The growth of this great collection of medical literature well illustrates the advantage of allowing a specialized library to develop along its own lines, without being hampered as must otherwise be the case, if merely a department of a great general library. The contrast between the national medical and law libraries well illustrates this. The Law Library of Congress was established in 1832, Congress requiring that it be maintained as a separate unit in "an apartment near the Library of Congress." This collection has frequently been neglected and has received but little money. Several law libraries in the United States are superior to the Law Library of Congress in some fields, while the Harvard Law Library is far larger and superior in every way, containing (1933) 435,000 volumes to the 275,000 of the Law Library of Congress. Contrast this with the growth of the Army Medical Library, which in twenty years passed the medical collections of the two largest general libraries in Europe, as well as those of America. "Undoubtedly," wrote the Law Librarian of Congress in 1933, "had the Law Library been independent from its foundation in 1832, the government would have possessed the best law library in the world to-day, instead of lagging behind, with many serious gaps in the collection." He therefore urged the friends of the Law Library of Congress to crystalize sentiment through the country to aid the Law Library to become as eminent in law as the Surgeon General's Library is in medicine.

In Europe one sees the disadvantages of merging a specialized library in a general collection. Billings himself always stressed this and showed that neither the medical collections of the Bibliothèque Nationale de France nor that of the British Museum has been able to develop as would otherwise have been possible. Medical writers make comparatively little use of these collections, preferring to use the special medical libraries of London and Paris, which are under the direction of medical bibliographers. I mention all this because from time to time one hears the suggestion that the Army Medical Library be added to the Library of Congress. The librarian of Congress, Dr. Putnam, recognizes the disadvantages of such a consolidation, adding that the Army Medical Library should "be administered by those familiar with that field."

I have sometimes thought that medical writers and students of the medical sciences in general are, bibliographically speaking, divided into two classes, those who know the Army Medical Library well, and those who do not know it at all. There are no half tones. Such folk are either in the high lights or the shadows, as it were. Those in other fields of learning may, perhaps far oftener than they may think, find material to their tastes and interests in this mighty collection of a million items. Its Index Catalogue is a tool that many other hands than those of physicians may use to good effect. It should be of interest to all men of letters, as well as of science, to know how to use a work which indexes practically everything of value in medical science, including every worthwhile article in every issue of every journal of every country in every language. Then, if not before, does one come to appreciate the soundness of dictum of the late Dr. William H. Welch, that the "Army Medical Library and its Index Catalogue are America's greatest gift to medicine."[3]

WAVES AND CORPUSCLES IN QUANTUM PHYSICS[1]

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It is a well-known fact that macroscopic phenomena, like the reflection, refraction, diffraction and the propagation along curved paths of matter and light rays, can be described by means of the corpuscular theory as well as by means of the wave theory. As to microscopic phenomena of atomic dimensions, one can apply the two classical models only to a certain degree, the limits of the corpuscular description being drawn by the Heisenberg uncertainty principle. Nevertheless, many physicists seem to prefer the corpuscular picture when they are asked as to what is happening "in reality."

Take for instance the usual statistical *corpuscular interpretation of Schrödinger's wave function* ψ; here $|\psi|^2 = \rho$ is said to mean in reality the probability density of particles in space. To make this statistical distribution possible one has afterwards to resort to

[1] Address given at the Ohio Physics Club in Cincinnati, December, 1936.

[3] The discussion of this paper was opened by Dr. Arnold C. Klebs, of Nyon, Switzerland, who said: "To us of the older generation who were privileged to visit under the inspiring guidance of Osler, when Billings, Fletcher and Garrison were still there, this great institution which later was so sympathetically and efficiently presided over by Colonel Hume, his report of past achievements and future problems makes a singular appeal. Does the present generation fully realize that we have there much more than a mere collection of books for use of the medical officers of the Army, much more even than a National Medical Library? In my wanderings abroad through numerous libraries I have always made it a point to ask the librarians how they advised those that were preparing medical monographs in the gathering of relevant material. The answer was invariably that the Index Catalogue was first consulted and often supplied all that was wanted. And when we consider that these rows of green books did not only grace the shelves by the side of the tomes of

rather artificial additional hypotheses. One has to endow the particles with a mysterious power of preferring regions where associated waves have their intensity maxima, in contradiction to the causal laws of mechanics. Sometimes the ψ-function seems to direct the particles even to regions where their kinetic energy would be negative and their velocity imaginary. On the other hand, one often applies a *wave interpretation of corpuscular phenomena:* It is said that the vibrational energy of matter or light waves within a vessel is confined to certain quantized levels, in contradiction to the continuous process of damping asked for by the wave theory.

I want to show here that these apparent contradictions are not at all inherent features of quantum theory, but are entirely the result of uncritical over-interpretations of the observed facts. Quantum theory in the contrary is based on the fundamental *complementarity* of waves and corpuscles, neither of them having a preference over the other, but either one describing the observed facts consistently without contradictions, as long as we confine ourselves to describing what we see. In order to become more critical towards a customary statement about the "real" nature of an observed process it is a good policy to compare the statement with a complementary statement in which the rôle of waves and corpuscles has been interchanged. If the antithesis obtained in this way proves to be unsatisfactory, then the original thesis ought to be considered as questionable, too. We are then better prepared to criticize both of them.

Let us recall that the general theory of relativity, too, started from a twofold interpretation of physical facts. The motion of a stone can be explained in two equivalent ways, either by the assumption of a field of gravity, or by reference to an accelerated system of coordinates. It would be quite a mistake, however, and contrary to the basic idea of relativity to apply the two explanations simultaneously and to ask, for instance, for the seat of gravitational forces *within* the accelerated frame. But it is just this kind of over-interpretation that can be found in the corpuscular interpretation of Schrödinger's wave function as well as in the aforementioned wave interpretation of selected energy levels.

Let us take the example of a *linear harmonic oscillator.* A piece of matter can be said to consist of microscopic oscillators if we observe it reacting *as though* it consisted of such oscillators. We might, for instance, illuminate the piece of matter with light waves of a given frequency ν. If the transmitted light shows, beside the original color ν, the new colors $\nu+\nu_0$ and $\nu-\nu_0$ (Raman-effect), and if, beside the original ray, a bundle of new diffracted light waves is emerging, then we may explain this effect in two independent ways, without contradictions.

(*a*) According to the wave theory of light, the color effect is produced by resonating matter which has a proper frequency ν_0. And the angular diffraction is explained by a certain continuous distribution of the resonating matter in space forming a cloud of density ρ_0 that serves as a Huyghens source of the secondary radiation $\nu \pm \nu_0$.

(*b*) The same optical effect of color change and diffraction can secondly be interpreted in corpuscular terms. The light is then supposed to consist of photons of energy E and of momentum P. The color effect indicates that the resonating matter consists of particles which exchange energy amounts E_0 with the photons so that the latter emerge with energies $E+E_0$ and $E-E_0$. Furthermore, the matter particles transmit momentum to the photons P and deflect them from their original direction. An analysis of the angular intensity distribution of the diffracted photons would tell us now how many particles have the momentum p and how many have the other momenta $p', p'' \cdot\cdot$, assuming that matter particles change their momentum from p' to p'' with a probability proportional to the product $\sigma(p') \cdot \sigma(p'')$, where $\sigma(p)$ is the *abundance* of various momenta p in the assembly of particles.

Either explanation is self-consistent. But it would be unreasonable to fuse them into one inconsistent idea. If we receive an optical signal reading "Camels," we can interpret it consistently in two ways. Either we assume the signal to come from a Bedouin in the desert, or from a smoker of cigarettes in America. But nobody would reasonably infer that the sender is an American smoker who is located in the desert. Likewise, it is unreasonable to infer that the matter particles which were introduced as the hypothetical source of corpuscular transmissions of energy $\pm E_0$ (first interpretation of the signal) are located in space in a manner described by the vibrating density ρ_0 (second interpretation). Nor would it be sensible to assume that the resonating wave density ρ_0 which was introduced as the hypothetical source of a wave radiation $\nu \pm \nu_0$ (second interpretation) changes its vibrational energy suddenly by such amounts E_0 as were introduced in order to explain the optical effect in a corpuscular way (first interpretation).

Over-interpretations like this and the attempts to fuse contradictory ideas have become the source of

the old classical bibliographers such as Gesner and Haller in European lands, but extended into the Far East and Far South, we could not resist a feeling of pride and warm admiration for the organizing genius of Billings, the fastidious classifier that was Fletcher, and the historical sensibilities of a Garrison, who had created an instrument of such far-reaching potentiality. Truly if there is one unifying emotion capable of bringing together a much split-up profession it might be aroused by this great achievement and its continuance in the future.''

many difficulties that have worried the students of quantum theory. This applies, for instance, to the *apparent failure of causality* in microphysics. A train of parallel light passing a small disk of microscopic dimensions (we could just as well use our former example of an oscillator) chooses to diffract its photons through a bundle of directions as though the photons had knowledge of the interference rules of waves. The photons, instead of going straight ahead, disregard the laws of causality and follow the guidance of a wave function; this is the current opinion. The paradox and its philosophical consequences disappear, however, if we describe the diffraction by a disk (or oscillator) consistently in pure wave or in pure corpuscular terms. The wave theory of light considers the disk of radius r as the Huyghens source of secondary waves. The density function of the disk is $\rho \begin{matrix} = \text{const. inside} \\ = 0 \text{ outside} \end{matrix} \Big\}$ of the radius r. The corpuscular theory explains the same phenomenon by means of photons of momentum P. It then has to describe the disk in corpuscular terms as well. Instead of having the density $\rho(r)$ as the Huyghens source of waves, the disk is now to be represented as an assembly of particles, in which various momenta p are present with an abundance $\sigma(p)$. The diffraction is explained by collisions between the photons and the matter particles which exchange their energies and momenta according to the causal conservation laws of mechanics, the number of transitions of the matter particles from p' to p'' being proportional to $\sigma(p') \cdot \sigma(p'')$. In the wave description disks of various shapes and sizes differ by their density distribution $\rho(r)$. From the corpuscular point of view various disks differ with respect to their spectrum $\sigma(p)$ (abundance function) of momenta. But it would be a violation of the basic idea of quantum theory to say that particles of matter with their distribution of momenta $\sigma(p)$ are located preferably in the maxima of the density function $\rho(r)$, the latter having been introduced only for explaining the diffraction from the wave point of view. Nor would it be reasonable to say that the matter waves which give rise to the aforementioned wave density $\rho(r)$, change their momenta and energies in such finite steps as were postulated in the corpuscular interpretation.

In contrast to the two independent interpretations of the "Camel message," however, the two interpretations $\rho(r)$ and $\sigma(p)$ of the optical message are mathematically dependent. The purpose of quantum theory is to find the mathematical rules for calculating the density function ρ when its complementary abundance function σ of the momenta is given, and *vice versa*. In fact, quantum theory gives direct mathematical relations between the density *amplitude* $\psi(r)$ and the abundance *amplitude* $\chi(p)$ whose absolute squares are $|\psi|^2 = \rho$, $|\chi|^2 = \sigma$. In the case of free particles (plane waves) each is a Fourier expansion of the other:

$$\psi(r) = \int \chi(p) \cdot e^{\frac{2i\pi}{h}(p \cdot r)} \, dp \text{ and its inversion.}$$

$$\chi(p) = \frac{1}{h} \int \psi(r) \cdot e^{\frac{-2i\pi}{h}(p \cdot r)} \, dr$$

But are there not many instances where the corpuscular interpretation of the ψ-function actually works in spite of the objections raised above? Indeed, the corpuscular interpretation of ψ works in describing *macroscopic* observations, for instance, in describing the structure of an interference pattern on a screen. The wave function ψ of the light amplitude predicts the time average of the intensity distribution on the screen with its maxima and minima; but the enumerable scintillations observed on the screen at low intensity comply indeed with the corpuscular interpretation of ψ. All this holds, however, only to a very limited extent. It is true that far away from the microscopic sources, in regions of small curvature, both the corpuscular and the wave theory are capable of explaining the macroscopic distribution of intensity—as far as *averages* in time are concerned. The relative fluctuations of the intensity, however, depend on the absolute magnitude of the intensity. Only if the latter is small is it true that one obtains relative fluctuations *as though* the ray consisted of a shower of particles, namely, scintillations and sudden registrations of Geiger counters. At large absolute intensity, however, one finds fluctuations of a quite different type known as interference fluctuations, as though the ray consisted of waves.

It is only because both classical theories are capable of describing *averages* of the intensity that one can proceed in the following two ways. (1) Calculate the average intensity by means of the wave theory (ψ-function); then, if its absolute value is small, calculate its fluctuations in a corpuscular way. This calculation gives then the impression as though the wave function ψ were "in reality" only a probability amplitude for particles. (2) Or proceed as follows: Calculate the average intensity by means of the corpuscular theory; then, if the absolute value of the intensity is large, calculate its fluctuations from interferences of waves. This calculation suggests, then, to consider the rays as consisting "in reality" of waves. How fallacious it is to believe in either of these interpretations is seen from the fact that at intermediate intensities the fluctuations follow a law which is neither corpuscular nor wave-like but is a compromise between both of them (Einstein's fluctuation formula).

I hope to have shown in the first part of these considerations that the usual corpuscular interpretation of Schrödinger's ψ-function rests upon an unjustified overinterpretation of the observed facts, in contrast to the basic idea of quantum theory, which is the idea of complementarity. In the second part I tried to point out that, although the corpuscular interpretation is working in the case of small intensities, it represents only a very limited point of view in describing what is observed in reality.

OBITUARY

SARA GWENDOLEN ANDREWS

On December 13, 1936, there passed away a woman with the rare gift of genius, Mrs. Ethan Allen Andrews, the wife of Professor E. A. Andrews, of Johns Hopkins. Mrs. Andrews, born Sara Gwendolen Foulke, died suddenly of a heart attack at her home in Baltimore. She had lived a retired life for years and many biologists in recalling her personally must go back to the memory of the beautiful, gracious young woman who made such a charming figure in the Woods Hole circle of the early 1890's.

Mrs. Andrews was born at Bala Farm in Pennsylvania in 1863. She studied at private schools and later for a time at Bryn Mawr, the University of Pennsylvania, Woods Hole and Roscoff on the French coast. She was married to Professor Andrews in 1894. Her earlier investigations dealt with infusoria and rotifers, but she became deeply interested in the structure and habits of protoplasm in general. And this is the theme of her classic memoir, "The Living Substance as Such: and as Organism," published as a special supplement of the *Journal of Morphology* in 1897, a memoir which carried her name and aroused admiration in biological circles throughout the world.

"The Living Substance" is not a paper with a definite contribution of fact or relationship between facts to be laid away after its essence has been incorporated in the handbooks. It is that and more. It has both depth and a grasp of many ideas. And one can read to advantage and with pleasure to-day this record of the multifarious experiences of a very thoughtful mind and a remarkable pair of eyes, aided by the best microscopic equipment of the time, in an exploration of the appearance and behavior of living protoplasm in protozoa, myxomycetes, leucocytes of invertebrates, sea-urchin and starfish embryos, fish eggs and other things.

The living substance, because of its tendency to take up water, exhibits itself to us as a Bütschli-structure, having the form of an emulsion, but it is only the continuous substance, separating and surrounding the droplets of included material, water and other things, that is alive. This is constantly active and its behavior is pictured as leading to changes in the general appearance of protoplasm. The alveoli, containing the discontinuous non-living stuffs, are increased or diminished in size or rearranged with the production of thin membranes, pellicles, within a protoplasmic mass or at its surface, constituting in the latter location a cell membrane. The thin lamellae between the alveoli may burst and disappear or their substance may "crawl or flow away," thinning and breaking in places and thickening elsewhere, or it may flow out at the surface of the mass or into the alveoli in the shape of delicate filose pseudopods forming in some cases new lamellae, one series of such changes in what Martin Heidenhain ("Plasma und Zelle," 1907) has called the architectural structure of cytoplasm culminating in cell division.

The histological section of this notable work is followed by a survey of the various phenomena of living nature as exhibited by individual organisms, all looked on as the outcome of the activities of substances, species-plasms or idioplasms, conceived of as isomorphic, everywhere differentiative and directive, and not optically analyzable. But while the potential features of a species are not localized within its idioplasm, the latter may transform itself into visible intra-cellular differentiations of many kinds for the discharge of particular functions. All these are designated "substance organs." Whether such ideas are tenable time and the future history of our present concept of genes as persistent and self-perpetuative entities will show. However that may be, the reader turning the pages of this memoir, now forty years old and which did not come into its own at once but encountered some inept criticism, will readily recognize, employing the words of von Baer, that we have here "observations and reflections" of genius.

H. V. Wilson

RECENT DEATHS

The death at the age of sixty-one years is announced of Dr. H. B. Carey, professor of materia medica, botany and pharmacognosy and dean of the College of Pharmacy at the Medical Center, San Francisco.

Dr. Geoffrey M. James, formerly professor of chemistry at the University of Pennsylvania, died on February 17 as the result of an automobile accident. He was forty-five years old.

Dr. Henry M. Chance, mining and consulting engineer of Philadelphia, from 1874 to 1884 assistant state geologist of the Pennsylvania Geological Survey, died on February 19. He was eighty-one years old.