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SCIENCE AND PHILOSOPHY

CAUSALITY IN MAX PLANCK'S PHILOSOPHY OF SCIENCE

WILLIAM EGAN, S.J.

In order to understand Max Planck's philosophy of causality in natural science, it is necessary to know something of the circumstances out of which this philosophy grew. We may presume that Dr. Planck's philosophy of science was at least implicitly the basis of his scientific thought and his investigations in theoretical physics, but the fact that he has considered it important enough to develop and set forth in three of his books causes us to inquire further into its origins.[1] We are unaccustomed to having scientists set forth any philosophic basis for their theories. They are usually content to postulate their principles, either explicitly, or, more often, implicitly, and then to work out the facts in view of these principles.

ASSUMPTIONS OF CLASSICAL PHYSICS

Classical physics was based on the assumption that there is a strict causal nexus between antecedent and consequent, so that if one were known the other could be discovered. This assumption had been derived from the regularity of the normally observable phenomena of nature. It was seen that definite laws could be formulated, so that, given a particular set of conditions, it could be known that a definite other set of conditions would always follow. It was thus assumed that this regular sequence of the events of nature was a necessary sequence. This regular, necessary sequence was what the scientist's laws were intended to express and this was what he called "causality."

This assumption was verified without exception in those phenomena of nature where normal sense observation is possible. The scientist then assumed that it would hold in all nature, in the microscopic world as well as in the macroscopic, if only the microscopic phenomena could be observed.[2] To make this observation possible, measuring instruments of suitable accuracy were introduced. Here, of course, it had to be presupposed that measurement gives immediate information about the nature of a physical event.

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[1]Max Planck, *The Universe in the Light of Modern Physics*, *Where Is Science Going*, *The Philosophy of Physics*.

[2]By macroscopic phenomena are understood those where normal sense observation is possible, by microscopic those which are so small as to be beyond the reach of such observation.

It followed from this assumption that the events were independent of the instruments used for measuring them. Hence, whenever a physical measurement takes place, a distinction must be made between the objective and actual event, which takes place with complete independence of the observer, and the process of measuring, which is occasioned by the event and renders it perceptible. This is necessary because physics deals with the actual, independently occurring events, and its object is to discover the laws which govern these events. Should it ever become impossible to make this essential distinction, the entire method would break down.

BREAKDOWN OF THE METHOD

The breakdown came when physicists, following out the course on which they had entered by using ever more delicate methods of measurement, found that there was a limit beyond which accurate measurement was impossible because beyond that limit it was impossible to distinguish the objective event from the process of measurement. Beyond that limit, they found, the process of measurement, no matter how delicate, interferes with and changes the event so that it is no longer the independently occurring event, the proper object of physics.

Werner Heisenberg has shown that this limit is not the fault of any defect in applying the methods of measurement, but is rather inherent in the nature of the case, and is governed by what is called the Indeterminacy Principle. In general it may be explained by the example of measuring the position and velocity of a very small object such as an electron.[3] In order to determine its position at all we must illuminate it; but this means that we let light rays, made up of photons, fall upon it. The photons impinging on the electron change its velocity in a way which it is impossible to determine. Therefore, whenever we measure the position of an electron, we are uncertain of its velocity. Again, since greater accuracy in the measurement of position requires illumination by light of a shorter wave length (the photons of which have greater energy), the more accurately we measure the position, the more we disturb the velocity.

Thus we can never actually measure both the position and the velocity of an electron. The accuracy of one measurement varies inversely with that of the other.

It follows from this that, since the differential equations of classical physics presuppose a knowledge of both position and velocity, these equations can never be applied on the infinitesimal level, and so lose their fundamental importance here. Thus the scientists were

[3] *The Philosophy of Physics*, p. 62. Other physicists speak of momentum rather than of velocity.

faced with the startling fact that, for the time being at least, the problem of discovering in all their details the laws underlying the real physical processes was insoluble.

EXISTENCE OF LAWS UNAFFECTED

This failure of the laws of classical physics when applied to the microcosm was interpreted as the failure of the Law of Causality. It is at this point that Planck comes to the parting of the ways with many scientists. Finding it impossible to discover basic physical laws in the microcosm, many scientists conclude that such laws do not exist. Planck makes it very clear, as a cardinal point of his position, that such an inference is unjustified. He says:

> But of course it would be incorrect to infer that no such laws exist: the failure to discover a law will, on the contrary, have to be attributed to an inadequate formulation of the problem and a consequently incorrect posing of the question. The question now is wherein the mistake consists and how it can be removed.[4]

Planck, therefore, does not propose that all that has gone before should be rejected as false. He does not admit that a new start must be made in the sense of erecting a new structure. "The successes attained by classical physics," he says, "are far too important to permit such drastic action."[5] He points out that the classical physics will always retain its importance in the field of macro-physics, which deals with relatively large bodies, spaces, and times; a fact which he adduces as proof that the mistake is not in the fundamentals of the classical theory, but must be sought in some one of the assumptions used for building the theory up from those fundamentals.

What are these fundamentals of the classical physical theory of which Planck speaks? Planck sets down the following: first, theoretical physics is based on the assumption that there exist real events not depending upon our senses; secondly, classical physics has always further assumed the possibility of obtaining a complete grasp of the laws governing the real events, the method of obtaining this grasp being a progressive, spatial and temporal subdivision in the direction of the infinitely small.

EXAMINATION OF THE CLASSICAL ASSUMPTIONS

Of the first of these fundamentals, Planck says, "This assumption must in all circumstances be maintained; and even physicists of positivist leanings make use of it."[6] Planck then gives a brief refutation of Positivism based on the fact that even those who maintain the priority of the senses as the sole foundation of physics are compelled

[4]*The Philosophy of Physics*, p. 19.
[5]*Loc. cit.*

to assume that there are such things as individual deceptions of the senses and hallucinations. This, he says, implies that the functional relations between sense data contain certain elements not depending upon the observer's personality nor upon the time and place of observation. It is precisely these elements which we describe as the real part of the physical event and of which we attempt to discover the laws.

The real hub of the scientific crisis, however, is to be found not in the first, but in the second, of the principles enunciated by Planck. This principle has been stated by Planck in another way besides that given above, as follows: the real outer world is not directly knowable. By the real outer world Planck here means the basic, elementary laws as well as particular events. Classical physicists have aways assumed that, although these laws are not directly knowable, they can be completely understood by following out the method of spatial and temporal subdivision. They saw no reason why this method could not be pursued indefinitely in the direction of the extremely small. This was their solution of the apparent opposition between the two cardinal theorems of their structure of physical science.

ROOT OF THE DIFFICULTY

It is this assumption which Planck marks out as the root of the difficulty. He declares that when this assumption is more closely considered it must be largely modified, since it leads, for example, to the conclusion that the laws governing a real event can be completely understood if it is separated from the event by which it is measured. But why should this require modification? Planck's reason is his first venture into the basic problem of causality.

Planck defines a physical law as, "Any proposition enunciating a fixed and absolutely valid connection between measurable physical quantities—a connection which permits us to calculate one of these quantities if the others have been discovered by measurement."[7] He points out that it is evident that the process of measuring can inform us about the real event or about some law only if there is some kind of causal connection between the two events, and that, if there is such a connection, then the process of measuring will in some degree influence and disturb the event, with the consequence that the result of the measurement is falsified. Now, this falsification and the consequent error will be great in proportion as the causal nexus between the real objective and the measuring instrument is close and delicate; it will be possible to reduce it by relaxing the causal nexus, or, to express it differently, by increasing the causal distance be-

[6]*The Philosophy of Physics*, p. 20.

[7]*The Universe in the Light of Modern Physics*, p. 62.

tween the object and the measuring instrument. It is never possible to eliminate the interference altogether, since, if the causal distance is assumed to be infinitely great, i. e., if we completely sever the object from the measuring instrument, we learn nothing at all about the real event. The measuring of extremely small quantities and times, however, which becomes necessary in the method of progressive subdivision, requires extremely delicate and sensitive methods and hence implies a close causal nexus.

Does Planck here imply that experimental knowledge of physical laws on the level of the extremely small is impossible? In order to evaluate his views on this topic, we must consider the place of physical law in general in Planck's philosophy of science.

PLANCK'S THREE "WORLDS"

Since all measurement requires sense perception, Physics, which is an exact science dependent on measurement, must ultimately refer all its ideas and laws to the world of the senses. This world of the senses is the first factor in Planck's philosophy of science. He notes that many think it is the only world of physics, but rejects this position on the ground that Reason tells us that the whole world which we perceive through our senses is in no way affected by any human brain, but existed before us and will continue to exist after us.

We are thus compelled, Planck says, to assume the existence of another world of reality beyond the world of the senses; a world which has existence independent of man, and which can only be perceived indirectly through the medium of the world of the senses.

Besides these two worlds, however, there is for Planck a third world, to be carefully distinguished from the first two. In Planck's philosophy of physics this third world is most important. He calls it the World of Physics, or the physical world image. It is in this world that the work of theoretical physics is done. It differs from the other two worlds, for it is a deliberate hypothesis put forward by a finite human mind, and as such it is subject to change and a kind of evolution. The function of this world image may be considered either as the completest possible apprehension of the real world or as the simplest possible description of the world of the senses.

PLANCK'S INTERPRETATION OF THE SYSTEM

Of course physicists will work from various viewpoints and in different directions in elaborating this world view of physics, but their aim will always be the same, to establish a law connecting the events of the world of sense with one another and with those of the real world. Planck points out that the evolution of the world image has been a steady progress in one direction, becoming more and more abstract and moving farther and farther away from the world of sense. Despite the fact, however, that the structure of the world image is receding from the world of sense, it is leading to greater knowledge and domination of events in that world, as the practical applications of physics prove. In Planck's opinion there is only one rational explanation of this paradox, which he offers on the basis of a common sense view of the world, professing himself unable to give any logical proof.

His explanation consists in saying that as the view of the physical world is perfected, it simultaneously recedes from the world of sense; and this process is tantamount to an approach to the world of reality. Will it ever arrive at a point where our world view coincides with the world of reality? For Planck this is a goal which is theoretically unobtainable, but it is the goal:

> Physics would occupy an exceptional position among all the other sciences if it did not recognize the rule that the most far reaching and valuable results of investigation can only be obtained by following a road leading to a goal which is theoretically unobtainable. This goal is the apprehension of true reality.[8]

PLACE OF PHYSICAL LAWS

Where do physical laws fit into this system? In Planck's writings it is evident that two types of physical law are spoken of. First, there are the physical laws of the real world. These are the objective laws which govern the relations between the real events of nature. "Physics deals with the actual events, and its object is to discover the laws which these events obey."[9] These, however, are not the only physical laws of which Planck makes mention. There are also laws in the physical world image, the hypothesis set up by the scientist. These latter do not govern events in the real world, but are intended both to explain events in the world of sense, and to approximate as closely as possible the laws of the real world.

Throughout Planck's writing he implicitly assumes that the physical laws of the real world are stable and unchanging. There is no variation or evolution in these laws, although so many factors enter into their operation that we may never be able to follow them exactly nor calculate the future course of the events governed by them. He believes firmly that each factor is strictly governed by law. The laws of the world image, on the other hand, are, together with that whole world, undergoing continuing change and evolution. They must be modified constantly in order to square with the observed facts of experiment. It is chiefly with these laws that the physicist is concerned. They are the fruit of all his labor and the

[8] *The Universe in the Light of Modern Physics*, p. 15.
[9] *The Philosophy of Physics*, p. 17.

purpose of all his experiment. "Every measurement first acquires its meaning for physical science through the significance which a theory gives it."[10]

CAUSAL LAW OR STATISTICAL LAW?

From experiment, therefore, the physicist wishes to derive laws. He is faced with the problem of what principle he shall use to develop his statement of law. Is he to attempt to assign a cause for the observed facts or is he merely to summarize those facts and the probability of their recurrence? In other words, should the laws of the physical world view be causal laws or statistical laws? And if they are to be causal laws we must inquire into his definition of a causal law and his concept of cause.

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[10] *Where Is Science Going*, p. 92.

(to be concluded in the next issue)

CHEMISTRY

NATURAL SCIENCE CONTRIBUTIONS TO HOMILETICS

Rev. Bernard A. Fiekers, S.J.

The faithful as well as the preacher are conscious of the profound effect of the use of scientific material in a sermon. As preachers we become too familiar with our arguments and illustrations at times, and tend to discard from our reportoire items that to us alone have become cut and dried. At times the value of such obsolete material dawns on us anew, as it did on the writer who had recent occasion to read Dr. Tihamer Toth's "God's Amazing World." The reading suggested that one with philosophico-theological training, combined with something technical and scientific, should try in critical fashion to sort these scientific topics and offer them to the more professional preacher.

There are many sources of scientific topics that lend themselves to pulpit oratory. The Divine Teacher Himself has drawn from similar topics: from architecture, if you wish, in the example of the man who would build the tower and count the cost in advance; from military science in the king who planned an invasion; from lowly agriculture in His many parables, especially in the example of the hen gathering the brood under her wing. All of these were adapted to the minds and outlook of the audience. Today radar and plastics are household words; electric switches and fluorescent lamps are household necessities; for many a veteran, "getting on the beam" was stern reality. An analysis of other types of illustration may perhaps bring us beyond the ephemeral and give us homiletic principles of lasting value.

First of all, let us consider the evidences of order and design in the universe. These are the indisputable property of the preacher. His is a clear title to this material for any valid argument he can draw. For God produced such evidence for His own glory and the preacher can make the glory formal.

The preacher's use of this topic, however, is limited by certain external conditions. He should have practical certitude of his facts; otherwise the application cannot surpass mere illustration in its forcefulness. Rhetoric imposes other conditions. Can galaxies in an infinity of space be readily comprehended? Will dramatic presentation of a Saint Ignatius in the contemplation of it aid the preacher's purpose? Certainly, the "Madonna of the Stars", conceived by Father John P. Delaney and published in THIS BULLETIN, (17, 176, 1939), combines science, art and worship in a way that the humblest can be brought to understand. Without doubt, rhetoric is capable of similar contributions.

Less compelling, perhaps, is the topic taken from the history of scientific endeavor. The exemplary lives of Catholic Scientists is a powerful argument in the hands of a clever preacher. Good example is contagious—and it is the preacher in this case who makes the contact. He can show negatively that Pasteur's "Breton peasant faith" in no wise diminished his scientific stature. He can grasp examples from the lives of Mendel, Ampere and Lavoisier to show that these found no conflict between the facts of science and supreme truth. He can show further that the Church provided the monastery garden for Mendel's experiments in heredity; provided laboratory and equipment for our own Father Theodor Wulf's discovery of cosmic rays and for Father Vitoria's contribution to chemical education in the world of the Spanish tongue. With some probability the faith kept Lavoisier experimenting in the shadow of the guillotine, and without doubt Pasteur kept the nightlong watch over his first rabies-injection case, with timorous conscience perhaps, but with full motivation founded in faith. The Church does not fear science. She supports it.

In executing the argument from exemplary lives, certain precautions are likewise in order. A mere baptismal certificate does not make Madame Curie a "Catholic scientist." Nor are the great minds of science necessarily Catholic. For the Church's mission is not scientific. Still, Newton might be considered in some sense debtor to the Catholic age that preceded his—, just as some consider Shakespeare in literature. Cantor's correspondence with Father Hontheim gives some evidence of this mathematician's debt to the Church. It would be a sad mistake, however, for the preacher to formalize the glory of the scientist when his true aim is God's greater glory. Science glamorizes its vigils today, extols its martyrs and publicizes its miracles. It packs its facts with power, and all the while gives but grudging concession to the principle underlying true miracles, that the more powerful cause prevails in producing its effects! With this in mind, the preacher may choose to work against the spirit of the times as occasion demands and make his scientific material as diaphanous a medium as he himself should be in channelling the word of God.

A third scientific topic is the official attitude of the Church toward science. Would Niagara, Boulder or Muscle Shoals have achieved electrification today if the missioner's paddle had not once churned their tributaries? For ages, the Church has prepared the stage for modern science, exploring the realm of thought as well as the realm of space. She fosters science in this age through her official Roman Pontifical Academy of Science, through the seismological, astronomical, weather and radio stations throughout the world. She supports scientific schools of worldwide renown and balances her scientific curricula to the genuine needs of country, time and place. We can still publicize the engineering schools of Madrid and the Gramme Institute of Liege. It does no harm to remind the Universities of Munich, Würsburg and Prague of their Jesuit origin; to point with pride to the Catholic Universities in mission lands and in our own. We can be proud of Father Eric Wasmann for his stand against the Berlin evolutionists at the height of their ascent to power.

Church legislation is claimed by some to be counter-scientific because it is adamant on the dignity of human life from the moment of its conception and on the sanctity of the family from its very foundation. Is research powerless to show the contribution to the advance of medicine that such legislation has stimulated?

A fourth and still more powerful source of argument from natural science is the direct use of scientific fact. An individual fact may be used here and there to stem for the moment some new wave of misunderstanding that is about to break. To mention, for example that recent excavations in the East have raised no serious objections to the truth of biblical narrative, and then to align three or four discoveries that have confirmed the Scriptures, has the effect of showing that in the long run confirmation of Scripture is assured.

A last source of scientific topics comprises the common illustrations of the day that are drawn from scientific discovery. This is an age of science and thus it devolves on the good judgment of the preacher and all the dictates of experience and rhetoric to determine how far he can go with the stream and still elevate the minds and hearts of his hearers to conversation with God. The preacher has to be keen often to revise such a fact collection with fresh findings. For scientific "facts" are sometimes overthrown and disappear from vogue. No preacher wishes to develop into an illustrating "Rodriguez" within his own lifetime.

An old Dartmouth Alumnus once confided in me his admiration for the synthesis of the scientific and the supernatural that is operative in our educational system. He compared the supernatural to Yale's annual aerial attack against his own Alma Mater in the Bowl at New Haven. It was admittedly very effective. On the other hand, Dartmouth, during his undergraduate years, seldom preferred the pass to the plodding off-tackle or the end sweep. This he compared to the scientific approach. It gained more yards for Dartmouth than points. We agreed that, under the circumstances, the judicious use of both might have been much more successful than either.

Many of these topics have been used judiciously and with success by so-called scientists among us and by non-scientists. In our formal education, however, the Society has insisted on solid foundations in science and it is our choice to use this advantage as occasion presents.

Father Jon "Nonni" Svenson is neither a scientist nor a preacher. As a modern writer of Nordic sagas he has caught some of the true scientific spirit that is rooted in man by evoking wide-eyed wonder at the expanses of unblemished nature. The late Father Charles Lyons, likewise not a scientist, had towards the end of his life considerable success with lay audiences in the use of scientific material. On the other hand, the late Father Aloysius B. Langguth, professor of chemistry, was also a preacher of renown in certain circles, and still a careful study of sermon publications of his in the Catholic Mind does not give the slightest clue to his scientific avocation. The late Father George F. Strohaver, equally great as preacher, chemical educator and organizer, could dramatize a scientific topic or one on the "species impressa" from scholastic psychology as readily as Father Pardow could arouse sympathy for motherless, lamp-incubated chicks. A truly great scientist of our times, Father Theodor Wulf, on parish work during many summers in the Moselle Valley, is said never to have used a scientific illustration in the pulpit.

Apostolic in the laboratory, in the pulpit or in both, scientific training can be of the utmost value to the Jesuit of today, if he cares to avail himself of its advantages.

PHYSICS

COLOR, WAVELENGTH AND FREQUENCY

JOSEPH F. MULLIGAN, S.J.

The question of the relative importance of the concepts of wavelength and frequency in explaining the phenomena of light has always been of interest to the physicist. In the days of classical optics, when light was regarded as a modification of the 'luminiferous ether', it was quite natural to stress the wavelength, especially since the wavelength was the quantity obtained from measurements in interferometry and spectroscopy. But even in those days the theoretical explanation of the interaction of light and matter forced physicists to admit the importance of the concept of frequency (Cf. "The Classical Theory of Dispersion", BULLETIN A.A.J.S., March, 1946). With the advent of the quantum theory, however, and its notable success in explaining spectra, the emphasis has been more and more on the concept of frequency. This is to be expected, for the fundamental equation of the quantum theory equates the energy of a photon of light to the product of Planck's constant and the frequency of the light. As a result, it is "now important for the student of modern optics to be able to think of light both in terms of frequency and wavelength."[1]

An interesting problem in this regard is the nature of color. Both physicists and psychologists have always been interested in the answer to the question: "Is the concept of frequency or that of wavelength more fundamental in any explanation of the physical nature of color?" On which can color be said to depend?

The fundamental fact in solving this problem is that the velocity of light is given by the product of its wavelength and its frequency, $v = \lambda v$. If, now, a beam of monochromatic light travels from air into a medium of index of refraction n, its velocity changes from c to c/n. This is evident from elementary physics and is also substantiated by the previous article on dispersion theory. Since the velocity changes, and since the velocity is the product of the wavelength and the frequency, it follows that either the wavelength or the frequency, or both, must change. Since it is clear, as we shall see, that the color remains constant, either the frequency or the wavelength must also remain constant, and be the factor on which color seems to depend. Hence the question: "Does the frequency remain constant and the wavelength change, or is the opposite true?"

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[1] Robert W. Wood, *Physical Optics*, p. 10.

In answering this question we might be tempted to reason as follows: "If the wavelength changes the color must change, since color is usually said to depend on wavelength. But the color does not change, as is clear from observing a beam of monochromatic light (say sodium light) first in air, and then with the eye under water so that the light passes from air into water and then into the eye. Hence the wavelength must also remain constant, and the frequency change." Such reasoning would be correct if only the premisses were correct, but as we shall see, the primary supposite of the argument is false, for color does not depend on the wavelength, but on the frequency.

The physicist can prove this fact experimentally in a number of ways. Since this point is often a source of confusion, it may be well to indicate a few of the proofs here.

PHYSICAL PROOFS

From an analogy with sound we would expect color to depend on frequency. "As the pitch (or musical color) of a note is determined by the frequency of its vibrations, so it appears to be the frequency of the vibration . . . that determines the color"[2] The frequency of a musical note is not changed when the sound-wave is propagated through different media. So too we would not expect the frequency of a light wave to be changed. If a wave motion is propagated from one medium to another, the vibration in the second is excited and forced by the vibration in the first. There is no mechanism at the boundary between the media which would alter the frequency of the vibration. Since the velocity does change, and the color does not, ". . . the natural inference is that the color impression on the eye depends on the vibration frequency rather than on the absolute wavelength."[3]

Both the wave and the quantum theory afford striking confirmations of this fact. We will confine ourselves to a few examples from each. Perhaps the best proof is that of Newton's Rings, a familiar example of interference phenomena. If a plano-convex lens is placed with its curved face on the plane face of a glass block, the thin film between the two surfaces increases radially in thickness outwards from the point of contact. If monochromatic light is directed down through the lens, and the reflected light observed in a microscope, alternate dark and bright circles are observed. These are interference fringes, caused by the interaction of the light-waves reflected from the convex surface of the lens and those reflected from the flat surface of the glass block.

According to the theory of this experiment, for interference and hence dark fringes, the following relations must hold (supposing normal incidence):

$$T = m\lambda/2n = r^2/2R$$

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2 Preston, *Theory of Light*, p. 43.

3 *Loc. cit.*

where T is the thickness of the film between plate and lens, m is the number of the dark ring observed, r is the radius of the m^{th} ring, n is the index of refraction of the film, R is the radius of curvature of the lens, and λ is the wavelength of the light used.

From this equation it is clear that r^2 varies as λ/n, for m and R are constant. In air n is practically unity, and so the radius of the rings varies directly as the square root of the wavelength of the light used. If water is used instead of air between the lens and the plate, even though the light source remain the same, the radius of the m^{th} ring is observed to be much smaller. Since r^2 varies as λ/n, this indicates that the wavelength of the light decreases in the water, or, more exactly, changes from λ to $\lambda/1.33$, where 1.33 is n, the index of refraction of the water. It can be seen that the cause of this decrease in wavelength is a decrease in velocity in the water, for here the thickness of water required to retard one component on the other by a definite amount is less than the thickness of air which would produce the same result.

Now though the velocity and the wavelength have changed when the light enters the water, the color of the light does not change in passing from air to water, as was shown above. Therefore, since the wavelength changes but the color does not change, we have a proof that color does not depend on the wavelength.

This experiment affords an easy means of testing the relationship that the wavelength in water is equal to $\lambda/1.33$, where λ is the wavelength in air. The wavelengths in air and water vary as the squares of the radii of the rings, and so by measuring the radii of the rings, first with air as the film, and then with water, the value of the wavelength in water can be found. In an actual laboratory experiment, the wavelength of the green light of mercury in water was computed from the measured radius of the rings, and this relation verified at least approximately.

Another convincing experimental proof that the wavelength changes with the velocity is derived from Michelson's Interferometer. Interferometer methods of measuring the velocity of light in different media presuppose that the ratio of the wavelengths in the two media is identical with the ratio of their velocities.[4] By observing the shift in interference fringes due to the change in wavelength when a piece of glass or other transparent substance is held before one of the light beams, it is possible to find the velocity of light in the glass. This method is often used to find the index of refraction of a medium, for the index of refraction is the ratio of the wavelength in air to that in the medium. For this reason, the interferometer was originally called the "interferential refractometer", since it was first used to find the index of refraction by Fresnel and Arago in 1816.

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[4] Michelson, *Light Waves and Their Uses*, p. 51-3.

Both these phenomena show that the wavelength is not constant, but varies with the velocity. On the other hand, monochromatic light of a definite color will never change directly to light of another color, no matter how much it is reflected or refracted, and no matter how many different media it may pass through, supposing there is no selective absorption. There must then be some constant factor in light on which color depends. Since $v = \lambda v$, and λ varies as v, as we have seen above, v, the frequency, must be this constant factor. This is easily seen from the fundamental equation of the quantum theory, $E = hv$, where E is the energy of a quantum of light, h is Planck's constant, and v is the frequency. Since h is the same no matter the source of radiation, and since E remains constant, v must also remain constant and hence is the factor on which color seems to depend.

SOURCE OF CONFUSION

Though frequency thus seems to be the fundamental factor in any explanation of color, still many elementary physics books, like Duff, Weld and Palmer, and Black, emphasize wavelength in their treatment of color, and have little or nothing to say of frequency. This seems to be due to the fact that their treatment of optics is based mainly on the wave theory, where wavelength naturally is the more important concept. This is often a source of confusion to the beginner in physics, who is led to believe that color actually depends on wavelength. Again, practically all physical tables of color radiation are given in terms of wavelengths, not frequencies. The reason for this is obvious. Wavelengths can be measured experimentally with far greater precision, since they can be measured independently of the velocity of light by means of interference and diffraction phenomena. The interferometers of Michelson and Fabry-Perot give wavelength measurements of the greatest precision yet known in science, and other optical instruments, like spectrometers and spectroscopes, yield very accurate results. With the frequency it is a different story. The only way we can determine the frequency is to know both the wavelength and the velocity, and apply the formula $v = v/\lambda$. Though the wavelength can be found to a high degree of accuracy, the measurement of the velocity leads in general to much less precise results. As a consequency, the value of the frequency suffers from the experimental errors of both, and is nowhere near as precise as is the determination of the wavelength.

For this reason it is customary to speak of colors in terms of wavelengths of light. However, it must be understood that this is only correct with reference to some standard medium under standard conditions. These conditions are given by Robertson:

> "We describe a kind of light, therefore, by stating either the frequency giving rise to it, or the resulting wavelength in some standard medium. Light of a particular

quality then corresponds to a note in sound. The latter is usually described by giving its frequency but might be described by giving its wavelength in air. In light it is usual to describe the quality in terms of wavelength in air at 20° c. and 760 mm. pressure, though sometimes frequency is used."[5]

If these conditions are specified, the colors of the spectrum can be described more accurately in terms of wavelengths. But despite this fact, wavelength is never more than a factor which, under normal conditions, varies more or less as the color does.

As noted above, with the advent of the quantum theory, the stress has shifted more and more to frequency. "With the modern developments of the theory of spectra it has turned out that the frequency is the thing that matters, and very definite relations between the various lines of the spectrum of a given substance appear as soon as we substitute frequencies for wavelengths."[6] As a result practically all researches in the theory of spectra are now given in terms of frequencies and not wavelengths. This is certainly the more logical way to define color, since the frequency, as we have seen, remains the same while the wavelength changes with every passage of the light across a boundary separating media of different optical densities.

PSYCHOLOGICAL IMPLICATIONS

In conclusion it may be well to indicate a few psychological implications of the foregoing. The dependence of color on frequency, and not on wavelength, contributes much to a sound psychological explanation of color-vision, and avoids a serious difficulty implicit in the wavelength hypothesis. As noted above, it makes the analogy with sound more obvious, and thus shows the unity of nature. The pitch of the sound we hear depends on the frequency of the sound-waves; so too the color of the light we see depends on the frequency of the light-waves. This gives an obvious reason why all radiation of the electromagnetic spectrum is not visible. The eye is attuned to only a very small range of frequencies, and in these cases alone do we see color, in the same way as the ear is attuned to a certain range of frequencies only, and outside of these nothing is heard.

Again, this fact gives a much more satisfactory starting-point for any theory of color-vision. Wavelength refers only to a certain le gth or distance in the medium outside the eye. It is difficult to see how such a factor could so affect the retina as to produce a definite color sensation. On the other hand, the frequency refers to the number of times a second the stimulus strikes the retina. It is much easier to see how these wave-pulses could produce chem-

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[5] Robertson, *Introduction to Physical Optics*, p. 121.

[6] Wood, *Physical Optics*, p. 10.

ical changes in the retina of the eye, such as are postulated by most theories of color-vision. Perhaps these vibrations set up like vibrations in the atoms of the retina, which in turn are in some mysterious way converted into nervous impulses. Without attempting a psychological explanation, this does seem possible from an analogy with the known fact of the selective absorption of color caused by resonance between the light-frequencies and the vibration-frequencies of the atoms of the medium. This interaction of light and matter was considered in the previous article.

Another important psychological and philosophical consideration is the fact that if color did depend on the wavelength, we would never see colors as they really are.- As we have seen, the wavelength changes in proportion to the velocity, and the velocity depends on the index of refraction of the medium. Now in the human eye the space just in front of the retina contains the vitreous humor, whose index of refraction is 1.3365. Hence if color depended on wavelength, the original wavelength λ would be changed to $\lambda/1.3365$ when it reached the retina. Thus if the original color was the green light of mercury with a wavelength 5461 A, we would really see a violet light of wavelength 4106 A. This certainly would militate against the possibility of seeing things as they really are outside the seeing self.

The same would be true of underwater vision, where we should observe a very definite change in color from that observed in air. The ratio of change would be about the same as that indicated above, and would certainly be sufficient to be observable. Thus a red apple should appear green when observed underwater. It is clear from experience or simple experiment that we never observe such a change.

Since color really depends on frequency, these difficulties are avoided, and we have a more satisfactory starting-point, both physically and psychologically, for any attempted explanation of color-vision. Despite this fact, many psychology texts like those of Harmon, Gruender, Brennan and Dashiell, contain such statements as: "Wavelength is the physical property upon which color primarily depends"; "As applied to light, 'physical color' is synonymous with wavelength within the limits of the visible spectrum"; and many others of like tenor. It seems that the psychologists have adopted the usage of many physicists who speak of colors in terms of wavelengths, but have failed to observe that this is only possible under certain rigid conditions, and that frequency is the fundamental factor in any explanation of color. Though the exact physical nature of light must be more completely determined before an adequate psychological explanation of color-vision can be expected, still any attempted explanation would seem to require this physical fact as a basis.

SEISMOLOGY

AIR WAVES IN SEISMOLOGY

Daniel Linehan, S.J.

The field seismologist has two types of air waves to contend with. One is the ordinary sound wave travelling in air with an approximate velocity of 1,088 ft./sec. at 0°C. Since this wave is recorded on seismographs even when inaudible it is commonly referred to as the "air wave." This also distinguishes it from the sound waves transmitted through the ground or bedrock. We shall refer to it in this paper as the "air wave." The other wave transmitted through air is known as the "blast wave." This wave is not so commonly known, nor have all of its qualities been determined, indeed, ordinary Physics texts rarely refer to it, and many advanced books on Sound or Acoustics give it but a passing reference. We shall treat of the blast wave in this paper first.

The blast wave has common origin with the air wave, but unless the source is a strong one, as an explosion, it remains unnoticed. Some of the earlier tests on this wave were made near gun muzzles, and due to the almost simultaneous reception of three different waves, the bow wave from the projectile, the blast wave and the air wave, it was difficult to separate them for study. As one moved away from the source the blast wave disappeared, as it is short lived. During the late War this blast wave came into greater notice again with the development of the great "earthquake bombs" and "blockbuster bombs,' and of course, the Atomic Bomb. Scientific studies have again been made, but the results of these have not yet been made public. Two facts are known, however, first, the great amount of energy of the blast wave; and secondly, for a wave travelling through air, its very high velocity.

The energy of the blast wave has been displayed in the manner with which it would knock down stone and brick walls of buildings, strip the clothes from people, pulverize window glass, etc. In the case of the Atomic Bomb we have seen from the released pictures how Japanese buildings were flattened, and large objects, as trucks and busses were hurled several blocks through the ruined cities.

The velocity of the blast wave from the A-Bomb has been described in some popular journals as approximately 1,000 mi/hr for a maximum value. This value appears too small as the observed values of the blast waves from some of the bombs that fell in London during the War, were determined at 25,000 ft/sec. A series of tests we have conducted at Weston show this blast wave to have a velocity from 25,000 to 30,000 ft/sec. We have no data to show whether this velocity changes with distance.

In the Weston tests the measurements were made with portable seismometers, electronically amplified and recorded photographically. The accuracy for time readings was only .001 sec. which might account for the wide range of velocities given above. The seismometers were placed 5 feet apart on a line from the charge and the blast was allowed to blow out of the shot hole. The range of this blast wave is small and could be detected to distances of only 30 to 40 feet when a ½ lb. charge of 60% nitro-glycerine was used. The air wave from an identical charge would be detected for a mile or more. In general the velocity of the blast wave averages 25 to 30 times greater than that of the air wave. As data are released from the various A-Bomb tests we shall, no doubt, learn more about the other characteristics of this blast wave.

In seismic work this blast wave is a cause for interference at times when the profile is arranged for close detail, short spacing is employed from seismometer to seismometer and the charge is planted in a shallow hole. In swamplands especially, the charge blows out too easily and the high velocity blast wave wipes out the recordings of the much slower ground waves. It is impossible to operate a survey under these conditions. Where the shot hole is deep, and the instrument spacing greater there is little, if any interference.

Treating now the slower air wave, or sound wave, we find a disturbance that has been both a help and a hindrance to the seismologist.

In the early days of seismic prospecting for petroleum this wave was employed to time the moment the shot was fired. Due to its low velocity it came in long after the sound waves through the ground which travel from 5,000 to 30,000 ft/sec. Knowing the air temperature and the distance from shot holes to instrument, the seismologist could compute the moment the explosion took place. The determination was not too accurate as winds and varying thermal layers in the atmosphere would lessen the accuracy. Later seismic crews have developed the method of sending this shot signal either by radio or wire. During the past War, while operating explosive tests at Camp Miles Standish, Massachusetts, we were able to use air waves in determining the distances of the shot points from instruments within an accuracy of 30 feet to the mile. Actually, these measurements were a little side play from the real problem.

The tests at Camp Miles Standish were primarily made to determine the effects of the air waves and ground waves on buildings at distances of several miles, when charges of 100 pounds or more of 40% nitro-glycerine were used. These tests did show that the air waves had far greater effect than any of the ground waves. The effects varied, or course, depending upon the wind direction, screening by trees, hills and houses.

As might be expected we have frequently been asked whether we recorded any earth tremors on the Weston seismographs from the Atomic Bombs dropped on Japan. Our answer is "No!" The public has the wrong idea on the relative intensity of the A-Bombs and an earthquake. As far as the seismologists can guess it would take quite a few A-Bombs to equal an ordinary earthquake. We must remember that the A-Bombs were exploded in the air several hundreds of feet above the ground so the blast wave could do its work more efficiently, hence most of the energy, as far as earth motion was concerned, was wasted in the air. If it had been buried beneath the surface, perhaps some local station might have recorded earth motion. However, we did record the air wave from the test bomb that was set off in New Mexico, July 16, 1945.

Some of the data are still restricted on this New Mexico test, but we may state here, that the average velocity of this air wave to Weston was 1158 ft/sec. This would require an average air temperature of 65° to 70°F. between New Mexico and Massachusetts which is plausible for the month of July. Two other stations, much closer to the explosion site had average air velocities of much the same figure. We believe, although we are not certain, that this represents the furthest distance that an air wave has been accurately timed.

Air waves are a distinct handicap to the seismologist when they are generated by a passing truck, bus, tractor or airplane. While operating a seismic survey near a busy highway it is necessary to stop all traffic, not only to save them from falling gravel and boulders if the shot hole blows out, but also to save ourselves some trouble. We usually have to insist that they turn off their motors as well. A nervous driver might suddenly race his motor just as the shot was fired and the resulting air disturbance would wipe out the registrations of the ground waves. A truck shifting gears, with the accompanying motor race, a mile away, or a tractor ploughing on a farm a similar distance renders seismic work void. At times we must ask the driver to stop for a moment, or again we wait till he drives below a hill or some other screening device. At times we may increase the amount of explosive, lower the magnification of the instruments, and try to "shoot through" the noise.

Airplanes cause the greatest number of seismological headaches and of these the bombers, cargo and passenger planes are the worst. The propeller frequency of these planes is about 45-90 cycles when travelling from 250-300 mi/hr, which is just within the range the standard field seismometer is tuned for. A plane ten miles away generating a frequency of this range will affect our equipment even though the sound is inaudible. If we happen to be working along a regular air route we wait until the disturbance is over. If the plane is simply flying around in circles, or if we are near an airfield, we try all sorts of dodges. If the wave is not too strong it is possible to shoot the record and sometimes the ground wave may be distinguished from the air wave by a slight change in frequency.

It is interesting to observe the light spots in the recording camera during such air wave disturbances. A group of bombers flying in formation register a steady vibration; two planes at different speeds register "beats"; a single plane at a distance will frequently register "beats", due, no doubt, to the onset of two waves, one direct and the other reflected or refracted from other layers in the atmosphere.

The faster pursuit and fighter planes do not bother us unless they are close at hand. Their frequency is too high. At times, in a power dive away from the instrument set-up, they will register the lower frequencies created by the Dopoler Effect.

Various methods have been tried to eliminate plane disturbances. We cannot change the instrumental frequencies as these are tuned to the dominant earth cycles we desire to record. Burying the seismographs helps somewhat, but the covering dirt must be packed tightly to eliminate the lower frequency levels, and this cannot always be done. Some have suggested using artificial covers, but this entails a good seal between the cover and the earth, and this is impractical when there are a dozen or more instruments to set out every time a profile is run. Our only solution to date, is to smoke another pipeful and wait out the passing plane. We have toyed with the idea of mounting an anti-aircraft battery on the truck roof.

BOOK REVIEW

VINCENT BEATTY, S.J.

Recent Advances in the Chemistry and Biology of Sea Water. H. W. Harvey. Cambridge: at the University Press. 1945. MacMillan Company. Pp. vii 164, 10s. 6d. net.

The sea has always been fascinating to the poets and prose writers alike. The layman too has found in the sea a source of wonderment. He beholds an endless sight which enthralls him but about whose science he knows little. Many a chemist and biologist might shamefully admit his ignorance of such a wealth of plant and animal life in the sea and especially its relation to the chemical constituents of sea water.

This thoroughly scientific book, organized into a framework of ten chapters, includes much of the latest data on the chemical and biological sea. Appended to each chapter is an excellent and complete bibliography averaging thirty-six (36) references to a chapter. These alone constitute an invaluable aid to one interested in this discipline. Quoted are the works of A. C. Redfield, H. B. Bigelow, N. Rakestraw, T. G. Thompson, S. A. Wakesman, H. W. Harvey, W. R. G. Atkins, C. E. ZoBell and others, whose authority on this subject leave the reader with the realization of having spent his time on a reliable and competent work of the world's best oceanographers and men most familiar with the scientific sea.

THE INTRODUCTION (Chapter 1.) treats turbulence, inshore characteristics, estuarine conditions and marine organisms known as plankton. These flora and fauna of the sea are not only active in their natural habitat but can bring about notable changes in a bottle of sea water after one or two days in the light or in the dark.

SALINITY, CHLORINITY, SPECIFIC GRAVITY (Chapter 2.) Here is described an accurate method for determining the chlorinity of sea water. Differences in samples can be found by titrating a "Standard Sea Water" (obtainable in sealed tubes from the Laboratoire Hydrographique, Copenhagen) whose chlorinity has been determined by both gravimetric and volumetric analyses and comparing this result with that obtained from the unknown. This provides an excellent universal criterion for workers of all parts of the world.

THE MAJOR CONSTITUENTS are

(Chapter 3.)	Na'	30.00%	$'Cl$	55.20%
	Mg''	3.40%	$''SO$	7.20%
	Ca''	1.16%	$'Br$	0.19%
	K'	1.10%	H_3BO_3	0.07 %
	Sr'	0.04%	$'HCO_3+''CO_3$	0.35%

and a formula for artificial sea water from laboratory reagents according to Lymen & Fleming is also given in this chapter.

THE MINOR CONSTITUENTS (Chapter 4.) Some thirty-five (35) elements whose sum does not exceed 0.025% of the major constituents lend themselves to a dichotomy of those absorbed and used by plant organisms, and therefore their quantities fluctuate, and those that are not so used. There are two agencies which control the concentrations of the heavy metals in the waters of the ocean—adsorption on surfaces and combination with large organic molecules to form insoluble salts or co-ordination compounds which are only very slightly dissociated. Spectrographic analysis of seaweed dried to one-eighth its original wet weight, set to read in mg. per kilo has given excellent results in the determination of these minor constituents. In addition to these elements a small quantity of organic matter can be found dissolved in sea water.

DISSOLVED OXYGEN (Chapter 5.) The oxygen content (at 25°C and 760mm pressure 4.86 cc of oxygen (STP) dissolve in one liter of sea water containing 20% chlorine), the rate at which oxygen enters unsaturated water from the atmosphere, and the distribution of dissolved oxygen in the oceans have all been studied in the past fifteen years, and in this chapter can be found the essentials of the results obtained. Detectable diurnal variations have been observed due to the photosynthesis by py phytoplankton during the summer and in estuaries with rich flora of seaweeds.

THE CARBON-DIOXIDE SYSTEM (Chapter 6.) Sea water contains CO_2 as bicarbonate and carbonate ions, as undissociated molecules of CO_2 and as H_2CO_3 all in equilibrium with each other. The pH increases with rising temperature and decreases with great pressures and the measurement of such changes is described in this chapter.

THE DISTRIBUTION AND ESTIMATION OF PHOSPHATE AND OF SALTS CONTAINING NITROGEN (Chapter 7.) is short but of importance because of the effect of phosphate and nitrogen upon the fertility of the organisms of the sea.

CHANGES DUE TO BACTERIA (Chapter 8) is a remarkably fact filled chapter. Enumerated here are some of the changes brought about through the agency of marine bacteria, viz. decomposition of chitin, cellulose, petroleum hydrocarbons, lignin, and urea. Other chemical changes, everywhere in the sea are oxidation-reduction reactions and the formations of concretions containing iron and manganese oxides. Nature's care of the human being manifests itself in two discoveries: first, the finding of Bertel—that bacteria increase in numbers with depth, while at the surface they are killed by strong sunlight and, second, fresh water bacteria perish in the sea. Coliform bacteria from sewage soon disappear in the sea water, killed by the environment. An interesting contrast is the amount of oxygen used per gram of actually growing marine bacteria (30cc per hour at 22°C) and per gram of living tissue in marine animals (a maximum of 1cc per hour at 22 C.)

REGENERATION OF PHOSPHATE AND SALTS CONTAINING NITROGEN (Chapter 9.) The rate at which phosphates and nitrogen compounds are utilized by plants, returned to the sea and again utilized, is a direct measure of productivity or fertility.

FERTILITY OF OCEAN WATERS (Chapter 10.) The productivity of any extensive water mass has been defined as the quantity of organic matter produced by the phytoplankton over a period of time. The organic matter (whose quantity is dependent on the N & P cycle) is food for both marine animals and bacteria. The following factors may affect the growth rate of phytoplankton in the sea and at times slow down the growth and so limit production.

1. The effect of light, temperature and turbulence on the growth of phytoplankton. Turbulence limits production especially during the winter and in all temperate seas. Conditions for greatest production occurs in the sea where the relation of turbulence to quantity of incident light is at an optimum.
2. The effect of concentration of nutrient salts on the growth rate of phytoplankton.
3. The supply of iron, silicates, and CO_2 to phytoplankton.
4. The effect of other minor constituents of sea water on the growth of phytoplankton.
5. The magnitude of the standing crop of plants.
6. The magnitude of the animal production.
7. Consumption of phytoplankton by animals.
8. Fluctuation in production of plants and animals from year to year.

Much of the work described in this book has been done by Dr. Harvey himself and by other members of the staff at the Marine Biological Laboratory at Plymouth.

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