On Wheeler's Quantum Circuit

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1 Introduction

The Meaning Circuit Hypothesis (MCH) is a synthesis of ideas providing John Wheeler's outline of ultimate physics, which he fine-tuned over several decades from the 1970s onward. It is a 'working hypothesis' in which 'existence is a 'meaning circuit"' that portrays the world as a "system self-synthesized by quantum networking." It was strongly advocated by him for roughly two decades and since then has had an increasingly strong impact on the approach of many investigators of quantum theory [1–3]; in particular, elements such as the quantum participator and 'it from bit' are now considered by others as candidate components of a foundation for quantum theory in which information is involved essentially; cf., e.g., [4–6]. Therefore, it is worthy of review and critique.[1]

[1]This paper is written on the occasion of the 60th birthday of Andrei Khrennikov, whose scientific life has included the service to the international physics community of organizing and running a continuous series of similarly interdisciplinary yearly conferences on the foundations of quantum theory that has spanned two decades, held in Växjö, Sweden, not far from Copenhagen, Denmark where Wheeler carried out his own postdoctoral studies with Niels Bohr. The Växjö quantum foundations conference series, which began with the new millennium, has been singular in its openness to a broad range of intellectual perspectives ranging from mathematical physics to the philosophy and history of science, all of which relate to this analysis and its fostering connections between quantum information studies and the foundations of quantum theory. It has been a privilege to participate in these meetings during which, as it turns out, my own work has run much of the gamut of areas touched on by the ideas of Wheeler's synthesis.

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A. Plotnitsky and E. Haven (eds.), *The Quantum-Like Revolution*,
https://doi.org/10.1007/978-3-031-12986-5_2

Physical theory can be viewed as prescriptive and/or proscriptive, setting out what must happen and/or what is forbidden from happening in the physical world (cf., e.g. [9]), and the more metaphysically ambitious of physicists have used it to venture or support theses about what can, must, or cannot *exist* in the physical world, that is, its ontology which has often been rather imprecisely referred to in the physics literature as simply 'reality', as Wheeler himself did. Physical laws and a small number of mathematically oriented mechanical principles have been held to ground physics since at least the introduction of Newtonian mechanics; in its mature period, physics has considered equations of motion, conservation laws, or symmetries as illuminating the structure of physical world and its behavior. It has been possible for physicists to find, or come close to finding sets of axioms serving as a consistent mathematical basis for fundamental physics in addition to techniques for predicting physical behavior with high precision. However, for quantum theory, some of these accomplishments proved more illusive than in classical theory, leading to a re-evaluation of what had been considered self-evident and basic elements of physics.

The apparent foundational difficulties in quantum mechanics led Niels Bohr, Wheeler's postdoctoral supervisor to introduce new notions into the physics of the atomic and subatomic scale such as *the quantum phenomenon* and *the significance of measurement configuration to the definiteness of physical properties*, in addition to its defining element, the quantum of action, $\hbar$. Wheeler believed that "nobody has had a better picture of what quantum theory is and means" than Bohr [7], p. 59. Wheeler viewed the MCH as building "only a little [further] on the structure of Bohr's thinking" that showed "how information may underlie reality." He characterized his own approach to science as a sort of "radical conservative-ism," the conservative aspect being its building on the ideas of the founders of quantum mechanics including Bohr and its connection to experiment, and its radical aspect being the demotion of objective matter-energy and spacetime as fundamental and viewing them as arising from the processing and communication of information resulting from observation. The development of the MCH took place while quantum information science (cf., e.g. [8]), which relates physics, communication, and computation, was developing into a discernible subject area that has also recently been involved in the ongoing investigation of the foundations of quantum theory [3, 4]. Although it takes information as fundamental, the MCH goes far beyond standard quantum information science in its attempt to identify a common basis for both quantum theory and space-time theory—in Wheeler's view, by providing an answer to the question "Why the quantum?" that he saw as essential for understanding both these areas of physics and, indeed, for offering an ultimate conception of reality itself.

Up at least up until the early 1970s, for Wheeler and the physics community at large, the ontology of quantum theory was thought to be one of particles and/or fields (cf., e.g. [10]): The evolution of Wheeler's thinking preceding the MCH has been described as involving first "a major shift …concerning the fundamental ontology of the universe, from a world of particles (with fields as convenient fictions) to a world of fields (from which particle-like aspects can be derived). This shift can also be seen to have radically altered Wheeler's creative process" in conceiving new physical theory; cf. [11], Sect. 2. With the MCH, Wheeler attempted to shift from the conventional view, proposing that the quantum physical world picture is one where neither matter nor even space and time are primary but, instead, one where reality is 'built up' through the accumulation 'meaningful' information which, in his view, logically precedes them. This notion was captured by his now famous phrase "it from bit" and explicated in a process which he schematized as a circuit, the "meaning circuit" [3].[2] Following this lead, axiomatic foundations for physics involving information have recently been sought; for a review of these attempts, cf. [4].

Wheeler saw information-centric physics as the latest, "third era" of physics following "Era I—Motion with no explanation of motion: the parabola of Galileo and the ellipse of Kepler" and "Era II—Law with no explanation of law: Newton's laws of motion, Maxwell's thermodynamics, Einstein's geometrodynamics, modern chromodynamics, grand unified field theory, and string theory" ([1], p. 109). The closed nature of the universe, in particular, poses a problem: None of the conserved-quantity requirements can be applied there; "For example, every method to determine the mass-energy of a system goes back to or is in some way equivalent to placing a planet in orbit about that system, measuring the period and size of that orbit and applying Kepler's law,"

$$\text{mass (in cm)} = \left(\frac{2\pi}{\text{period, in cm of light travel time}}\right)^2 (\text{radius, in cm})^3 \quad (1)$$

([2], p. 14). Wheeler argued that physical laws as we have conceived them cannot be stated without the involvement of space and time, but space and time themselves cannot be fundamental, he claims, because they must come into existence at the putative beginning and possible end of the known universe according to observationally confirmed implications of general relativity such as an initial singularity and black holes.

Accordingly, it became Wheeler's view that future physical laws—of what he called "Era III" of the history of physics—cannot be absolute and invoke space and time as fundamental but must, instead, be mutable and, so, follow from deeper notion(s), including that of "the quantum" in terms of which space and time themselves can be understood. Through its explication of ultimate reality, Wheeler believed that the meaning circuit resolves two suggested paradoxes: one, that "The universe exists 'out there' independent of acts of registration, but the universe does not exist out there independent of acts of registration" captured by quantum theory; the other, that "The bounds of time tell us that physics comes to an end. Yet physics

[2] The "It from bit" slogan has been since been taken up by others, for example, Jeffrey Bub arguing "assuming the information-theoretic constraints are in fact satisfied in our world, no mechanical theory of quantum phenomena that includes an account of measurement interactions can be acceptable, and the appropriate aim of physics at the fundamental level then becomes the representation and manipulation of information" [12, 13], something extreme in that most physicists accord with the view of John Bell that measurement should be understood as just another physical process—most processes having nothing obvious to do with information—despite the quantum-*mechanical* measurement problem; cf. [14].

has always meant that which goes on its eternal way despite all surface changes in the appearance of things. Physics goes on, but physics stops; physics stops, but physics goes on" ([15], p. 341). Here, Wheeler's MCH hypothesis for resolving these paradoxes is reviewed and critiqued.

2 Development of the Meaning-Circuit Schema

Let us begin by briefly reviewing Wheeler's 'circuit' model for the conception of physical reality, its development, and a number of his arguments in support of it which are dealt with in greater detail in later sections. In this section, this is done primarily through the statements of Wheeler himself, in no small part because his discussions were often analogical and metaphorical, even poetic. The development of the MCH had begun at least as early as 1971 as evidenced by a presentation in Fribourg, "Beyond the End of Time," where the relationship of measurement and physics was considered. Wheeler began with the following question and answer. "[M]ay the universe in some strange sense be 'brought into being' by the participation of those who participate? …'Participator' is the incontrovertible new concept given by quantum mechanics: it strikes down the term 'observer' of classical theory, the man who stands behind the thick glass wall and watches what goes on without taking part. It can't be done" ([16], p. 180). This image encapsulates his view of the role of the 'observer' in physics, a notion invoked by Bohr's approach to quantum mechanics but with a reach extended beyond the physics of light and matter to that of space and time; his precise position as to what constitutes an 'observer' was to change over time and the *community* of observers, also mentioned by Bohr, would later be argued to play an even more central role in the meaning circuit model than the 'observer'.

In an article of 1973, "From Relativity to Mutability," Wheeler elaborated the metaphor of observer and glass barrier. "Even to observe so minuscule an object as an electron, he must shatter the glass. He must reach in. He must install his chosen measuring equipment. It is up to him to decide whether he shall measure position or momentum. To install the equipment to measure the one prevents and excludes his installing the equipment to measure the other. Moreover, the measurement changes the state of the electron. The universe will never afterwards be the same. To describe what has happened, one has to cross out that old word 'observer' and put in its place the new word 'participator'. In some strange sense the universe is a participatory universe" ([17], p. 244). The main differences in this approach from that of classical physics are that the physical state and even "the universe" is supposed to change as a result of observations and their communication, not merely that any measurement involves physical interaction and a record of the result. Wheeler would later offer a corresponding experiment as a concrete illustration of such cosmic participation.

In a presentation following within a year's time, "Is Physics Legislated by Cosmogony," Wheeler turned more precisely to the spatial aspect of the universe, "No one see any longer how to defend the view that geometry was created on 'Day One' of creation, and quantized on Day Two.' More reasonable today would appear the contrary view, that 'the advent of the quantum principle marked Day One, and out of the quantum principle geometry and particles were both somehow built on Day Two"' ([18], p. 544). So, it appears to him that "[the quantum principle] promotes observer to participator", one whose participatory observations are enabled on Day Two ([18], p. 560). For Wheeler, the 'quantum principle' also "tells what question it makes sense for the observer to ask" in order to obtain 'meaningful' observations, which are of greater significance to understanding reality than theory is ([18], p. 544). In "Include the Observer in the Wave Function?", a paper prepared for a May, 1974 conference in Strasbourg, Wheeler wrote in section entitled "The Role of the Observer" that "That the 'observer' should have a special place in the scheme of quantum mechanics has often been contested. Bohr himself argued at one point that an 'irreversible amplification process' is all it takes to 'complete' a measurement, only to stress on other occasions that an observation is only complete when there is an observer …Fission, and by extension the pulse of a Geiger counter and the blackening of a silver halide crystal, are only then guaranteed to be indelible in the relevant sense when the act has registered in the consciousness of the observer"—this conclusion supported by the in principle reversibility of fission with the addition of "'mirrors' set up to give sufficient time delays and sufficient accuracy of return of the outgoing particles and radiation…" to reverse it [19]. Here, Wheeler suggests that it is the character of observation by a conscious observer that is necessary for and precipitates the novel change of physical state involved in quantum theory and so alters existence at a basic level with each "meaningful" measurement.

In a following, 1975 presentation, "Genesis and Observership," Wheeler went on exactly to explore "the working hypothesis that 'observership is the mechanism of genesis"' as an answer to Leibniz' question "'Why is there something rather than nothing"' which "William James translated" into "the more meaningful …'How comes the world to be here'…" ([2], p. 3), and the position that "Quantum mechanics promotes the mere 'observer of reality' to 'participator in the defining of reality'. It demolishes the view that the universe sits 'out there'." Thus, Wheeler rejects any fully objective view of reality ([2], pp. 5–6), which for him came to be one *constructed* by physics of a kind that is intimately connected with a process of observation yielding information which is considered primary to it.[3] Four ideas, "(1) 'mutability', (2) 'no ultimate underpinning', (3) 'observership as prerequisite for genesis' …(4) 'observer-participator as definer of reality'," were presented as bearing on the origin of existence. Wheeler argued that to lend coherence to this collection and provide an answer "…demands a central theme and thesis. …Up to now, however, no pattern suggests itself from the available clues except this, to interpret quantum mechanics as evidence for the tie between genesis and observership" ([2], p. 8). He also recalled

[3] This is in direct opposition to the position held by many physicists, for example, John von Neumann, that physical theories are required to accommodate a physical correlate to subjective perception according to the principle of psycho-physical parallelism: "it is a fundamental requirement of the scientific viewpoint—the so-called principle of psycho-physical parallelism—that it must be possible to describe the extraphysical process of the subjective perception as if it were in reality in the physical world—i.e., to assign to it parts equivalent physical processes in the objective environment, in ordinary space" ([20], pp. 418–419).

"Bohr's words about the Schrödinger state function, 'that we are here dealing with a purely symbolic procedure, the unambiguous physical interpretation of which, in the last resort, requires a reference to a complete experimental arrangement."' Wheeler adds "'that all departures from common language and ordinary logic are entirely avoided by reserving the word 'phenomenon' solely for reference to unambiguously communicable information'" ([2], p. 24). This already indicates the significance of information theory in Wheeler's ultimate scheme which connects it with Copenhagen approach to interpreting the quantum formalism wherein meaningful information is the sort of information *communicable within a community* of participators.

In a 1977 magnum opus, the lecture "Frontiers of Time" for Course LXXII of the Enrico Fermi School of Physics in Varenna, Wheeler reiterated Bohr's reply to Einstein that the "…conditions [of measurement] constitute an inherent element of any phenomenon to which the term 'physical reality' can be attached.' …[This requires] a final renunciation of the classical ideal of causality and a radical revision of our attitude towards the problem of physical reality"' ([21], p. 7). Under the MCH, all physical form is to arise through acts of observer-participation, even that of space-time: "…individual events. Events beyond law. Events so numerous and so uncoordinated that, flaunting their freedom from formula, they yet fabricate all physical form …Nowhere more clearly than in the ending of spacetime are we warned that time is not an ultimate category in the description of nature" ([21], p. 143). To support the claim, Wheeler offered an argument involving a defining characteristic of the physics of his Era III: "Law without law." "The absolute central point would seem to be this: The universe had to have a way to come into being out of nothingness, with no prior laws, no Swiss watchworks, no nucleus of crystallization to help it—as on a more modest level, we believe, life came into being out of lifeless matter with no prior life to guide the process. …" where "when we speak of nothingness we mean nothingness: neither structure, nor law, nor plan" ([21], p. 16). In the anticipated Era III of physics, he held, it will be held that only chance events take place with collective behavior agrees with the laws of Era II in the "everyday world." The connection to the novelty of quantum theory is made specifically as follows. "The necessity for [the] line of separation [between the observer-participant and the system under view] is the most mysterious feature of the quantum. We take that demarcation as being, if not the central principle, the clue to the central principle in constructing out of nothing everything" ([21], p. 17).

Although Wheeler suggested that Bohr rejected a universe that is simply "out there," he nonetheless pointed out that "For Bohr the central point is not 'consciousness,' not even an 'observer,' but an experimental device—grain of silver bromide, Geiger counter, retina of the eye–capable of an "irreversible act of amplification". This act brings the measuring process to a 'close.' Only then, he emphasized, is a person able "to describe the result of the measurement to another in plain language" ([21], p. 19). For Wheeler, this constraint is understood to extend to the earliest moment of the universe, so that "The universe is a self-excited circuit. As it expands, cools and develops, it gives rise to observer-participancy. Observer-participancy in turn gives what we call 'tangible reality' to the universe" ([21], pp. 22–25). As an example of the manifestation of observer-participancy and its cosmogonic significance, Wheeler considered the measurement of photon properties at large times. "There is no more remarkable feature of this quantum world than the strange coupling it brings about between future and past, between (1) the way one will choose to orient his polarization analyzers two years down the road and (2) what one can then say about the photons that already—as judged by us now—had their genesis 3 years ago. There is a sense in which the polarization of those photons, already on their way, 'was' brought into being by the disposition of the polarization analyzers that the observer has yet to make and will make. Moreover there is no difference in principle whether the time between the emission of a photon and its detection is 5 years; or a nanosecond, as it is when one is looking at an object a foot away; or 10^{10} years, as it is when one is receiving direct or indirect radiative evidence of what went on in the first few seconds after the big bang. In each case what one chooses to ask …forms an inseparable part of a phenomenon that in earlier thinking one would have said had'already happened'. In this sense it is incontrovertible that the observer is participator in genesis" ([2], pp. 24–25).

This 'coupling' raises the question of the definiteness and ontological status of the past in general. "How can an observation made now have any influence whatsoever on what has already happened?" along with the point that in the quantum realm, "'what has already happened' is not so easy to say" ([21], pp. 25–26), pointing to the notion of a delayed-choice experiment, one spanning nearly the duration of the history of the universe. "The photons of the primordial cosmic fireball radiation that enter our telescope today, we customarily assume, already had an existence in the very earliest days of the universe long before life evolved. However, not until we catch a particular one of those photons in a particular state with particular parameters, not until the elementary phenomenon is an observed phenomenon, do we have the right even to call it a phenomenon" and, as for the "unbelievably more numerous relict photons that escape our telescope…their 'reality' is of a much paler and more theoretic hue"; ibid., pp. 26–28. And, while there is some tension in the very way these sentences are formulated, in that Wheeler is talking about "catching photons" that become "phenomena," if one keeps in mind that free photons can be thought of—indeed, at the moment, are standardly thought of—as excitations of quantum fields rather than as individual systems of their own, it is a consistently posed statement that relates to more than the polarization but even the presence of each photon. Accordingly, "an immense labor of imagination and theory" is required to provide a conception of physical reality grounded in intersubjectively communicated observation results; ibid., p. 28.

Turning to space and time themselves, Wheeler argued that spacetime is a "deterministic classical concept, applicable only at the level of approximation theory" in light of complementarity ([21], pp. 36–37) and asks "how can any elementary building process be an elementary process for building existence and law unless it transcends the category of time? To identify an elementary building process that transcends time…The act of observer-participancy in such an experiment, right now, irretrievably alters what we have the right to say about 'the past.' In that sense, that carefully restricted sense, that act is an inescapable part of the actual building of 'the past.'"; [21], pp. 42–43. He held that, given both quantum theory and geometrodynamics, "time is transcended, laws are mutable, and observer-participancy matters. 'Before' and 'after' don't rule everywhere, as witness quantum fluctuations in the geometry of space at the scale of the Planck distance. Therefore 'before' and 'after' cannot legalistically rule anywhere. Even at the classical level, Einstein's standard closed-space cosmology denies all meaning to 'before the big bang' and 'after the big crunch.' Time cannot be an ultimate category in the description of nature. We cannot expect to understand genesis until we rise to an outlook that transcends time …There never was a law of physics that did not require space and time for its statement. With collapse the framework falls down for everything one ever called a law. The laws of physics were not installed in advance by a Swiss watchmaker, nor can they endure from everlasting to everlasting. They must have come into being" ([21], pp. 44–45), the Planck length being

$$l_P = (\hbar G/c^3)^{1/2} \,, \tag{2}$$

where G is the gravitational constant, c is the speed of light in vacuum, and $\hbar$ is the reduced Planck constant (the quantum of action), and all constants on the right-hand side are all given the value 1. And so, he argued, determinism must be abandoned: "one has to forgo that view of nature in which every event, past, present, or future, occupies its preordained position in a grand catalog called 'spacetime.' There is no spacetime, there is no time, there is no before, there is no after. The question what happens 'next' is without meaning" ([21], p. 105).

However, Wheeler also recognized that there are apparent limitations to a physics based on participancy; he instructs one, at least for now, as follows. "Don't try to 'take time apart' into elementary quantum acts of observer-participatorship out of which we conceive it—and everything—to be built. Instead, sticking to the solid ground of physics as we know it, identify domains where familiar concepts of time and causality come to the limit of applicability and have to be modified. We have just finished exploring one such frontier. We have seen how both time and spacetime, according to existing theory, lose all application at the Planck distance and the Planck time; but how out of a description that transcends time–out of superspace–we come back in the appropriate correspondence principle limit to familiar views of time" ([21], p. 117), where the Planck time is

$$t_P = (\hbar G/c^5)^{1/2} \,. \tag{3}$$

Accepting this view of space and time, one must of course contend with the implications for causality, which Wheeler did by considering, as a basic example, the situation of the emission of electromagnetic radiation in a system of point charges coupled with each other by elementary electromagnetic actions-across-a-distance—which are individually time symmetric in the sense that the force exerted on a particle by one particle on the other is given by half the retarded field of the first, as usually calculated, plus half the advanced field—and the particle is suddenly accelerated.

> This links past and future in a maze of backward and forward running light rays. Nowhere can the slightest change be made without altering motions everywhere into the indefinite past and future. we want to establish in this one example a point of more general application:

> The apparent inability of an action taken now to influence the past by no means rules out a direct influence of the present in 'bringing about that which we call the past.' It is in no way suggested here that this is the actual mechanics by which acts of observer-participancy in the present bring [about] that which we call the tangible or communicable reality of the universe at an era when no observers existed. That is a deeper question with which physics is not yet prepared to deal. However, one is open to believe that the kind of considerations that elucidate the one may clarify the other ([21], p. 118).[4]

Similarly, "the irreversibility of the emission process is a phenomenon of statistical mechanics connected with the asymmetry of the initial conditions with respect to time…an order in time, ostensibly causal, can originate from an underlying machinery that is very far from causal. …we here have a sample law, causality, emerging from a description of nature that contains no such law" ([21], pp. 120–121).

Wheeler continued his investigation of physical law as mutable and the possibility of the non-primacy of space-time in a 1979 article "Beyond the Black Hole."

> 'Physical space-time is not mathematical space-time' is the one lesson of mutability; the other, 'Physical law is not ideal mathematical law.' Law that comes into being at the beginning of time and fades away at the end of time cannot be forever 100% accurate. Moreover, it must have come into being without anything to guide it into being…The laws of physics themselves, coming into being and fading out of existence: in what else can they have their root but billions upon billions of acts of chance? What way is there to build law without law, field without field, substance without substance except 'Individual events. Events beyond law. Events so numerous and so uncoordinated that, flaunting their freedom from formula, they yet fabricate firm form?' ([15], p. 352).

Several of the above ideas were reiterated along with some other contributions that quickly followed in 1980 and 1981 to form a shorter 1983 article "Law without Law" ([23], pp. 182–213). Wheeler had raised a challenge to physics with these speculative arguments, and he was optimistic regarding their significance and ability to explain how 'something may arise from nothing.' "No test of these views looks more like being someday doable, nor more interesting and more instructive, than a derivation of the structure of quantum theory from the requirement that everything have a way to come into being out of nothing. If you would have an epitome of this summary, let it be this: Nothing. No time. The line. Acts. Statistics. Law. Spacetime. Substance. Observer-participant Closed circuit. Test." ([21], p. 46).

Wheeler offered a comprehensive model illustrating the structure of the MCH in a presentation of 1986 entitled "How come the quantum?". In this model, discussed in detail below in Sects. 3 and 5, the establishment of physical reality is explained as follows.

> Physics gives rise, …to light, pressure, and sound. They provide means of communication, of the importance of which Niels Bohr notes, '. . . every analysis of the conditions of

[4] As he was later to describe this, in the mid-1980s, one finds "an unbelievable maze of light-like connections running backward and forward in time. Nevertheless, when the number of particles is sufficiently great to guarantee absorption of all radiation, the maze translates itself into the familiar full-strength pure retarded electromagnetic interactions, plus the familiar radiative reaction. No contradiction with everyday notions of causality is to be seen. No less has to be expected of an information-theoretic account of physics;" [22], p. 31.

> human knowledge must rest on considerations of the character and scope of our means of communication. Physics is also the foundation of chemistry and biology, out of which arise communicators....' From meaning back to physics, the circuit under examination makes its way by a less apparent or underground sequence of linkages. Meaning rests on action. Action forces the choosing between complementary questions and the distinguishing of answers. Distinguishability, in the realm of complementary possibilities, demands for its measurement complex probability amplitudes. The change in the phase of a complex probability amplitude around a closed circuit not only measures the flux of field through that circuit, but can even be regarded as the definition and very essence of that field. Fields, in turn, can be viewed as the building stuff of particles; and fields plus particles generate the world of physics with which the hypothesized meaning circuit began ([3], pp. 304–305).

Here, Wheeler's 'meaning' is "the joint product of all the evidence that is available to those who communicate." (This is the subject of Sect. 5.4 below.) After having presented the elements of the MCH by the mid-1980s, Wheeler continued to clarify his views on its detail and implications. For example, in a 1988 follow-up "World as System Self-Synthesized by Quantum Networking," he presents the MCH "in contrast to the view that the universe is a machine governed by some magic equation," it is the "view that the world is a self-synthesizing system of existences, built on observer-participancy via a network of elementary quantum phenomena" [1].

Wheeler's goal was a conception of the physical world in which space and time are no longer considered primary, incorporating the novelties of quantum mechanics in a way consistent with the known natural science, which had been developed with a methodology similar to that used in discovering classical physics but eschewing the mechanistic approach in favor of a focus on communicable information. He believed that the "elementary quantum phenomenon is the strangest thing in this strange world. It is strange because it has no localization in space or time. It is strange because it has a pure yes-no character—one bit of meaning. It is strange because it is more deeply dyed with an information-theoretic color than anything in all physics" ([1], p. 115). Broadly speaking, with the MCH Wheeler went beyond Bohr's position that science, as a human activity, involves the communication of results of its contributors, to a direct grounding of physical systems and processes in the information that is communicated within science. Nonetheless, his extension to the experimental 'asking questions of nature' remains in the spirit of Bohr's understanding of physics, in particular, in its use of the notion of the complementary nature of physical measurements [24]. "In brief, complementarity symbolizes the necessity to choose a question before we can expect an answer...We once thought, with Einstein, that nature exists 'out there', independent of us. Then we discovered—thanks to Bohr and Heisenberg—that it does not" ([1], p. 113).[5]

Throughout the development of his MCH, Wheeler was either vague or vacillated with regard to the question of whether there is a necessary role for consciousness—something he consistently recognized as itself not well understood by science—in elementary quantum phenomena. Finally, in the 1990s, he expressed an affinity for

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[5] One should take care not to accept this statement of Wheeler as a correct understanding of the views of Bohr and Heisenberg themselves, which often differ from those of their interpreters like Wheeler; cf., e.g. [25].

the notion of quantum potentiality, which plays a central role in the Heisenberg's mature understanding of the quantum state as indicating a genuine mode of existence and not mere logical possibility; Heisenberg's later view was that measurement outcomes and observations arise independently of human participation, even if they are brought about only through coincidence with the greater physical world; cf. [26]. In the following section, the central elements of Wheeler's conception of physics as represented via the MCH are considered in succession. These include "question and answer feature of the elementary quantum phenomenon" and the concomitant role of distinguishability in it, why the quantum probability amplitude is complex, the attribution of meaning to measurement results, and the circuit as the alternative to a hierarchical built upon a traditional foundation, taking into consideration the issues with his MC model, the role of 'communication' in physics, and the 'It from bit' thesis. Wheeler himself noted some difficulties with the assertion of aspects of this synthesis, and these considered along with a number of other deep concerns.

3 How Come the Quantum? A Critique

Although information plays a fundamental role according to the MCH, the physical mechanism involved in measurement is nearly as significant: "…the meaning-creating community of observer-participants, past, present, and future, is brought into being by the machinery of the world." Indeed, consistently with his late affinity with the potentiality interpretation of quantum state amplitudes in the 1990s, the "machinery" and that the information obtained using it in measurement can be understood on par with each other, for it is the machinery of the world that provides the signal-records through which information is obtained. This machinery and the information it provides to observers relate to *different*, however intimately related domains—those of existence and human knowledge of that existence—that Wheeler failed to adequately distinguish in his writings of the 1970 and 1980s. The hypothesis "goes on to interpret this very world of past, present, and future, and of space, time, and fields, to be (despite all its apparent continuity, immensity, and independence from us) a construction of imagination and theory" where elementary quantum phenomena form "the iron posts of discrete acts of observer-participancy, the ant-like but magnificent labor of a community stretching from far in the past to even farther in the future" and time is "not primordial, precise, and supplied from outside physics, but secondary, approximate, and derived" [3], p. 313. The observed and communicated bits of information are considered the strongest elements of a reality understood as constructed from these facts and scientific knowledge. Yet, consciousness is not required for the signaling of these bits, only for the existence of knowledge to which they may give rise. And, in the long run, Wheeler relinquished the view that observation and measurement *require* consciousness.

And, despite his strong views as to the significance of measurement and information theory to physics, Wheeler was certainly *not* advocating a form of idealism; rather, like Bohr, he put forward a very subtle form of realism, a 'participatory realism.' Wheeler rhetorically raised the question, "How does quantum mechanics today differ from what Bishop George Berkeley told us two centuries ago, '*Esse est percipi*,' to be is to be perceived? ...Yes, and in an important way. Berkeley—like all of us under everyday circumstances—deals with multiple quantum processes ...Anything macroscopic that happened in the past makes, we know, a rich fallout of consequences in the present. ...the number of quanta that come into play is so enormous that the unseen quantum individuality of the act of observation can hardly be said to influence the event observed"; [27], p. 186. And just this is required for the occurrence of an observed quantum phenomenon capable of yielding the communicable information so important to his meaning-circuit model, its "genesis." Two crucial questions are involved in the process of 'genesis' Wheeler hypothesizes: (i) what the 'density' (variable) of such signposts in reality is at various stages of its history, and (ii) how essential, if at all, to their appearance living or conscious observers (who when the universe existed) are.

Regarding (i), Wheeler commented that "If life wins all, then the number of bits of information being exchanged per second can be expected to rise enormously compared to that number rate today. ...And how great must that future total be—tally as it is of times past—to furnish enough iron posts of observation to bear the smooth plaster which we of today call existence? Bits needed. Bits available. Calculate each. Compare. This double undertaking, if and when it becomes feasible, will mark the passage from clues about existence to testable theory of existence" [1], p. 126. However, this is an essentially epistemic question having to do with the facts serving as the basis of our own theorizing rather than with the existence of the physical world that the resulting physical theories are to describe and explain. While it is true that the degrees of (in)determinacy of properties of subatomic systems relate to measurement, the Heisenberg indeterminacy principle—which is what is most relevant here in the quantum realm—regards the relative definiteness involved in the complementary measurement activities that themselves still require physically distinct and mutually excluding apparatus configurations to yield information to observers.

Regarding (ii), Wheeler proposed that, due to presence of the quantum of action, "The observer is elevated from 'observer' to 'participator.' What philosophy suggested in times past, the central feature of quantum mechanics tells us today with impressive force: In some strange sense this is a participatory universe"; [2], pp. 5–6. Space, time, particles, and fields are all "brought into being" from quantum information-yielding events, and only by a "dethronement from primordial and precise to secondary, approximate and derived can 'time' be reduced, like all the rest of physics, to an information-theoretic foundation" [22], p. 30. Thus, the second question is again one about the process of obtaining information by observers and the manner in which that information is rendered meaningful and communicated, which is an epistemic one. Wheeler argued that for this "we possess no other model [than the Meaning Circuit] that puts in central place the quantum and the question of 'how come the quantum?"' [3]. However, this is not so. One need not assume that the entities of physics are *brought into being* in information-transfer events simply because of the presence of the quantum of action in measurement interactions. Standard quantum measurement theory explains how measurements provide records of the properties of quantum systems in the past whose possible different properties upon measurement are made definite at some moment—much, though of course somewhat differently, as the exact color of Caesar's clothing on a particular day could have been more or less better inferred, even from an extreme temporal distance, by an author whose writings we now possess, and be useful as a fact knowable to historians to be combined with other possibly later-obtained information—providing data to those who might attribute it meaning and communicate it between themselves. Wheeler's MCH is a hypothesis that transcends physics and concerns itself with the manner in which physical knowledge and theory arise, claiming that these are the determinants of existence but without sufficient justification.[6]

To reassure those who might be concerned about that the role given observer in the MCH might threaten the unity of the universe, Wheeler notes that his view of quantum theory does not amount to a "many worlds" view: "What keeps the images of something 'out there' from degenerating into separate and private universes: one observer, one universe, another observer, another universe? That is prevented by the very solidity of those iron posts, the elementary acts of observer-participancy. That is the importance of Bohr's point that no observation is an observation unless we can communicated the results of that observation to others in plain language"; [27], p. 203. Wheeler argued further that the *self* is not independent of others.

> The heart of the matter is the word self. What is to be understood by the word self we are perhaps beginning to understand today as well as some of the ancients did. We know that in the last analysis there is no such thing as self. There is not a word we speak, a concept, we use, a thought we think which does not arise, directly or indirectly, from our membership in the larger community. On that community the mind is as dependent as is the computer. A computer with no programming is no computer. …programming by parents and community that makes a mind a mind. The heart of mind is programming, and the heart of programming is communication. ([1], p. 127)

Thus, "*Communication* is the essential idea. If I see something, but I'm not sure whether it's a dream or reality, there's hardly a better test than to check whether someone else is aware of it and can confirm my observations" [7], p. 62. This is certainly important for establishing the objectivity of data of the senses but, again, is beside the point for physics itself; it regards the validity of data, not its ultimate origins.

Thus, the MC model portrays physical systems and their behavior between measurements as ultimately (inter)subjective creations of the scientific community based on the physical facts (phenomena) arising through measurement. This model is illustrated by Wheeler as a corn-kernel shaped 'meaning circuit,' sketched metaphorically as running about a slope, with the abstract elements—questions and quantum formalism—underground and the signaling apparatus sub-grouped into "means of communication" and "communicators" above ground: its two large parts are shown as two towers labeled "physics," at base and "meaning," at peak. That "part of circuit…is well known"; [28], p. 404. However, no detail is offered in this model regarding the

[6] Indeed, Wheeler repeatedly admits that it is precisely the nature of cognition located in the meaning circuit which is inadequately understood, as shown below.

important distinction between meaning and information/data; as with consciousness, Wheeler regarded this as a part of science that is only emerging: "New aspects of what we mean by 'meaning' are beginning to emerge from recent studies in computer science and in information theory that put quantum at center stage"; [28], p. 404. What is said regarding meaning is that physics "gives rise to chemistry and biology and, through them, to communica*tors*. The communicators and the communications between them generate meaning. This is the first part of the meaning circuit. It makes meaning the child of physics. Physics itself, however, according to this view, is also the child of meaning. The return portion of the meaning circuit, the connection that leads back from meaning to physics, runs 'underground,' out of sight." [22], p. 25. For Wheeler, the elementary quantum phenomenon, which is connected with the summit of his circuit and is a notion the origins of which are clearly traceable to Bohr, "displays two characteristic features: (1) complementarity in the choice of the question and (2) statistics in the distinguishing of the answer." [3], p. 306. The important pair of successive points *below ground* labeled "ask question" and "distinguish the answer" are the two elements of the extraction of information, the basis-choice/measurement as the decoding of information carried by the state-signal—do clearly appear in it, although the opposite side of the loop from this pair; the referent, and hence 'meaning', of a click depends on the physical measurement basis.

Although communication theory standardly connects information and physics via the notion of signaling and provides methods for the quantification of information that can be encoded in signals, the relation between physics and information suggested by Wheeler is anything but standard: It is strongly reductionist in the opposite sense from what is the standard relation where systems in physical states are understood to provide signals that *could be used to communicate information* via a freely chosen encoding/decoding method; instead, he views physical systems as *made of and constructed from information*. Wheeler referred to elementary quantum phenomena as being of a "meaning-theoretical character" [7], p. 66, indicating a conflation of two matters: (i) recording and collecting data and (ii) giving meaning to data.[7] Data collection, on the one hand, and the interpretation of data arising in physical events in terms of the elements of theory (much less the creation of theories of the world or reality), on the other, are very different. Indeed, the operation of the circuit—its provision of meaningful experimental results—was summarized by Wheeler as follows. "Evidence available to the communicator comes from the asking of a question [via an experiment] and the distinguishing of an answer" by observing the result of it ([3], p. 305).

Wheeler offered very different examples of the putative reduction of an 'it' to a 'bit' via 'it from bit', a relatively exotic example being that of a black hole: He claimed that "The it, the area of the horizon of a black hole, expressed in units of the basic Bekenstein-Hawking area

$$4(\hbar G/c^3)\log_e 2\,, \tag{4}$$

[7] And this would be so even if he were understood to considering primarily cognitive.

is given by the bit count, N, of that black hole. Here N represents the number of bits of information it could have taken to distinguish the initial configuration of particles and fields that fell in to make this particular black hole from the 2^N alternative quantum configurations that would have produced a black hole externally identical to it" ([29], p. 555).[8] A less exotic example he considered repeatedly in his writing is that of the amount of information obtained in the determining the polarization of a photon, one bit.[9] One could ask, considering an even more concrete example, the *spin* of an electron, does one bit actually constitute the *spin* and does this bit, together with the other bits corresponding to distinguishing the other properties of the electron, *constitute* the electron? The important point to note here is that, on this view, a physical system is no longer considered physical in any usual sense but rather is *only the information corresponding to its state*.

Perhaps the most striking of the examples of 'it from bit' Wheeler provides is that of "reducing the 'how much' of the field measurement to the 'many a chance yes-no' of elemental quantum phenomena" [22], p. 29. This is to be accomplished through dichotomous measurement results signaled by detector clicks: to find the magnetic field strength in a region, "it is enough to illuminate the atom [chosen to observe a Zeeman shift] with monochromatic radiation of a precisely chosen frequency…just enough for photoionization when the magnetic field is 'on'. The electron, once freed, is drawn…into a device like a photomultiplier. A pulse is registered on a counter. The elemental quantum phenomenon is brought to a close by this irreversible act of amplification. An item of information is generated which one person can communicate to another 'in plain language'. Out of sufficiently many such items of 'yes, no' information obtained for slightly different values of frequency…we determine more and more precisely the value of the Zeeman level shift and measure—and define—the magnetic field" ([22], p. 29). Perhaps, but this does not mean that the magnetic field has thereby come into existence; rather, its properties merely become *more or less definite and knowable* to those contemplating the corresponding experimental records, even when that record is a flash recorded by the nervous system of a human being and immediately attended to by its conscious mind.[10]

Despite the circuitous character of his view of experimentation, Wheeler took an ontological-reductionist as well as theory-reductionist stance wherein all of reality is 'theory' constructed from and relating such insubstantial information-theoretically quantifiable and elementary quantum phenomena to each other, conditioned on the circumstances of their recording. He reduces matter and space-time to 'meaning' in his conception of physical reality. "Physical space-time is not mathematical space-time" and "Physical law is not ideal mathematical law" ([15], p. 352). The issues noted in this section are delved into in greater detail in Sect. 5, below, after the consideration in the next section of Wheeler's views on quantum phenomena and the world

[8] The event horizon of the black hole is implicitly considered here identical with the area.

[9] Again, however, this is as a matter of fact dependent on the circumstances of preparation and encoding/decoding assumed and would be rather *at most* one bit.

[10] It is noteworthy that Wheeler's views in the 1990s which brought quantum potentiality into consideration, appear to recognize this.

between quantum preparation and measurement events—what Hans Reichenbach called "interphenomena"—as well as their relationship to space and time [30].

4 Quantum "Smokiness'

An important aspect of Wheeler's theoretical methodology is that, for every grand physical proposal he produced, he offered a related, ultimately feasible experiment, as Misner, Thorne, and Zurek commented. "This is his enduring legacy: Do not be afraid to think big, but make sure that in the end you have a blueprint for an experiment" [31]. For Wheeler, thought experimentation and speculation must to be connected with concrete experience. His view of the physical past according to the MCH was that it is indeterminate ('smoky'), in particular, contingent on subsequent or future interventions for its 'existence', something intimately related to the secondary character of time by comparison to quantum phenomena, and he offered the class of 'delayed-choice' experiments designed to lend support to this view [31]. These experiments, designed to illustrate the operation of the 'meaning circuit,' can in principal be performed with a relatively simple physical apparatus often realized in quantum optics.[11]

4.1 Delayed-Choice

The delayed-choice experiment which, from a mathematical point of view, is the simplest of those Wheeler provided in relation to the MCH is one with an apparatus that can be quickly switched between (i) simple light-beam splitting system allowing for measurement along one of two paths, or (ii) a (Mach–Zehnder) interferometric configuration allowing for the complementary measurement of interference visibility [3].[12] This experiment serves as the archetype of what is now commonly called a "delayed-choice experiment," the idea being to defer the specific configuration until a time *after* beam components could, assuming travel at light speed, be considered to have entered the apparatus and be already headed toward the detection suite at the opposite end.

Both configurations are made possible, as follows. In one configuration of the apparatus, input light first strikes (at an angle of 45 °C) an evenly balanced beam-splitter located at one corner of a rectangle which provides for two, orthogonal beam paths (say, along the axes in two-dimensions); next, the resulting paths turn 90 °C (one clockwise along a "high" path and one counter-clockwise along a "low" path) at mir-

[11] It is noteworthy that photons are special in that the have minimal self-interaction and are able to travel exceptionally long distances without disturbance, unlike ordinary matter composed of electromagnetically charged particles such as electrons and protons.

[12] For an analysis of the associated complementarity relation cf., e.g., [32].

rors toward a common locus through which they could freely pass at the diagonally opposite corner of the rectangle; in each of these two orthogonal directions *beyond* that locus, a photodetector capable of single-photon counting is placed. Detection of energy in a given direction suggests that any detected photon traveled—assuming it must travel along a path—along the path leading to straight into the detector located along it. In the alternate configuration, in addition, a second evenly balanced beamsplitter is located precisely at the second locus of path-intersection, i.e. at the far corner of the path rectangle, allowing for path recombination in both of the two directions described above. Due to this overlapping coincidence of the last portions of the two paths, this second configuration plainly renders impossible the retrodictive determination of which path a given photon must have traveled—assuming it must travel along one—in the apparatus and instead allows a relative-phase determination and self-interference for an ensemble of identically prepared photons.

Thus, the experimenter may 'ask' one of a pair of alternative 'questions about the photon's behavior' by configuring the apparatus without or with a second evenly balanced beamsplitter at the far corner of the rectangle. In this way, the corresponding 'question' thus 'asked' will be 'answered' by the obtaining of one of two distinguishable outcomes in each configuration. In this experiment, Wheeler said, "We can ask which path does an arriving photon follow-the high road or the low road? That is one choice of question, and the photon detectors stand ready to answer it. To ask for the phase relation between the two beams is a complementary choice of question"; [3], pp. 306–307.The distinguishing of an answer is to be done on the basis of the counting statistics of repeating the experiment.[13] Because one can consider such an apparatus with a beam-path rectangle sufficiently long that one could implement choice *after* an initially localized photon would putatively have passed the first beamsplitter but not yet reached the opposite side of the rectangle, Wheeler argued, "This circumstance shows how wrong it is to say that we are finding out in the one case 'which route' and in the other case the relation of phases in a 'two-route mode of travel.' The world is built in such a way that it denies us the possibility to speak in any well-defined way of 'what the photon is doing' in its travel from point of entry to point of reception" ([3], p. 307).

The delayed-choice experiment was taken by Wheeler to illustrate the dictum "No elementary quantum phenomenon is a phenomenon until it is a registered phenomenon, brought to a close by an irreversible act of amplification"; one is to note that "Definite as are the point of entry and point of detection of the photon, what it is doing in between is totally smoky. Equally smoky is any concept of the path of an electron through an atom. Termination of the smokiness by an act of detection is as close as we can get to establishing reality at the microscopic level"; ibid.. Wheeler's "smokiness" corresponds to the *non-deterministic character of the properties of quantum systems*; formally, these measurable quantities correspond to non-commuting operators in the theory of sharp quantum measurements. Wheeler argued that this "smokiness" can be extended to universe as a whole and that its very genesis involves its own self-

[13] Broader conclusions aside, what this example does clearly illustrate is that complementary properties are complementary, that is, the more definite is one the less definite is the other.

observation as a result, as a "self-excited circuit," which he symbolized iconically by a letter "U" with an eyeball (of observation at one end) on one of its verticals directed at the opposite vertical at the other (the deep past) ([21], p. 23), a rather swift conclusion given the gross character of the universe, drawn in part from the additional assumption that all existence arises from quantum phenomena.[14]

Midway through his elaboration of the details of the MCH, in 1983, Wheeler along with his student Warner Miller reviewed a broad range of relevant experiments in an article entitled "Delayed-choice Experiments and Bohr's Elementary Quantum Phenomenon," wherein a number of scenarios of delayed-choice experiments were provided where various complementary quantum degrees of freedom were treated: direction/angular momentum, "which slit"/interference, transverse position/transverse momentum, and time-of-emission/energy [33]. More advanced such experiments were later performed by others. Let us consider now one of these, which was subsequently offered by Anton Zeilinger et al., who viewed their experiment as providing yet greater insight into the relationship between this experiment and the universe [34]. Zeilinger introduced these experiments and commented on them as follows."In Wheeler's own words, 'One decides whether the photon should have come by one route or by both routes after it has already done its traveling.' …we brought Wheeler's thought-experiment into the laboratory and carried it a step further. The idea was to demonstrate that it can be decided after the photon has been registered already whether the phenomenon observed can be understood as a particle or as a wave" [34].

Aside from the question of the value or lack thereof of being concerned about the choice of 'visualization' of the system (as 'particle' or 'wave'), a less contentious matter is more clearly addressed, namely, whether it is momentum or position that becomes (more) definite of a system given the timing of the configuration setting. An innovation of this extension of Wheeler's basic optical delayed-choice experiment is that it goes beyond the measurement of a solitary photon to one where a photon can be considered part of a greater, precisely specified system, one which can enter measurable entangled states [34]; in their experiment, Zeilinger et al. considered photons within pairs of entangled-photon pairs produced via type-I spontaneous parametric down-conversion from an appropriate crystal pumped by a laser; cf., e.g., [35, 36]. These pairs were created entangled in energy-momentum, being constrained only by joint energy-momentum with each having indeterminate values upon their creation, but the values of both are determined upon the direct measurement of one regardless of their separation in space and time. What is tested here is whether a given one of the photons from those produced pairwise at a downconversion crystal has either a determinate path or a determinate momentum upon measurement given that the sort of measurement is arranged after production of the pair, that is, in delayed-choice fashion.

[14] Less dramatically, one can imagine the distant, future detection event at the far side of the rectangle involved to "determine" what happened at the first beamsplitter. However, such retrodiction is not sanctioned by standard quantum mechanics and, notably, it is suggestive of a species of retrocausality in that it suggests that what takes place in quantum measurement determines what has already happened in its past.

To probe momentum entanglement, one photon was sent to a double-slit arrangement with a movable single-photon detector (rather than the usual screen), and the other in an orthogonal direction to a suite containing a Heisenberg lens and a single-photon Heisenberg detector capable of placement anywhere behind it. Then, with the detector located behind at focal distance f, the precise individual momentum eigenstate of the detected photons was determined; the individual positions were, therefore, indeterminate, that is, which of the two slits (i.e. path) the other photon would pass through is indeterminate—as it is thereby also in a determinate momentum eigenstate and a standard two-slit interference pattern in position resulted. When, alternatively, positioning the same detector behind the Heisenberg lens at a distance $2f$, the same detection plane was $2f$ in front of the lens, as measured from the lens through the the crystal to the two slits, the corresponding photon positions were precisely found and no interference pattern was found.

What is novel in this experiment is that the first of the two considered photons was detected after the second photon *had already itself been detected*. This was characterized by these experimenters as follows, "whether we obtain the two-slit pattern or not depends on whether the possible position information carried by the other photon has been irrevocably erased or not" [34]; to them,

> The important conclusion is that, while individual events just happen, their physical interpretation …might depend on the future; it might particularly depend on decisions we might make in the future concerning the measurement performed at some distant spacetime location in the future. It is also evident that the relative spacetime arrangement of the two observations does not matter at all. …The experiment just discussed also provides a clear illustration of the role of the experimentalist. By choosing the apparatus the experimentalist determines whether the phenomenon observed can be seen as a wave or as a particle phenomenon and once the observer has made this choice, Nature gives the respective answer and the other possibility is forever lost. Thus, we conclude, by choosing the apparatus the experimentalist can determine which quality can become reality in the experiment. [34]

They conclude along with Wheeler, though in a qualified manner, that "In that sense, the experimentalist's choice is constitutive to reality, yet one should be warned strongly against a subjective interpretation of the role of the experimentalist or of the observer. It is clear that the consciousness of the observer does not influence the particle at all, in contradiction to a widespread but unfortunate interpretation of the quantum situation" [34]. This discussion is predicated on the validity of retrodiction involved in discussions about the past actual properties, that is, inferences about past properties. In particular, the results involved are *statistical* in nature, so that although the original, Copenhagen sense of the significance of measurement context (cf. [37]) is evident, no retro-causation of individual measurement event is demonstrated in this experiment.

Leaving the question of the validity of quantum retrodiction aside, it is again important to note that it is a property of a (subatomic) object that is understood as determined in the experiment, and not the existence of the object itself. When the behavior observed in such an experiment is considered to extend logically to situations involving distances significant at the scale of the universe, is the central issue surrounding the idea of the role of the observer as a cosmological participator.

However, unless quantum state superpositions are possible of truly macroscopic systems, in the statistical mechanical sense, such an extension is *cosmologically* irrelevant, even aside from the question of the validity of retrodiction in general using the quantum calculus that it would require.

4.2 Genesis via Live Participation

The first of the delayed-choice experiments considered in Sect. 4.1 with possible photon paths extended to billions of light-years was considered by Wheeler was given by him the same interpretation, that of demonstrating the role of the choice of configuration on the information obtainable about the system is responsible for determining the photon's past reality. The remarkable implication of the experiment for Wheeler was what it suggested about the time: In his publication, "Genesis and Observership," Wheeler noted that "No consideration argues more forcibly that the 'observer' has nothing to do with the scheme of physics that the disparity in size of 26 powers of 10 between man and the universe; and none argues more strongly that life and consciousness are a rather unimportant development in a faraway and not particularly relevant part of space. Quite another assessment of the situation develops when one turns one's attention from scales of distance to scales of time" ([2], p. 18). Wheeler argued that in

> no way is one led more directly into this altered approach than through the considerations of Dicke (1961). Paraphrased, Dicke asks what possible sense it could make to speak of 'the universe' unless there was someone around to be aware of it. But awareness demands life. Life in turn, however anyone has imagined it, demands heavy elements. …[which] requires thermonucIear combustion. Thermonuclear combustion in turn needs several times 10^9 years cooking time in the interior of a star. But for the universe to provide several times 10^9 years of time, according to general relativity, it must have a reach in space of the order of several times 10^9 lyr. Why then is the universe as big as it is? Because we are here! ([2], p. 18)

An experiment performed in the present on light naturally prepared by the universe in the distant past was viewed by him as directly affecting what can be communicated about its origin and so that affects the origin itself. For him, this grounds an anthropic requirement on the universe, namely, that any universe must last long enough for life to arise in it via such nuclear and biological processes so as to endow it with reality.

However, although it is certainly the case that a consistent scientific theory of the world must be such that living observers are not precluded from arising according to its laws—given the existence proof via the fact that we are present in it—a physical universe without observers is certainly physically possible according to what we know about the purely physical behavior of the physical world, with or without consideration of its quantum aspect; although a universe without life would not be exactly our particularly universe, in that certain sets of facts might be different, it would still be one that could have been realized within the requirements of our physical laws, even if certain properties at certain places and times might not become definite in the way that they would have been in our universe in which life is present.

Given what we know about nature, there is no a priori reason why life need have arisen at all within it for our physics to operate, as it clearly did before our appearance in it. That our universe is one in which sharp quantum observables do not all take determinate values appears to have very little in itself to do with life.[15]

4.3 Existence and the Quantum

Whatever might be the case with biology as a basis for gathering data, the ultimate proof and answer to 'why the quantum?' for Wheeler was to show that the *quantum* is necessary for *existence itself*. Indeed, he quotes Leibniz in relation to this question. "Leibniz put it in his famous words, 'Why is there something rather than nothing?' William James (1911), translated the 'why' to the more meaningful 'how': 'How comes the world to be here'... We ask today, "How did the universe come into being?" …in the absence, as here, of some clear indication that the question is meaningless or undecidable, the question must be faced and the relevant evidence sought out" ([2], p. 3). Here, Wheeler considers the implications of general relativity to suggest that the universe, at least time and space, came into being because, in closed-universe solutions of its governing equation, time and space can be finite, which for Wheeler raises the question of what physics could, and for him should, be 'beyond' time; he concluded that a model for the explanation of existence, being capable of accounting for the boundaries of time, should be independent of time in itself.

One must also consider the obvious, simpler alternative explanation for its current existence: that it has always existed and persisted with time and nothing in physics requires it ever to not exist, but only perhaps be finite in physical measure in what is all of the physically well-defined past.

5 Closure of the Circuit: The Seven Questions

By placing a profound emphasis on the role of information in the structuring of reality through the operation of the 'meaning circuit', Wheeler had discarded his previous positions regarding physical ontology: By 1976, he had made "a clean break with this 'everything is fields' curved spacetime era" of physics, which was to be followed by the "everything is information" era ([31], p. 45); he argued that "With particles owing their definition and existence to fields, with fields owing their definition and existence to phases, with phases owing their definition and existence to distinguishability and complementarity, and with these features of nature going back for their origin to the demand for meaning, we have exposed to view (at least in broad outline) the main features of the underground portion of the model of existence as a meaning circuit

[15] And, as seen in Sect. 3 above, Wheeler was ultimately to back away from any necessary role for consciousness in measurement itself.

closed by observer-participancy" ([3], p. 309) reviewed here in Sect. 2. Despite being confident that with the MCH he had found a way of achieving the outlines of the ultimate physics, Wheeler still did recognize a number of issues to be addressed in order to make progress in filling out the picture.

Wheeler formulated seven questions for approaching the issues raised by his model, which for the most part differ in their specificity from those raised in Sects. 3 and 4 above.

> Before this would-be model can ever rise to the status of a proper model and be subject to quantitative analysis, some questions and difficulties require clarification: (1) What reality does the model ascribe to the physical world before the advent of any meaning-making community? (2) In what respect does it differ totally from the familiar anthropic principle on the issue of why the dimensionless constants of nature have the values they do? (3) What are we to understand by such a term as the community character of meaning? (4) What is the status of an elementary quantum phenomenon that is not put to use in the establishment of meaning? (5) How are we to reconcile the continuum of the world of physics with the discrete yes-or-no character of elementary quantum phenomena? (6) How can we ever hope to quantify meaning? Finally, (7) why a meaning circuit? Why any closed loop at all? ([3], p. 309)

Wheeler's answers to most of these questions, in various forms in which he stated them, are now critically considered.

5.1 Reality and the Status of the Past

The first of the above questions, "(1) What reality does the model ascribe to the physical world before the advent of any meaning-making community?" addresses the issue of the extent to which this participatory model of physics requires *subjectivity* (briefly discussed also in Sect. 3 above). This question arises because it is suggested by the meaning circuit model that reality depends essentially on the attribution of meaning by communicating subjects: Indeed, according to the MCH, reality is ultimately a theoretical construct built from currently available records due to the element of "observer participancy" inherent in quantum phenomena: "…through the quantum-level questions we put to nature we are participators in the making of what we call reality" [3].[16] An example offered as demonstration of this was the

[16] Wheeler makes use of the term *reality* in his writings without provide a fixed definition, but he does refer his readers to books of Bernard d'Espagnat for "a survey of many sides of the quantum principle as one knows it today" and "what one already knows from quantum mechanics" about its central notions such as non-separability [18], p. 599; d'Espagnat discusses the relationship of physics to existence and summarizes it a way consistent with Wheeler's usage of the term. In his *In Search of Reality*, d'Espagnat writes "As regards physics, it seems quite clear that its present stage of development is sufficient to justify considering it to be the universal natural science—a science of that very 'nature' that, apparently at least, it seems appropriate to identify with reality. Even though this latter view should be corrected to some extent…it is certainly quite a good working assumption" [40], p. 2. As shown here in previous sections, various statements by Wheeler suggest that his view of the realm of science as reducible to physics, albeit one which is psycho-physical.

delayed-choice experiment discussed in Sect. 4.1, above. Wheeler argued that "the respect in which what we ask, or do, in the present has an inescapable consequence for what we have the right to say about the past—even a past long before life. This is the sense in which (through the quantum-level questions we put to nature) we are participators in the making of what we call reality" [3]. This he indicated with the phrase 'observer-participator as definer of reality' ([2], p. 7), where "the 'observer,' far from being isolated from the surrounding world except insofar as he opens upon it one-way windows of perception, is in a certain sense coextensive with it" ([18], p. 695).[17] In particular, Wheeler suggests a positive answer to the question "Is the architecture of existence such that only through 'observership' does the universe have a way to come into being?" ([2], p. 7).

In "How Come the Quantum" [3], the question of whether the participatory activity described by the MC model endows reality to anything other than the present; in particular, its relation to the past is engaged. "If life and mind and meaning are so important in the scheme of things, then what is the status of the past?" For him, according to a strict adherence to quantum theory, the physical world of earlier eras of the universe—the present local effects of which being what are understood by astronomers as what is perceived at our telescopes—are at least equally capable of evidentiary establishment in the present as some aspects of the present. "Through the photons that reach the telescope, we see more clearly a quasar event of six billion years ago (before there was any life anywhere) than we can perceive the three-encyclopedia-long sequence of bits in our own DNA, in the here and now" ([3], p. 309); according to the MC hypothesis if the past exists, and exists only "in the records of the present …then the past ranks no lower and no higher than the rest of what we call existence…reality is theory" [3].[18] Thus, according to the MCH the past is constructed in a significant sense by phenomena of the present. "Not until the one or the other of the appropriately paired photodetectors (the yes-counter and the no-counter) clicks have we distinguished an answer. Not until then do we have the right to attribute a polarization to the received photon" ([3], p. 309).

Wheeler argued that "There is no more remarkable feature of this quantum world than the strange coupling it brings about between future and past, between (1) the way one will choose to orient his polarization analyzers two years down the road and (2) what one can then say about the photons that already—as judged by us now—had their genesis 3 years ago. There is a sense in which the polarization of those photons, already on their way, 'was' brought into being by the disposition of the polarization analyzers that the observer has yet to make and will make. Moreover there is no difference in principle whether the time between the emission of a photon and its

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[17] The manner in which this understood to take place is discussed in Sect. 3 above. Note that it would have been far less controversial for Wheeler to have written "…definer of physics" or "…definer of our physical world view" rather than "…definer of reality", but it appears that the goal of the MCH is exactly to transcend traditional physics to provide a basis for all of existence so far as it is empirically knowable. Nonetheless, Wheeler also argued that the central role played by the *community* of observer-participators precludes solipsism, as discussed Sect. 5.2 below.

[18] "The past is not really the past until it has been measured. Or put another way, the past has no meaning or existence unless it exists in a record in the present" ([7], pp. 67–68).

detection is 5 years; or a nanosecond, as it is when one is looking at an object a foot away; or 10^{10} years, as it is when one is receiving direct or indirect radiative evidence of what went on in the first few seconds after the big bang. In each case what one chooses to ask (as for example by the setting of the polarization analyzer) forms an inseparable part of a phenomenon that in earlier thinking one would have said had 'already happened'. In this sense it is incontrovertible that the observer is participator in genesis" ([2], pp. 24–25).

The genesis of the polarization value at the moment of a photon's measurement along a polarization basis in which it was not previously prepared surely does constitute the definition of a physical property *value* at that moment, but retrodicting from such a quantum measurement a *determinate value* of that property in the past is questionable. The significance of genuine *observer*-participancy is for *directly observed quantum* events rather than those of which records were created long ago by natural information recording systems, for example, environments creating 'microfossils,' so to speak, that could do work similar to deep-space probes, say, that land on an asteroid made of material that is billions of years old. The only clear sense in quantum theory in which a physical system may be understood to come into existence is for a quantity on the grounds of which its existence is considered to depend to become definite. However, this is not the case for classically describable systems, only those requiring quantum theory to be describable *at all*, for example, field quanta upon a number-operator measurement of the field.

Of course all 'observations of the past' about which direct observation is unavailable are indirect by definition; no matter the physics involved, they require inference from direct observations of records *in the physical "here and now."* Moreover, those observations in quantum theory considered above regard only system properties, not the very existence of systems observed, and involve only the inherent limitations on the co-measurement of properties at physical scales that require quantum theory to be most precisely described. In such circumstances, the evidence regarding new observations that is available at a space-time distance from their preparatory circumstances depends on physical circumstances local to their direct observation, and the relevance of the biological or cognitive aspect to this is entirely speculative.[19] It is important to recognize that, for past measurements—for example, from deep-space probes such as the Voyagers or other, possible deep penetrating probes from other, older civilizations elsewhere in the universe—which have produced robust physical records transmitted away as readily detected classical signals, current quantum considerations are irrelevant, just as books written in Caesar's time about the color of his clothing would have no effect on their color but are only records that allow us, now, to obtain knowledge of it. As argued above, by talking about quantum measurement as he did, Wheeler invoked a reductionist view of macroscopic systems in which the properties physical records are describable on the basis of their micro-composition,

[19] As one commentator on Wheeler's model in relation to biology put it, "Wheeler's dictum, as applied to the biological realm should therefore read more as 'it from bit from it', where lower of levels of matter dictate the informational state of a system which then in turn dictates its future evolution" ([38], p. 264).

something which is not justified for all but perhaps the tiniest fraction of highly unusual composition.[20]

The notion of observer-participation is an even more radical one if the observing subject is required to contribute something non-physical to the phenomena or to the observational evidence beyond the framing of the observation via the physical circumstances of observation and measurement. And, quantum phenomena always arise under clear physical circumstances. Moreover, Wheeler recognizes that physical records can be destroyed without being communicated among a community in order to be used as the ground of its knowledge. Use of the term 'records' suggests that the phenomena involved in *their* observation are not ephemeral but are understood to be the result of some previous real, completed process the facts about which different subjects could, in principle, have agreed had they (incidentally) observed them. It is also notable that the meaning circuit involves the establishment of physical records "above ground" and that this portion of the circuit is continuously revisited as the history of the universe becomes established in these records; cf. [24]. Wheeler appears to question the adequacy of our standard physicalist theories of autonomous, non-cognitive macroscopic systems that will have recorded the past, yet he equivocates with regard to significance of physical records. This equivocation is mirrored by his ambivalent position toward the necessity of consciousness or living beings in observation-participation despite having the physical portion of the circuit 'above ground' in the model being supported 'from below' by the cognitive portion ('below ground'). Unlike Bohr, who consistently emphasized the role of classicality in the interpretation of quantum theory, Wheeler often only obliquely recognizes the need for the independent existence of the world outside the mind, in that it is needed to supplying signals bearing information that if properly processed further could serve as knowledge about the world; how does the universe's first "bit" arise if there is no signal-bearer, one must ask.

In the quantum realm, any observer plays a role as a physical system in the determination only of property *values* not of the existence of measured systems themselves. Although there is indeed no question in quantum theory of the physical pre-determination of future values of quantum-system properties—in the absence of knowledge of previous state preparation—information related to a system's past is to be found only in a stable, classical record of property values obtained in preparatory experimental measurement as well as current measurements; these jointly allow one to obtain information about system properties and their history. In the absence of information as to previous state preparation one must assume a fully mixed state preparation, and a current measurement provides information only about the current state of the measured system. Natural preparatory environments, such as the cosmic microwave background, do exist naturally in deep space and obtaining such classical records provides valuable information that can be used in conjunction with more recent measurements to understand the history of a quantum system. But, equally if not more certainly, the world itself must already be present for any record to be pro-

[20] The reduction of classical physics to quantum physics has proven problematic and has not been accomplished, if it ever will be; cf., e.g. [39].

duced, that is, for signals providing information regarding property values to reach the the physical correspondent of the cognitive apparatus of any observer indicating the determinacy of any property upon proper attention. Thus, observers obtain information about pre-existing physical objects rather than bringing them into existence; state preparation is not a matter of system genesis but rather state determination. That the existence of a beam (say, of a mole of photons) is the immediately result of its detection or, more to the point, the genesis of the (say, electromagnetic) field *itself* by such measurement is more than doubtful. Here, one must ask of *what* is the purported 'genesis'? The answer is property values and information about them, not of physical systems.

Wheeler argued that humanity's theory of existence will be limited so long as the history of the universe is still, so to speak, being constructed from communicated experience: "If space is closed, if—following on the present phase of expansion—the system of galaxies contracts, if temperatures rise, all in line with the best known Friedmann cosmology, and if life wins all, then the number of bits of information being exchanged per second can be expected to rise enormously compared to that number rate today. The total count of bits …And how great must that future total be—tally as it is of times past—to furnish enough iron posts of observation to bear the smooth plaster which we of today call existence?" ([1], p. 126). Note that, in itself, this could instead be understood as simply emphasizing limitations of the ability of the collective evidence of science to determine the theory and the incidental particulars of the history of the world and, in a sense, it is just that; the question of whether the MC model ascribes reality to the physical world *before* the advent of any meaning-making community turns on the sense of reality involved and, so, is ambiguous exactly because the model involves both an epistemic aspect, which is "below ground," and an ontological aspect, which is "above ground," which Wheeler consistently fails to distinguish clearly.

A clearer representation of what is involved in the development of the physical world picture which is still largely in accordance with the quantum aspect of the MCH would be not a simple closed circuit but rather an *ever-expanding spiral*, where the physical world with its physical ontology induces the data—the basis of human knowledge—delivered to the community of scientists via measurement records that continually inform all of the natural sciences. However, this would also swap the 'below ground' with the 'above ground' of Wheeler's model and, thereby, be at odds with his view of information as primary. Wheeler's reductive thesis that "we know that every bit of information, every item of sight or touch or sound, goes back in the last analysis for its transmission to elementary quantum phenomena" is unjustified, in that: (i) at best, it only as regards *information about properties*, not the very existence physical systems, and (ii) such elementary phenomena are insignificant for any system that can be adequately described without the need of quantum theory: a distant quasar will not change in any existential way because it has been seen for the first time by telescope, only our evidence about it will become accessible and might influence our cosmological *theories*.

5.2 Measurement and Knowledge

"Question three: Are there then as many pasts, as many presents, and as many futures as there are observer–participators? A proposal so extravagant overlooks the community character of everything we call knowledge. Already at the quantum level, Niels Bohr warns us …that no measurement is truly a measurement unless the result can be communicated from one person to another 'in plain language.' In a wider context, we know that meaning itself would be impossible without communication. There is not a word we speak, a concept we possess, or an idea we conceive that is not rooted in the larger community" ([3], p. 310). With this, Wheeler makes clear that, at a minimum, intersubjective comparability of observations and measurements is essential to the MC model. Despite his emphasis on the contingent nature of quantum-physical events, no matter how far back in time their preparatory development may be considered to have been initiated, following Bohr, Wheeler required the communicability of observations and measurement results, placing a clear constraint on the subjectivity of scientific data.

However, Wheeler went beyond requiring intersubjective communicability of data by attributing the knower–scientist the role of direct participant in the actualization of what his/her senses reflect of physical properties; he held these data to be 'fence-posts of reality': "…Curie tells us that physics deals with things only—not people. Today, the quantum forces on us a different outlook. It tells us that existence is not a deterministic machine grinding away out there. It is senseless for the uninvolved to try to speak *in abstracto* of what is happening out there at the microscopic level. Involvement is essential: observer-participancy. Not until a choice has been made and not until one or another complementary question has been posed can there be an answer" [3], p. 311. But, again, the focus is on phenomena for which quantum theory is *necessary* to their description, as indicated by the term 'microscopic' here. Despite any ostensible role of the observer-measurer as participator, there is no reason to believe that any *essentially quantum* events, which would be (eventually) considered associated with the distant past but were *not yet already measured or recorded in nature* to be of any significance for the macroscopic-level description of the physical reality of the past universe.[21]

For Bohr, it was precisely the classicality of measurement records—that they do not require a quantum description—that enables the communication of physical values, that is, that makes it sensible to speak publicly about what is the case with an observed quantum system.[22] Although physics requires quantum theory at the atomic scale and below, it rarely needs it to describe and explain what is large in the various physical senses, certainly not to justify a belief in the existence the universe as a whole and its past. By contrast, before the late stages of consideration of the MC

[21] Regarding the meaning of "macroscopic" here, see [44].

[22] This is much like an example from Hilary Putnam: For a key to be understood, there is no need to have a ultimate fine-grained, physical explanation of its actions in the opening of a lock, because its geometry and, I would add its impenetrability, suffice to understand its propriety and ability to function.

model, Wheeler went far beyond requiring the establishment of physical records for the attribution of reality to what is measured: he included (at least proto-)conscious observation and communication between of results between (at least primitive) conscious entities. In a 1985 discussion, he commented that “Although this word conscious is a little tricky here because one can think of animals as having brains that are they are so primitive that they may not be so completely aware as you or I are, and, if some flash of light—some elementary quantum phenomenon—occurs in which they’re able to respond to in some way, they meaning has come into being even if it has involved consciousness at a pretty low level. So I would not like to put stress on consciousness even though that is a significant element in this story” and that there is a distinction depending crucially on the difference between living and inanimate objects, with there being “a most difficult question of where we draw the line” between these [7], p. 64. Still, there is a vitalist element in this requirement of the presence of life for the production of a communicable record.

Wheeler finally retreated from the requirement of the presence of (proto-)consciousness by the late 1990s. In discussion of the ‘self-excited circuit,’ he withdrew any requirement that measurement-observation be performed by living beings. “By ‘measurement’ I do not mean an observation carried out by a human or a human-designed instrument-or by any extraterrestrial intelligence, or even by an ant or an amoeba. Life is not a necessary part of this equation. A measurement, in this context, is an irreversible act in which uncertainty collapses to certainty. It is the link between the quantum and classical worlds, the point where what might happen-multiple paths, interference patterns, spreading clouds of probability-is replaced by what does happen: some event in the classical world, whether the click of a counter, the activation of an optic nerve in someone’s eye, or just the coalescence of a glob of matter triggered by a quantum event. The event that I am calling a measurement is what Niels Bohr called ‘registration.’ …What the particle might have done-or, in a quantum sense, all the things it is doing simultaneously-is replaced by what it did in fact do. Not all potentiality is converted to actuality in any finite time.” ([41], pp. 336–337). It is particularly important to note, in this regard, that potentiality can be understood as a mode of existence that is independent of thought; cf. [26]. In this distancing of himself from the requirement that life and consciousness be present for quantum actualization, Wheeler also invoked Heisenberg’s thread of the Copenhagen perspective; cf. [26]. This raises the question of the extent to which the existence of his participatory universe requires participation in the sense described by the truly closed, circuit model of the original MCH.

Early on in its development, Wheeler had offered a nearly vitalist circuit metaphor to describe the role of the ‘participator’: that it acts like the electricity in an electric motor, the point being that it is essential to the functioning of the universe: “the universe would be nothing without observership as surely as a motor would be dead without electricity” [2], p. 21. Connecting this view with experiment, he argued that the study of quantum observership “has the equivalent of Franklin’s kite and key experiment in the Einstein–Podolsky–Rosen experiment” [2], p. 21. It is also notable that electricity is just as physical as the bulk-material motor it causes to move. And the choice of measurement to be made is still tantamount to a physical configuration of measurement apparatus. It is illuminating to consider Wheeler's "U" icon, that is, the relation of this to his final views on cosmogony, "The point is that the universe is a grand synthesis, putting itself together all the time as a whole. Its history is not a history as we usually conceive history. It is not one thing happening after another after another. It is a totality in which what happens 'now' gives reality to what happened 'then,' perhaps even determines what happened 'then'." [41], p. 337. Again, while this may be the case regarding current events, and perhaps inferences regarding the past of a system between preparation and measurement in special circumstances in which state-measurement/preparation basis and measurement basis agree, it regards only quantum-level facts and, even then, involves a suspect mode of retrodiction.

In later discussions, Wheeler further related his model and quantum 'smokiness' to the perspectives of Heisenberg and Bohr and offered a less radical view of *existence* while still holding information as fundamental to it. "Measurement, the act of turning potentiality into actuality, is an act of choice, choice among possible outcomes. After the measurement, there are roads not taken. Before the measurement, all roads are possible-one can even say that all roads are being taken at once. …The laws of physics tell us only what may happen. Actual measurement tells us what is happening (or what did happen). Despite this difference, it is not unreasonable to imagine that information sits at the core of physics, just as it sits at the core of a computer. …Niels Bohr wrestled for most of his life with the question of how acts of measurement (or 'registration') may affect reality. It is registration—whether by a person or a device or a piece of mica (anything that can preserve a record)—that changes potentiality into actuality. I build only a little on the structure of Bohr's thinking when I suggest that we may never understand this strange thing, the quantum, until we understand how information may underlie reality. Information may not be just what we learn about the world. It may be what makes the world" ([41], pp. 338–340).

Nonetheless, one must recognize that communicable physical facts are not established only, or even primarily at the microscopic level; the subtle aspect of the universe in which quantum state actualization is significant only where quantum descriptions are necessary, which at large scales are only those relatively rare situations in which such small signal-capable objects have effects are very dramatically amplified. Some have considered a possible "initial quantum fluctuation" that might have been amplified at the very beginning of the universe, but the magnitudes of the quantities such as mass-energy that would have to have been present, assuming the continual validity of conservation laws, would have been extremely large. An extreme amplification—and a 'mechanism' for this amplification, and by *what*—of an ur-signal would be required if such an explanation of the origins of the structure of the universe is to be considered at hand. Even then, it is difficult to see what this mechanism would have to do with cognition in any clearly specifiable manner.

5.3 Measurement and Information

Regarding the relationship between information and meaning, Wheeler posed "Question four: What significance, if any, are we to attribute to an elementary quantum phenomenon that is not put to use to establish evidence and meaning? Despite all that we know about measurement theory in the realm of the quantum, nothing is more puzzling than the linkage between the counter's click and the community that makes meaning" [3] and suggested as an example for consideration "a crystal of zinc sulfide thrown up by nature on the back side of the moon. It stops a cosmic-ray proton. Ten million photons emerge, which is an irreversible act of amplification if there ever was one. The signal, however, dissipates out into space. No use is made of it. ... the amplifying device consists of some 10^{22}–10^{25} particles coupled by a complex of electromagnetic interactions. …Surely all over the universe, in regions out of sight, interactions are going on all the time and between particles that are stupendous in number compared to the count ... here" ([3], p. 311). This may appear problematic for autonomous physical measurement in that, even if irreversibly generated in the absence of life or consciousness, an amplified signal serving as a physical record of an event can be, practically speaking, unrecoverable and incapable of providing information, and so knowledge to any finite observer. Wheeler argued that, more generally, "There is no irreversible act of amplification that may not later be erased. Not unless it is put to use in the establishment of meaning does the elementary quantum phenomenon win any special status" (ibid.). However, it is not clear why any "special status" should be attributed to the mere occurrence of any given quantum-level physical event relative to any another, even in the Copenhagen understanding of physical observation and measurement, or why the provision of *meaning* to them need be relevant to the reality of anything physical.

Although there is no measurement record that cannot be degraded or ignored in principle, this "degradation" is only epistemically significant; it is not intrinsically *physically* significant. Wheeler did view 'meaningful' observation and the mere creation of a quantum phenomena as distinct: the "vital distinction between the elementary quantum phenomenon …on the one hand and the putting of that observation, that elementary quantum phenomenon, to use in the establishment of meaning …and it's not enough for just one observer to put it to use—you need a community" ([7], p. 63). Very well. But this relates to the meaningfulness of the results to the community in question, not to the existence of the phenomena that might influence its theorizing. Moreover, any communicated meaning of any kind can be lost through the dissipation of the brains of the members of the community in question. Does the universe cease to be real if the human race ceases to exist?

Wheeler also argued that "the quantum …tells us that existence is not a deterministic machine grinding away out there." Although that may be true for phenomena requiring quantum mechanics for their description, it is by no means the case that nature does not establish a manifest, independent history at large scales and over large times in the absence of living observers or communities thereof, only that the past of essentially quantum systems may have a different character from those well described by classical mechanics. The perspective of the renowned information-theorist Rolf Landauer, to whom Wheeler often referred during the development of the MCH, provides a clear view of the relation between quantum measurement and information. Landauer held that "Information, numerical or otherwise, is not an abstraction, but is inevitably tied to a physical representation. There really is no software, in the strict sense of disembodied information, but only inactive and relatively static hardware. Thus, the handling of information is inevitably tied to the physical universe, its content and its laws" [42]; he viewed the primary significance of the elements of Wheeler's circuit to be that they allow for a consistent picture of *information processing* involving physical signals.

> Wheeler has given us …the "meaning circuit". In this, physics gives rise to all the phenomena whose study has usually occupied us. …Wheeler reminds us that the discovery of laws is, or involves, quantum mechanical measurement. The results of measurement are not independent of the act of measurement, and the outcome of the measurement was not there, all along, to be revealed in its finally measured form. If I can be presumptuous enough to differ from Wheeler, it is related to his stress on human observers and their posing of questions. Measurement does not require intelligent beings, the environment is continually acting on a system, and making measurements. [42]

Only, it is better said in the above that '…the discovery of laws may involve quantum mechanical measurement', for many valid physical laws have been established without the need for specifically quantum measurements, however much the smallest structures within measuring apparatus would be amenable to quantum mechanical description were they in isolation.

5.4 The Meaning Circuit

The question of the closed nature of the 'meaning circuit' which relates to the issues discussed above is addressed with the final question:

> Question seven: Why speak of a circuit? Why not seek instead for a foundation? There is an old legend about the foundation that supports the world: Our globe rests on the back of a great elephant. The elephant stands on the back of a giant tortoise. …"And what does it stand on," she inquires. The lecturer's reply is famous: 'Tortoises, madam; on and on, nothing but tortoises.' How different is the account we give today of the foundation of existence? Matter is built on molecules. The molecule is built on atoms. The atom has a nucleus. The nucleus is built on nucleons. The nucleon is built on quarks. The quark is built on fields. The field is built on geometry of one or another dimension. …Is there ever to be an end? How can there be an end if we ask always for foundation of foundation of foundation. . .? No escape is evident from this view of worlds without end-or tortoises without end-except in a line of influence that closes on itself, that forms a loop, that makes a circuit. No model for such a loop is available to us today except one of information-theoretic character, the model of existence as a meaning circuit. [3]

Wheeler points out here that an approach to physics where theories, even if they are each approximately capable of reduction to another, is unsatisfactory when each new, ostensibly more fundamental theory requires a yet more fundamental one, which he saw as being the case so far in the history of physics. This critique focuses specifically on the seemingly endless search for deeper ontic levels in physics.

Wheeler then argued that a potential logical infinite regress this history suggests can be avoided by adaptation of a circuit-like schema, such as that he offers on the basis of the MCH. Of course, there is an alternative solution which is a natural one given what has become increasingly clear to experimental physics over the past century, namely, that there is an inherent physical limit to the ability to probe for data providing information about any possible "deeper" structure, anyway: to abandoning reductionist absolutism and to accept accurate theories appropriate to each new physical realm.[23] In fact, in the current era of physics, theorizing about the ontology of the smallest spatial scales is proving extremely challenging, this challenge being posed primarily by an apparently inevitable dearth of empirical input. Given that probing small-scale structure requires ever greater energies, our capacity to probe is limited by the availability of local sources of energy to be harnessed, even by the universe itself through astrophysical phenomena. Theorizing may soon find itself largely incapable of experimental verification, something already manifest with regard to string theory; this far more conservative position is at least as satisfactory philosophically if not so to the curiosity of physicists. Indeed, Wheeler's question only arises from the acceptance of a reductionist imperative. Discovering physical structure is scientifically valuable, but demanding always to find deeper levels of it, as opposed to simply understanding it always better, is another matter.

In his discussions of the novel element of his 'meaning circuit,' Wheeler often turned "to the role of observation in defining meaning, that central topic in the philosophical thought of our time, we have these words of Føllesdal (1975) in the great Oxford Lectures on Mind and Language, 'Meaning is the joint product of all the evidence that is available to those who communicate'." ([2], p. 25). But, unlike information as clearly related to physics, the question of meaning goes beyond the scope of the problem at hand, namely, the basic question of the nature of physical reality. And, ultimately, Wheeler even decided to "steer clear of the issues connected with 'consciousness.' The line between the unconscious and the conscious begins to fade in our day as computers evolve and develop—as mathematics has—level upon level upon level of logical structure. We may someday have to enlarge the scope of what we mean by a 'who'. This granted, we continue to accept—as essential part of the concept of it from bit—Føllesdal's guideline" ([43], p. 320).[24]

[23] Consider, for example, Heisenberg's position regarding elementary particles: "Because particle number is not conserved in high-energy interactions it may be meaningless to ask about the constituent parts of elementary particles; perhaps the central question is dynamics" [45]. There are other reasons besides lack of particle-number conservation per se for holding this that are also evident in the results of quantum field theory, including "virtual-particle clouds" [46].

[24] Others have recently continued pushing on with ways of continuing the meaning circuit program beyond physics proper; cf., e.g., [47].

6 Conclusion

The development and content of John Wheeler's Meaning Circuit Hypothesis is discussed above and a number of significant difficulties with it are found. The most suspect of its propositions is that existence itself, not simply the precise determination of physical properties of micro-systems, is contingent on the participation of observer-participators or communities thereof. This is seen to follow from Wheeler's particular, unusual form of tacit reductionism in which quantum theory is universally required and existence itself is reduced to 'meaningful' communicated information corresponding to individual quantum phenomena where, however, the connection to meaning is never actually provided in any specificity.

When considering this grand attempt to find an explanation of the origin of existence in the novel aspect of quantum theory, the omnipresence of the quantum (of action), it is valuable to reconsider Einstein's rhetorical question, 'Is the moon not there when nobody looks?' Physical experience demonstrates that neither the moon nor the history of anything classically describable depends on any community of communicators or their observations to exist; there is now an empirically well-supported history of the four-billion Earth–Moon system which theory—the existence and details of which of course are based on human-collected data and theory from non-quantum mechanical observations of pre-existing physical objects not built of elementary quantum phenomena involving observers in any precisely demonstrable sense. Explaining the presence of the moon when no-one looks involves no quantum theory whatsoever, and the the Moon did not come into existence with the appearance of astronomers of even the most primitive level; to expect that the universe itself came into existence, say, when the cosmic microwave background was discovered, is even less plausible. Based on the evidence and arguments presented in his various writings on the topic, Wheeler's Meaning Circuit Hypothesis is better understood as an explanation of how quantum *theory* arose and is validated rather than one of how the physical *universe* arose.

Better service to physics is done by pursuing a model containing the elements of the MCH that emphasizes the role of information in the development of our scientific understanding of the world, to which the physical theorizing of Wheeler and his students have clearly and definitively contributed, rather than suggesting a reduction of physics to information or knowledge, particularly considering the speculative leap involved in connecting elementary quantum phenomena directly to cognition. The result of this clarification corresponds not to a 'circuit,' but to an ever-expanding spiral of history and knowledge creation and verification of the character of that history, where evidence continually informs all of the natural sciences and more facts about the world of the essentially quantum are accumulated, a spiral that first began in the absence of any living observer with the beginning of time but has now accelerated with the advancement of science ever more deeply and broadly in the quantum realm.

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