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Experimentation as the Foundation of Quantum Mechanics: Its Heuristic Essence

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ABSTRACT

Most practicing scientists are experimental realists. They place equal emphasis on both theory and experiment, even though often priority and significance are apparently ascribed to theorization in science. Max Planck once argued that experiment is always a question posed to Nature and the results from experiment are Nature's answers. But, then, many philosophers of science downplay experiment in the discussions of the history and philosophy of science. The feeling is that scientific experiment does not play any pivotal role in unfolding the secrets of nature. This paper, therefore, addresses the issue and urges that the phenomenon of neglect of scientific experiment which has eaten into every fabric of philosophy of science discourse should be halted. The paper attempts its specific resolution from the viewpoint of the place of experiment in quantum mechanics. Quantum mechanics sheds a whole lot of light on the unappreciated heuristic value of scientific experiment. The respect quantum physicists show to experiment is enough pedagogical lessons for any willing investigator. Since this paper does not involve any thoroughgoing experimental or empirical research, I use the simple method of textual analysis.

Keywords: Quantum Mechanics, Experimentation, Foundation, Heuristic, and Essence

Introduction

In relatively recent times, modern empirical science seems to have led much emphasis on theorization at the expense of experimentation. This is a sure inheritance of the positivist philosophy of science. Experiment has been so undermined that it loses any heuristic, cognitive and epistemological values. This unwarranted neglect of scientific experiment is what spurs this paper to make a brief historical trajectory from the beginnings of quantum mechanics in order to recover the heuristic (discovery) essence of scientific experiment. In other words, quantum mechanics has been adopted here as a basis for discussing and establishing the enduring significance of experimentation in science. Quantum mechanics is fundamentally one of those exceptional comprehensive theories in the entire history of science that emerged from an experiment on black-body radiation. Its advocates are still enmeshed in the art of intuiting unimaginable predictions and designing scientific experiments. To be sure, quantum physics is all about making experiments, even though measurement remains it relentless nightmare. This is another way of saying that in quantum mechanics experimentation has reached its zenith – an all-time best in scientific investigations.

Quantum physicists were men who truly penetrated and explored the infinitesimal part of the universe, giving us, as it were, new ways of exfoliating and using Nature or the cosmos to our utmost benefit or advantage. New quantum-enhanced technologies are witnesses to the achievements of quantum scientists. This clearly shows that quantum principles, in their own rights, lead to workable experiments that guarantee technological breakthroughs. Therefore, a short historical excursus on quantum mechanics provides a perfect answer to the question of heuristic essence of experiment. Scientific experiments are not just there to illustrate scientific theories or grant the theories some rhetorical powers and a lot more. Scientific experiments are there to show us how to interact with nature and exploit it; for as Theodore Arabatzis corroborates: experiment is "the active interrogation of nature, an intervention in natural processes, and a manipulation of nature's forces" (Arabatzis 2014, p.191). A historical recourse to Roger Bacon's and Francis Bacon's analysis of how the lion's tail could be twisted through the experimental art provides a window to how Nature's secrets could be revealed.

Max Planck, Niels Bohr, Louis de Broglie, Werner Heisenberg, Erwin Schrödinger, Paul Dirac, Albert Einstein, Max Born and Wolfgang Pauli, among other quantum-relativity physicists, are part of the revolutionary light of the contemporary science. The yawning sub-atomic depths of quantum physics were overreached to a reasonable level of satisfaction by these early shapers of quantum theory. But in this paper, I can, at best, make a very brief navigation of their theoretical exploits and supervening respect for the experimental aspect of science. Hence, the shimmering light that comes from this paper could be gleaned from the fact that experiment must be present in any worthwhile quantum investigations. This is to say that quantum mechanics thrives on the basis of experimentation.

In terms of methodology, I shall concentrate on textual analysis that has nothing to do with actual collection of experimental data. The paper focuses on making a brief roll-call of just a few revolutionary figures that helped to build a new pigeon-hole for the contemporary quantum-relativity science that displaced Newtonian science and pushed scientific investigations beyond the bounds or frontiers of moderately moving macroscopic objects to the real microscopic supersonic highway of the speed of light that has something to do, especially, with waves, force-field or energy, to be precise. I shall then look at the experimental starting-point of quantum physics and Planck's early interpretations; I shall examine the early views of Bohr and Einstein, alongside their favorable dispositions towards experiment. This will be followed by short discussions of the views of Heisenberg and Schrödinger. I shall continue with a philosophical critique of quantum mechanics and, then, render a conclusion.

Quantum Beginnings in experimentation and Planck's pioneering Interpretation

The formative years of the quantum physics that was born in 1900 spanned over three decades. But the 19th Century research in radiation and thermodynamics was what gradually paved way for the emergence of quantum physics. But before anyone pushes forward to Planck's investigations of the black-body radiation, there is need to point out that the very concept *black-body* was coined by Gustav Robert Kirchhoff in 1859, a year after the birth of Planck (1858-1947). It was a time when scientists were saddled with much problems relating to the atoms and thermodynamics or heat radiation. A black-body is considered as a substance that absorbs and emits radiation of all frequencies without reflecting any surface light. With incremental application of heat the black-body, which may not necessarily be black in colour, turns red, blue, and white, indicating a rise in energy frequency or increase in energy packets as Planck later explained. Kirchhoff taught that the energy E emitted by any black-body is a product of the temperature T and frequency (or wavelength) V of the emitted energy. The simple mathematical equation covering it is $E=J(T,V)$. Hence, the scientific community was charged with the duty of finding appropriate role and value for J. As it stands, Joseph Stephan, Ludwig Boltzmann and Wilhelm Wien, among others, put their fingers on it. But, unfortunately, the experimental investigations of the laws/theories set forth by these scientists "proved" them wrong.

In Heisenberg's historical account of the foundations of quantum mechanics in experimentation, he writes: "The origin of quantum theory is connected with a well-known phenomenon, which did not belong to the central parts (of) atomic physics" (1958, p.30). The phenomenon or effect is often created when a piece of matter is heated and it gradually begins to glow from red, blue, to white as the temperature increases. Nonetheless:

> The colour does not depend much on the surface of the material, and for a black body it depends solely on the temperature. Therefore, the radiation emitted by such a black body at high temperatures is suitable object for physical research; it is a simple phenomenon that should find a simple explanation in terms of the known laws of radiation and heat. The attempt made at the end of the nineteenth century by Lord Rayleigh and Jeans failed, however, and revealed serious difficulties… When Planck, in 1895, entered this line of research he tried to turn the problem from radiation to the radiating atom... It was just at this time, during the summer of 1900, that Curbaum and Reubens in Berlin had made very accurate new measurements of the spectrum of heat radiation. When Planck heard of these results he tried to represent them by simple mathematical formulas which looked plausible from his research on the general connection between heat and radiation… This [eventually led to]…the discovery of Planck's law of heat radiation (1958, pp.30-31).

Amid this discovery, fortune was merry when Planck dredged up a universal constant dubbed as "Planck's constant". In this early quantum orientation, "Planck assumed the sources of light exchanged quantized ['packets' or 'bundles' of] energy". Pretty clearly, "Lummer, Pringsheim, Rubens and Kurlbaum" were the noble experimentalists that covered the tracks for Planck, especially with their experiments "on the spectrum of black-body radiation" (Franklin 1986, p.1). To be sure, these experiments, according to Allan Franklin, "formed an important part of the background to Planck's introduction of quantization" (1986, p.1). However, in *Physics and Philosophy: Revolution in Modern Science*, Heisenberg illuminates the initial hiccups of the issue of quantization and its resolution as he writes:

> The idea that energy could be emitted or absorbed only in discrete energy quanta was so new that it could not be fitted into the traditional framework of physics. An attempt by Planck to reconcile his new hypothesis with the older laws of radiation failed in the essential points. It took five years until the next step could be made in the new direction. This time it was the young Albert Einstein, a revolutionary genius among the physicists, who was not afraid to go further away from the old concepts. There were two problems in which he could make use of the new ideas. One was the photoelectric effect, the emission of electrons from metals under the influence of light. The experiments, especially those of Lenhard, had shown that the energy of the emitted electrons did not depend on the intensity of the light, but only on its colour or, more precisely on its frequency. This could not be understood on the basis of the traditional theory of radiation. Einstein could explain the observations by interpreting Planck's hypothesis as saying that light consists of quanta of energy travelling through space. The energy of one light quantum should, in agreement with Planck's assumptions, be equal to the frequency of the light multiplied by Planck's constant" (1958, p.32).

Here, one learns that, going a radical but convincing step farther from Planck's half-hearted position, Einstein was able to vociferate that light itself is quantized. To be sure, light consists of particles called photons. This revolutionary idea broke or parted ways with the then well-grounded wave theory of light (Pagels 1982, p.50). Einstein advanced the photonic model of light in a paper he published in 1905 on photoelectric effect. The American physicist, Arthur Holly Compton, conducted experiments on photon scattering, wherein "an X-ray photon undergoes a collision with an electron initially at rest. The result of this collision is that the photon is scattered, which changes its direction and energy" (Walker 2007, p.1014). The outcome of this experimental process of applying the photonic model of light is today called Compton Effect.

Henceforth, quantum mechanics became the new physics of the twentieth century "at the atomic scale of measurement. In quantum mechanics, quantities such as energy are not continuous: instead they come in discrete lumps, or *quanta*. The size of a single quantum is desperately small, given by tiny number known as Planck's constant" (Stewart 1989, p.292). Now, it is a historical fact that Planck initially never accepted the implied element of discontinuity latent in his early vision of quantum physics. But, then, further developments in the twentieth century physics helped him make up his mind in the now new advancing quantum mechanics. As Thomas S. Kuhn recounts:

> What then changed his mind appears to have been interaction with Lorentz who, in April of 1908, gave a major address on the black body problem to an international assembly of mathematicians in Rome… It is in a letter to Lorentz about that lecture, a letter written in October 1908, that Planck's first known statement of the discreteness of the energy spectrum and the need for discontinuity occurs (Kuhn 1984, pp. 237-238).

This conviction of Planck eased the way for further experimental investigations into the ghostly quantum world. To all intents and purposes, it is truly an invisible world of many possibilities and probabilities; a world both Bohr and Einstein admired and investigated, despite their celebrated disagreement and debate that eventually appears in Bohr's *Discussion with Einstein on Epistemological Problems in Atomic Physics*.

Early views of Niels Bohr and Albert Einstein as Co-Founders of Quantum Mechanics

The humane and ambitious Bohr (1856-1962) keyed into the new quantum world by paying initial obeisance to Planck and launching quantum physics into a full scale atomic and subatomic discipline. This atomic physics discussion reached its climax, wherein sub-atomic particles are no longer considered as particles, but are seen as some kind of waves or force-fields. Paul Dirac was able to craft the wave function equation for quantum mechanics. In this new quantum outlook, the "wave-particle duality [is] described by a quantum-mechanical wave-function" (Stewart 1989, p.292). However, this wave feature of quantum reality is inadvertently demonstrated in the new quantum periodic table. As it stands, electron is the only sub-atomic element on the table that could be said to have a slight character of a particle; yet it is known that in most circumstances, it behaves like a wave. The rest of the occurring elements such as the muon, tau, their neutrinos and the up, down, strange, charm, bottom, and top quarks, including the Higgs field, are all wave-like.

Bohr was taught at Cambridge by J. J. Thomson (1885-1962), the man who experimentally discovered electron in 1897 as a cathode ray. Of course, Thomson's discovery was a landmark event in the history of science; for it made good the ancient prediction of Strato of Lampsacus that the atom itself must be divisible. This leads the scientific community to a rigorous search for atomic structure. "In the meantime the experiments of Becquerel, Curie and Rutherford had led to some clarification concerning the structure of the atom. In 1911 Rutherford's observation on the interaction of α-rays penetrating through matter resulted in his famous atomic model" (Heisenberg, 1958, p.33). In point of fact, different atomic models have been superseding one another in the long history of empirical science as Makpu, Stella and Christian C. Emedolu recount the

> …proliferation of atomic theories or models that successively replaced one another over centuries of scientific tinkering with atom. No doubt, these recurrent changes or persistent revolutions began from the gentle rise of modern empirical science … through its maturation in the twentieth century quantum physics with the entire floury saga surrounding the Copenhagen interpretation of quantum phenomenon and so on (2019, p.53739).

Eventually, Bohr was fortunate or able to establish his dream Cavendish-type of laboratory at Copenhagen and became the titan of quantum physics. He afforded the Copenhagen interpretation of reality that was not in tune with predictability and deterministic worldview of classical physics. Even though Einstein (who claimed that God does not play dice) and Planck, among a few others, opposed Bohr's strange picture of the atomic and sub-atomic world and its characteristics, the idea caught on with others, especially, the younger generation of scientists. This is to say that, there were so many up-to-speed scientists who supported Bohr's quantum theory advancement through a favorable combination of mathematical and experimental skills at such an imposing laboratory at Copenhagen.

More to his credit, Bohr used certain radiation experiment to exhibit the two competing aspects/facets of light, namely *wave* and *particle* theory. He genuinely considered these two aspects as complementary. In a very short biographical note on Bohr, Mortimer J. Adler makes reference to the issue of "complementarity" in the following manner:

> In 1913 he [Bohr] published three papers on the constitution of the atom. In these it became clearer that there was a gap if not a conflict between classical physics and the new quantum physics. Experimental evidence provided especially by the study of radiation showed that light, for example, in some ways functions as a wave, while in others it acts like particles or quanta. In other words, light acts as though it's both continuous and discontinuous, but the wave description had become the dominant one (1990, p.299).

Heisenberg, for his part, summarizes this scenario when he ultimately submits: "Therefore, Bohr advocated the use of both pictures which he called 'complementary' to each other. The two pictures are of course mutually exclusive, because a certain thing cannot at the same time be a particle…and a wave…, but the two complement each other. By playing with both pictures, by going from the one picture to the other and back again, we finally get the right impression of the strange kind of reality behind our atomic experiments. Bohr uses 'complementarity' at several places in the interpretation of quantum theory… The space-time description of the atomic events is complementary to their deterministic description" (1958, p.49). This wave-particle duality of the quantum world was also talked about by Louis de Broiglie in 1927 when he was still a Ph.D student. To be sure, de Broiglie was rebuffed and embattled, narrating his ordeals in his foreword to David Bohm's *Causality and Chance in Modern Physics* (1957).

Now, a lot of implications for the notion of repeatability of experiment in quantum science could be found in the probabilistic picture of quantum leap, super-positioning, quantum tunneling, uncertainty principle, etc. If electron-spin position, for instance, keeps changing randomly each time new measurement is taken, then there is no guarantee that electron is going to behave the same way the next time one tries to "shake its folds" (just to borrow a phrase from Francis Bacon).

Thus far, as we have already noticed, the lineage of quantum physicists does not exclude Einstein who made enormous contributions towards its development. Einstein, indeed, helped to support the quantum physics inaugurated in 1900 by Planck who arrived at the quantum point with the initial experimental investigations of black-body radiation. In point of fact, Einstein waded into quantum physics and "…took the idea of quantized energy seriously and applied it to the then current discourse of radiation in the blackbody. Einstein proposed that light comes in bundles of energy, called *photons*, that obey Planck's hypothesis of energy quantization" (Walker 2007, p.1007). Pretty clearly, Einstein made good the practice of contemporary physics by meshing quantum mechanics with his relativity physics, though Einstein sometimes battled Born and Bohr. In Einstein's letter to Born, for instance, he writes: "You believe in a god who plays dice, and I in complete law and order" (Stewart 1989, p.1). Whence, one gleans the very source of Einstein's celebrated quarrel over Bohr's quantum indeterminacy. Heisenberg classifies Einstein as a member of the third group of critics that criticized Bohr's Copenhagen Interpretation of quantum theory:

> Their essential arguments may be stated in the following terms: The mathematical scheme of quantum theory seems to be a perfectly adequate description of the statistics of atomic phenomena. But even if its statements about the probability of atomic events are completely correct, this interpretation does not describe what actually happens independently of or between observations. But something must happen, this we cannot doubt; this something need not be described in terms of electrons or waves or light quanta, but unless it is described somehow the task of physics is not completed. It cannot be admitted that it refers to the act of observation only. The physicist must postulate in his science that he is studying a world which would be present, essentially unchanged, if he were not there. Therefore, the Copenhagen interpretation offers no real understanding of the atomic phenomena (Heisenberg 1958, pp.143-144).

Be that as it may, the relativity physicist, Einstein, could still be accurately characterized as a quantum revolutionary figure. Out of modesty or intellectual humility, he merely believed he only advanced Newtonian science. It is generally known, of course, that Einstein refuted Newton's centripetal and centrifugal forces or the so-called gravitational perturbations keeping the planetary system intact. Contrary to Newton's postulation, Einstein claims that, "…the planets are merely constrained by the deformation of space-time itself, and would wonder off into the blackness of space if it wasn't for the vast astronomical trough at the centre of our solar system" (Dicken 2016, p.2). Even though he could be seen as the last standing giant of the Newtonian or classical science (with a degrading passport for ether), Einstein brought creativity in his wake in the first two decades of the 20th century. He could actually be seen as an *Amphibium*, astride of the classical Newtonian world and the contemporary world of quantum-relativity physics. In other words, it could be said that contemporary science was partly inaugurated by the last of the classical physicists, Einstein himself. The veracity of this claim is evident in the spectacular utterance of Heins Pagels': "Einstein pioneered the transition from Newtonian physics to the quantum theory of atoms and radiation, a new non-Newtonian physics" (1982, p.5).

Werner Heisenberg and Erwin Schrödinger

In point of fact, the heroes list of the new generation of quantum scientists cannot be complete if one fails to mention the inventor of matrix mechanics, Heisenberg (1901-1976) who, from the start, was a strong supporter of Bohr. Heisenberg believes that for centuries experimentation in science has been progressing by leaps and bounds, so much so that any scientific investigation can arrive at some mathematical deductions of some possible properties or solutions and get to checking "the correctness of the solution by experiment in every detail. This possibility of checking the correctness of a statement experimentally with very high precision and in any number of details gives an enormous weight to the statement that could not be attached to the statements of early Greek philosophy" (Heisenberg 1958, p.75). At any rate, given the real quantum situation, Heisenberg insists that "…the theoretical interpretation of an experiment requires three distinct steps: (1) the translation of the initial experimental situation into a probability function; (2) the following up of this function in the course of time; (3) the statement of a new measurement to be made of a system, the result of which can then be calculated from the probability function" (1958, p.46).

Heisenberg made a mathematical invention of the matrices which was somewhat refined by the ebullient Paul Dirac with his perfect wave-function equation. Dirac "wrote a lucid paper formulating the new matrix mechanics and showed how it was a complete dynamical theory that replaced classical mechanics" (Pagels 1982, p.59). Another contributor to this matrix mechanics was the bashful and brilliant Wolfgang Pauli (1900-1958) who is best identified with the Pauli Exclusion Principle. The other figures were Max Born and Pascual Jordan, both of whom Heisenberg was in close contact. In spite of the possibility of checking the correctness or accuracy of some important scientific statements experimentally, Heisenberg goes ahead to postulate his much celebrated Uncertainty Principle in quantum experimental measurement. As a matter of fact, Heisenberg is best known for the treatment of uncertainty principle in quantum physics.

The thrust of Heisenberg's uncertainty principle is that it is practically impossible to accurately measure simultaneously the position and the velocity of an electron. Getting some level of accuracy in the measurement of the position of an electron undermines accuracy or exactitude in the measurement of its velocity. He focuses on the wave function, wherein the position of an electron, for instance, is given by the amplitude and the momentum is resolved by the wavelength. This implies that the more accurate one becomes in locating or measuring the position of an electron, the less accurate it becomes to measure the momentum and vice versa. The fact is that experiments were actually conducted to drive home the Thesis or question of uncertainty principle.

Heisenberg, following the tracks of Bohr, believes that, "The knowledge of the position of a particle is complementary to the knowledge of its velocity or momentum. If we know the one with high accuracy we cannot know the other with high accuracy; still we must know both for determining the behavior of the system" (1958, p.49). Heisenberg argues that the reason why we experience most kinds of uncertainty in quantum experiment "is due to the fact that matter has wavelike properties." (Walker 2007, p.1021). Yet it must be emphasized that quantum experimental measurement seems to inhibit the wave function. Be that as it may, Heisenberg uses the case of double slit experiment which provides two different interference patterns made by electrons passing or going through two different slits. Here, "the point is that as any given electron passes through the two-slit apparatus, *it is not possible to predict exactly where that one electron will land on the screen*. We can give the probability that it will land at different locations, but the fate of each individual electron is uncertain." (Walker 2007, p.1021). The launching of quantum mechanics into deeper uncertainty and endless probability has defined the role of statisticians in experiment. To be sure, "in recent years, research workers have turned increasingly to statisticians for help both in planning their experiments and in drawing consolations from the results." (Cochran and Cox 1957, p.1).

Now, towards the end of these formative years of quantum mechanics there was a marriage between the matrix mechanics and what is daubed as the new wave mechanics (invented by Louis de Broglie and Erwin Schrödinger). The man who replaced Planck at the University of Berlin, an Austrian physicist, Erwin Schrödinger (1887-1955) whose name forever goes with the ***cat*** paradox and Dirac were the officiating ministers of this sacred union. Both of them were able to harmonize the already existing two explanations of atomic phenomena – i.e., Heisenberg's matrix mechanics and de Broglie-Schrödinger's wave mechanics. This somewhat implies that the strongly experimentally confirmed wave dimensions of matter can no longer collapse save in the minds of those that can switch-off from palpable reality; for as Heisenberg strongly declares: "Actually we need not speak of particles at all. For many experiments it is convenient to speak of matter waves" (1958, p.48). As a testimony to this, Robert P. Crease and Charles C. Mann vociferate:

> It had not escaped Schrödinger that the indeterminacy relations restored visualizability to physics, and that wave functions were an integral part of the theory. He and Planck talked often, it seems, about waves and matrices; now he [Schrödinger] wrote: 'In a brand new

> article by Heisenberg, my-much-smiled-at wave packets are said to have at least found their correct interpretation as "probability packets"… well as God wills. I keep quite' (p.66).

As is the norm in scientific community, every idea, theory, or experiment must be criticized and re-examined before it gains wide acceptance. Schrödinger and Heisenberg did a whole lot of battles, but the happy fact is that at the appointed time "he (Schrödinger) and Heisenberg found themselves on the same podium, smiling fraternally as the Swedish Academy award them both the Nobel Prize for physics…. Their conjoined work became part of the common lore of physics. Schrödinger's wave methods are used by all the workers in the field, while his premises have been rejected; despite the celebrity of Heisenberg's premises, the matrix methods he pioneered are now rarely used for the purposes he had hoped" (Crease & Mann 1991, p.66). This simply shows that most times not all the aspects of a scientific theory are accepted for application in the scientific community and beyond. More so, not even the logico-mathematical representation of any theory can account for its full physical contents.

Philosophical Critique

It goes without saying that Newton took experimental philosophy or modern empirical science to an enviable height. But the so-called death of classical Newtonian science was something that came quite imperceptibly. Newtonian science was gradually undermined by its very practitioners who hardly understood the damage they were doing to that glorious science of modernity. By the time the scientific community realized it, the house was already crumbling. A new paradigm was enthroned and the brilliant modern Galilean or Newtonian science was somewhat shelved, even though it can still be applied to the moderate moving/accelerating macro-physical world. This new quantum paradigm was a bye-blow of an experimental investigation on/with black-body radiation. Being founded on experiment, the new quantum science placed an unmatchable emphasis on scientific experimentation, to such a point that a given scientific theory has little or no value if experiment cannot be further deployed in unveiling some hidden aspects or characteristics of reality.

The exaltation of experiment in quantum science remained imperceptible throughout the philosophical discourses of science in the twenty century in the Anglo-American and continental traditions. The logical positivists, the logical empiricists, the constructivist empiricist, the social constructivists, the radicals, and the strong programme members, among others, are all embroiled in scientific realism debate with much leaning on scientific theorization. Moritz Schlick, Rudolf Carnap, Hans Reichenbach, Carl Hempel, Karl Popper, R.N. Hanson, Thomas S. Kuhn, Paul K. Feyerabend, Imre Lakatos, Harry Collins Bruno Latour, Hilary Putnam, and Bas C. van Fraassen, among others (whether they be realists or anti-realists) were all engaged in this over-exaltation of theory to the detriment of experiment. To say it more appropriately, philosophers of science have been enjoying the boon of what Rom Harré (in "The Materiality of Instruments in a Metaphysics for Experiment") regards as an era of "invisibility of …experiment (:) the period during which logicism dominated" all facets of the discussions of the scientific enterprise (2003, p.19). Of course, neither the common-place scientist who fails to comprehend the intricacies of many minor theories within the more comprehensive quantum theory, nor the philosopher of science whose experiences witness some sort of blackout in the presence of quantum mystery experiments should be lampooned, for everything is, willy-nilly, soaked in the mire of obfuscation.

Be that as it may, it took the boldness or reawakening brought about by Ian Hacking, in his 1983 *Representing and Intervening*, for emphasis to be shifted to discussions of experimental realism. Hacking strives to draw attention to the importance of scientific experiment. He argues that experiment has been underestimated and theory overestimated. The neglect of experiment should be reversed by establishing the autonomy of scientific experiment. He tries to do this in two phases. In Hacking's first-tier argument in defense of autonomy of scientific experiment, I seem to think that he failed woefully, precisely because he failed to mention any classic example, wherein experiment comes before a theory, save his cited case of one hypothetical crazy experiment found in the musing of George Darwin's blowing of "the trumpet on the tulips every morning" (1983, p.154). Hacking still brings up another unique case wherein an experiment and a theory coming from different directions meet each other. As it stands, "The particular experiment Hacking cites on the occasion of this happy-meeting of a theory coming from a given direction to collide with a destitute experimental result is the one connected with the transatlantic radio transmission in 1965 where radio astronomers, Arno Penzias and R.W. Wilson, discovered 'a small amount of energy which seemed to be everywhere in space, uniformly distributed'" (Emedolu 2017, pp.16-17).

Now, the most surprising aspect of Hacking's autonomy of experiment argument at the level of primacy – i.e., Which one comes first, theory or experiment? – is that he failed or forgot to cite the instance of quantum mechanics. This would have been a favorable ground for him to clearly establish the autonomy of scientific experiment at the level of primacy, at least. But after Hacking, many scholars, like Allan Franklin, Brian Ellis, Rom Harré, John Robert Ackermann, John Warrall, Simon Schaffer, W.D. Hackmann, Thomas Nickles, Andy Pickering, Hans Radder, and many others have given some level of credence to experiment from different philosophical angles. Many international conferences, especially, the Bath conference in the mid-1980s, have been organized to re-dress what I may call forgetfulness or oblivion of experiment (to borrow Martin Heidegger's terms).

The rise of quantum science from a certain experimental situation is often down-played, so much so that theorization continues to be exalted to the detriment of experimentation. Small wonders, Franklin (1984) observed, in his review of Ian Hacking's *Representing and Intervening*, that most historians of science focus more on scientific theory to the neglect of experimentation. Of course, Franklin substantiates his claim thus:

> Thomas Kuhn, who has written a three hundred and fifty page book on the origins of quantum theory, *Black-Body Theory and the Quantum Discontinuity* [1978], makes almost no mention of the experiments on black-body radiation which caused the discrepancy between theory and experiment and led to the suggestion of the quantum (1984, p.381).

Henceforth, it remains a well-worn fact that quantum theory arises out of experimental investigation in black body radiation as is evident and amply demonstrated above. This is borne out by the fact that experiment has remained the pivot of quantum physics. Being so attached to experiment explains why quantum mechanics is most amenable to technological advancement in the contemporary world. This is the case precisely because experiment itself arose from the technical or craft tradition. From the counter-intuitive idea of quantum entanglement, which Einstein ridiculed as spooky action at a distance, quantum mechanists have been able, for instance, to build a teleportation machine. This is purely a magical result that ordinarily appears impossible to a work-a-day or classical scientist. The quantum physicists are also considering the possibility of building a sophisticated time-travel machine (or chronovizer) that will deploy gamma-rays. The measurement catastrophe experienced between the quantum world (wave function) and our own world (visible matter) does little or no damage to the experimental successes of quantum science. The issues of superposition, uncertainty principle, energy quantization, quantum tunneling, and entanglement, among others, make up the oxygen that keeps the flame of experimental investigations in quantum mechanics alive and going. To be sure, the ease with which experiments are designed in quantum science shows the remarkable role of experiment in enabling us to master bits and pieces of both the physical world and the ghostly quantum world of force-fields or wave functions.

Generally speaking, one must note that, a scientific theory is always like a building that has different apartments that serve different purposes. More significantly, a few of the apartments contain some syntactic furniture or devices that can never be experimentally shown to be useful in terms of practical application. Some other apartment merely serves as the attic, containing the stone tablet of general laws or experimental laws guiding the justification of the empirical or physical contents of the theory. Following Pierré M. Duhem, "successful theories do colligate, or bind together, experimental laws". In fact, Duhem clearly speaks "of theories as 'representing' a group of laws, and contrasted this 'representative' function with an 'explanatory' function that most theories are presumed to have" (qtd. Losee 1980, p.133). On his view, Ernst Mach would say that, these scientific laws are not found in nature hanging on a tree or lying in some marshy groves: for instance, "The law of refraction is a concise compendious rule, devised by us for the mental reconstruction of a fact, and only for its reconstruction in part, that is, on its geometrical side" (qtd. Dicken 2016, p.44). Paul Dicken further explains this by saying that "When we talk about laws of nature, for example, we are not talking about the fundamental structure of reality – we are merely talking about our most useful and wide-ranging generalizations" (2016, p. 44). But, then, the truth of the matter is that so long as the experimental or phenomenological laws or any other form of generalization guide us through the making of certain discoveries about our world, one should care less whether they are our own inventions or not.

Planck, Einstein, Bohr, Heisenberg, Schrödinger, and so forth, are all respecters of quantum experiments. That Einstein questioned the principle of quantum entanglement because it encourages the idea of non-locality (spooky action at a distance) and faster-than-light motion does not mean that he was not willing to accept any pragmatic success achieved through any quantum experimental demonstration. Of course, it cannot be said that Einstein also rebuffs mathematics because the uncertainty principle supports statistical inanities. Einstein will forever wait for experimental results, no matter how ugly they appear. Giant experimental strides made in quantum dot, quantum computer, and other applications of the quantum in many areas of science were the kind of things that gave him joy. It follows that the sophisticated quantum experiments, beyond the fabrics of mere *Lebenswelt* experiments (Lange 2003, p.121), are indispensable in discovering a lot about the universe and in exploiting the knowledge thereof to man's advantage. One unique feature of quantum mechanics is that its standard model theory or theory of everything can correctly predict every single experiment that could be done in the field of empirical science. Therefore, the logic is that experimentation can never be undermined or neglected in science if truth is actually one of the outstanding goals of science.

Say what one may, not so many scientists have actually understood the digital complexity of the 20th century quantum experimental life. We can only pass the buck to people like Einstein, Planck and their heirs for involving too many counter intuitive scenarios in quantum reasoning and practice. In spite of this, much kudos should be given to the instrumental technicians and all those who use the results of quantum and relativity experiments to bring about technological applications of the quantum theory. Why these people should be praised is that they have proved themselves very competent in catching on with the near phantasmagoric scientific dreams of the great revolutionary geniuses of quantum and relativity physics.

Conclusion

It remains an obvious fact that the list of who is who in the contemporary period of science is endless and that the hodgepodge of battles in Quantum-Relativity scientific revolution is quite overwhelming. Apart from Planck, Bohr, Heisenberg, Schrödinger, Born, Dirac, Pauli, Einstein, and Compton, among others, there were so many other minor and significant figures in the first half of the twentieth century that helped in building the comprehensive theory of quantum physics, such as, C. J. Davisson, John Bell, and so forth. Some experimental facts and mathematical equations that were brought to life by these quantum scientists cannot be glossed over in a comprehensive understanding of quantum science; for quantum mechanics is that which was founded on black-body experimentation and has mathematical measurement round its neck as an albatross as it wades across the divide or barrier between the quantum wave function and the ordinary physical/material world.

In point of fact, the grandiose job done by numberless experimenters in the quantum dispensation of contemporary science should also never be glossed over or demeaned in any way (logical, statistical or otherwise). It is true that amid genuine oppositions and varied interpretations in the quantum debates, the mast of classical or Newtonian physics was brought down and the new flag of quantum-relativity physics was hoisted as exemplar for 20th and 21st century science. Now, quantum-relativity physics should never in any way be taken as the last word in science. The manner in which it overthrew Newtonian or classical physics will certainly be the same manner in which it will in turn be superseded by some other scientific paradigm (to borrow a phrase from Kuhn). Yet, its deeper legacy in experiment may never be forgotten or "passed over in silence" (as Ludwig Wittgenstein would say); for if any theory dies, a lot could still be archived in terms of successes in its experimental exploits.

References

Adler, M. J. *et al*. (1990). *Great Ideas*, 2nd ed. Vol.56.

Arabatzis, T. (2014). "Experiment". *The Routledge Companion to Philosophy of Science*, 2nd ed. Edited by Martin Curd and Stathis Psillos. Oxon: Routledge. Pp.191-202.

Bohm, D. (1957). *Causality and Chance in Modern Physics*. London: Routledge and Kegan Paul Ltd.

Bohr, N. (1990). *Discussion with Einstein on Epistemological Problems in Atomic Physics*. In *The Great Ideas*, 2nd ed. Vol. 56. Chicago: Encyclopaedia Britannica Inc.

Cochran, W.G. & G.M. Cox. (1957). *Experimental Design*, 2nd ed. New York: John Wiley and sons.

Crease, R.P. & Mann, C.C. (1991). *The Second Creation: Makers of the Revolution in 20th–Century Physics*. Lagos: Page Publishers Services Ltd.

Dicken, P. (2016). *A Critical Introduction to Scientific Realism*. London: Bloomsbury.

Emedolu, C. C. (2017). "Ian Hacking on Primacy and Autonomy of Scientific Experiment: Perspectives in the History of and Philosophy of Science." *Explorer: African Journal, Arts, and Social Sciences*. Vol. 1. No. 1. Pp.8-20.

Franklin, A. (1984) "The Epistemology of Experiment". *The British Journal for the Philosophy of Science*. Vol. 35. No. 4. Pp. 381-390.

Franklin, A. (1986). *The Neglect of Experiment*. New York: Cambridge University Press.

Harré, R. (2003). "The Materiality of Instruments in a Metaphysics for Experiments". *The Philosophy of Scientific Experimentation*. Edited by Hans Radder. Pittsburgh: University of Pittsburgh Press. Pp. 19-38.

Heisenberg, W. (1958). *Physics and Philosophy: The Revolution in Modern Science*. New York: Harper Torchbooks.

Kuhn, T. S. (1984). "Revisiting Planck". *Historical Studies in the Physical Sciences*. Vol. 14. No. 2. Pp.231-252.

Lange, R. (2003). "Technology as Basis and Object of Experimental Practices". *The Philosophy of Scientific Experimentation*. Ed. Hans Radder. Pittsburgh: Pittsburgh University Press. Pp. 119-137.

Losee, J. (1980). *A Historical Introduction to the Philosophy of Science*, 2nd ed. London: Oxford University Press.

Makpu, S. S. and Emedolu, C. C. (2019). "Bas C. van Fraassen's Objection to Un-observable Entities: A Studied Rebuttal with the Case of Mycobacterium Tuberculosis." *Elixir Biosciences*. Vol. 135. Pp. 53539-53549.

Pagels, H.R. (1982). *The Cosmic Code: Quantum Physics as the Language of Nature*. New York: Bantam Books.

Stewart, I. (1989). *Does God Play Dice? The Mathematics of Chaos*. Cambridge: Blackwell.

Walker, J. S. (2007). *Physics*, 3rd Ed. San Francisco: Pearson Educational Inc.