EINSTEIN’S OTHER BLUNDER

QUANTUM ID

WWW.QUANTUMID.SCIENCE

A NEW PERSPECTIVE BY K. STRANG

Radiation as Quanta: The Photo-electric Effect

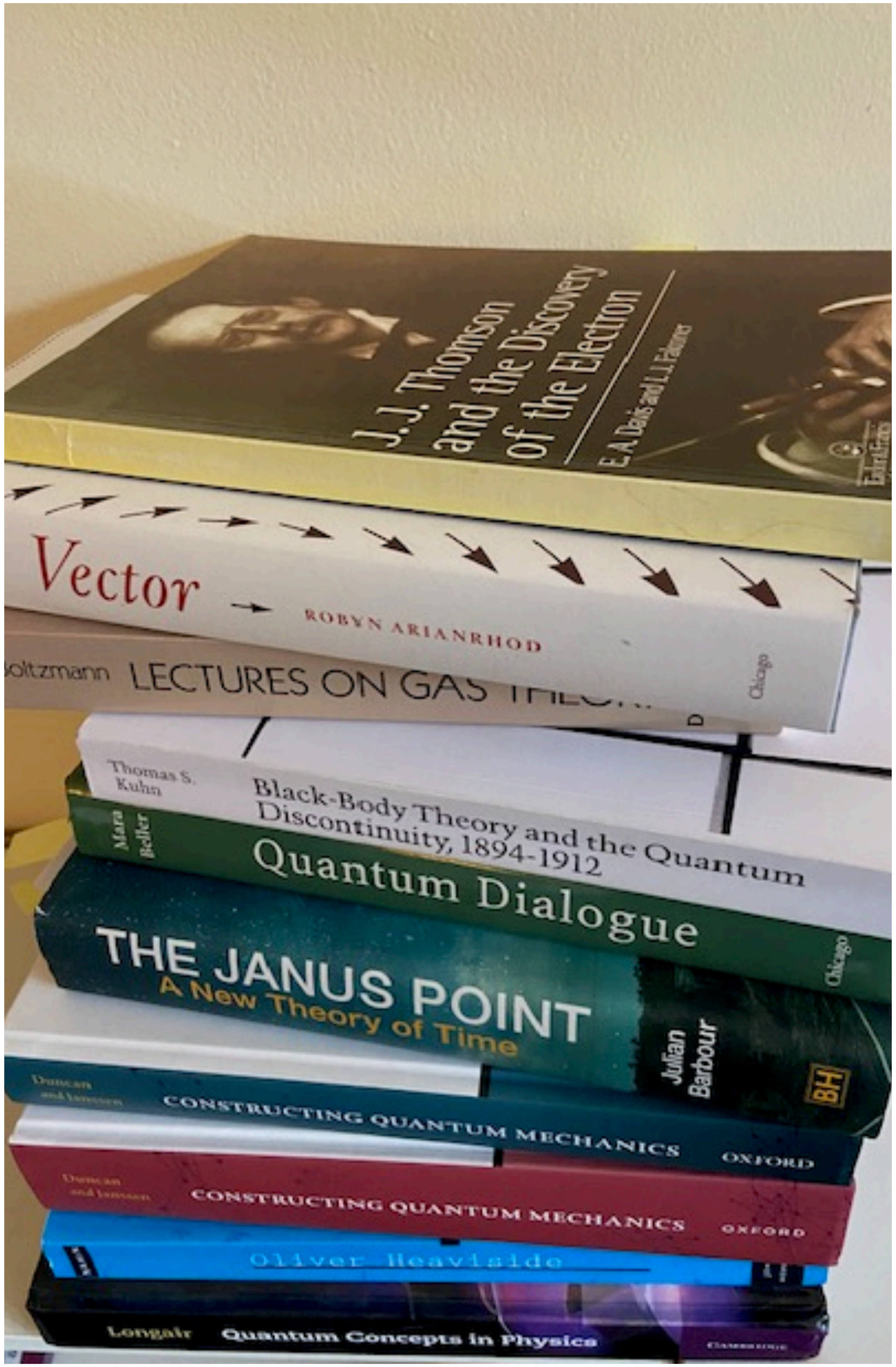
The question is why was Boltzman's mathematical artifice accorded ontological status in the hands of Planck? It could have been reconstructed as Boltzman implies to form a continuous wave.

'No molecule may have an intermediate or a greater kinetic energy. When two molecules collide, they can change their kinetic energies in many different ways. However, after the collision the kinetic energy of each molecule must always be a multiple of ε. I certainly do not need to remark that for the moment we are not concerned with a real physical problem. It would be difficult to imagine an apparatus that could regulate the collisions of two bodies in such a way that their kinetic energies after a collision are always multiples of ε. That is not the question here. In any case we are free to study the mathematical consequences of this assumption, which is nothing more than an artifice to help us calculate physical processes. For at the end we shall make ε infinitely small and pε infinitely large, so that the series of kinetic energies . . . will become a continuous one, and our mathematical fiction will reduce to the physical problem treated earlier.' [Boltzman, 1872]

The answer is that Planck's solution to the UVC was supported by Einstein's interpretation of the photo-electric effect. To demonstrate the discontinuous nature of radiation he examined three different phenomena: (i) the frequency of photo-luminescent emissions being less than the frequency of the incident light (Stokes' Rule) (ii) the photoelectric effect and (iii) photoionisation of gases. As it is (ii) that attracts the most attention, it is worth examining in more detail.

The photo-electric effect had been discovered by Herz in 1887 in experiments that confirmed Maxwell's equations. Light is directed at a metal (eg., potassium) and electrons are released as radiation. Lenard (1862-1947) discovered that the energy of the electrons was independent of the intensity (strength or power) of the light beam. Einstein's solution was that the key was the frequency of the light directed at the metal: only light of a certain frequency would dislodge the electrons; the greater the intensity of the directed light the greater number of electrons would be released but only at that frequency.

'The usual conception that the energy of light is continuously distributed over the space through which it propagates, encounters



very serious difficulties when one attempts to explain the photoelectric phenomena, as has been pointed out in Herr Lenard's pioneering paper[P.Lenard, Ann.Phys.,8,169,170(1902)]. According to the concept that the incident light consists of energy quanta of magnitude Rβv/N, however, one can conceive of the ejection of electrons by light in the following way. Energy quanta penetrate into the surface layer of the body, and their energy is transformed, at least in part, into kinetic energy of electrons. The simplest way to imagine this is that a light quantum delivers its entire energy to a single electron: we shall assume that this is what happens. The possibility should not be excluded, however, that electrons might receive their energy only in part from the light quantum.'

[A. Einstein *Towards an Heuristic Point of View Towards the Emission and Transformation of Light*. Annalen der Physik, Volume 322, Issue 6, pages 132–148, 1905]

Einstein's theory was 'confirmed' by experiment in 1916 by R.A. Millikan [*A Direct Photoelectric Determination of Planck's "h"*,1916 Physical Review, Vol. VII. No. 3 p 355-388] and A.H. Compton in 1923 [*A Quantum Theory of the Scattering of X Rays by Light Elements*, Physical Review 1923 Vol. 21, No. 5 p 483] and Einstein won the Nobel prize. I do not believe that Compton's experiments nor those of Millikan were conclusive. As Compton's experiment was the more convincing of the two, it is examined in more detail in the additional material accompanying this essay.

The acceptance of quanta of electromagnetic radiation was not adopted as the prevailing ontological view until these scattering experiments in the 1920s. It then paved the way for the quantisation of matter, quantum mechanics and quantum field theory.

2.5.4 The initial objections to Einstein's theory were broadly:

' . . . by around 1913 almost all physicists rejected Einstein's light-quantum hypothesis, and they had good reasons for doing so. First, they believed that Maxwell's electromagnetic theory had to be universally valid to account for interference and diffraction phenomena. Second, Einstein's statistical arguments for light quanta were unfamiliar and difficult to grasp. Third, between 1910 and 1913 three prominent physicists, J.J. Thomson, Arnold Sommerfeld, and O. W. Richardson, showed that Einstein's equation of the photoelectric effect could be derived on classical, non-Einsteinian grounds, thereby obviating the need to accept Einstein's light-quantum hypothesis as an interpretation of it. Fourth, in 1912 Max Laue, Walter Friedrich, and Paul Knipping showed that X-rays can be diffracted by a copper-sulfate crystal, which everyone took to be clear proof that they were electromagnetic waves of short wavelength. Fifth, in 1913 Niels Bohr insisted that when an electron undergoes a transition between two stationary states in a hydrogen atom, an electromagnetic wave, not a light quantum, is emitted . . .' [Roger H. Stuewer, *Einstein's Revolutionary Light-Quanta Hypothesis* Presented at The Centenary of the Photon Conference, 30 August 2005, Warsaw, Poland. Vol. 37 (2006) Acta Physica Polonica B No 3 p543]

Also Niels Bohr in his Nobel Lecture in 1922 stated:

'In spite of its heuristic value, . . . the hypothesis of light quanta, which is quite irreconcilable with so-called interference phenomena, is not able to throw light on the nature of radiation . . .' [Niels Bohr, *The Structure of the Atom*, Nobel Lecture, December 11, 1922, in Nobel Foundation, Nobel Lectures including Presentation Speeches and Laureates' Biographies: Physics 1922–1941, Amsterdam: Elsevier, 1965, pp. 7–43, on p. 14.]

Bohr, in discussions with Einstein, struggled to accept the characterisation of light as streams of photons:

'Notwithstanding its fertility, the idea of the photon implied a quite unforeseen dilemma, since any simple corpuscular picture of radiation would obviously be irreconcilable with interference effects, which present so essential an aspect of radiative phenomena, and can be described only in terms of a wave picture. The acuteness of the dilemma is stressed by the fact that the interference effects offer our only means of defining the concepts of frequency and wave-length entering into the very expression for the energy and momentum of the photon . . .' [*Discussion with Einstein on Epistemological Problems in Atomic Physics 1949*, Atomic Physics and Human Knowledge, Dover Publications, Inc 2010 p34]

I take this to mean that Bohr knew that in defining the energy of a photon as *hf,* (Planck's constant times frequency) that Einstein and Planck were effectively digitising wave phenomenon. He concludes that de Broglie in 1925 extending wave-particle duality to material particles, exacerbated the problem:

' . . . the paradoxical aspects of quantum theory were in no way ameliorated, but even emphasised by the apparent contradiction between the exigencies of the general superposition principle of the wave description and the feature of individuality of the elementary atomic processes.' [Bohr, ibid]

Despite these reservations or misgivings, the solution was to conclude that radiation and matter could exist in both states or at least exhibit characteristics of both waves and quanta. Bohr argued for this compromise at his lecture in Como (1927) under the concept of 'complimentarity', while still favouring a wave interpretation. He refers to photons and quanta as 'wave packets':

'As is clear from these writings (Bohr's *Collected Works*), Bohr in his original struggle with the physical interpretation of quantum theory leaned heavily on the idea of a wave packet – a superposition of waves of different frequencies that results in a wave field limited in space and time. Bohr uses the imagery of a wave packet whenever he describes light waves or electrons, both in cases of free individuals and in cases of interactions between them. The position of the light quantum is the position of such a limited wave field, rather than that of a mass point.

***"Only by the superposition of harmonic waves of different wavelengths and directions is it possible at a given time to limit the extension in space of the wave field . . . if we ask about the position of a light quanta, we find that no more than in the case of its energy and momentum, we can define a position of a light quanta at a given time, without consideration of complimentary waves"* (1927b,69-70)**

'Using the idea of wave packets, Bohr directly derived the uncertainty relations, a derivation that is opposed to Heisenbergs, (which was) based on the idea of point-like electrons and protons.' [Mara Beller, *Quantum Dialogues, The Making of a Revolution*, University of Chicago Press, 1999 p122]

Schrödinger, at around the same time, starting from consideration of Boltzman's statistical mechanics, had analysed the picture perfectly:

'He [Schrödinger] wanted to give an explanation of Planck's radiation law in terms of a gas of light quanta and by applying the Bose-Einstein statistic developed the year before [by A.Einstein 1924 *Quantum Theory of a Monoatomic Ideal Gas*]. Schrödinger was unsatisfied with the fact that the particles … are counted in a way which he regarded as physically artificial, and he thought that something in their nature must explain why. However, instead of providing a microscopic description of the gas, Schrödinger proposed to treat the gas as a whole, … he used de Broglie's theory to describe the gas not as a collection of particles but as a matter wave. By doing this he showed that the Bose-Einstein counting procedure can be used as a counting method for standing wave modes . . .

". . .particles are nothing more than a kind of 'wave crest' on a background of waves."

Schrödinger already in this paper entertained the possibility that particles could be reduced to localized wave packets, even if he immediately realized that such a packet would quickly spread out.' [Valia Allori, Introduction to *Shrodinger's Collected Papers on Wave Mechanics*, Minkowski Institute Press, 2020 pviii -ix]

I believe it certainly is true that the *mathematical treatment* of light and matter can alternate between the two possibilities, but not that this necessarily corresponds to any ontological conclusion. Especially not the one where Nature is both wave and particle-like (i.e. that both light and matter could each behave sometimes as a wave, namely when travelling through space and sometimes as a particle, namely when being detected on a screen). This conclusion however, dominated future discussions so we arrive at a rather schizoid view of the world's ontology. It certainly ignores Newton's Rule III,

'We are certainly not to relinquish the evidence of experiments for the sake of dreams and vain fictions of our own devising; nor are we to recede from the analogy of Nature which is wont to be simple and always consonant to itself.' [Rules of Reasoning in Philosophy, *Philisophiae Naturalis Principia Mathematica*, Bk.III, 1686]

I suspect from a social and psychological stance, too much research had been completed and Nobel prizes awarded, for any recantation to take place, and the only option was to marry the two disparate approaches, and move forward. The key problem was not that an instrumentalist approach was adopted over a scientific realist approach, but that the former was dressed up as scientific realism. Particles should be viewed as a fraction of a wave (i.e. a snapshot of a wave for a very short time interval) and have no independent existence. So if one takes this view, it is obvious Einstein's analysis was a blunder of greater proportion than the cosmological constant.

Note: See additional material 'The Compton Scattering Experiments'.

Note: De Broglie in his 1924 paper speculates that electrons also have wave-like properties and his equation for the wavelength is h/p where h is the Planck constant and p the momentum (mass x velocity). The faster an electron travels, the greater the momentum and the smaller the wavelength.