MAGIC PARTICLES

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A NEW PERSPECTIVE BY K. STRANG

Action at a Distance: Entanglement

In order to obtain a clear picture of what is occurring, an initial examination is needed of what is meant in QM by the notion that two 'particles' are in an entangled state. Theoretical discussions of entanglement or 'spooky action at a distance' commenced with the EPR paper in 1935 when Einstein, Podolsky and Rosen set out to demonstrate that the Copenhagen interpretation of QM was an incomplete theory. Their argument was that the foundation of QM was based on contradictory hypotheses: (a) the Uncertainty Principle stated that if the position of a particle is known then the momentum cannot be known and *vice versa*; (b) that particles are in a superposition of states until measured and only have defined positions or momentum once the measurement has occurred and the wave function collapsed.

They held that a necessary condition in determining the completeness of a physical theory was that:

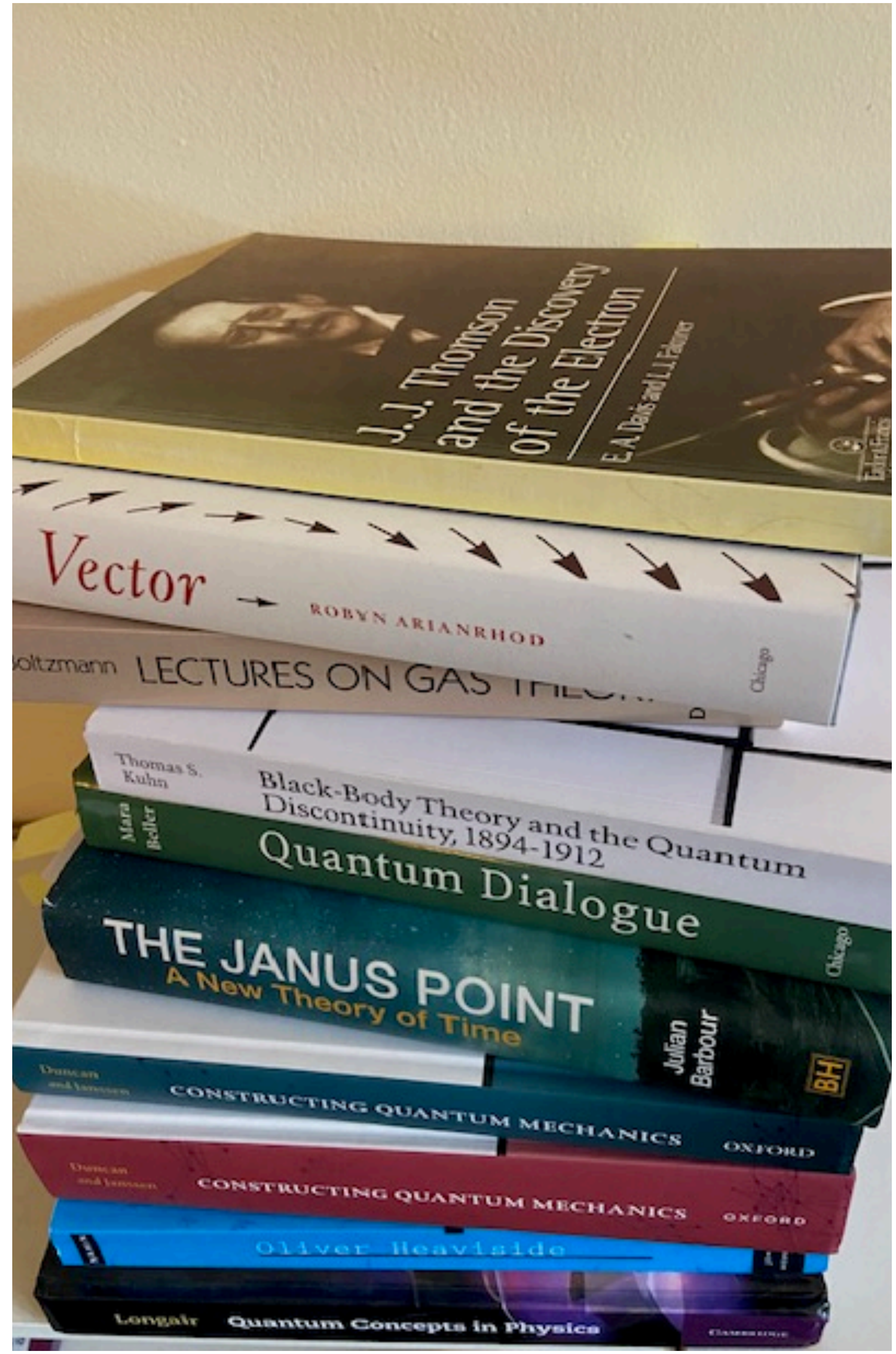
' . . . every element of the physical reality must have a counterpart in the physical theory.' [A. Einstein, B. Podolsky and N. Rosen, Institute for Advanced Study, Princeton, New Jersey, *Can Quantum- Mechanical Description of Physical Reality Be Considered Complete' ?* (Received March 25, 1935) Physical Review 15 May 1935]

and a sufficient definition of 'physical reality':

'If, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity .'

The EPR paper concludes firstly that the Uncertainty Principle which states that of the two quantities, position and momentum, only one can be predicted means that *either* QM is incomplete or the two quantities cannot have simultaneous physical reality.

An examination of Heisenberg's explanation of the inherent uncertainty in measuring the two variables, namely position and momentum, reveals that when dealing with matter at the Planck scale, it is mathematically and experimentally impossible to accomplish what is easily done in Newtonian mechanics in determining the position and momentum of large objects. The measurement of a particle's position is taken by directing a beam of light at it and as it bounces off the particle it carries information as to the particle's



position. The shorter the wavelength of the light the more accurate the measurement but the greater the energy transmitted and so the particle is given a kick and its momentum at that instant cannot be determined. It is based on Fourier transforms which mathematically illustrates why no better result is possible.

They then tackle the wave function which is assumed to provide a *complete* description of the physical reality of the state of a system.They proposed a thought experiment whereby a particle decays into two particles, A and B of equal mass travelling in opposite directions; the conservation laws mean that each particle has the identical momentum but in opposite directions, and this means that as their velocity is identical (apart from the direction) then their positions will be equidistant from the centre. See Figure 2 below

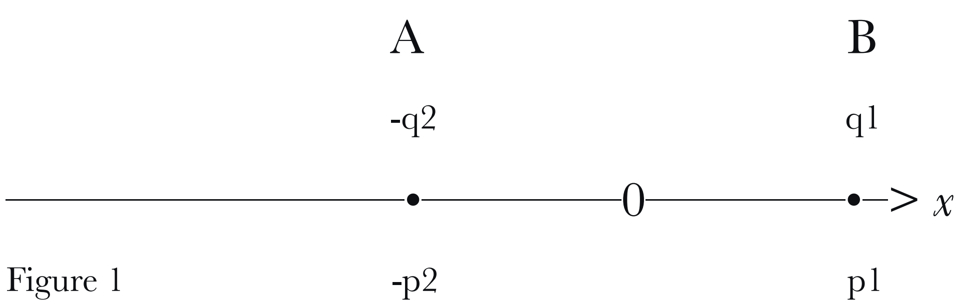


Figure 1

Using the wave function to measure A for momentum and position it is possible to predict with certainty these qualities in B. This contradicts the Uncertainty Principle.

'Thus, by measuring either A or B we are in a position to predict with certainty, and without in any way disturbing the second system, either the value of the quantity *P* . . . or the value of the quantity *Q* . . . In accordance with our criterion of reality, in the first case we must consider the quantity *P* as being an element of reality, in the second case the quantity *Q* is an element of reality. But as we have seen, both wave functions . . . belong to the same reality.' [ibid.]

So the contradiction is:

'Previously we proved that either (1) the quantum-mechanical description of reality given by the wave function is not complete or (2) when the operators corresponding to two physical quantities do not commute the two quantities cannot have simultaneous reality. Starting then with the assumption that the wave function *does* give a complete description of the physical reality, we arrived at the conclusion that two physical quantities, with non-commuting operators, *can* have simultaneous reality. Thus the negation of (1) leads to the negation of the only other alternative (2). We are thus forced to conclude that the quantum-mechanical description of physical reality given by wave functions is not complete.' [ibid.]

Einstein accepted that there were restrictions on what can be *known* about quantum systems because of the limitations of measurement but did not rule out aspects of the systems which might be hidden. The question resolved itself into whether the quantities being measured: (i) only came into existence when measured or (ii) existed independently.

Einstein supported (ii) and a deterministic universe; Bohr believed in (i) and countered the EPR paper with one of his own, [*Can the Quantum Mechanical Description of Reality be considered complete,* Physical Review 48 (1935)].

Bohr takes exception to the definition of physical reality given in the EPR paper and argues that in classical physics the system is always disturbed by the scientist. He argues that this will necessarily lead to:

' . . . a final renunciation of the classical ideal of causality and a radical revision of our attitude towards the problem of physical reality . . .'

He backs this up with reference to the theories of relativity where we abandon the usual distinction between space and time:

'The dependence on the reference system in relativity theory, of all readings of scales and clocks may even be compared with the essentially uncontrollable ex- change of momentum or energy between the objects of measurements and all instruments defining the space-time system of reference . . .'

This may be true but it seems that Bohr and others evade the issue pin-pointed in the EPR paper, namely that the Copenhagen interpretation of QM is a self-contradictory theory.

Hi-jacking the thought experiment

The subsequent discussions morphed into 'entanglement' *per se* and the possibility of particles communicating faster than the speed of light or whether 'hidden variables' were involved. While theoreticians discuss spin-1/2 particles (usually electrons), the experimenters have used polarised photons. I believe this caused a great deal of confusion. In order to evaluate the theoretical discussion, (a) the origin of 'spin' needs to be reviewed, followed by an evaluation of (b) Bell's Inequality and then (c) the experiments designed to demonstrate the correctness of QM predictions; and (d) any conclusions.

(a) <u>Thought Experiment revised to include Spin</u>
Turning to the theoretical arguments: David Bohm in 1951 restated the problem in the EPR paper using 'spin' with two possible orientations as opposed to position and momentum: the very notion of 'spin' is controversial and is examined in the previous essay in this series, *Atomic Circus: Jumps and Spins*.

(b) <u>Bell's Inequality</u>
Notwithstanding this, the 'spooky' action at a distance arising from the restated thought experiments in terms of spin seemed to contradict special relativity and so could not stand. Einstein's, Podolsky and Rosen thought the most reasonable explanation was that the second particle had definite values ever since it split up from the first particle. This has been viewed as a 'hidden variable'.

In a 1964 paper entitled *On the EPR paradox* [Physics,1:195-200], John Bell devised a test, 'The Bell Inequality' whereby three particles *a*, *b*, and *c* have two possible states, 0 and 1. There are eight possible combinations and two correlations, namely when *a* occurs but not *c*, then either (*a*, not *b*)or (*b*, not *c*) occurs and this provides the following inequality where P is the probability: P(*a*,-*b*) + P(*b*,-*c*)) ≥ P(*a*,-*c*). For a hidden variable theory to be correct it must conform to this. If it is violated then QM is correct.

Many experiments were conducted which showed that the inequality was violated and Bell's theorem stated that no physical theory involving local hidden variables can reproduce all the predictions of quantum mechanics. Therefore local realism as defined in the EPR paper could not stand. Bell's Inequality was revised in 1969 by Clauser, Horne, Shimony and Holt and are referred to as the CHSH inequalities but sometimes the revised tests are loosely described as 'Bell's Inequalities'. This revised version was considered more suitable for experimental testing. In the rush to close any loopholes in the experiments it appears as though the original contradiction in the EPR paper was forgotten and all weird effects of the Copenhagen interpretation were crowned as real phenomena.

c) <u>Experiments using Polarised Photons</u>
Turning to the experiments with polarised photons. As indicated in the first two essays in this series, a photon is an artificial entity, produced mathematically by digitising a wave. Waves by their very nature are in constant motion. Taking a sine wave representing some form of electro-magnetic radiation and trying to pin point a 'particle' or 'photon' whose energy is defined as *hf*, will have most success homing in on the crest of the wave, where the signal is strongest i.e. most intense, but it could be anywhere on the sine wave. It would be true to assume that immediately prior to this measurement at the peak, the photon would be lower than the wave peak, and immediately after, if the wave is travelling from left to right along an *x* axis, it would be some way down the right side of the wave. As the choice of which point of the moving wave to view as a particle or photon is *arbitrary*, this has been taken to mean that prior to this choice the photon has no position, stationary or otherwise or is in a 'superposition of states' until a measurement is taken and this described as 'the collapse of the wave function'.

Keeping in mind that the photon is travelling at the speed of light i.e. 300 x 10^8 ms^{-1} this is specious reasoning. Added to which, Heisenberg's Uncertainty Principle states broadly that when the position of a particle is measured along one axis then its momentum along the same axis cannot be known and *vice versa*. So even if the position or orientation is determined, the momentum of a photon is *already* known in the experiments as it is defined as Planck's constant multiplied by its wavelength and presumably the scientist conducting the experiment knows the wavelength of the electro-magnetic radiation being used and the axis along which the measurements are taken. The contradiction pointed out in the EPR paper remains and something must be missing in QM.

To use photons in experiments designed to demonstrate entanglement or to refute the EPR paper, cannot get off the ground when it patently contradicts this foundational principle.

Notwithstanding these oddities, the Nobel Prize for physics in 2022 was awarded to Alain Aspect, John F. Clauser and Anton Zeilinger for conclusive experiments on 'Bell's Inequalities' using many polarised photons. I believe they had to have recourse to the 'fair sampling hypothesis' where it is assumed that the registered events are a faithful representation of the whole.

(d) Conclusions

There is a logical flaw in the discussions and experiments alleged to demonstrate the impossibility of a hidden variable or local realism account of the phenomena. Bell's Inequality is based on separate distinct classical mechanical entities and the probabilities of correlations arising from them; whereas the experiments are conducted using waves i.e. continuous electro-magnetic phenomena.

The better interpretation is to accept at the outset that if a phenomenon such as entanglement exists then 'entangled' means that both particles are points on the same wave (light or matter) and so their positions will always compliment each other – as in Einstein's example of a pair of gloves. There is no need for hidden variables, just an accurate assessment of the structure of the actual phenomena rather than *ersatz* mathematical representations. Once that has been agreed there is no violation of the Inequality.

It is also worth noting that Schrödinger examined the entanglement claims in two papers dated 1935 and 1936 and I have included links to them in the scientific papers section of my website. In them, Schrödinger analyses and dismisses the notion of entanglement:

'It is suggested that these conclusions, unavoidable within the present theory but repugnant to some physicists including the author, are caused by applying non-relativistic quantum mechanics beyond its legitimate range. An alternative possibility is indicated.'

The proponents of entanglement, unashamedly mis-represent Schrödinger as having supported their thesis by taking a sentence from the first paper out of context:

'I would not call that *one* but rather *the* characteristic trait of quantum mechanics, the one that enforces its entire departure from classical lines of thought.'

The extraordinary lengths taken by the ruling orthodoxy to maintain their views is reminiscent of the Schoolmen of the Dark Ages.