John Archibald Wheeler: Law Without Law

Pages 182–213 in:

Quantum Theory and Measurement

Edited by
John Archibald Wheeler
and
Wojciech Hubert Zurek

Princeton Series in Physics

Princeton University Press, 1983

I.13 LAW WITHOUT LAW

JOHN ARCHIBALD WHEELER

* * * * *

The second phase of the dialog began in Europe but continued in America from Einstein's arrival at Princeton in October, 1933, to his death there in April, 1955. Here Einstein tried to show that quantum theory — in making what happens depend upon what the observer chooses to measure —is incompatible with any reasonable idea of reality.[18] Bohr's reply[19] briefly summarized was this: Your concept of reality is too limited.

THE BEAM SPLITTER

Of all the idealized experiments taken up by the two friends in their effort to win agreement, none is simpler than the beam splitter of fig. 4. With the final half-silvered mirror in place the photodetector at the lower right goes click-click as the successive photons arrive but the adjacent counter registers nothing. This is evidence of interference between beams 4a and 4b; or, in photon language, evidence that each arriving light quantum has arrived by both routes, A *and* B. In such experiments,[20] Einstein originally argued, it is unreasonable for a single photon to travel simultaneously two routes. Remove the half-silvered mirror, as at the lower left, and one will find that the one counter goes off, or the other. Thus the photon has traveled only *one* route. It travels only one route, but it travels both routes; it travels both routes, but it travels only one route. What nonsense! How obvious it is that quantum theory is inconsistent!

[18] A. Einstein, B. Podolsky and N. Rosen, "Can quantum-mechanical description of physical reality be considered complete?" *Physical Review* **47:** pp. 777-780 (1935).

[19] N. Bohr, "Can quantum-mechanical description of physical reality be considered complete?" *Physical Review* **48:** pp. 696-702 (1935).

[20] The center of discussion in the Bohr-Einstein dialog was more often the so-called double-slit experiment than the beam splitter depicted in figure 4. The latter is made the focus of attention here because it presents the central point without getting into the physics of interference patterns.

The first section between stars (* * * * *) appeared in Wheeler, 1981a; the next section between stars from Wheeler, 1979; the following from Wheeler, 1980; and the final section (a single paragraph) from Wheeler, 1981b. Preparation for publication of all four items was assisted by The University of Texas Center for Theoretical Physics and by NSF Grant PHY78-26592.

Bohr emphasized that there is no inconsistency. We are dealing with two different experiments. The one with the half-silvered mirror removed tells which route. The one with the half-silvered mirror in place provides evidence that the photon traveled both routes. But it is impossible to do both experiments at once. One can observe one feature of nature, or the complementary feature of nature but not both features simultaneously. What we choose to measure has an irretrievable consequence for what we will find.

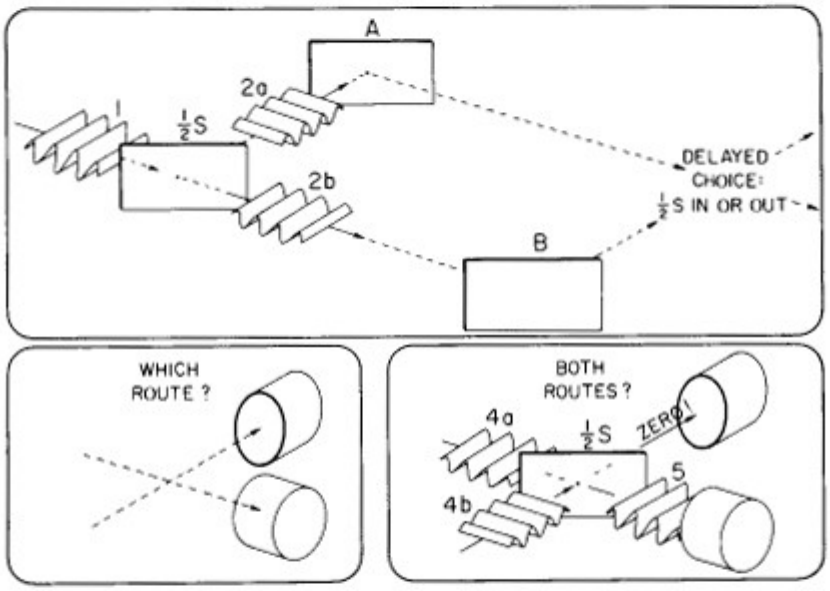

Fig. 4. Beam splitter (above) and its use in a delayed-choice experiment (below). An electromagnetic wave comes in at 1 and encounters the half-silvered mirror marked "½S" which splits it into two beams, 2a and 2b, of equal intensity which are reflected by mirrors A and B to a crossing point at the right. Counters (lower left) located past the point of crossing tell by which route an arriving photon has come. In the alternative arrangement at the lower right, a half-silvered mirror is inserted at the point of crossing. On one side it brings beams 4a and 4b into destructive interference, so that the counter located on that side never registers anything. On the other side the beams are brought into constructive interference to reconstitute a beam, 5, of the original strength, 1. Every photon that enters at 1 is registered in that second counter in the idealized case of perfect mirrors and 100 per cent photodetector efficiency. In the one arrangement (lower left) one finds out by *which* route the photon came. In the other arrangement (lower right) one has evidence that the arriving photon came by both routes. In the new "delayed-choice" version of the experiment one decides whether to put in the half-silvered mirror or take it out at the very last minute. Thus one decides whether the photon "shall have come by one route, or by both routes" after it has "*already done* its travel."

THE DELAYED-CHOICE EXPERIMENT

In our own day we have learned to state the point even more sharply by way of a so-called delayed-choice experiment.[21] There we make the decision whether to put the final half-silvered mirror in place or to take it out at the very last picosecond, after the photon has already accomplished its travel. In this sense, we have a strange inversion of the normal order of time. We, now, by moving the mirror in or out have an unavoidable effect on what we have a right to say about the *already* past history of that photon.

"PHENOMENON"

The dependence of what is observed upon the choice of experimental arrangement made Einstein unhappy. It conflicts with the view that the universe exists "out there" independent of all acts of observation. In contrast Bohr stressed that we confront here an inescapable new feature of nature, to be welcomed because of the understanding it gives us. In struggling to make clear to Einstein the central point as he saw it, Bohr found himself forced to introduce the word "phenomenon."[7] In today's words Bohr's point — and the central point of quantum theory — can be put into a single, simple sentence. "No elementary phenomenon is a phenomenon until it is a registered (observed) phenomenon."[8] It is wrong to speak of the "route" of the photon in the experiment of the beam splitter. It is wrong to attribute a tangibility to the photon in all its travel from the point of entry to its last instant of flight. A phenomenon is not yet a phenomenon

[21] J.A. Wheeler, "The 'past' and the 'delayed-choice' double-slit experiment," in A.R. Marlow, ed., *Mathematical Foundations of Quantum Theory* (Academic Press, New York, 1978), pp. 9-48.

[22] "Closed by irreversible amplification", p. 73; "irreversible amplification," p. 88: N. Bohr, *Atomic Physics and Human Knowledge* (Wiley, New York, 1958).

[23] A homely illustration of this idea is provided by the old parlor game of Twenty Questions in the "surprise version" described by the author in several places, most recently in "Beyond the black hole," a chapter in H. Woolf, ed., *Some Strangeness in the Proportions: An Einstein Centenary Celebration* (Addison-Wesley, Reading, Mass., 1980).

until it has been brought to a close by an irreversible act of amplification such as the blackening of a grain of silver bromide emulsion or the triggering of a photodetector.[22] In broader terms, we find that nature at the quantum level is not a machine that goes its inexorable way. Instead what answer we get depends on the question we put, the experiment we arrange, the registering device we choose. We are inescapably involved in bringing about that which appears to be happening.[23]

CONCERN ABOUT OBSERVER-PARTICIPANCY TODAY

Most applications of quantum theory deal with stationary states of elementary particles, of atomic nuclei, atoms, molecules and larger systems, and with processes of collision between one quantum system and another. Only in recent years has increasing attention come back to the point of central concern of Bohr and Einstein, the elementary quantum phenomenon, the process of measurement, the involvement of the registering device in bringing about that which appears to be happening, the strangest part of a strange subject. How can one contemplate indeterminism, complementarity and "phenomenon" without being reminded of the words of Gertrude Stein about modern art? "It looks strange and it looks strange and it looks very strange; and then suddenly it doesn't look strange at all and you can't understand what made it look strange in the first place." Many investigators, believing that the greatest insights are to be won from nature's strangest features, are — in research papers, review articles and books — giving fresh coverage of the strange "observer-participancy" forced to our attention by the quantum.[24]

[24] See for example B. d'Espagnat, ed., *Foundations of Quantum Mechanics* (Academic Press, New York, 1971); E.P. Wigner, "Interpretation of quantum mechanics," 93 pages of mimeographed notes of lectures delivered at Princeton University in 1976 on deposit in Fine Library, Princeton University, Princeton, N.J.; M.M. Yanase, M. Namiki and S. Machida, eds., *Theory of Measurement in Quantum Mechanics* (Physical Society of Japan, Tokyo, 1980); J.A. Wheeler, "Frontiers of time," in N. Toraldo di Francia, ed., *Problems in the Foundations of Physics*, Rendiconti della Scuola Internazionale di Fisica 'Enrico Fermi', LXXII Corso (North-Holland, Amsterdam, 1979).

MANY QUANTA VERSUS ONE QUANTUM

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?[25] Does the tree not exist in the forest unless there is someone there to see it? Do Bohr's conclusions about the role of the observer differ from those of Berkeley? Yes, and in an important way. Bohr deals with the individual quantum process. Berkeley — like all of us under everyday circumstances — deals with multiple quantum processes.

Pondering the difference between the individual quantum phenomenon and the tree that falls, unobserved, in the forest, we walk through the art gallery on our way to visit again a favorite picture. We pass by the painting "Impressions," first shown by Claude Monet in 1863 at the Salon des Refusés. From a tiny dab of color on that canvas in the single second of our passage the pupil of our eye receives 50,000 photons. Each is accidental in its direction and time of arrival. The quanta in that hail of information are so numerous that they give the impression of perfect steadiness of illumination. What one of us busy mortals has the time to count them all? We rely instead on some gross and handier measure of intensity, such as the eye so aptly passes to the brain. There is no place in that message for the qualifying words, "with a root mean square fluctuation of 224 relative to an average number of photons of 50,000." Who needs to know about quanta to know the dot of color is there?

Unexpectedly the power blacks out. A guard with electric torch pointed at the floor guides our return. Our eye receives no photons from the dab of paint on the canvas. However, a touch of the hand as we pass the painting in the dark is enough to comfort us that it is still there. It would outreach any on-the-spot bookkeeping to count the 10^{16} atomic points of contact between the fingers and the picture frame, or the even more numerous quantum processes that impinge from the frame onto the fingertips. The message is still clear. How-

[25] G. Berkeley (1685-1783) in M.W. Calkins, ed., *Berkeley: Essays, Principles, Dialogs, with Selections from Other Writings* (Scribner, New York, 1929, as reprinted in 1957), pp. 125-126.

ever, we now go through a longer chain of theory and interpretation in reaching the conclusion that the dab of paint is still there. Or was the luminous dot of color an illusion created by trick illumination from a concealed lamp? That was conceivable when we passed it first but highly unlikely given the integrity of the museum and the difficulty of the undertaking. During the exit through the dark it is more difficult to check against deception but the best indirect evidence one has says that the painting is still there with all its dots of color. Moreover, one is free to stop and extend the investigation and transform questionable evidence into convincing evidence.

When we emerge from the gallery and start thinking again of the tree, we recognize that this problem differs from the case of the picture only in degree, not in kind. The supposition that it fell we can check more and more conclusively according to the amount of effort we are willing to put into investigating impact points, ground dislocations and acoustic records. Anything macroscopic that happened in the past makes, we know, a rich fallout of consequences in the present. But whether we deal with the fall of the tree or the evidence for the dab of paint on the canvas or the motion of the moon through the sky, 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.

In contrast the choice of question asked has a decisive consequence for[26] the elementary quantum phenomenon. For illustration it is enough to recall the inquiry of fig. 4 about the "track" of the photon, or a similar inquiry about the "path" of an electron through a beam splitter or the "motion" of an electron in an atom. In each of these examples, moreover, at least one of the available choices of question to be asked (which route for the photon or electron; or what position or momentum does the electron have in the atom) has a

[26] Why not change "has a decisive consequence for . . ." to "makes all the difference in the elementary quantum phenomenon"? The word "difference" is not allowable. We can do the one experiment or the other experiment but the two experiments simply will not fit into one place at one time. We are dealing with one phenomenon, one "act of creation." The very individuality of the quantum phenomenon leaves no place for comparing what is with what might have been.

completely unpredictable answer. We can send a million photons through the beam splitter when it is operated in the "which route" configuration at the lower left of fig. 4. Then we can be assured half a million photons, more or less (statistical variations of the order of magnitude ± 500) will be recorded by each counter. However, when via the same arrangement we deal with a single photon we have not the slightest possibility to tell in advance which of the two counters it will strike.

QUANTUM OUTCOME: GOVERNED BY HIDDEN VARIABLES?

Is there not some underground machinery beneath the working of the world which one can ferret out to secure an advance indication of the outcome? Some secret determiner, some "hidden variable"? Every attempt, theoretical or observational, to defend such a hypothesis has been struck down.[27] Not the slightest hard evidence has ever been found that would throw doubt on the plain, straightforward prediction of quantum mechanics, the prediction that no prediction is possible. Probability? Yes. A definite forecast? No. Einstein could be unhappy that "God plays dice"; but Bohr could tell him jokingly, "Einstein, stop telling God what to do."[28]

QUANTUM OUTCOME: ALLAH WILLED IT?

If no identifiable machinery is at hand to tell the lone photon which way to go then why not simply say of the route it actually takes, Allah willed it? And willed the outcome of every other individual quantum process?

To strike down a proposal of this kind, it has been

[27] For a review of relevant experiments, see especially F.M. Pipkin, "Atomic physics tests of the basic concepts in quantum mechanics," pp. 281-340 in *Advances in Atomic and Molecular Physics* (Academic Press, New York, 1978).

[28] N. Bohr as quoted by J. Bronowski, *The Ascent of Man* (Little, Brown and Co., Boston/Toronto, 1973), p. 122.

pointed out more than once,[29] is beyond the power of logic. One has to appeal instead to pragmatism. In the struggle for survival, other things being equal, that way of life will go under that takes all that comes in a blindly fatalistic spirit. To evade danger and to seize opportunity every faculty has to be mobilized to predict what lies ahead of peril and promise. Society charges science with the task of prediction. Science makes some progress with the task. In the individual quantum process, however, prediction comes to the end of the road. Science does not have to be ashamed of its finding. It has only to be honest about it. Why demand of science a cause when cause there is none?

QUANTUM OUTCOME: ELEMENTARY ACT OF CREATION?

How did the universe come into being? Is that some strange, far-off process, beyond hope of analysis? Or is the mechanism that came into play one which all the time shows itself?

Of the signs that testify to "quantum phenomenon" as being the elementary act of creation, none is more striking than its untouchability. In the delayed-choice version of the split-beam experiment, for example, we have no right to say what the photon is doing in all its long course from point of entry to point of detection. Until the act of detection the phenomenon-to-be is not yet a phenomenon. We could have intervened at some point along the way with a different measuring device; but then regardless whether it is the new registering device or the previous one that happens to be triggered we have a new phenomenon. We have come no closer than before to penetrating to the untouchable interior of the phenomenon. For a process of creation that can and does operate anywhere, that reveals itself and yet hides itself, what could one have dreamed up out of pure imagination more magic —and more fitting—than this?

[29] For a discussion of this point I am indebted to Professor Andrew Gleason.

DELAYED CHOICE AT THE COSMOLOGICAL SCALE

Of all the features of the "act of creation" that is the elementary quantum phenomenon, the most startling is that seen in the delayed-choice experiment. It reaches back into the past in apparent opposition to the normal order of time. The distance of travel in a laboratory split-beam experiment might be thirty meters and the time a tenth of a microsecond; but the distance could as well have been billions of light years and the time billions of years. Thus the observing device in the here and now, according to its last minute setting one way or the other, has an irretrievable consequence for what one has the right to say about a photon that was given out long before there was any life in the universe.

Two astronomical objects, known as 0957 + 561A,B (fig. 5), once considered to be two distinct quasistellar objects or "quasars" because they are separated by six seconds of arc, are considered now by many observers to be two distinct images of one quasar.[30] Evidence has been found for an intervening galaxy, roughly a quarter of the way from us to the quasar. Calculations indicate[31] that a normal galaxy at such a distance has the power to take two light rays, spread apart by

[30] D. Walsh, R.F. Carswell and R.J. Weymann, "0957 + 561A,B: twin quasistellar objects or gravitational lens?" *Nature* **279**: pp. 381-384 (1979); R.J. Weymann, F.H. Chaffee Jr., M. Davis, N.P. Carleton, D. Walsh, and R.F. Carswell, "Multiple-mirror observations of the twin QSO 0957 + 561A, B," *Astrophysical Journal* **233**, L43-L46 (1979); P.J. Young, W.L.W. Sargent, J.A. Kristian and J.A. Westphal, "CCD photometry of the nuclei of three supergiant elliptical galaxies: evidence for a supermassive object in the center of the radiogalaxy NGC6251," *Astrophysical Journal* **234**: pp. 76-85 (1979); D.H. Roberts, P.E. Greenheld and B.F. Burke, "The double quasar 0957 + 561: a radio study at 6 centimeters wavelength," *Science* **205**: pp. 894-896 (1979); G.G. Pooley, I. Browne, E.J. Daintree, P.K. Moore, R.G. Noble and D. Walsh, "Radio studies of the double QSO 0957 + 561A,B," *Nature* **280**: pp. 461-464 (1979); P.E. Greenheld, D.H. Roberts and B.F. Burke, "The double quasar 0957 + 561: examination of the gravitational lens hypothesis using the very large array," *Science* **208**: pp. 495–497 (1980); P.J. Young, J.E. Gunn, J.A. Kristian, J.B. Oke and J.A. Westphal, "Q0957 + 561A,B: a gravitational lens formed by a galaxy at z = 0.39," *Astrophysical Journal*, in press (1980); B. Wills and D. Wills, "Spectrophotometry of the double QSO 0957 + 561," *Astrophysical Journal* **238**: pp. 1-9 (1980); B.T. Soifer, G. Neugebauer, K. Matthews, E.E. Becklin, C.G. Wynn-Williams and R. Capps, "IR observations of the double quasar 0957 + 561A,B and the intervening galaxy," *Nature* **285**: pp. 91-93 (1980).

[31] C.C. Dyer and R.C. Roeder, "Possible multiple imaging by spherical galaxies," *Astrophysical Journal* **238**, L67-L70 (1980); C.C. Dyer and R.C. Roeder, "A range of time delays for the double quasar 0957 + 561A,B," *Astrophysical Journal*, submitted for publication June 16, 1980.

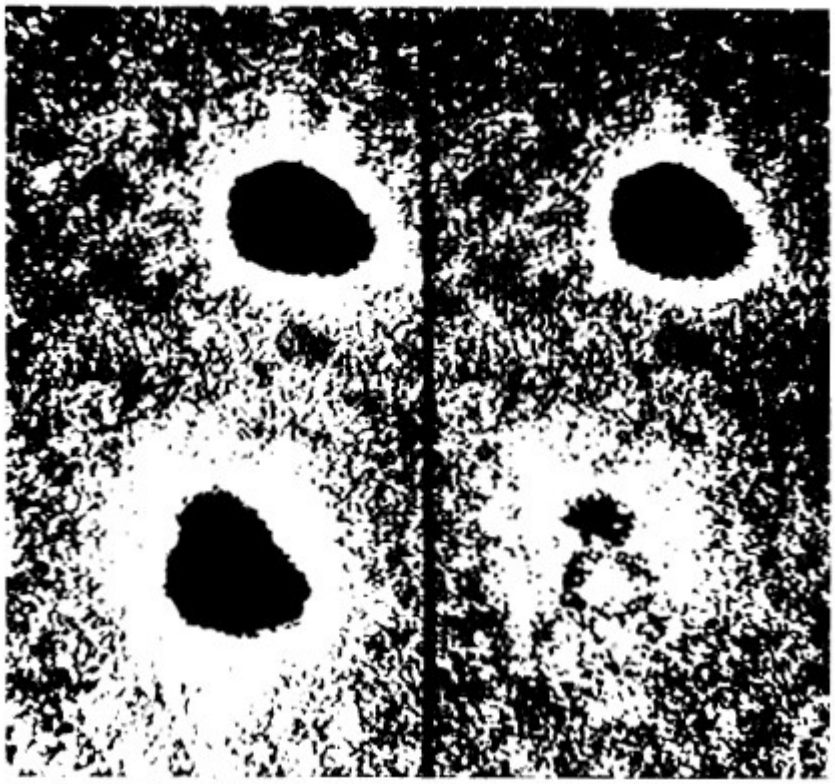

Fig. 5. Left, the double quasistellar object ("quasar": red shift $z = 1.41$), identified by its right ascension and declination as 0957 + 561A,B, and suspected to be the two images — produced by gravitational lens action — of one and the same quasar. This photograph, made at the University of Hawaii telescope by Alan Stockton and kindly communicated and discussed by Derek Wills of the University of Texas at Austin, is the digital sum of five one-minute exposures in red light (5700 to 7000Å). The stellar images appear elongated because of a telescope tracking problem. Right, the same digital photographic record after a stellar profile has been subtracted from the southern image (B), the residual being compatible with the existence near B of a lensing galaxy (G-1). Evidence has been found by Young, Gunn, Kristian, Oke and Westphal at Caltech for such a galaxy (0.02" to the West and 0.8" North of B; red shift $z = 0.39$), much closer to B than to A (which is 1.2" to the West and 6" North of B), and for its membership *in* a cluster of perhaps 1000 to 10,000 galaxies (centered 2" to the West and 15" North of B).

fifty thousand light years on their way out from the quasar, and bring them back together at the Earth. This circumstance, and evidence for a new case of gravitational lensing,[32] make it reasonable to promote the split-beam experiment in the delayed-choice version from the laboratory level to the cosmological scale as illustrated in fig. 6.

We get up in the morning and spend the day in meditation whether to observe by "which route" or to observe interference between "both routes." When night comes and the telescope is at last usable we leave the half-silvered mirror out or put it in, according to our choice. The monochromatizing filter placed over the telescope makes the counting rate low. We may have to wait an hour for the first photon. When it triggers a counter, we discover "by which route" it came with the one arrangement; or by the other, what the relative phase is of the waves associated with the passage of the photon from source to receptor "by both routes" — perhaps 50,000 light years apart as they pass the lensing galaxy G-1. But the photon has already *passed* that galaxy billions of years before we made our decision. This is the sense in which, in a loose way of speaking, we decide what the photon *shall have done* after it has *already* done it. In actuality it is wrong to talk of the "route" of the photon. For a proper way of speaking we recall once more that it makes no sense to talk of the phenomenon until it has been brought to a close by an irreversible act of amplification: "No elementary phenomenon is a phenomenon until it is a registered (observed) phenomenon."

[32] R.J. Weymann, D. Latham, J.R.P. Angel, R.F. Green, J.W. Liebert, D.A. Turnshek, D.E. Turnshek and J.A. Tyson, "The triple QSO PG1115+08: another probable gravitational lens," *Nature* **205**: pp. 641-643 (1980).

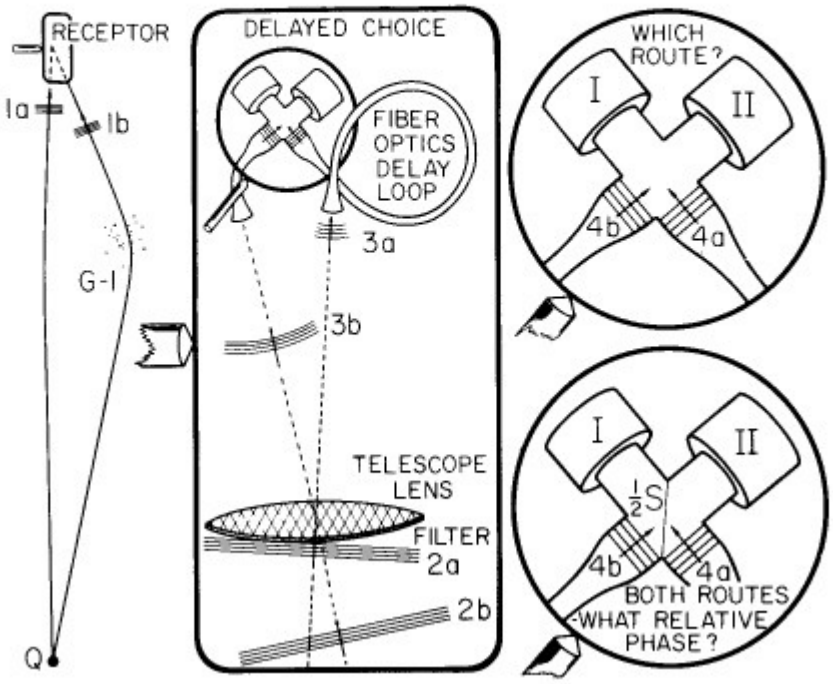

Fig. 6. Proposed delayed-choice experiment extending over a cosmological reach of space and time. Left, quasar Q recorded at receptor as two quasars by reason of the gravitational lens action of the intervening galaxy G-1. Middle, schematic design of receptor for delayed-choice experiment: (a) filter to pass only wave lengths in a narrow interval, corresponding to a long wave train, suitable for interference experiments; (b) lens to focus the two apparent sources onto the acceptor faces of two optic fibers; (c) delay loop in one of these fibers of such length, and of such rate of change of length with time, as to bring together the waves traveling the two very different routes with the same, or close to the same, phase. Right, the choice. Upper diagram, nothing is interposed in the path of the two waves at the crossing of the optic fibers. Wave 4a goes into counter I, and 4b into counter II. Whichever of these photodetectors goes off, that — in a bad way of speaking — signals "by *which* route, a or b, the photon in question traveled from the quasar to the receptor." Lower diagram, a half-silvered mirror, ½S, is interposed as indicated at the crossing of the two fibers. Let the delay loop be so adjusted that the two arriving waves have the same phase. Then there is never a count in I. All photons are recorded in II. This result, again in a misleading phraseology, says that "the photons in question come by *both* routes." However, at the time the choice was made whether to put in ½S or leave it out, the photon in question had *already* been on its way for billions of years. It is not right to attribute to it a route. No elementary phenomenon is a phenomenon until it is a registered phenomenon.

THE "PAST" IN THE LIGHT OF THE DELAYED-CHOICE EXPERIMENT

To use other language, we are dealing with an elementary act of creation. It reaches into the present from billions of years in the past. It is wrong to think of that past as "already existing" in all detail. The "past" is theory. The past has no existence except as it is recorded in the present. By deciding what questions our quantum registering equipment shall put in the present we have an undeniable choice in what we have the right to say about the past.

What we call reality consists (fig. 7) of a few iron posts of observation between which we fill in by an elaborate papier-maché construction of imagination and theory.[33]

Spacetime in the prequantum dispensation was a great record parchment. This sheet, this continuum, this carrier of all that is, was and shall be, had its definite structure with its curves, waves and ripples; and on this great page every event, like a glued down grain of sand, had its determinate place. In this frozen picture a far-reaching modification is forced by the quantum. What we have the right to say of past spacetime, and past events, is decided by choices — of what measurements to carry out — made in the near past and now. The phenomena called into being by these decisions reach backward in time in their consequences as indicated in fig. 8, back even to the earliest days of the universe. Registering equipment operating in the here and now has an undeniable part in bringing about that which appears to have happened. Useful as it is under everyday circumstances to say that the world exists "out there" independent of us, that view can no longer be upheld. There is a strange sense in which this is a "participatory universe."

[33] In this connection see especially E.H. Gombrich, *Art and Illusion: A Study in the Psychology of Pictorial Representation* (Princeton University Press, Princeton, N.J., 1961, 2nd edition, revised), pp. 273, 329 and 394.

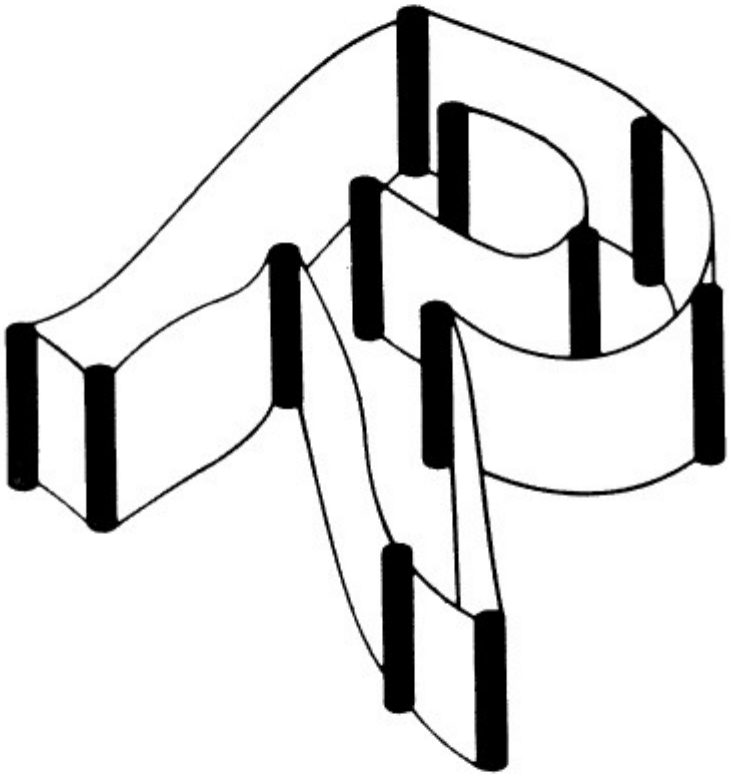

Fig. 7. What we call "reality," symbolized by the letter "R" in the diagram, consists of an elaborate papier-maché construction of imagination and theory fitted in between a few iron posts of observation.

FROM MEASUREMENT TO MEANING

We cannot speak in these terms without a caution and a question. The caution: "Consciousness" has nothing whatsoever to do with the quantum process. We are dealing with an event that makes itself known by an irreversible act of amplification, by an indelible record,[34] an act of registration. Does that record subsequently enter into the "consciousness" of some person, some animal or some computer? Is that the first step in translating the measurement into "meaning" — meaning regarded as "the joint product of all the evidence that is available to those who communicate"?[35] Then that is a separate part of the story, important but not to be confused with "quantum phenomenon."

IS THE UNIVERSE CONSTRUCTED OUT OF ELEMENTARY PHENOMENA?

From this caution we turn to the question: If the elementary quantum process is an act of creation, is an act of creation of any other kind required to bring into being all that is?

At first sight no question could seem more ridiculous. How fantastic the disproportion seems between the microscopic scale of the typical quantum phenomenon and the gigantic reach of the universe! Disproportion, however, we have learned, does not give us the right to dismiss. Else how would we have discovered that the heat of the carload of molten pig iron goes back for its explanation to the random motions of billions of microscopic atoms and the shape of the elephant to the message on a microscopic strand of DNA? Is the term "big bang" merely a shorthand way to describe the

[34] F.J. Belinfante, *Measurements and Time Reversal in Objective Quantum Theory* (Oxford University Press, Oxford, 1975); terminology "indelible," p. 39.

[35] D. Føllesdal, "Meaning and experience" in S. Guttenplan, ed., *Mind and Language* (Clarendon Press, Oxford, 1975), pp. 254. Føllesdal's article, the other articles in this book and the references they make to the still larger literature of meaning, a central topic of philosophy in Britain and America in recent decades, will indicate the representative character of this statement.

cumulative consequence of billions upon billions of elementary acts of observer-participancy reaching back into the past, as symbolized in fig. 8?

An old legend describes a dialog between Abraham and Jehovah. Jehovah chides Abraham, "You would not even exist if it were not for me!" "Yes, Lord, that I know," Abraham replies, "but also You would not be known if it were not for me."[36]

In our time the participants in the dialog have changed. They are the universe and man. The universe, in the words of some who would aspire to speak for it, says, "I am a giant machine. I supply the space and time for your existence. There was no before before I came into being, and there will

[36] Thanks are expressed here to Professors Lawrence P. Horwitz, Zvi Kurzweil, Yuval Ne'eman, Asher Peres, Shmuel Sambursky, Lawrence Schulman and Elie Wiesel, each for his part in leading the author to this legend and documenting it, as follows: (i) H. Freedman and M. Simon, translators and eds., *Midrash Rabbah, Genesis I* (Soncino Press, London, 1939), p. 238, commentary on "Noah walked with God": "*The God before whom my fathers Abraham and Isaac did walk*, etc. (Genesis 48:15). R. Berekiah in R. Johanan's name and Resh Lakish gave two illustrations of this. R. Johanan said: It was as if a shepherd stood and watched his flocks. Resh Lakish said: It was as if a prince walked along while the elders preceded him [Footnote: As an escort, to make known his coming. Similarly, Abraham and Isaac walked before God, spreading His knowledge]. On R. Johanan's view: We need His proximity. On the view of Resh Lakish: He needs us to glorify Him [Footnote: By propagating the knowledge of His greatness]." (ii) *Ibid*, p. 357, commentary on, "And he blessed him, and said: blessed be Abram of the God most high, who has acquired [Koneh = maker of] heaven and earth" (Genesis 14:19): "From whom then did He acquire them? — Said R. Abba: [Acquired is attributive,] as one says, So-and-so has [Koneh = in possession of] beautiful eyes and hair. R. Isaac said: Abraham used to entertain wayfarers, and after they had eaten he would say to them, 'Say a blessing.' 'What shall we say?' they asked. 'Blessed be the God of the Universe of Whose bounty we have eaten,' replied he. Then the Holy One, blessed be He, said to him: 'My Name was not known among My creatures, and thou hast made it known among them: I will regard thee as though thou wast associated with Me in the creation of the world'. . . . " (iii) Deuteronomy 32:10: "He found him [Jacob] in a desert land, and in the waste howling wilderness; he led him about, he instructed him, he kept him as the apple of his eye," as commented on in *Sifrei* [analogous to the *Midrash* of (i) and (ii) but contains in addition to the Aggadic or legend of the Midrash the Halakhic or law; ed. in the Holy Land before the end of the 4th century A.D.] §313, "he led him about": "This is related to Genesis 12:1, 'Get thee out of thy country' . . . .; 'he instructed him': . . . . before our father Abraham came into this world it seemed as if the Lord, Blessed Be He, reigned only in Heaven, since it is said, 'The Lord, God of Heaven, which took me from my father's house' (Genesis 24:7). But once *Abraham* had come into the world [= was born], he Abraham [thereby] enthroned Him over Heaven *and Earth*" (translation from the Hebrew by Y. Ne'eman). (iv) Isaiah 43:10: "Ye are my witnesses, saith the Lord, and my servant whom I have chosen; that ye may know and believe me, and understand that I am he: before me there was no God formed, neither shall there be after me."

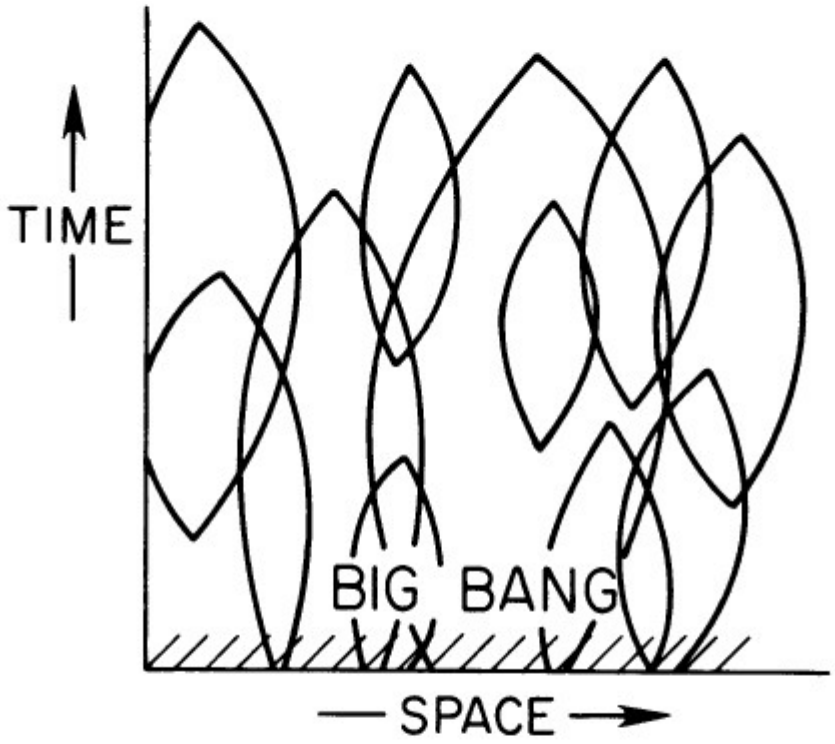

Fig. 8. Symbolic description how all that "has happened" in the past is influenced by choices made in the present as to what to observe. The upper tip of each "leaf" stands for the elementary act of registration. The lower end of each leaf stands for the beginning of the elementary phenomenon being investigated by the observational means at hand. Is anything else required to make up space and time and all their burden of physical content except the information carried in the elementary quantum acts thus symbolized? [Details in the original publication.]

be no after after I cease to exist. You are an unimportant bit of matter located in an unimportant galaxy."

How shall we reply? Shall we say, "Yes, oh universe, without you I would not have been able to come into being. Yet you, great system, are made of phenomena; and every phenomenon rests on an act of observation. You could never even exist without elementary acts of registration such as mine"?

Are elementary quantum phenomena, those untouchable, indivisible acts of creation, indeed the building material of all that is? Beyond particles, beyond fields of force, beyond geometry, beyond space and time themselves, is the ultimate constituent, the still more ethereal act of observer-participancy? For Dr. Samuel Johnson the stone was real enough when he kicked it. The subsequent discovery that the matter in that rock is made of positive and negative electric charges and more than 99.99 per cent empty space does not diminish the pain that it inflicts on one's toe. If the stone is someday revealed to be altogether emptiness, "reality" will be none the worse for the finding.

Roland M. Frye, in reminding us[37] of Shakespeare and of ways of seeing, gives us opportunity to recall those words of almost four hundred years ago,

> And as imagination bodies forth
> The form of things unknown, the poet's pen
> Turns them to shapes, and gives to airy nothing
> A local habitation and a name.

Are billions upon billions of acts of observer-participancy the foundation of everything? We are about as far as we can be today from knowing enough about the deeper machinery of the universe to answer this question. Increasing knowledge about detail has brought an increasing ignorance about plan. The very fact that we can ask such a strange question shows how uncertain we are about the deeper foundations of the quantum and its ultimate implications.

[37] R.M. Frye, "Ways of seeing: unities and disunities in Shakespeare and Elizabethan painting," *infra*, pp.43 ff.

THE QUANTUM: ITS USES — AND ITS USE

To encounter the quantum is to feel like an explorer from a faraway land who has come for the first time upon an automobile. It is obviously meant for use, and an important use, but what use? One opens the door, cranks the window up and down, flashes the lights on and off, and perhaps even turns over the starter, all the time without knowing the central point of the thing. The quantum is the automobile. We use the quantum in a transistor to control machinery, in a molecule to design an anesthetic, in a superconductor to make a magnet. Could it be that all the time we have been missing the central point, the use of the quantum phenomenon in the construction of the universe itself?

We have turned over the starter. We haven't got the engine going.

* * * * *

1. – Law without law.

species will never vary, and have remained the same since the creation of each species.

Charles LYELL [1], writing almost three decades before *The Origin of Species*

[The astronomer Sir John Frederick William] *Herschel says my book is 'the law of higgledy-piggledy'.*

Charles DARWIN [2], 18 days after the November 24, 1859 publication of *The Origin of Species*

Are the laws of physics eternal and immutable? or are these laws, like species, mutable [3] and of « higgledy-piggledy » origin?

The hierarchical speciation of plant and animal life, we now know, arises out of the blind accidents of genetic mutation and natural selection [5, 6]. Likewise the gas laws, the pressure-volume-temperature relation for water and for other substances, and the laws of thermodynamics take their origin in the chaos of molecular collisions. But as for the molecules themselves, the particles of which they are made and the fields of force that couple them, is it conceivable that they too derive their way of action, their structure and even their existence from multitudinous accidents?

Such questions about the « plan » of physics we would hardly raise if we had the skeleton of it in hand. But we don't. Now and then we meet a colleague in another realm of thought who still thinks physics is in possession of this plan. He cites the words of Laplace [7] and reiterates the Laplacean vision as he understands it: the laws are definite, the initial co-ordinates and momenta are definite, and therefore the future is definite. The Universe is a machine.

No, we have to tell him: that is a cracked paradigm. Quantum mechanics allows us to know a co-ordinate, or a momentum, but not both. Of the initial-value data that LAPLACE needed, the principle of complementarity [8] or indeterminacy [9] says half do not and cannot exist.

. . . . . .

You tell me what isn't the plan of physics, our friend rejoins. If you understand quantum mechanics so well, why don't you tell we what *is* the plan of physics?

No one knows, we reply. We have clues, clues most of all in the writings of Bohr [23-25], but no answer. That he did not propose an answer, not philosophize, not go an inch beyond the soundest fullest statement of the inescapable lessons of quantum mechanics, was his way to build a clean pier for some later day's bridge to the future.

What kind of a « plan of physics » do you think BOHR had in mind, our colleague asks. I know Einstein's words [26], « Physics is an attempt to grasp reality as it is thought independently of its being observed ». I know Bohr's reply [28], « These 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 ». But if I could have asked BOHR, how did he think the Universe came into being, and what is its substance, what would he have said?

It is too late to ask. The plan is up to us to find.

The Universe can't be Laplacean. It may be higgledy-piggledy. But have hope. Surely someday we will see the necessity of the quantum in its construction. Would you like a little story along this line?

Of course! About what?

About the game of twenty questions. You recall how it goes—one of the after-dinner party sent out of the living room, the others agreeing on a word, the one fated to be questioner returning and starting his questions. « Is it a living object? » « No. » « Is it here on earth? » « Yes. » So the questions go from respondent to respondent around the room until at length the word emerges: victory if in twenty tries or less; otherwise, defeat.

Then comes the moment when we are fourth to be sent from the room. We are locked out unbelievably long. On finally being readmitted, we find a smile on everyone's face, sign of a joke or a plot. We innocently start our questions. At first the answers come quickly. Then each question begins to take longer in the answering—strange, when the answer itself is only a simple « yes » or « no ». At length, feeling hot on the trail, we ask, « Is the word ' cloud '? » « Yes », comes the reply, and everyone bursts out laughing. When we were out of the room, they explain, they had agreed not to agree in

advance on any word at all. Each one around the circle could respond « yes » or « no » as he pleased to whatever question we put to him. But however he replied he had to have a word in mind compatible with his own reply—and with all the replies that went before. No wonder some of those decisions between « yes » and « no » proved so hard!

And the point of your story?

Compare the game in its two versions with physics in its two formulations, classical and quantum. First, we thought the word already existed « out there » as physics once thought that the position and momentum of the electron existed « out there », independent of any act of observation. Second, in actuality the information about the word was brought into being step by step through the questions we raised, as the information about the electron is brought into being, step by step, by the experiments that the observer chooses to make. Third, if we had chosen to ask different questions we would have ended up with a different word—as the experimenter would have ended up with a different story for the doings of the electron if he had measured different quantities or the same quantities in a different order. Fourth, whatever power we had in bringing the particular word « cloud » into being was partial only. A major part of the selection—unknowing selection—lay in the « yes » or « no » replies of the colleagues around the room. Similarly, the experimenter has some substantial influence on what will happen to the electron by the choice of experiments he will do on it; but he knows there is much unpredictability about what any given one of his measurements will disclose. Fifth, there was a « rule of the game » that required of every participator that his choice of yes or no should be compatible with *some* word. Similarly, there is a consistency about the observations made in physics. One person must be able to tell another in plain language what he finds and the second person must be able to verify the observation.

Go on!

That is difficult! Interesting though our comparison is between the world of physics and the world of the game, there is an important point of difference. The game has few participants and terminates after a few steps. In contrast, the making of observations is a continuing process. Moreover, it is extraordinarily difficult to state sharply and clearly where the community of observer-participators begins and where it ends.

This comparison between the world of quantum observations and the game of twenty questions misses much, but it makes the vital central point. In the real world of quantum physics, *no elementary phenomenon is a phenomenon until it is an observed phenomenon.* In the surprise version of the game no word is a word until that word is promoted to reality by the choice of questions asked and answers given. « Cloud » sitting there waiting to be found as we entered the room? Pure delusion! Momentum, $p_x = 1.4 \cdot 10^{-19}$ gcm s, or position, $x = 0.31 \cdot 10^{-8}$ cm, of the electron waiting to be found as we start to probe the atom? Pure fantasy! MANN may be going too far when he suggests [29] that « ... we are actually bringing about what seems to be happening to us ». However, it is undeniable that each of us, as observer, is also *one* of the participators in bringing « reality » into being.

. . . . . .

To say « no elementary phenomenon is a phenomenon until it is an observed phenomenon » is to make no small change in our traditional view that something has « already happened » before we observe it. The word « cloud », we mistakenly thought, already existed in the room before we « uncovered » it. 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. This is the sense, the limited sense, but the inescapable sense, in which we, here, now, have a part in bringing about that which « had already happened » at a time when no observers existed.

But what about the unbelievably more numerous relict photons that escape our telescope? Surely you do not deny them « reality »?

Of course not; but their « reality » is of a paler and more theoretic hue. The vision of the Universe that is so vivid in our minds is framed by a few iron posts of true observation—themselves also resting on theory for their meaning—but most of the walls and towers in the vision are of papier-maché, plastered in between those posts by an immense labor of imagination and theory. In this labor, « ... we can never neatly separate what we see from what we know ... what we call seeing is invariably coloured and shaped by our knowledge (or belief) of what we see » [61]. « Without some initial system, without a first guess to which we can stick unless it is disproved, we could ... make no 'sense' of the milliards of ambiguous stimuli that reach us from our environment. In order to learn, we must make mistakes ... the simplicity hypothesis cannot be learned. It is ... the only condition under which we could learn at all » [62]. « ... our mind will still react to the challenge of this conundrum [of what we 'see'] by throwing out a random answer, making ready to test it in terms of consistent possible worlds. It is these answers that will transform the ambiguous stimulus pattern into the image of something 'out there' » [63].

What keeps these 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 observership-participancy. That is the importance of Bohr's point that no observation is an observation unless we can communicate the results of that observation to others in plain language [49].

. . . . . .

The only thing harder to understand than a law of statistical origin would be a law that is not of statistical origin, for then there would be no way for it—or its progenitor principles—to come into being. On the other hand, when we view each of the laws of physics—and no laws are more magnificent in scope or better tested—as at bottom statistical in character, then we are at last able to forego the idea of a law that endures from everlasting to everlasting.

Individual events. Events beyond law. Events so numerous and so uncoordinated that, flaunting their freedom from formula, they yet fabricate firm form.

« Fabricate form »? Do you suggest that even the 4-dimensional space-time manifold is only a fabrication, only a theory—irreplaceable convenience though that theory is?

Yes! Compare space-time with cloth. Each it is useful under everyday circumstances to call a manifold. Yet each is exactly then most obviously not a manifold where it comes to an end, whether in the selvedge made by the loom, or in the geodesic terminations made by one of the « gates of time »—big bang or big crunch [31, 32] or black hole [33]. Nowhere more clearly than in the ending of space-time are we warned that time is not an ultimate category in the description of Nature [34].

Aren't you being extreme? I see the lesson of the game of twenty questions. I begin to believe with you that no elementary phenomenon is a phenomenon until it is an observed phenomenon. I accept that events of observer-participancy, as you call them, occupy a special place in the scheme of things. I agree that that word « cloud » was brought into being entirely through such elementary events. But that such events, however numerous, should be the *sole* blocks for building the laws of physics—and space and time themselves—seems to me preposterous. You surely have been involved enough in times past with nuts-and-bolts physics to know the difference between science and poetry; yet if I appreciate the drift of what you say, you might as well be quoting SHAKESPEARE [35],

> ... These our actors,
> As I foretold you, were all spirits and
> Are melted into air, into thin air:
> And, like the baseless fabric of this vision,
> The cloud-capp'd towers, the gorgeous palaces,
> The solemn temples, the great globe itself,
> Yea, all which it inherit, shall dissolve
> And, like this insubstantial pageant faded,
> Leave not a rack behind. We are such stuff
> As dreams are made on ...

I can't believe any such dreamlike vision of the physical world. As Samuel JOHNSON used to say, I have only to kick a stone to find it real enough.

Why do you say « preposterous »? Perhaps SHAKESPEARE understood this universe of ours better than we do ourselves! You have known for years that the atom is more than 99.99 percent emptiness. If matter turns out in the end to be altogether ephemeral, what difference can that make in the pain you feel when you kick the rock? And how can matter—and space-time—be anything but mutable, coming into being at one gate of time and fading out

of existence at the other? No physics before the big bang, or after the big crunch? No! The lesson of Einstein's standard closed-space cosmology is different and stronger. It denies all meaning to such terms as « before the big bang » and « after the big crunch ».

Particles or fields or mathematics won't do for ultimate building blocks. They can't come into being or fade out of existence [30].

Yes, I appreciate the reasons given [36] against believing in any « magic particle » or any « magic field » or [37] any « magic mathematics » as the foundation of physics; but isn't it even more difficult to think of acts of observer-participancy as the magic ingredient?

Difficult, yes; inconceivable, no.

Go on!

No, we have to stop here. It is beyond the power of today to fit together the pieces of the puzzle.

Don't stop! You've carried me halfway into an exciting mystery story. You can't leave me without the traditional half-way-point review of the important clues and first try at a working hypothesis.

Review? A proper review would be impossibly ambitious. And how can one advance a working hypothesis that will not be wrong tomorrow and ridiculous the day after?

I appeal to you to go on. You have told me more than once that science advances only by making all possible mistakes; that the main thing is to make the mistakes as fast as possible—and recognize them. You like to quote the motto of that engine inventor, John KRIS: « Start her up and see why she don't run ». You point to Einstein's definition of a scientist, « An unscrupulous opportunist ». If you believe all this, and are a true colleague of mine, you must go on.

You leave no escape!

Good!

Then let us agree to go on; but let us replace the comprehensive review of clues that you wanted by something more modest. How would it do, for example, to survey some of the lessons we have learned from the study of time, and how those lessons bear on « observer-participancy »?

I accept, and with many thanks. But first tell me the central point as you see it.

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 [5, 6, 38].

When we say « out of nothingness » we do not mean out of the vacuum of physics. The vacuum of physics is loaded with geometrical structure and vacuum fluctuations and virtual pairs of particles. The Universe is already

in existence when we have such a vacuum. No, when we speak of nothingness we mean nothingness: neither structure, nor law, nor plan.

A conception more clearly impossible I never heard!

Preposterous we have to agree is the idea that everything is produced out of nothing—as preposterous, but perhaps also as inescapable, as the view that life had its origin in lifeless matter.

But how?

« Omnibus ex nihil ducendis sufficit unum », LEIBNIZ told us [39]; for producing everything out of nothing one principle is enough. Of all principles that might meet this requirement of Leibniz nothing stands out more strikingly in this era of the quantum than the necessity to draw a line between the observer-participator and the system under view. Without that demarcation it would make no sense to do quantum mechanics, no sense to speak of quantum theory of measurement, no sense to say that « No elementary phenomenon is a phenomenon until it is an observed phenomenon ». The necessity for that line of separation 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.

Let me ask if your reasoning couldn't be turned around. You talk of the observer-participancy of quantum theory as the mechanism for the Universe to come into being. If that is a proper way of speaking, would the converse not also hold: The strange necessity of the quantum as we see it everywhere in the scheme of physics comes from the requirement that—via observer-participancy—the Universe should have a way to come into being?

Your point is exciting indeed. If true—and it is attractive—it should provide someday a means to *derive* quantum mechanics from the requirement that the Universe must have a way to come into being [40].

I know that in that empty courtyard many a game cannot be a game until a line has been drawn—it does not matter where—to separate one side from the other. I know that no Gaussian flux integral can be a flux integral until the 2-surface over which it runs—bumpy and rippled though we make it and deform it as we will—has been extended to closure. But how much arbitrariness is there in this more ethereal kind of demarcation, the line between « system » and « observing device »?

Much arbitrariness! BOHR stresses [42] that the stick we hold can itself be an object of investigation, as when we run our fingers over its surface. The same stick, when grasped firmly and used to explore something else, becomes an extension of the observer or—when we depersonalize—a part of the measuring equipment. As we withdraw the stick from the one role, and recast it in the other role, we transpose the line of demarcation from one end of it to the other. The distinction between the probed and the probe, so evident at this scale of the everyday, is the without-which-nothing of every elementary phenomenon, of every « closed » quantum process.

Do we possess today any mathematical or legalistic formula for what the line is or where it is to be drawn?

No.

Then what is important about this demarcation?

Existence, yes; position, no. It is the mark of an observation to leave an « indelible » record, according to BELINFANTE [43]. WIGNER argues that an observation is only then an observation when it becomes part of « the consciousness of the observer » [44] and points to « the impressions which the observer receives as the basic entities between which quantum mechanics postulates correlations » [45]. 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 » [47]. This act brings the measuring process to a « close » [48]. Only then, he emphasized, is one person able « to describe the result of the measurement to another in plain language » [49]. He 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 » [50].

I would have felt very uncomfortable if BOHR had used the term « consciousness » in defining the elemental act of observation. I would not have known what he meant. However, I am beginning to understand and accept the terms he actually adopts, « brought to a close by an irreversible act of amplification » and « communicable in plain language ». What *was* his position on consciousness?

We have asked Jørgen KALCKAR, who collaborated with BOHR in his last months, and he has kindly replied [51], « During work on the preparation of some lecture, to define the phenomenon of consciousness, BOHR used a phrase somewhat like this: a behaviour so complex that an adequate account would require references to the organism's 'self-awareness'. I objected jokingly that with this definition he would soon have to ascribe a consciousness to the highly developed electronic computers. This did not worry BOHR. 'I am absolutely prepared', said he, 'to talk of the spiritual life of an electronic computer: to state that it is reflecting or that it is in a bad mood .... The question whether the machine *really* feels or ponders, or whether it merely looks as though it did, is of course absolutely meaningless'. »

Other outstanding thinkers have argued otherwise. For them « consciousness » makes an unclimbable difference of principle between even the most powerful imaginable computer and the brain [52].

Do you agree with that argument?

How can we possibly accept such a difference of principle?

Do we not believe that brain function itself will someday be explained entirely in terms of physical chemistry and electrochemical potentials? What escape is there from the reasoning of von Neumann [53] and Bohr and many

active present-day investigators? When one of the three discoverers of the mechanism of supereonductivity today gives us, chapter by chapter and verse by verse, an entirely cellular account of the mechanism of memory [54-56], who can dismiss it?

When a distinguished computer expert and student of the structure of society details, one by one, the distinctions proposed in times past between « consciousness » and the computer, and painstakingly analyzes each down to nothingness [57], what case can anyone possibly maintain for *any* distinction of principle between the computer and the brain?

I am happy not to have to delve today into the term « consciousness ». I find it hard enough to know what to make of « irreversible act of amplification ». Never have I heard of an act of amplification that was not characterized by an amplification factor, or an equivalent quantity: and never an amplification factor that was not a finite number.

Between infinity and a finite number there may be a difference of principle: but between one finite number and another there is only a difference of degree. How big does the grain of silver bromide have to be, or the avalanche of electrons in the Geiger counter, before we count the measuring process as brought to a close by an irreversible act of amplification?

According as I specify one or another number as the critical level of amplification, don't I make all the difference between rating or not rating a given process as an « elementary phenomenon »?

According as the closed Gaussian surface encloses a given elementary charge or not, we find an unmistakable difference in the surface integral of the electric flux. Nevertheless, we know enough about the relevant invariance principle never to question the correctness of always identifying flux with enclosed charge. About « elementary quantum phenomenon » we have not today learned, but have a deep obligation someday to learn, enough to display a similar covariance with respect to where we draw the line. That is what « complementarity » is all about.

Even if neither you nor I know how to define that line, I like the idea that the « game » in the empty courtyard is only then possible when *a* line is drawn. May I question you now about the game itself? How would you describe it if forced to commit yourself?

* * * * *

From "nothingness ruled out as meaningless,"[106] to the line of distinction that rules it out; from this dividing line to "phenomenon"; from one phenomenon to many; from the statistics of many to regularity and structure: these considerations lead us at the end to ask if the universe is not best conceived as a self-excited circuit[107] (Fig. 22.13): Beginning with the big bang, the universe expands and cools. After eons of dynamic development it gives rise to observership. Acts of observer-participancy — via the mechanism of the delayed-choice experiment — in turn give tangible "reality" to the universe not only now but back to the beginning. To speak of the universe as a self-excited circuit is to imply once more a participatory universe.

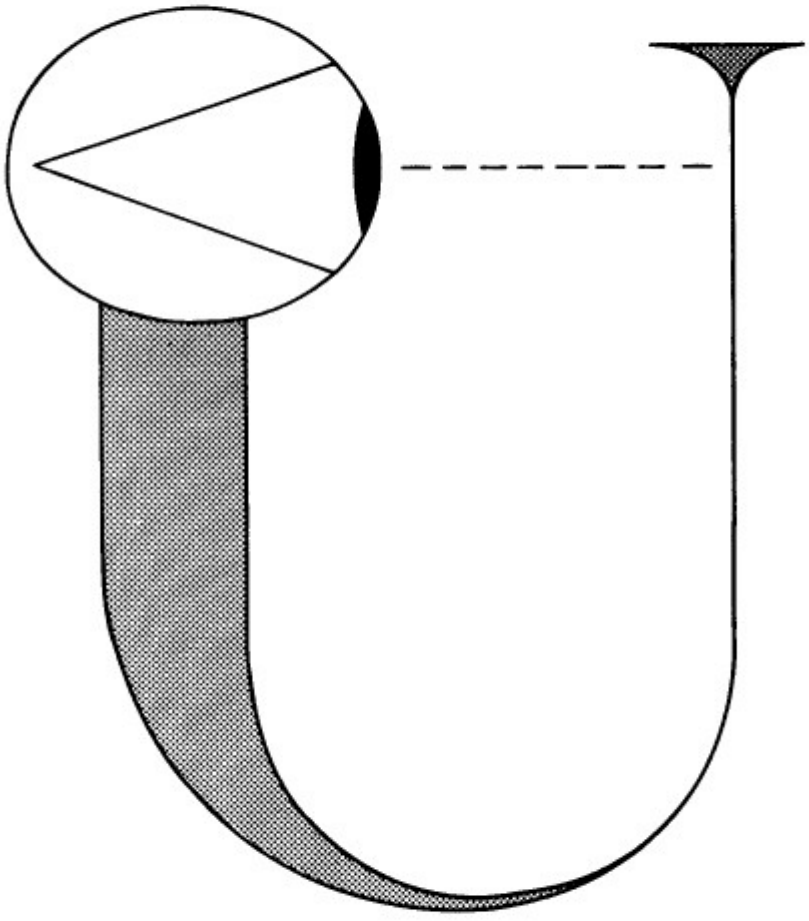

Fig. 22.13 The universe viewed as a self-excited circuit. Starting small (thin U at *upper right*), it grows (loop of U) and in time gives rise (*upper left*) to observer-participancy — which in turn imparts "tangible reality" (cf. the delayed-choice experiment of Fig. 22.9) to even the earliest days of the universe.

[106, 107] See the original publication for these rather long references.

If the views that we are exploring here are correct, one principle, observer-participancy, suffices to build everything. The picture of the participatory universe will flounder, and have to be rejected, if it cannot account for the building of law; and space-time as part of law; and out of law substance. It has no other than a higgledy-piggledy way to build law: out of the statistics of billions upon billions of acts of observer-participancy each of which by itself partakes of utter randomness.

Two Tests

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[108] — as the word "cloud" was brought into being in the surprise version of the game of twenty questions. No prediction lends itself to a more critical test than this, that every law of physics, pushed to the extreme, will be found to be statistical and approximate, not mathematically perfect and precise.

The Challenge of "Law without Law"

We can ask ourselves if it is not absolutely preposterous to put into a formula anything at first sight so vague as law without law and substance without substance. How can we hope to move forward with no solid ground at all under our feet? Then we remember that Einstein had to perform the same miracle. He had to reexpress all of physics in a new language. His curved space seemed to take all definite structure away from anything we can call solidity. In the end physics, after being moved bodily over onto the new underpinnings, shows itself as clear and useful as ever. We have to demand no less here. We have to move the imposing structure of science over onto the foundation of elementary acts of observer-participancy.[109] No one who has lived through the revolutions made in our time by relativity and quantum mechanics — not least through the work of Einstein himself — can doubt the power of theoretical physics to grapple with this still greater challenge.

* * * * *

Recent decades have taught us that physics is a magic window. It shows us the illusion that lies behind reality—and the reality that lies behind illusion. Its scope is immensely greater than we once realized. We are no longer satisfied with insights only into particles, or fields of force, or geometry, or even space and time. Today we demand of physics some understanding of existence itself.

[108] See the original publication for these rather long references.

REFERENCES

[1] C. LYELL: *Principles of Geology, being an attempt to explain the former changes of the earth's surfaces, by reference to cause now in operation*, Vol. II (London, 1830-1833).

[2] C. DARWIN: as quoted in H. WARD: *Darwin: The Man and His Warfare* (Indianapolis, Ind., 1927), p. 297.

[3] J. A. WHEELER: *From relativity to mutability*, in ref. [4], pp. 202-247.

[4] J. MEHRA, editor: *The Physicists' Conception of Nature* (Dordrecht, 1973).

[5] M. EIGEN: *The origin of biological information*, in ref. [4], pp. 594-632.

[6] M. EIGEN and R. WINKLER: *Das Spiel: Naturgesetze steuern den Zufall* (München, 1975).

[7] P. S. LAPLACE: *Essai philosophique sur les probabilités* (Paris, 1814), 2nd edition, pp. 3-4.

[8] N. BOHR: *Das Quantenpostulat und die neuere Entwicklung der Atomistik, Naturwiss.*, **16**, 245-257 (1928).

[9] W. HEISENBERG: *Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik, Zeits. Phys.*, **43**, 172-198 (1927).

[10] J. BURCKHARDT: *Die Kultur der Renaissance in Italien* (Leipzig, 1860); authorized English translation from the 15th edition, by S. G. C. MIDDLEMORE: *The Civilization of the Renaissance in Italy* (New York, N. Y., 1929).

[11] P. GAY: *Style in History* (New York, N. Y., 1974).

[12] H. EVERETT III: *The theory of the universal wave function*, doctoral dissertation, Princeton University (1957); published in abbreviated form in ref. [13]; published in full for the first time in ref. [14].

[13] H. EVERETT III: *« Relative state » formulation of quantum mechanics, Rev. Mod. Phys.*, **29**, 454-462 (1957); reprinted in ref. [14].

[14] B. S. DEWITT and N. GRAHAM, editors: *The Many-Worlds Interpretation of Quantum Mechanics* (Princeton, N. J., 1973).

[15] J. VON NEUMANN: *Mathematischen Grundlagen der Quantenmechanik* (Berlin, 1932); translated as *Mathematical Foundations of Quantum Mechanics* (Princeton, N. J., 1955).

[16] J. A. WHEELER: *Assessment of Everett's « relative state » formulation of quantum mechanics, Rev. Mod. Phys.*, **29**, 463-465 (1974); reprinted in ref. [14].

[17] E. P. WIGNER: *Epistemological perspective on quantum theory*, in *Contemporary Research in the Foundations and Philosophy of Quantum Theory*, edited by C. A. HOOKER (Dordrecht, 1973), pp. 369-385.

[18] E. P. WIGNER: *Remarks on the mind-body question*, in *The Scientist Speculates*, edited by I. J. GOOD (London, 1962), pp. 284-302.

[19] E. P. WIGNER: *Are we machines?*, *Proc. Amer. Phil. Soc.*, **113**, 95-101 (1969).

[20] E. P. WIGNER: *Physics and the explanation of life, Found. Phys.*, **1**, 35-45 (1970).

[21] C. F. VON WEIZSÄCKER: *Classical and quantum decriptions*, in ref. [4], pp. 635-667.

[22] J. A. WHEELER: *Include the observer in the wave function?*, in *Quantum Mechanics, a Half Century Later*, edited by J. LEITE LOPES and M. PATY (Dordrecht, 1977).

[23] N. BOHR: *Atomic Theory and the Description of Nature* (Cambridge, 1934).

[24] N. BOHR: *Atomic Physics and Human Knowledge* (New York, N. Y., 1958).

[25] N. BOHR: *Essays 1958-1962 on Atomic Physics and Human Knovledge* (New York, N. Y., 1963).

[26] A. EINSTEIN: *Autobiological Notes*, in ref. [27], quotation from p. 81.

[27] P. A. SCHILPP, editor: *Albert Einstein: Philosopher-Scientist* (Evanston, Ill., 1949), and subsequent paperback editions elsewhere.

[28] N. BOHR: *Can quantum-mechanical description of physical reality be considered complete?*, *Phys. Rev.*, **48**, 696-702 (1935); the quotation comes from p. 697.

[29] T. MANN: *Freud, Goethe, Wagner* (New York, N. Y., 1937), p. 20; translated by H. T. LOWE-PORTER from *Freud und die Zukunft* (Vienna, 1936); the cited words were included in the lecture given at the 80th birthday celebration for Sigmund FREUD, 8 May 1936.

[30] C. S. PEIRCE: *The Philosophy of Peirce: Selected Writings*, edited by J. BUCHLER (London, 1940); paperback reprint, *Philosophical Writings of Peirce* (New York, N. Y., 1955); « fallibilist », p. 358.

[31] B. K. HARRISON, M. WAKANO and J. A. WHEELER: *Matter-energy at high density; end point of thermonuclear evolution*, in *La structure et l'évolution de l'univers, Onzième conseil de physique Solvay* (Bruxelles, 1958), pp. 124-146; terminology « crushing points », pp. 134-136.

[32] J. R. GOTT III, J. E. GUNN, D. N. SCHRAMM and B. M. TINSLEY: *Will the Universe expand forever*, *Sci. Amer.*, **234**, 62-79 (March 1976); terminology « big crunch », p. 69.

[33] J. A. WHEELER: *Our universe: the known and the unknown*, address before the American Association for the Advancement of Science, New York, December 29, 1967; *Amer. Scholar*, **37**, 248-274 (1968); terminology « black hole », pp. 258-262.

[34] J. A. WHEELER: *Superspace and the nature of quantum geometrodynamics*, in *Battelle Rencontres: 1967 Lectures in Mathematics and Physics*, edited by C. DEWITT and J. A. WHEELER (New York, N. Y., 1968), pp. 242-307; « no before, no after », p. 253.

[35] W. SHAKESPEARE: *The Tempest*, London, about 1610; Prospero in Act IV, Scene I, lines 148-158.

[36] J. A. WHEELER: ref. [3]; no magic particle, no magic field, p. 235.

[37] C. M. PATTON and J. A. WHEELER: *Is physics legislated by cosmogony?*, in *Quantum Gravity*, edited by C. J. ISHAM, R. PENROSE and D. W. SCIAMA (Oxford, 1975); no magic mathematics, pp. 589-591. © Oxford University Press 1975, by permission of Oxford University Press. Appreciation also expressedl to Charles PATTON for permission to quote cited passages.

[38] A. I. OPARIN, editor: *Evolutionary Biochemistry, Proceedings of the V International Congress on Biochemistry* (Moscow, 1961; London, 1963), pp. 12-51.

[39] G. W. LEIBNIZ: source of quotation not traced.

[40] J. A. WHEELER: *Genesis and Observership*, ref. [41], pp. 3-33; see p. 29.

[41] R. E. BUTTS and K. J. HINTIKKA: *Foundational Problems in the Special Sciences* (Dordrecht, 1977).

[42] N. BOHR: ref. [23]; Bohr's stick, p. 99.

[43] F. J. BELINFANTE: *Measurements and Time Reversal in Objective Quantum Theory* (Oxford, 1975); terminology « indelible », p. 39.

[44] E. P. WIGNER: *Are we machines?*, *Proc. Amer. Phil. Soc.*, **113**, 95-101 (1969); quotation from p. 97.

[45] E. P. WIGNER: *The philosophical problem*, in ref. [46], pp. 1-3; quotation from p. 3.

[46] B. D'ESPAGNAT, editor: *Foundations of Quantum Mechanics* (New York, N. Y., 1971).

[47] N. BOHR: ref. [24]; irreversible amplification, p. 88.

[48] N. BOHR: ref. [24]; closed by irreversible amplification, p. 73.

[49] N. BOHR: ref. [25]; plain language, p. 3.

[50] N. BOHR: ref. [25]; unambiguously communicable, pp. 5, 6.

[51] J. KALCKAR: letter to J. A. WHEELER dated June 10, 1977. Appreciation is expressed here to Dr. J. KALCKAR both for the letter and for subsequent permission to quote from it. He adds that he cannot guarantee to have correct wording; and that Bohr's reply, as so often, was a joke with a definite « point »—hence to be taken seriously, but not *quite* seriously.

[52] K. R. POPPER and J. C. ECCLES: *The Self and Its Brain* (Berlin, New York, N. Y., and London, 1977); see especially pp. 207-208, 438-440 and 515.

[53] J. VON NEUMANN: *The Computer and the Brain* (New Haven, Conn., 1958); see especially pp. 60-61.

[54] L. N. COOPER: *A possible organization of animal memory and learning*, in *Nobel Symposium on the Collective Properties of Physical Systems*, edited by B. LUNDQVIST and S. LUNDQVIST (New York, N. Y., 1973), pp. 252-264.

[55] M. M. NASS and L. N. COOPER: *A theory for the development of feature-detecting cells in visual cortex*, *Biol. Cyber.*, **19**, 1-18 (1975).

[56] L. N. COOPER: *A theory for the acquisition of animal memory*, in *Lepton and Hadron Structure (1974 International School of Subnuclear Physics, Erice, Trapani, Sicily: July 14-31, 1974)*, edited by A. ZICHICHI (New York, N. Y., 1975), pp. 808-839.

[57] G. E. PUGH: *On the Origin of Human Values* (New York, N. Y., 1976), chapter « Human values, free will, and the conscious mind »; preprinted in *Zygon*, **11**, 2-24 (1976).

[58] INTERNATIONAL UNION OF PURE AND APPLIED PHYSICS: *Report of the Commission on Symbols, Units and Nomenclature* (Amsterdam, 1948).

[59] J. A. WHEELER: *The « past » and the « delayed-choice » double-slit experiment*, in ref. [60].

[60] A. R. MARLOW, editor: *Mathematical Foundations of Quantum Theory* (New York, N. Y., 1978).

[61] E. H. GOMBRICH: *Art and Illusion: A Study in the Psychology of Pictorial Representation* (Princeton, N. J., 1961), 2nd edition, revised, p. 394. Appreciation is expressed to Prof. E. H. GOMBRICH and Princeton University Press for permission to quote cited passages in the text.

[62] E. H. GOMBRICH: ref. [61], p. 273.

[63] E. H. GOMBRICH: ref. [61], p. 329.

[64] A. EINSTEIN, B. PODOLSKY and N. ROSEN: *Can quantum-mechanical description of physical reality be considered complete?*, *Phys. Rev.*, **47**, 777-780 (1935).

[65] R. M. F. HOUTAPPEL, H. VAN DAM and E. P. WIGNER: *The conceptual basis and use of the geometric invariance principles*, *Rev. Mod. Phys.*, **37**, 595-632 (1965); see especially §§ 4.1-4.5 on pp. 610-616.

[66] C. N. YANG and R. L. MILLS: *Conservation of isotopic spin and isotopic gauge invariance*, *Phys. Rev.*, **96**, 191-195 (1954).

[67] S. HOJMAN, K. KUCHAŘ and C. TEITELBOIM: *New approach to general relativity*, *Nature Phys. Sci.*, **245**, 97-98 (1973).

[68] S. A. HOJMAN, K. KUCHAŘ and C. TEITELBOIM: *Geometrodynamics regained*, *Ann. of Phys.*, **76**, 88-135 (1976).

[69] C. TEITELBOIM: *Surface deformations, space-time structure and gauge invariance*, in *Relativity, Fields, Strings and Gravity: Proceedings of the Second Latin American Symposium on Relativity and Gravitation SILARG II* held in Caracas, December 1975, Universidad Simon Bolivar, edited by C. ARAGONE (Caracas, 1976).

[70] J. E. NELSON and C. TEITELBOIM: *Hamiltonian for the Einstein-Dirac field*, *Phys. Lett.*, **69** B, 81-84 (1977).

[71] J. A. WHEELER: ref. [3]; machinery hidden, pp. 236-240.

[72] J. A. WHEELER: *Beyond the end of time*, Marchon lecture, University of Newcastle Upon Tyne, May 18, 1971, and Nuffield lecture, Cambridge University,