ATOMIC CIRCUS: JUMPS AND SPINS

QUANTUM ID

WWW.QUANTUMID.SCIENCE

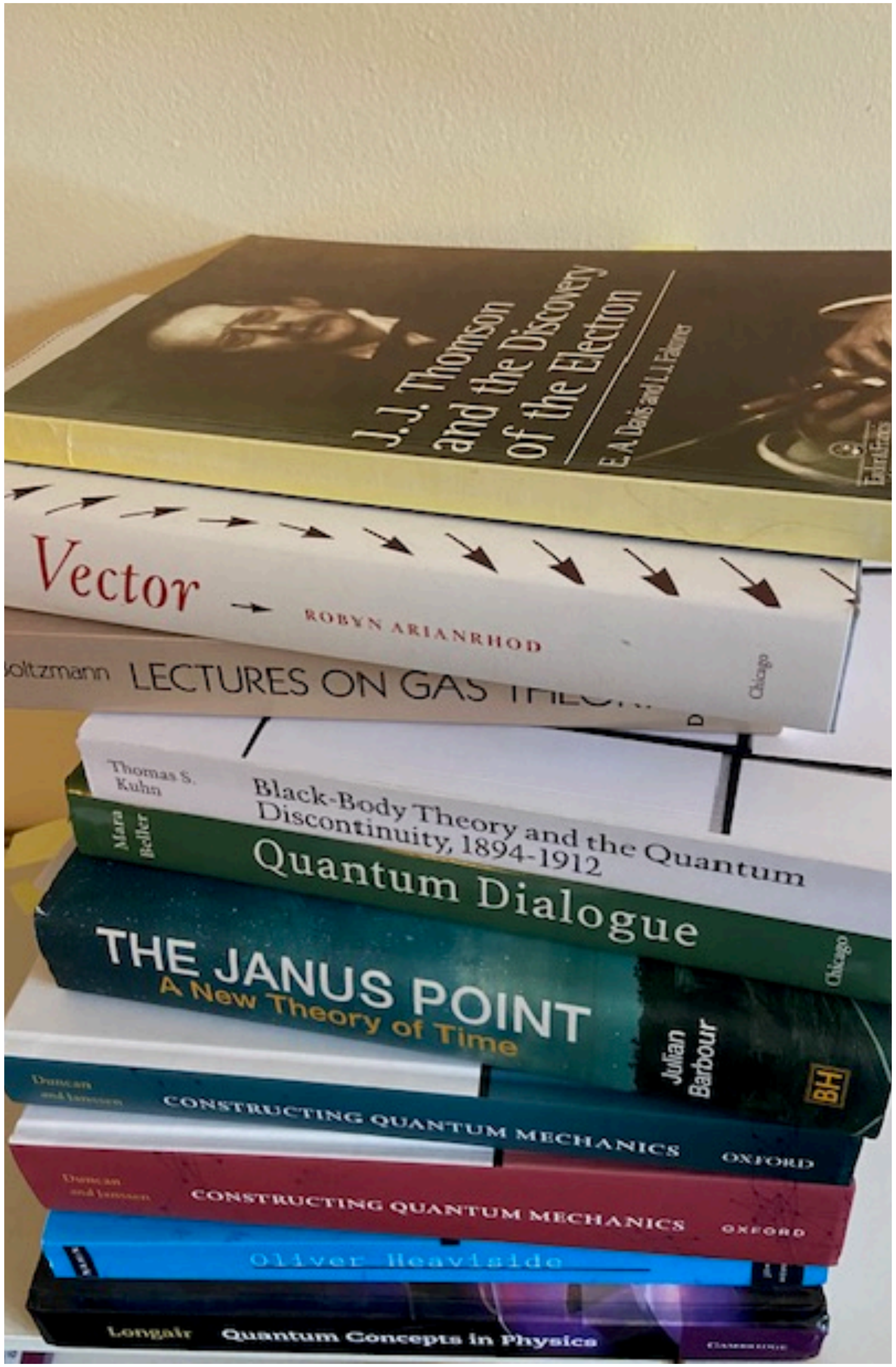
A NEW PERSPECTIVE BY K. STRANG

Jumps

The acceptance of the quanta enabled Bohr to complete his model of the atom which was of a nucleus containing protons and neutrons surrounded by shells of electrons, each shell having a defined energy state. These linked to the line spectra of the different elements. The absorption or emission of photons resulted in movement (jumps) from one energy level to another.

This led to a dispute between Schrödinger and Max Born over the true nature of reality. The former advocating continuous waves and the latter for discrete particles. Schrödinger in his paper *Are there Quantum Jumps* [The British Journal for the Philosophy of Science, Vol III August 1952, No 10,p109] argues that photons, and the line spectrum of atoms are useful mathematical shorthand but do not reveal reality which he maintains is continuous and is better described by wave mechanics.

'. . . for having shut our eyes to its one great deficiency: while describing minutely the so-called 'stationary' states which the atom had normally, i.e. in the comparatively uninteresting periods when nothing happens, the theory was silent about the periods of transition or 'quantum jumps' (as one then began to call them). Since intermediary states had to remain disallowed, one could not but regard the transition as instantaneous; but on the other hand, the radiating of a coherent wave train of 3 or 4 feet length, as it can be observed in an interferometer, would use up just about the average interval between two transitions, leaving the atom no time to 'be' in those stationary states, the only ones of which the theory gave a description. . . . The achievement of wave mechanics was, that it found a general model picture in which the 'stationary' states of Bohr's theory take the role of proper vibrations, and their discrete 'energy levels' the role of the proper frequencies of these proper vibrations . . . The principle of superposition not only bridges the gaps between the 'stationary' states, and allows, nay compels us, to admit intermediate states without removing the discreteness of the 'energy levels' (because they have become proper frequencies); but it completely does away with the prerogative of the stationary states . . . The perseverance in this way of thinking is understandable, because the great and genuine successes of the idea of energy parcels has made it an ingrained habit to regard the product of Planck's constant *h* and a frequency



as a bundle of energy, lost by one system and gained by another. How else should one understand the exact dove-tailing in the great 'double-entry' book-keeping in nature? I maintain that it can in all cases be understood as a resonance phenomenon.'

Think of the piano with definite notes ('proper frequencies') compared to a violin which can slide up and down between these notes.

This raises the question of the role of mathematics in determining ontological questions. Schrödinger's argument echoes Newton's qualification in *Principia*, which is worth quoting:

'The words 'attraction', 'impulse' or any propensity to a centre, however I employ indifferently and interchangeably considering these forces not physically but merely mathematically. The reader should hence be aware lest he think that by words of this sort I anywhere define a species of mode of action, or a physical cause or reason.'

Schrödinger also criticised Bohr and others for extrapolating from experiments with many electrons to reach conclusions about the behaviour of a single electron. When he wrote his paper in 1952, it was not possible to conduct experiments on what the electron was up to between two energy levels. Fast forward to 2019 and a paper published in *Nature* entitled *To catch and reverse a quantum jump mid-flight* by Z.K. Miner and others [03/06/2019, pp 200 - 204] concluded:

'The experimental results demonstrate that the evolution of each completed jump is continuous, coherent and deterministic.'

So the Copenhagen interpretation of the wave equation should be limited to a mathematical or statistical tool and not lay claims to any ontological conclusions.

Spins

When electron spin was first mooted it was dismissed by Henrik Lorentz (1853-1928) and Wolfgang Pauli (1900-1958) as 'unphysical'. However, expedience dictated it was used as a fourth quantum number to save Pauli's Exclusion Principle and explain the Zeeman effects i.e. additional line spectra of atoms when a magnetic force is applied.

Pauli's Exclusion Principle states that no two identical fermions (i.e., electrons) can exist in the same quantum state. Unlike two classical objects such as two billiard balls which are similar but not identical, all electrons are identical. Classical objects can follow well defined trajectories whereas if two electrons, identified as P and Q because of their different locations, cross paths or collide, it is impossible to determine afterwards, which is which. In QM terms, when their wave functions overlap the particles become indistinguishable. Pauli's principle identifies uniquely each electron in a system (i.e., an atom) by its 4 quantum numbers – the first three, namely (i) energy level, (ii) angular momentum and (iii) a magnetic property were accepted but the fourth, 'spin' was shoe-horned into the picture because the model of the atom and the mathematics involved needed a fourth attribute: the two electrons in the Helium atom share the first three numbers, so for the Exclusion Principle to work, a fourth distinguishing feature was required.

In 1925 two Dutch physicists, Samuel Goudsmit and George Uhlenbeck came up with the idea of 'spin' when studying the Zeeman effect and took it to their Professor Ehrenfest and Lorentz:

' . . . the electron was known to be very small, at least 3,000 times smaller than an atom—and atoms were already known to be about a tenth of a nanometer across, a million times smaller than the thickness of a sheet of paper . With the electron so small, and with its even smaller mass—a billionth of a billionth of a billionth of a gram— there was no way it could possibly be spinning fast enough to account for the angular momentum Pauli and others were searching for. In fact, as Lorentz told Uhlenbeck, the surface of the electron would have to be moving 10 times faster than the speed of light, a flat impossibility . . . Despite the fact that the electron couldn't be spinning, the idea of spin was widely accepted as correct—just not in the usual way. Rather than an electron actually spinning, which was impossible, physicists interpreted the finding to mean that the electron carried with it some intrinsic angular momentum, as though it were spinning,

even though it couldn't be. Nonetheless, the idea was still called "spin," and Goudsmit and Uhlenbeck were widely hailed as the progenitors of the idea.' [Adam Becker, *Quantum Particles Aren't Spinning So Where Does their Spin Come From?*, Scientific American, Nov 22, 2022]

This again appears to be a mathematical strategy to preserve the model of the atom, so when examining subsequent thought experiments expressed in terms of the 1/2-spin of entangled particles, some caution is surely required before pronouncing on any ontological conclusions. If 'spin' has been introduced to account for the coherence of the atomic model as a mathematical necessity, then why assume its presence when dealing with electrons on their own? Or attributing this quality to any other particle. It may also be the reason why experimental physicists use polarised photons.

The Stern Gerlach experiment which, I believe actually predated the advent of 'spin' and used silver atoms, is usually cited as proof that such a mysterious quantity exists. I do not believe it does for the same reason as many experiments in quantum mechanics fail: the presumption at the start of the experiment is that one is already dealing with a discrete particle whereas in reality one is dealing with waves.

Waves

As to Schrödinger interpretation – the beauty of his wave equation is that it was adapted from the classical wave equation used in fluid mechanics, light and acoustics. The upshot was that he viewed the electron as a standing wave (i.e. imagine a wavy circle) and this meant that the number of waves had to be a whole number (Pythagoras would have been pleased); when the electron absorbs a photon it's frequency and the number of waves would increase, the wavelength would decrease and this would alter the colour of the line spectra of the atom. He thought this a more natural way to explain the electron's behaviour than the circus style orbits and jumps in the Bohr model of the atom. Resonance is incorporated into this process. Schrödinger concludes in his first of six papers on Wave Mechanics:

'It is hardly necessary to emphasise how much more congenial it would be to imagine that at a quantum transition the energy changes from one form of vibration to another, than to think of a jumping electron. The changing vibration can take place continuously in space and time, and it can readily last as long as the emission process lasts empirically.'

It strikes me that in searching for a theory of everything, this would be the most natural place to start as there already is a conceptual link between classical and quantum worlds, namely waves. It would also resolve the arrow of time problem as the interference pattern caused by two colliding waves can not be reversed in the same way as the artificial construct of two identical particles colliding. So in both the quantum and classical world the arrow of time only points in one direction. I have included additional material on the website, *The Atom and the Brighton Rock* which covers the problems arising from a theory of identical particles.

Note: If one follows Max Born in thinking the wave equation when squared, provides values for the probability of finding an electron in a particular location, then that appears to work when the original wave is the positive half of a sine wave. When the full sine wave is squared the result is two peaks where the electron is likely to be found but also a point in the middle where there is no probability of finding the electron. If there is no continuity how can it be considered the same electron on either peak?

Note: A mathematical sleight of hand called 'normalisation' which has been elevated to a mathematical procedure amounts to reasoning *ex post facto:* the electron must be *somewhere* (even in an infinite universe) therefore the probability (area under the graph of the square of the wave function) must equal 1. If it does not, then a factor is applied to get this result!