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Albert Einstein on His Seventieth Birthday

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THE year 1905 was a notable year in that at the age of 26, Einstein published in that year's issue of the *Annalen der Physik* three brief but remarkable papers which have had very important bearings upon my own work as a physicist throughout my whole life. These three papers were on the following subjects: (1) the special theory of relativity; (2) the Brownian movements; and (3) photoelectric stopping potentials.

Everyone of these three papers represented new and far-reaching *generalizations* of immense importance. For the first and second of these the stage had already been set and the *experimental* foundations on which all sound generalizations must rest had already been built. In the case of relativity the prime experimental builder had been my own chief at the University of Chicago, Albert A. Michelson, who made his first experiment on aether-drift at Berlin in 1881, only two years after he had risen to fame by making in 1879 a very great improvement upon Foucault's rotating mirror method of determining the speed of light. With aid from Alexander Graham Bell he spent the next two years in Europe, and in Paris set up the first "Michelson interferometer." The next year he made with it the earliest attempt at an aether-drift determination. In his brief report on this experiment in the American Journal of Science **22**, 120, (1881), he is so sure of the correctness of the negative result obtained that he asserts that, in spite of the crudity of his apparatus, "the hypothesis of a stationary aether is thus shown to be incorrect."

But it was not until 1887 that this experiment, repeated at Case School of Applied Science with great care and refinement by Michelson and Morley, began to take its place as the most famous and in many ways the most fundamentally significant experiment since the discovery of electromagnetic induction by Faraday in 1831. The special theory of relativity may be looked upon as starting essentially in a generalization from Michelson's experiment. And here is where Einstein's characteristic boldness of approach came in, for the distinguishing feature of modern scientific thought lies in the fact that it begins by discarding all *a priori* conceptions about the nature of reality—or about the ultimate nature of the universe—such as had characterized practically all Greek philosophy and all medieval thinking as well, and takes instead, as its starting point, well-authenticated, carefully tested *experimental* facts, no matter whether these facts seem at the moment to be reasonable or not. In a word, modern science is essentially empirical, and no one has done more to make it so than the theoretical physicist, Albert Einstein. That, in a sentence, is, I take it, his greatest contribution to modern thought. It will stand out repeatedly in this brief review of the contributions I shall here touch upon.

Throughout the nineteenth century we had been building up what seemed a wonderfully consistent "natural philosophy" as to the nature of radiant energy—a beautiful wave-theory of light. This theory required that it be possible, by noting the difference in time *required* for a beam of light to get back to the observer when, on the one hand, it was sent forth in the direction of the earth's motion and back by reflection from a mirror to the observer, and when, on the other hand, it was sent a like distance forth and back at right angles to the earth's motion, to find the speed with which the earth is moving through the aether. But this experiment, after it had been performed with such extraordinary skill and refinement by Michelson and Morley, yielded with great definiteness the answer that there is no such time-difference and therefore no observable velocity of the earth with respect to the aether. That unreasonable, apparently inexplicable experimental fact was very bothersome to 19th century physics and so for almost twenty years after this fact came to light physicists wandered in the wilderness in the disheartening effort to make it seem reasonable. Then Einstein called out to us all, "Let us merely accept this as an established experimental fact and from there proceed to work out its inevitable consequences," and he went at that task himself with an energy and a capacity which very few people on earth possess. Thus was born the special theory of relativity.

My early contact with it came only because when I went to Chicago as a young assistant in 1896, Mr. Michelson was making elaborate experiments in the Ryerson Laboratory to see whether, though the earth at its surface "carried the aether along with it without slip," that slip might appear if the path taken by the light went to a considerable distance above the earth's surface.

I was only an onlooker in this experiment but later when I was struggling with cosmic ray effects I found I couldn't get anywhere without the use of the Einstein special relativity equation $m=m_0(1-\beta^2)^{-\frac{1}{2}}$. Furthermore, out of that same equation, also as a result of Einstein's boldness, came the stupendously important concept for 20th century physics that matter "m" itself might be transformed into radiant energy E through the relation $E=mc^2$. This Einstein equation has now become the most important relation in nuclear physics.

Turning now to the second of Einstein's great 1905 generalizations, the kinetic theory of gases had first been put on a quantitative basis by Joule's development in 1848 of the equation $p=\frac{1}{3}nmc^2$ and out of that came the first statement of the principle of equipartition of energy generally accepted in the case of gases by all modern atomists but vigorously denied by the school of so-called "energetikers" led by Ostwald and Helms and followed somewhat haltingly by so great a natural philosopher as Ernst Mach—a group which asserted that the facts of observation did not need the postulate even of the existence of atoms, to say nothing of their motions.

This principle of equipartition, however, under conditions of temperature and pressure not too far removed from the normal, had received, as most physicists thought, the best of *experimental* credentials through its success in predicting correctly the relative values of atomic weights, diffusion coefficients, and viscosities of different gases, the atomic weights of which ranged from that of the lightest atom, hydrogen, up to close to those like mercury, a hundred times heavier.

But though the Brownian movements had been experimentally discovered as early as 1827, we physicists before the time of Einstein had been extraordinarily blind in our failure to realize that there could be no reason to limit the principle of equipartition to bodies of atomic or molecular dimensions; that instead it should make no difference, on the basis of equipartition, whether the particles which were exchanging impacts with the molecules of a gas or a liquid which surrounded them were as big as an atom or as big as an orange—the average square of the particle-displacement in a time τ along a given axis X should in any case be given by the gas equation $\Delta x^2=(2RT/NK)\tau$ in which R/N is a gas constant and K is a resistance factor depending upon the viscosity of the medium and the size of the bombarded particle.

This quite obvious assumption or generalization was first made independently about 1905 by Einstein in Switzerland, Smoluchowsky in Poland and Sutherland in Australia. Furthermore, during the next few years Perrin in Paris had measured with the aid of the foregoing equation the extent of the random movements of emulsion-particles in liquids, and Harvey Flecher and I in connection with my oil drop experiments had done the same with much greater precision with suspended particles in gases, and thus verified experimentally the validity of Einstein's generalization.

As a result of these new researches the whole attack of the school of the "energetiker" upon the kinetic and atomic hypotheses had collapsed. Ostwald himself showed the greatness of his mind by publicly admitting that he had been wrong. Indeed in the preface to the next edition of his *Outlines of Chemistry*, published about 1913, he made the following clear and frank avowal of his changed position in the following words:

> "I am now convinced that we have recently become possessed of experimental evidence of the discrete or grained nature of matter for which the atomic hypothesis sought in vain for hundreds and thousands of years. The isolation and counting of gaseous ions on the one hand . . . and on the other the agreement of the Brownian movements with the requirements of the kinetic hypothesis . . . justify the most cautious scientist in now speaking of the experimental proof of the atomic theory of matter. The atomic hypothesis is thus raised to the position of a scientifically well-founded theory."

Einstein's third 1905 paper reveals more strikingly than either of the foregoing his boldness in breaking with tradition and setting up a photoelectric stopping potential equation $PD\cdot e=\frac{1}{2}mv^2=h\nu-p$ which at the time seemed completely unreasonable because it *apparently* ignored and indeed seemed to contradict all the manifold facts of interference and thus to be a straight return to the corpuscular theory of light which had been completely abandoned since the times of Young and Fresnel around 1800 A.D.

I spent ten years of my life testing that 1905 equation of Einstein's, and, contrary to all my expectations I was compelled in 1915 to assert its unambiguous experimental verification in spite of its unreasonableness since it seemed to violate everything that we knew about the interference of light. The contradictions between this equation could not be removed by any considerations which were available at that time to Planck, to Einstein or to any of the rest of us. These contradictions have now partially disappeared, however, through the development of the so-called "wave mechanics" by the work of Louis De Broglie, Schroedinger, Heisenberg, and Dirac. In accordance with these new concepts every material particle of mass m moving with a velocity v is describable by a series of waves of wave-length given by $\lambda=h/mv$. But Planck's universal constant h is so small (6.62×10^{-27} erg cm) and the m of all possible material particles or even of electrons is so large that these wave-lengths λ are in general infinitesimal in comparison with ordinary light or other electromagnetic waves. The results of their interference therefore produces essentially straight-line or particle-like propagation. In other words the *apparent* contradiction between particle and wave concepts now disappears and for the same reason as it did in the particle-wave controversy of a hundred fifty years ago, between Newton and Huygens.

In closing my tribute to Einstein I wish to say that much as I honor him for his immense contributions to physics, his greatest qualities lie in the field of character and morals. I worked with him for some years on a committee of the League of Nations and I also saw much of him in the two winters which he spent with us at the California Institute of Technology, and I came to admire him most for his extraordinary open-mindedness, his modesty, his honesty, and his complete readiness to admit that he had been wrong and to change his position entirely in the light of new conditions. His two-page statement found in a small pamphlet entitled "My Faith," printed and distributed by the American Weekly (New York, 1948) reveals a greatness of soul and keenness of intelligence and understanding rarely found in the history of mankind.

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L'Oeuvre d'Einstein et la Dualité des Ondes et des Corpuscules*

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M. Albert Einstein dont tout le monde savant célèbre aujourd'hui le soixante-dixième anniversaire a accompli une oeuvre scientifique d'une immense portée: en dehors de ces importants travaux sur la théorie des fluctuations et sur le mouvement Brownien, il a créé entièrement la théorie de la Relativité qui a tenu à juste titre une si grande place dans la Physique contemporaine et il a, à plusieurs reprises, apporté des contributions essentielles au développement de la théorie des Quanta. C'est lui en particulier qui a le premier souligné la dualité d'aspect onde-corpuscule dans le cas de la lumière et qui en a très finement analysé quelques unes des conséquences les plus importantes. Nous voudrions montrer dans les pages qui suivent le lien qui existe entre les deux parties essentielles de l'oeuvre d'Einstein; ce n'est pas par hasard que le créateur de la théorie de la Relativité a été aussi le précurseur de la Mécanique ondulatoire et des théories quantiques actuelles.

Le point de départ de la théorie de la Relativité restreinte a été l'invariance de l'equation de propagation des ondes lumineuses pour tous les observateurs galiléens, invariance qu'on peut considérer comme prouvée par la célèbre expérience de Michelson et d'autres expériences analogues. L'invariance en question entraine que l'on doit établir entre les coordonnées d'espace et de temps utilisées par divers observateurs galiléens des relations linéaires qui constituent les fameuses formules de Lorentz. Analysant avec une géniale profondeur les conditions de mesure des longueurs et des durées, M. Einstein a interprété les formules de Lorentz en admettant le caractère relatif de l'espace et du temps et en abandonnant ainsi la vieille conception newtonienne du "temps universel." Il a ainsi donné à la contraction de Lorentz et au ralentissement des horloges par le mouvement, qui sont des conséquences simples de la transformation de Lorentz, le caractère d'apparences observables. Puis il a montré que ces conceptions nouvelles conduisaient à une nouvelle cinématique reposant essentiellement sur de nouvelles formules de composition des vitesses différentes des formules classiques.

Cette réforme de la Cinématique devait inévitablement, Paul Langevin l'a montré plus tard, entrainer une réforme de la Dynamique. Il était d'ailleurs naturel d'admettre que les phénomènes mécaniques devaient être invariants pour le même groupe de transformation que les phénomènes électromagnétiques. Jusque là, on avait admis que les phénomènes mécaniques étaient invariants pour le groupe de Galilée, mais ce fait n'était vérifié qu'avec la précision assez limitée des mesures mécaniques; l'expérience de Michelson venant apporter, avec la très haute précision des mesures interférométriques, la preuve que les phénomènes électromagnétiques sont invariants pour le groupe de Lorentz, Einstein a été naturellement amené à penser qu'il fallait transformer les équations de la Dynamique de façon à les rendre invariantes pour le groupe de Lorentz, tout en conservant la validité approximative des équations anciennes dans le domaine des mouvements usuels à grande échelle où elles se sont montrées bien adaptées à la description des faits. Ainsi s'est développée la Dynamique relativiste qui ne diffère de la Dynamique ancienne que si les corps en mouvement sont animés de vitesses voisines de la vitesse c de la lumière dans le vide. L'une des plus remarquables conséquences de la Dynamique nouvelle a

* Editor's note: Because of the nature of this special issue, we are departing from our general practice of publishing only in the English language.