may be thought of as pure energy, but even radiation cannot be detected or studied apart from its effect upon matter. This classification into mass and energy is less fundamental and less comprehensive than the simpler classification into space, time and mass. It is, however, fundamentally valid, particularly for large scale phenomena, as evidenced by the laws of conservation of mass and energy, which are extremely fundamental and general in their application.

The famous Michelson-Morely experiment, in which an effort was made to measure a change in the velocity of light with a change in the velocity of the observer, and which led to a purely negative result, opened the way to a new approach to the study of the fundamental quantities of the physical universe. In an effort to interpret the negative result of the experiment, there was finally developed what is known as Einstein's relativity theory. This theory links together intimately the space and time entities, and the mass and energy entities.

We are accustomed to thinking of a wave motion, such as sound, as traveling with a definite velocity in such a way that the velocity of arrival at an observer is changed by the velocity of the observer. That is, if the observer approaches the source of sound, the apparent velocity of the sound is increased, whereas if he recedes from the source, its apparent velocity is decreased.

This is not true with light. As the observer approaches the source of light or recedes from it, his measured velocity of the light is the same. The reluctance with which we accept this fact results from our own limitations in being a part of the system which we are attempting to interpret. If it were possible for us to obtain a perspective where we would observe the system externally, these limitations would be removed. However, it is necessary for us to examine the universe from our own vantage point within it.

The ultimate result of the fact of the constancy of the velocity of light is that the velocity of light is an essential feature of the universe.

Velocity is a derived quantity, involving both space and time. The relationship referred to would seem to point to the fact that these two fundamental quantities are inter-related and not independent. In fact, Einstein's relativity theory links them together. Instead of the three-dimensional space and the one-dimensional time, the two are tied together in a four-dimensional relationship. This seems to us to be a strange relationship because we are accustomed to freedom of motion within each of the three space dimensions, but to no freedom whatsoever within the time dimension, whereas the four dimensional relationship of the relativity concept would seem to permit equal freedom in each of the four dimensions.

Mass is also included in this inter-relationship. One of the most significant results of the Einstein study was the conclusion that there was a relationship between energy and mass having the square of the velocity of light as a proportionality constant. No longer can we consider that energy and mass are independent quantities, each with its own fundamental law of conservation, as earlier postulated. Mass and energy are now known to be interchangeable, and the two conservation laws are merged into one law of conservation of the total mass-energy content of the universe.

This truth has opened up many new areas of understanding of the universe. For instance, the radiated energy of the stars, including our sun, has as its source the mass of the stars. In the area of the understanding of matter itself, it is now evident that this relationship is very fundamental to the structure and behavior of the atom. The electical nature of matter, including the fact of the positive charge on the atomic nucleus and the negative charge on the orbital electrons, was a very fruitful concept in interpreting the extra-nuclear behavior of the atom, but was entirely baffling in attempting to understand the nucleus itself in which many positive charges with tremendous forces of repulsion actually were held together in a stable combination. We now know that the formation and the decomposition of the atomic nucleus involves a mass-energy transition in such a way that the ultimate nature of the stability of the atomic nucleus must result from a maximum energy relationship in which the energy changes are accomplished at the expense of the mass of the nuclear material.

These relationships strike at the very heart of the problem of the ultimate nature of the universe. They reveal that we cannot think of the universe as composed of three more or less independent entities in which we intuitively think of mass as being independently placed within space, and of time as moving forward without any essential connection with either space or mass. We have been forced to recognize that these intuitive concepts are inadequate and that there is only one basic entity which we see in the triple aspect of space, mass and time.

Because we are a part of this universe, we can only with difficulty assume an imaginary external viewpoint from which we attempt to examine and understand the real character of the universe. If it were possible for us to stand off without limitations of space, time, or matter, and see the universe, many of these difficulties would no doubt disappear. It is just this detached viewpoint, however, which the Creator must of necessity have in producing and sustaining the creation. We may be able to get some small glimpse of the Creator as we attempt to interpret the universe from such a vantage point.

The Creator must, of necessity, be free from the limitations of the universe which He creates. An understanding of these limitations and of the situation in which the Creator is free from the limitations will give us some information as to the character of the Creator. God will not be limited by time as we are. He will not be limited by space, nor will he be limited by the matter which is a part of his creation. Let us examine briefly each of these three freedoms.

When God replied to Moses' request as to how he should tell the children of Israel who God was, He told Moses to say, "I am that I am." When Jesus was defending his own identity before the Jews who were questioning his authority, he said, "Before Abraham was, I am." Each of these statements is best interpreted as meaning that God is timeless. In other words, God is beyond the limitations of time. He is not carried forward with the flow of time between the future and the past as are we. He can grasp at one sweep the entire scope of time, and can, without hindrance, see and direct whatever is happening at any period of time. Peter said, "One day is with the Lord as a thousand years, and a thousand years as one day." In other words, time has no such meaning to God as it does to us.

Since God is free from time, it is absurd to speak of any beginning or ending of His existence. Neither is eternity, then, a matter of infinite existence in the past and continued infinite existence in the future, but merely of a timeless existence. With this viewpoint, eternity takes on a new meaning. Eternity is not an endless existence in which one always exists in the present with time flowing on for an infinitely long period, but simply a freedom from the stream of time which carries the universe forward.

We speak of God as being everywhere present. This is merely a way of saying that he is not limited by space. God can comprehend all of space without the necessity of concentrating on any one place or of moving his attention or his presence from one place to another. He is completely free from the necessity of existence within a particular portion of space such as we are. The place of God's existence, therefore, has no meaning in that His existence is beyond place.

Similarly, God is not limited by mass or matter. He is not composed of matter with its limitations of inertis and spacial and temporal existence. He does not have a body in the sense that we as humans must live in a physical body.

These views are necessitated by the fact that God is the Creator of the universe He must of necessity be superior to his creation and to its space, time and mass limitations. The fact that the space, time and matter existence of the universe is not a triple existence but a unit existence, in which the three entities are thoroughly integrated into the make-up of the universe, helps us to recognize that God's existence is entirely beyond the limitations of these three entities as we usually think of them. Also the unity of the physical universe points to the necessity of a single act of creation of this physical universe, including not a temporal creation of matter within space, but a simultaneous creation of time, space, and matter.

This view will be further clarified and will also shed light on our own existence if we examine our own eternal existence in the light both of the viewpoint presented here and of the teachings of God's revelation. God has stated that man is created in the image of God. We take this to mean that man has a personality similar to that of God and capable of fellowship with Him. In his present existence, however, man is limited by the limitations of the universe in space, time and matter. It is clearly stated, however, that man ultimately has a possibility of existence with God. Man's eternal existence will then take the form of complete identity with the nature of God and fellowship with Him. This existence must, therefore, be one in which limitations of space, time and matter are removed. Eternity will then become not a question of infinitely long time, but merely of timeless existence in which there will be no past, present, nor future. The place of this existence will also have no meaning in the sense of being somewhere in space. Conjectures as to where heaven is are, therefore, meaningless because the eternal existence will also be free from the limitations of matter. The glorified body of our existence will not be made of atoms and molecules, but will be, like God, completely without matter as we know it in the universe.

From this view, creation was not an act of the formation of mass within a previously existing framework of space and time, but was rather the formation of the universe as a whole, which, of necessity, brought into existence simultaneously the continuum which we now know as space, time and matter. Since it is impossible to describe the universe without having these three supposedly independent quantities very definitely inter-related, it is also impossible to think of either one of them existing without the others. By that same process of reasoning, we can conceive of this created universe not only to have had a beginning with the beginning of time, but also to come to an end with the end of time. In other words, the entire span of time must be contained in the existence of the universe and will not contain an eternity. If time and the universe of which it is a part come to an end, then there will remain the timeless existence of God and the creature he has created in his own image. The mysteries of this existence can be understood here and now only through the revelation God has chosen to give to us. This revelation gives us the assurance, however, that our existence is like His. We are promised eternal life, beginning now. This means that if we are in accord and in fellowship with God that this fellowship has a continuous existence. We may think of this existence as having two aspects, the first in time, and the second in timeless eternity. So long as our existence is in time, we are limited by the limitations imposed upon the universe of time, space and matter. After deliverance from these limitations, this existence will be like that of God himself where the limitations are removed. The Apostle John gives us a view of this existence with God when he says, "Beloved, now are we the sons of God, and it doth not yet appear what we shall be, but we know that when He shall appear, we shall be like Him."

THE EYE AS AN OPTICAL INSTRUMENT

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"Sturmius, says Paley, held that the examination of the eye was a cure for atheism'. Yet Helmholtz, who knew incomparably more about the eye than half a dozen Sturms, describes it as an instrument that a scientific optician would be ashamed to make; and Helmholtz was no atheist."

This quotation from Professor Ward's Gifford Lectures[1] is a reference to the celebrated popular lecture[2] of Helmholtz on vision. In view of the commanding influence on visual science which he has exerted for over ninety years since the beginning of the publication of his Handbuch der Physiologischen Optik (1856-66), his views on the characteristics of the eye as an optical instrument carry great weight. The importance of this subject from several standpoints has led the writer to assemble the latest measurements on the defects of the eye, as well as all the statements of scientific men of unquestioned authority in this field of enquiry that he could find.

First of all, the words of Helmholtz himself are given so that there may be no doubt as to what he did say.

"Now it is not too much to say that if an optician wanted to sell me an instrument which had all these defects, I should think myself quite justified in blaming his carelessness in the strongest terms, and giving him back his instrument. Of course, I shall not do this with my eyes, and shall be only too glad to keep them as long as I can--defects and all. Still, the fact that, however bad they may be, I can get no others, does not at all diminish their defects, so long as I can maintain the narrow but indisputable position of a critic on purely optical grounds....All these imperfections would be exceedingly troublesome in an artificial camera and in the photographic picture it produced. But they are not so in the eye - so little, indeed, that it was difficult to discover some of these....The chief reason (for not observing the defects) is that we are continually moving the eye, and also that the imperfections almost always affect those parts of the field to which we are not at the moment directing our attention....For the eye has every possible defect that can be found in an optical instrument, and even some which are peculiar to itself; but they are all so counteracted, that the inexactness of the image which results from their presence very little exceeds, under ordinary circumstances of illumination, the limits which are set to the delicacy of sensation by the dimensions of the retinal cones....The adaptation of the eye to its function is, therefore, most complete, and is seen in the very limits which are set to its defects....The defects which result from the inexactness of vision and the smaller number of cones in the greater part of the retina are compensated by the rapidity with which we can turn the eye to one point after another of the field of vision, and it is this rapidity of movement which really constitutes the chief advantage of the eye over other optical instruments."

The defects of the eye, which are set forth so prominently in this discussion, should be reviewed in the light of the most recent knowledge of visual optics which

1. Naturalism and Agnosticism. Black. London. 3rd Ed. 1906. 2 vols, Vol. 1, p. 6.

2. Popular Scientific Lectures. Trans. by Atkinson. London, 1873. The Recent Progress of the Theory of Vision, p. 219, et. seq.

has been assembled both by Duke-Elder[1] in his exhaustive treatise on ophthalmology, and also by Hartridge[2] in his recent investigation of the visual perception of fine detail. For no optical instrument has been examined so minutely, critically and accurately as the eye, by men of the highest genius such as Helmholtz, Gullstrand and Tscherning.

In the optical system of an instrument, such as the microscope or a telescope, the surfaces of the lenses should be perfectly spherical and they should be centered upon a common optical axis. The mathematical theory of such a dioptric system, as originally developed by Gauss, demands, in addition, that it should be of small aperture, not more than 10°, so that the rays of light are limited to the axial regions, of homogeneous media, and that monochromatic light should meet the refracting surfaces nearly at right angles. It is with such an ideal system that all practical optical instruments are compared.

Because of the nature of light and its mode of propagation, as well as the nature of the refracting media which form the image of an object, all optical systems are subject to many aberrations. These defects must in some way be overcome or minimized or the image will be more or less imperfect. The method of optical correction is to use combinations of several lenses of different refractive powers and curvatures. In the microscope, an achromatic object glass, which forms the image, is composed of as many as six lenses, and an apochromatic object glass may have ten. These lenses must be made of carefully selected glass with accurately figured surfaces, and adjusted to each other with extreme precision. The focal length is quite small. So perfect can the image be made, that magnifications of more than 1500 diameters are possible. They operate at a fixed distance from the object under observation, and the field of view is extremely small. In addition to the object glass there is the eyepiece with which the image is magnified and viewed. All the lenses are immersed in air so that the numerous surfaces have abrupt discontinuity with that medium. The telescope has fewer lenses, but the focal length is relatively large which minimizes or eliminates the most troublesome defects.

Compared with such complicated optical instruction, the human eye is rudimentary. The refracting system consists of the cornea, the aqueous humor, the lens and the vitreous humor or body. The lens, therefore, is immersed in the humors and not in air, which greatly minimizes the optical discontinuities. The indices of refraction of the two humors are practically the same (1.336), which differs but little from that of water (1.334). The lens is extra-ordinary in constitution since it consists of many layers or zones which vary in refractive index from 1.386 at the surfaces to 1.406 at the center. The cornea and aqueous humor taken together, form the major refracting medium of the eye, and the lens, by its power of accomodation, operates as the fine adjusting mechanism. The cornea-aqueous combination is about 2.5 times greater in refracting power than the lens, which is due to the relatively great difference in refractive index between the air (1.00) and the cornea (1.376), as compared with (refractive index) between the humors (1.336) and the surface of the lens (1.386). The rays of light are first refracted at the cornea and aqueous humor, second by the anterior zones of the lens, then by the core, and further by the posterior zones. In consequence of its structure, the lens has a greater refracting power if it were homogeneous with a refractive index equal to that of the core. Besides increasing the refractive power considerably, this arrangement diminishes the spherical aberration.

The fact of its decentration constitutes the main feature of the optical system of the eye. Strictly the cornea has no axis of symmetry, though the deviation is extremely small. The centering of the cornea and the two surfaces of the lens is never exact, nor are the various zones of the lens concentric with one another, and the lens itself is not concentrically placed upon the optic axis. The visual axis, which touches the fovea, makes an angle of about 5° with the optic axis upon which

1. Text-Book of Phythalmology. Kimpton, London, 1932. Vol. 1. Chaps. XVI and XVII. pp. 662-774.
2. Phil. Trans.Rou. Soc. London. Ser. B. Vol. 232, 1947, pp. 519-671

all refracting surfaces should ideally be centered. Vision therefore occurs obliquely through the system. "It is," remarks Duke-Elder, "as if one of the lenses of an optical instrument had slipped a little out of place and then when we looked through the instrument we tilted it very slightly. The deviations, however, are usually so small as to be functionally negligible, and they tend to some extent to minimize the aberrations of the eye."

It would seem, therefore, that the construction of the eye slightly violates all the conventions that apply to optical instruments. But the final result, nevertheless, is the formation of an improved image, as free from perceptible defects as those produced by the finest artificial systems.

The defects of dioptric systems, whether of glass or of the eye, comprise two main classes: first, aberrations originating from the composite nature of white light, termed chromatic aberration, and those arising from the structure of light and the manner of its propagation, called diffraction; second, monochromatic aberrations, or defects occuring with rays of light of a single wave-length: spherical aberration, the sine condition, refraction of eccentric rays, curvature and distortion of the image, and depth of focus, which is not a defect but a property of a lens.

The defects of the first group depend on the nature of light; those of the second group on the structure of the optical instrument.

The discovery of the spectrum by Newton (1664) established the composite nature of white light and the different refrangibilities of the colors. From these discoveries he erroneously concluded that an achromatic combination of lenses was impossible to devise. Apparently he gave no thought to the construction of the eye. As no chromatic aberration had ever been observed in it, Euler (1750), convinced that it was achromatic, stimulated the eminent optician Dollend (1758) to construct achromatic systems of lenses, such as telescopes, in which he was highly successful. He also discovered the chromatic aberration of the eye.

Chromatic aberration. Since white light is a mixture of many different wavelengths and as a lens has the nature of a series of prisms, the real image of a disc of white light formed by a convex lens consists of a superimposed series of images of all colors of the spectrum focused at slightly different distances from the lens. The violet image, formed by the most refrangible rays, is nearest the lens, and the red image the most remote. The chromatic difference of focus is very small, being from red to violet, about 0.47 mm. (Hartridge). Since the eye accommodates itself to the brightest yellow-green rays, the difference of focus is normally about half the amount for violet in front of the retina, and half for red, as it were, behind it. The separate color images or aberration discs are also of different sizes, termed the chromatic difference in magnification, varying, according to Hartridge, for the usual entrance pupil of 4 mm. diameter for the eye, from 0.0216 mm. in diameter for orange light to 0.0588 mm. for blue, the letter being 2.7 times the former. In ordinary vision these defects are extremely small, and since the blue image completely overlaps the red, it neutralizes that color into white leaving a narrow blue border which, because of its low luminosity, is practically invisible. The whole effect of chromatic difference in magnification tends to counteract the chromatic difference of focus. In the eye the effects of chromatic aberration are small; and with a 2 mm. diameter pupil, as Duke-Elder remarks, 70 per cent of the light falls on a retinal area of 0.005 mm. diameter. The remaining light is more widely diffused and normally is therefore unnoticed, so that images are free from colored borders, as common observation shows.

Diffraction. Diffraction is due to the spreading of the waves of light at the edges of the wave front. The effect is the opposite of chromatic aberration since it is greatest with the longest waves, the red, and least with the shortest, the violet. It follows from the nature of light that a point of white light is always brought to a focus as a small blurred disc (Airy's disc) of light and dark bands with a bright spot in the center. No point image can therefore be formed but only a diffraction pattern, which varies in dimensions directly as the focal length of the system and the wave-length of light, and inversely as the aperture, or area of the pupil, through which the light passes. Diffraction is inherent in the nature of light and its propagation and cannot be overcome. In optical instruments, such as the microscope, its effects are not troublesome except at very high magnifications about 2000 diameters, when the image itself becomes a complicated set of diffraction patterns.

The central bright spot of the diffraction pattern of a point source receives about 84 per cent of the incident light; the first ring 1/57th and the second 1/240th of the intensity of the central area. At a distance of only 0.02 mm. from the center, the light is of too low an intensity to be seen. Since the eye has a very short focal length of 22.78 mm., the diffraction effects with a pupil 4 mm. in diameter are correspondingly small.

Comparison of the figures for chromatic aberration and diffraction shows that they have the same order of magnitude, and are much too slight to be observed in the ordinary usage of the eyes. It is to be noted that the effects of chromatic aberration increase as the pupil widens; but as this condition changes act together to leave the actual definition of the image practically unchanged with alterations of the pupil. As pupillary areas are governed by the illumination, the definition of the image is therefore the same with all intensities of light.

These are the characteristics of the images of point sources. But "the extended source", according to Hartridge, "differs from the point source in an important respect, namely, that its image is largely composed of white light, and that color fringes are only found near its margins. Each of the fringes for a 4 mm. pupil is about 0.01 mm. wide. Only parts near the edge are strongly colored, and that as the distance from the edge increased the yellow fringes become progressively whiter and the blue fringe progressively blacker, until the yellow fringe merges imperceptibly with the white interior of the image, and the blue fringe merges similarly with the black background."

The mathematical theory of optical systems of lenses demands a very small aperture so that the rays are limited to the axial regions. In optical instruments an aperture of 10^{o} is considered to be the maximum compatible with efficiency. It is with this aperture that such instruments are designed to eliminate chromatic aberration and other defects. But the pupil of the eye is rarely less than 4 mm. in diameter which corresponds to an aperture at the cornea of 20^{o}. With a double size of aperture, therefore, the eye is equally free from aberrations, while optical instruments with such wide apertures would probably be useless.

<u>Spherical aberration</u>. In a biconvex spherical lens the peripheral or marginal rays are refracted more than the axial, so that the former come to a focus nearer the lens than the latter. This effect is called spherical aberration. It can be eliminated by grinding the lens so that its curvature decreases from the center to the periphery. Such lenses are termed aplanatic. Spherical aberration is diminished by making the curvature of the anterior surface of the lens, where the light enters, greater than that of the posterior surface. In the eye the lens has the opposite orientation since the anterior surface has a smaller curvature than the posterior.

With a glass lens of refractive index 1.5, immersed in air, the ratio of curvatures to give maximum spherical aberration is 1:6. With the lens of the eye, assuming an equivalent refractive index of 1.43, the ratio of curvatures would be 1:4, if surrounded by air. Actually the ratio is 1:1.7. The small degree of spherical aberration which the eye exhibits therefore indicates that the theory of glass lenses does not apply, in this regard to a lens of variable refractive index like the eye, when immersed in media of nearly the same index of refraction.

The chief corrective of spherical aberration is the pupil which shuts out the peripheral rays of light and admits the axial and those near it. The brighter the light, the more noticeable would be the aberration; but with greater illumination the smaller becomes the pupil, and the more axial become the rays admitted. "Although the eye does not form an aplanatic system", remarks Duke-Elder, "the effects of spherical aberration are small - much smaller than the effects of either diffraction or chromatic aberration. This is due partly to the fact that the cornea is flatter in the periphery than in the center, but more largely to the fact that the lens core is more highly refractive than the periphery. Both these circumstances cause the axial rays to be refracted more strongly than the peripheral ones, a tendency which counteracts the effect of spherical aberration....Regarding the eye as a whole, the axial area is usually under-corrected and shows a positive aberration, while the periphery is usually negative."

The Sine Condition. It is clear, therefore, that, by means of the automatic adjustable aperture of the pupil, as well as by other devices peculiar to the eye itself which are not available in any optical instrument, spherical aberration in the eye is reduced to such a small amount that no perceptible blurring occurs in the visual image.

Even though a lens system is designed to produce an image of a point free from spherical aberration, a wide pencil of light does not necessarily give a clear image of the area surrounding the point. Different zones of the lens may bring light from various parts of the object to different positions, so that the image is drawn out like the punctuation mark, the comma, the tail of which points to the optic axis. To prevent this from occurring, a certain mathematical condition must exist relative to the object in air and its image at the back of the vitreous body on the retina;namely, the product of the refractive index of air, the size of the object and the sine of the angle of divergence of the rays of light from it to the eye, must be equal to the product of the refractive index of the vitreous body, the size of the image and the sine of the angle of convergence of the rays forming it. This relationship is called the sine condition. "The eye," states Duke-Elder, "appears to obey the sine condition almost exactly, so that as far as comma is concerned the displacement of the fovea to the side of the optic axis is no disadvantage."

Refraction of Eccentric Rays. Since the eye is a decentred optical system, the pupillary line and the optic axis do not coincide, but differ in position by an angle of 5^{o}. The so-called determining ray to the foveais therefore somewhat peripheral or eccentric, and consequently suffers a little radial astigmatism. The determining rays are brought to a focus sooner than the equatorial rays which tend to interfere somewhat with visual acuity. The amount of the defect is only about one-eighteenth of the chromatic aberration, and still less of the spherical aberration; and is therefore of no significance in vision.

Curvature of the Field. It is a characteristic of a spherical lens to form a curved image on an object. On a plane surface the whole of the image cannot be in focus at once. The curvature of the field, as it is called, is corrected by having a curved image-plane. In the eye the retina is such a curved screen. Since its radius of about 10 mm. is shorter than the posterior focal distance (22.78 mm.) of the optical system, "it satisfies very closely the theoretical curvature for complete correction."

The image of an object formed by a lens is also subject to two kinds of distortion; one, in which straight lines crossing one another at right angles are either curved outwards, barrel-shaped, or inwards in the opposite direction in the image. At the same time the image is respectively diminished or enlarged in size compared with its normal area. The magnification of the ends of an object is also different from that of the middle. "Peripheral distortion of the image is almost theoretically corrected in the same way as curvature of the field," that is, but suitable curvature of the retina (Duke-Elder).

Depth of Focus. If several objects are at different distances from an optical system, their images will be formed at different distances also, so that if one is in facus the others will be slightly out of focus. The greatest distance of the objects from one to another, still having their images satisfactorily focused, is called the depth of focus. In other words, the greatest distance through which an object can be moved and still produce a satisfactory image without change of accommodation, is the depth of focus.

In the case of the eye, Hartridge has shown that with a pupil 3 mm. in diameter and with the eye focused for 24 meters, objects both at infinity and 12 meters will still be in focus at the same time. But if the eye is working at 25 cm., the normal reading distance, the depth of focus is reduced to 1.1 cm. As the pupil contracts during accommodation, the depth of focus increases. With bright light, a pupillary diameter of 2 mm. the depth becomes 3.2 cm. This property, therefore, relieves the strain of accommodation.

Loss of Light. In traversing the optical structures of the eye, light is reflected at all surfaces of sufficient discontinuity to do so. By this process a considerable quantity of light is deflected from the main dioptric path. There are six principal surfaces in the eye at which light may be reflected: the anterior and posterior surfaces of the cornea, the anterior and posterior surfaces of the lens and the surfaces between the zones of optical discontinuity within the lens. At each of them an image formed by reflected light can, by suitable means, be observed. But for four of the chief six images, the light forming them travels out of the eye and is lost. In the case of two, the light reaches the retina and tends to diminish the optical efficiency of the eye. In the case of microscope objectives there may be from 12 to 20 surfaces of such discontinuity where loss of light occurs. "The eye, however", says Duke-Elder, "sets a higher standard in this respect than most optical instruments, for the whole of the light thus lost does not equal 2 per cent." The loss of light is negligible in quantity since the refractive indices of the ocular media are so closely related, the lens being immersed in a medium of approximately the same index as itself. That of the humors of the eye is 1.336, and the refractive index of the outer layers of the lens is 1.386, so that the difference between them is extremely small; while in optical instruments the difference in refractive index between glass, 1.5, and air 1.0, is ten times larger.

Scattered Light. There is considerable scattered light reflected from the retina by which the fundus can be ophthalmologically examined. But very little of it confuses the retinal image. The shape of the fundus causes the reflected light to pass out at the pupil or to strike the insensitive anterior portion of the retina. The eye is also protected from oblique illumination by the nose and eyebrows, and the scattered light is effectively absorbed by the retinal pigment.

Halation. "Halation would appear to be of negligible amount. The term applies to the reflection of light back to the sensitive surface from other surfaces immediately above it; but the reflecting layer of the retina is so close to the rods and cones that this disturbance can be of little moment."

The defects which are recognized by ophthalmologists can all be detected by careful and expert examination. But by the vast majority of humanity they are never noticed, and they have no influence on the normal visual properties of the eye. Because they exist they can be referred to as defects, as the quotation from Helmholtz shows. But to exaggerate them grossly into an instrument that an optician would be ashamed to make, is to magnify them out of all proportion to the minute and unnoticed degrees in which they are to be found.

The mechanism of accommodation of the eye is the means by which accurate focusing of the image on the retina is automatically brought about. It is a muscular device which is optically and neurally controlled, and peculiar to the eye. It cannot be imitated in an optical instrument. The lens of the eye is quite plastic and enclosed within a transparent and highly elastic capsule which, under tension, is capable of moulding the lens into a more spherical form, but when relaxed permits the eye to resume its original shape.

In accommodation three elastic forces are involved which operate on the principle of double antagonism, that is beautifully adapted for protection of the lens from sudden and dangerous deformations. It has been fully described by Gullstrand[1]. The form of the lens is controlled by two antagonistic elastic forces, those of the choroid and the capsule; and at the same time the force of contraction of the ciliary muscle and the stronger of the two elastic forces, that of the choroid, act antagonistically. This arrangement protects the lens from the action of too strong external forces and from sudden variation of these forces. The elastic force of the capsule, that protects the change of form of the lens, is the weakest of the three, and, like all elastic forces, constantly diminishes in strength during the development of its effect, so that the movement terminates without any jerk. In the relaxation of accomodation, the greatest force producing the change of form is the elasticity of the choroid, and this force diminishes steadily during the movement, and at the same time the resistance of the lens capsule is continually increased by dilation. However, this means of protection would fail with decrease of power of the lens to change its form. Without that power every strong tendency to accommodation would result in a dangerous jerk on its structure. When it is realized that opacities, which impair or destroy vision, can occur in the transparent lens of the older person from its sudden and violent deformation, the great importance of the protective arrangement provided by the double antagonism of the forces acting in accommodation is obvious.

<u>Listing's Law</u>. A conspicuous and useful characteristic of the eyes is their extraordinary mobility which enables them to be voluntarily turned in perfect coordination in any direction within the obvious limits of possibility. No rolling motion of the eyes occurs as that would at once cause disorientation of the relative positions of corresponding retinal areas with a serious disturbance of vision. But when the eyes are moved in any direction, the movement is carried out with the greatest dispatch and the least expenditure of effort (Listing's Law). Operation according to this law causes the least degree of fatigue to the extra-ocular muscles which enables them to function for many hours a day. Listing's Law is a special case of the universal law of nature, known as Least Action, according to which all operations are performed with the least expenditure of time and energy. The law of economy of nature therefore operates with the eyes.

After reviewing the most recent estimates of the visual defects of the eye, it will be interesting to quote several other opinions of competent investigation.

Gullstrand[2] states: "Helmholtz's famous dictum that the monochromatic aberrations of the eye are such as would not be tolerated in any good optical instrument, is sometimes construed to mean that the eye is a very badly constructed optical affair - which Helmholtz never said and certainly did not mean. But another question that this statement raises is whether these aberrations are not serviceable and what is their purpose. First of all, it should be noted, as Helmholtz pointed out, that a limit is imposed by diffraction to the physical sharpness of the image."

In accommodation there is an elevation of the total index of refraction of the lens due to its structure which denotes a change of focusing out of proportion to the change of form that is unattainable with a lens of glass and is of the highest advantage. "The monochromatic aberrations," continues Gullstrand, "are the necessary evil

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[1]In Physiological Optics. Helmholtz. Eng. trans. Southall. Vol. I. p. 408.

[2]Ibid. pp. 440,443.

for obtaining this advantage; and even if the convergence of the rays is not as good as it might be, the clearness of the image in good illumination is still above the limit of the capacity of the eye as imposed by the laws of diffraction. Hence, the monochromatic aberrations are a witness for the perfection of the eye, if what is meant by the perfection of an optical instrument is good convergence of rays to the degree that is needed to obtain the greatest useful sharpness of image; anything in excess of this being sacrificed in order to gain some other end."

In regard to the statement of Helmholtz, Duke-Elder[1] remarks: "As in all optical systems, many aberrations are met with in the eye. It is frequently said that these are gross, and the statement is attributed to Helmholtz that the construction of the eye is such as would not be tolerated in any good optical instrument. If Helmholtz ever said this he certainly never meant it, for, as Helmholtz fully realized, the eye is constructed with extreme attention to detail in keeping the image as physiologically useful as possible, while at the same time retaining an immense range of adaptability. It is true that the peripheral field is sacrificed to some extent for the central field; but it is the latter which is of importance for the purposes of accurate function, and the functional capacity of this region is up to the limits imposed by the diffraction of light. For yellow light and a pupillary diameter of 0.6 mm. the limit of capacity would be a visual angle of 0.3 minute of angle; for a pupil of 3 mm. it would be 0.82 minute, and only for a pupil of 4 mm. is the angle for yellow light 1.22 minutes, while for green light it is 1.05 minutes. When these figures are compared with those of the minimum visual angle (0.40 minute) it is evident that the limit of possible visual capacity as imposed by diffraction is attained by the visual acuity. It would appear, therefore, that to sacrifice adaptability in the attempt to make the central acuity greater by optical means would merely be a task of supererogation."

It has also been remarked by Southall[2] : "The process whereby the normal eye is enabled to focus on the retina in succession sharp images of objects at different distances is called accommodation, and it is this marvelous adaptability of the human eye together with its mobility, which perhaps more than any other quality entitles it to superiority over the most perfectly constructed artificial optical instrument."

In the introduction to his extensive investigation of the visual perception of fine detail, Hartridge[3] states: "The resolution of a grating test object by a microscope requires that instrument to possess lenses of fine performace. These contain as a rule achromatic combinations of carefully figured lenses which have been adjusted in relative position with the utmost precision. The design of the eye appears rudimentary in comparison with such lenses, yet practical tests with grating and other test objects show that this elementary lens system, possessing apparently no chromatic correction of any kind, and certainly no flourite-like medium which could impart an apochromatic correction, behaves in an almost flawless manner. So good, in fact, is the apparent definition of the foveal image, that if the lens system of the eye could be removed and an apochromatic lens, selected for its good performance, could be substituted, it is doubtful if the possessor of this eye would detect any improvement in his perception of fine detail. What he would certainly notice would be a very serious deterioration at the periphery of his visual fields. His original eye lens gave him an angle of view exceeding a right angle. His new microscopic lens gives him a field of view almost insignificant in comparison. He now knows for the first time what it feels like to have 'tubular vision', that is, the type of vision produced by looking down a narrow tube. But other more subtle differences would soon be noticed. His original eye lens adjusted its focus automatically, and was almost equally good for observing near and distant objects. His new microscopic lens possesses no such valuable features.

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[1]Text-Book of Ophthalmology. Vol. I, p. 756.

[2]Mirrors, Prisms and Lenses. MacMillan. 3rd Ed. 1936, p. 434.

[3]Phil. Trans. Roy. Soc. Lond. B. 232, 1947, 523.

It has been designed to work at one fixed distance between object and eyepiece only, and a small error in this adjustment produces either over- or under-correction for spherical aberration. The performance of the eye lens is superior to that of the microscope lens, for the purposes for which it was designed."

The investigation of ophthalmologists which have been revised amply show that the optical defects of the eyes are so minute and unobtrusive in character that they are without detrimental effect on normal vision, as the testimony of the leading recent authorities indicate. It is therefore clear that the strictures on the eye in the first part of the remarks of Helmholtz are decidedly unjustified. But when the practical perfection of visual optical imagery, accommodation, rapidity of accurate focusing, breadth of visual field and mobility of the eyes, are added the remarkable acuity of vision and color sensations with which images are perceived in detail and adorned, as well as direction of vision, binocular coordination, perception of depth and adjust- of distance, all of which are automatic in action, the eyes obviously far surpass all possible optical instruments in performance.

Finally it should be remembered that the eye differs from all other optical instruments in being a living system, and is preeminently the organ of the chief intellectual sense. By itself its own minute defects are assessed. With its exquisite discriminating power it pronounces ultimate judgment on the degrees of perfection of performance attained by artificial instruments. No inferior instrument could give a valid judgment on a superior.

The Visual Apparatus As A Telescope. It is often stated that the eye resembles a camera in its construction, and in some ways the likeness is quite complete. But the eye itself comprises only half the visual apparatus, for the area striata in the cortex cannot be separated from the visual process for it is there that vision actually takes place. The striate area, however, exercises a much wider function than only to provide sensations of vision.

The area striata, or visual cortex, consists of a number of folds in the calcarine areas of both cerebral hemispheres. If spread out flat it would be oval in shape with a total surface of about 3000 sq. mm., about evenly divided between the macular and peripheral areas of the retina.[1] The area of the functional retina is about 905 sq. mm., of which the macula comprises only about 3 sq. mm. The optic nerve fibres, about 500,000 for each eye proceed from the retina to the lateral geniculate body, whence they continue in increased numbers, as the optic radiations, to the area striata. The macular fibres number about half the total; that is, there are as many nerve fibres reaching the striate area from the 3 sq. mm. of the macula, as there are from the remaining 900 sq. mm. of the rest of the retina. The macular fibres therefore spread out over the striate area of 1500 sq. mm., in the ration of 3:1500 or 1:500. There is clear evidence that both retinas are represented in the same striate area. Possibly the two macular images of an object differ sufficiently in the striate area so as to excite the perception of depth.

From these figures it follows that an image covering the macula is spread out over a striate area 500 times the size, or the image is magnified at least 500 times. Since there is an increasing concentration of cones, which function in form vision, from the boundary of the macular towards the central fovea, it is probable that in the striate area the part corresponding to the fovea is expanded in like proportion.

Marshall and Talbot[2] state that a pattern 1 minute of arc wide at the fovea expands in the striate area 100 times linearly, or 10,000 times in area. The area striata is also stated to be from 30 to 600 times as fine grained as the retina, which

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[1] G. Elliot Smith. New Light on Vision. Nature. 125, 1930, p. 820

[2] Biological Symposia. Cattell Press. 1942. VII, 117 - 165.

would counteract its relatively coarse mosaic structure.

The fovea, which is the retinal area of distinct vision, has an area of about 0.05 sq. mm. Its cortical expansion in the striate area will not be less than 500 times this amount, or 25 sq. mm., nor more than 10,000 times, or about 500 sq. mm. (1sq. in -- 645 sq. mm.). In other words the foveal image is magnified in the cortex by an undetermined amount between 500 and 10,000 times, possibly about their mean value.

These facts and computations signify that the visual apparatus as a whole represents a telescope, of which the eye is the objective, the area striata the magnifying device, and consciousness the observer. The macular image of a man's face at a distance of about 3 meters is approximately 0.75 sq. mm. in area. To detect in this minute image all the details of form and color would be little short of miraculous. But in an image enlarged several thousand times, the discrimination of fine detail and color would be easy, as experience shows to be the case.

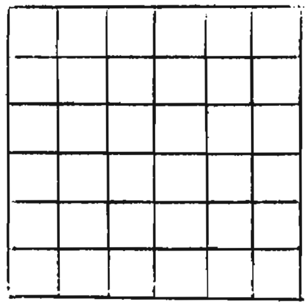
The optical magnification of retinal images in the cortex is obviously out of the question. But the neuro-mechanical magnification is effectively designed to take its place. In a telescope the eye-piece and the objective must always be kept rigidly in alignment. In the visual apparatus this is unnecessary since the vital connection between the two parts is neutral. Sufficient slackness in the optic nerve is allowed to permit all the delicately coordinated motions of the eyes in their orbits without interfering in the least degree with the conduction of the nerve impulses to the magnifying and perceiving area in the cortex. A flexible connection between the two parts in which optical alignment has no significance is impossible in artificial optical instruments.

To obtain a similarly enlarged image on the retina itself would mean redesigning the dioptric system of the eye in a form impracticable with living tissues. Such an eye would be much enlarged, sluggish in movement, slow and inaccurate in focusing and subject to considerable muscular fatigue as well as greatly, probably grotesquely, disproportioned to the size of the face and depth of the orbit. The increased retinal area would mostly be wasted in any case, as attention could be directed only to a very small portion at a time.

In their present form, due to their small volume (6.5 cc.) and weight (7 gr.), the eyes have a wide and easy mobility, swift and accurate accommodation, and perfect coordination, which enable rapid judgments of the form, direction and distance of objects under observation to be made. The magnifying cortex can unobtrusively and effectually supply the necessary enlargement of the images, the perception of detail and the appreciation of color. While magnifications as high as those in a microscope cannot be obtained, experience shows that they are unnecessary in the normal exercise of vision. If the retinal image were grossly defective, as sometimes erroneously asserted, the magnified image in the cortex would be useless for accurate visual purposes, and optical instruments designed for visual observation would be without value.

The magnificence of the achievement of the theoretical and practical designers of microscopes and telescopes in overcoming the natural defects of images due to the nature of light and lenses, and in obtaining the high magnifications which they have thereby accomplished, can scarcely be exaggerated. Infinitely greater is the glory of the Divine Designer not only in having contrived the far simpler and more efficient optical system of the eye, but also in establishing biological laws by which the minute details of ocular construction have been transmitted with precision to countless individuals of all generations of mankind.

Diffraction pattern produced by light passing through small circular aperature. Bands like these, but insignificantly small and practically invisible, are produced on the retina by the pupil.



Object

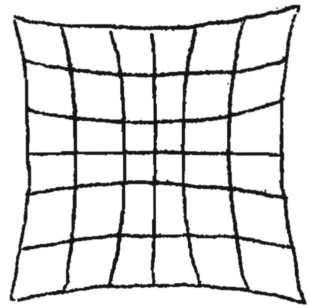
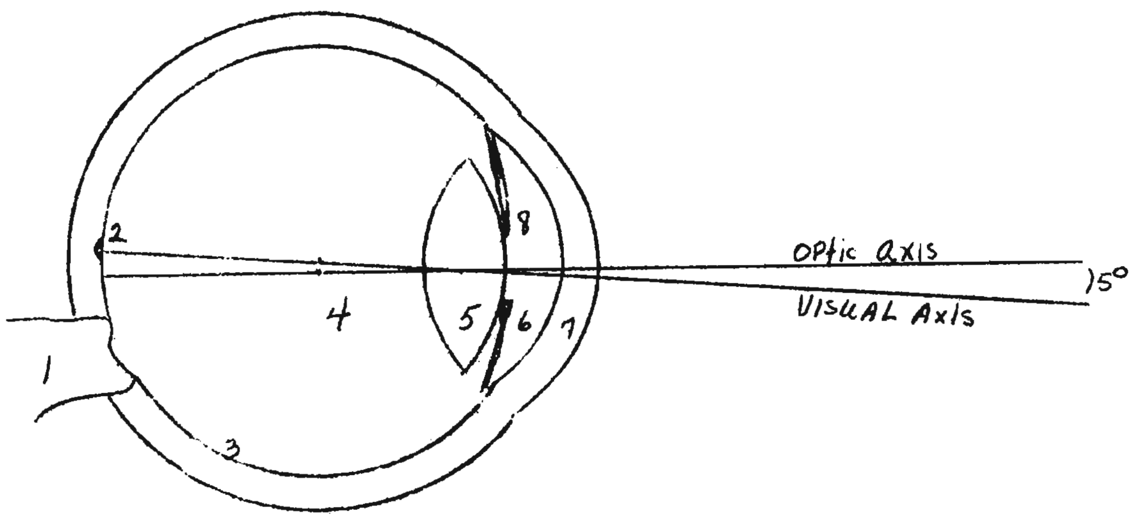


Image distorted by convex lens

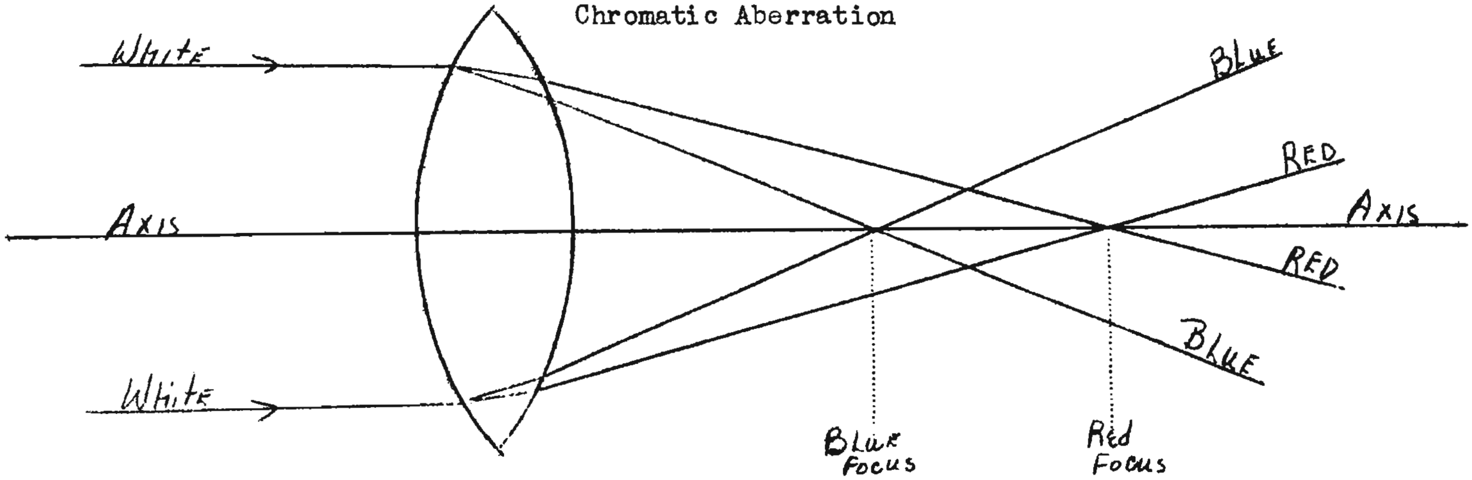
Distortion of Image

Diagram of the Eye



1. optic nerve, 2. Fovea, 3. Retina, 4. Vitreous body, 5. Lens, 6. Aqueous humor, 7. Cornea, 8. Iris.

Chromatic Aberration



The dispersion of the lens brings each color to a different focus; the most refrangible, blue, nearest the lens, the least refrangible, red, farthest, away, the other colors between them.

Spherical Aberration

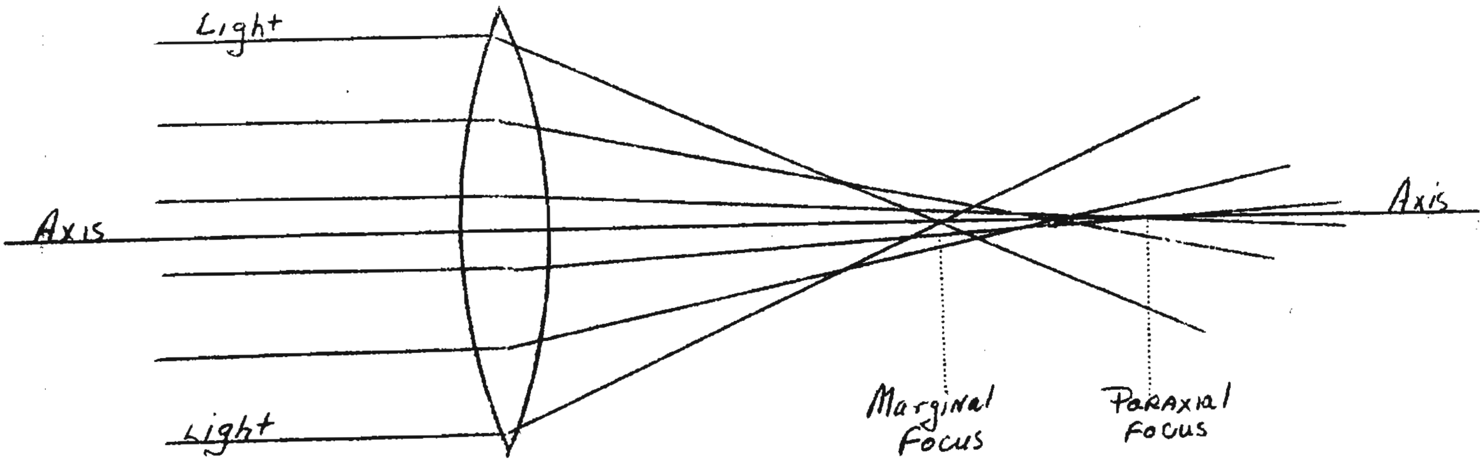
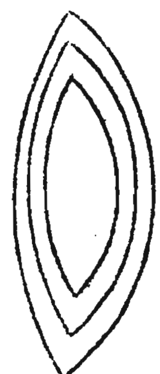


Diagram to show that rays of light passing through a lens at different places have different foci. Rays travel from left to right.

The lens of the Eye



Three zones of the lens of the eye. (diagrammatic) Innermost is the high refractive nucleus, the others being progressively less refractive outwards. The zones are very numerous.

"In all probability the complexity of its architecture, with its layers of graduated curvatures and zones of varying refractivities, is especially designed to counteract and neutralize the effects of spherical and chromatic aberration. It also increases the converging power of the lens, which is thus enabled to cover a greater range of accommodation and, in addition, tends to minimize the formation of secondary images in the eye."

(Duke-Elder: Text Book of Ophthalmology, Vol. I. p. 126).