John Archibald Wheeler

Man with Picturesque Imagination

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John Archibald Wheeler was a researcher and teacher par excellence who was responsible for popularizing the theory of general relativity amongst the academics in the United States. This article tries to provide glimpses of his contributions to gravitation as also some of the work of his distinguished students.

John Wheeler, a theoretical physicist par excellence, is best known to the present generation of physics students as the senior author of the mammoth book called *Gravitation*, the other two (younger) authors being his students Charlie Misner and Kip Thorne. If you open this book (hereafter referred to as *MTW*) on any page at random, you will see what I call Wheeler's stamp. This is the property of 'picturesqueness' which applies not only to the diagrams but also to the language. You would find it hard to believe that the writer is describing some intricate idea in relativity.

Though his early research work was in the areas of atomic and nuclear physics, and he was amongst the large group of scientists involved with the making of the atom bomb under the top secret Manhattan Project, in the post-war era, John Wheeler gradually changed his interests to gravitation and relativity. In fact, he is credited with the growth of interest in relativity amongst post-war American physicists. Here we will highlight some of his important contributions in the area of gravitation.

Keywords
Gravitation, quantum physics, action at a distance.

Take the notion of a *black hole*. The discovery of quasars in 1963 was accompanied by theoretical ideas on *gravitational collapse*, which is the inevitable shrinking of a massive object when its internal forces fail to hold in check the inward force of gravity arising from the object's own mass. Hoyle[1] and Fowler, in a classic paper in *Nature* [1] argued that the kinetic energy so generated may eventually be radiated by the quasar. But what happens to the collapsed object? In 1965, in a paper [2] that was to be the precursor to a series of important papers (See [3]), Roger Penrose showed how in general, under the normal states of matter and radiation, collapse to a spacetime singularity is inevitable. And, in such cases, the later stages of collapse are such that they lead to the formation of an event horizon around the collapsing object. If we maintain communication with an observer on the surface of the collapsing object, there will come a stage when no signal from that observer will be receivable once he or she has crossed the event horizon.

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[1] See *Resonance*, Vol.15, No.10, 2010.

It was John Wheeler who found a picturesque name for such a remarkable object: *Black Hole*. It is *black* in the sense that no light can come from it. It is *hole*-like in the sense that all objects in its vicinity are attracted by it and fall into it. The black hole therefore sucks in all objects in its vicinity and by preventing their escape, including that of light, it remains unseen. The minimum that can be said about this remarkable object is thus expressed in Wheeler's two-word phrase "Black Hole". However, there is more to it than that, of course.

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If you open *MTW* on pages 872–875 (the book has 1275 pages!) you will find a modern-day discussion between the Galilean characters Sagredus and Salvatius on *why* a black hole. It describes how the shrinking object that eventually becomes a black hole appears to be getting dimmer and dimmer. The notion of horizon is introduced: the point of no return. We cannot know *by any means* what goes on within it.

Although many readers, including professional relativists find it hard to get at the crucial information that they

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are looking for in MTW – because of its flowery Wheelerian language and meandering description – the book contains a mine of information on gravitation of which black hole is one manifestation. *Wormhole* is another. *Gravitational radiation* another still. Wormhole can be more difficult to relate to in daily life. It is a topological artifact that connects distant regions of spacetime. Thus going through a wormhole (if it exists) may save us time and money (or, even more valuable, gasoline!) in going long distances. Unlike black holes, we cannot as yet claim to have seen wormholes, although they could exist in space. Wheeler had been involved with popularizing this concept. Wormholes, like the time machine, provide material to the science fiction writer.

It was while studying such esoteric objects that Wheeler coined the word "geometrodynamics". This was probably inspired by the well-used word electrodynamics. This latter word has been part of a physicist's vocabulary for a century and a half. Just as it describes a changing electromagnetic field and its dynamical effects, so does geometrodynamics for the gravitational field. The parallelism is not obvious until we 'break open' the tightly-knit Einstein equations and examine combinations of terms in specific groups. Wheeler's geometrodynamics seeks to bridge the gap between two important basic interactions of physics. By examining the parallelism between electrodynamics and relativistic gravitation one may hope to understand the latter better. What is more, the formalism offers some clues towards quantization of gravitation, a hitherto unsolved problem. For example, the work done by Wheeler's students Arnowitt, Deser and Misner on geometrodynamics, often known as the ADM formalism attempts at quantizing gravitation. However, we cannot claim to have quantized gravity this way. Later Wheeler and Bryce deWitt, both relativists with great penchant for calculations combined their efforts to arrive at what is called the Wheeler–deWitt Equation. Like the Schrödinger wave equation, it tries to project how spacetime geometry would change under a quantum regime. Again, as with many other attempts at quantizing gravitation, this approach also does not seem to have progressed much despite its reliance on heavy mathematics. Indeed, a few years back, Bryce confessed to me somewhat bitterly that all that effort spent on quantizing was wasted.

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A somewhat novel interpretation of the field equations of relativity and electromagnetic theory led Wheeler to coin more picturesque phrases such as "charge without charge" and "mass without mass". To understand them, consider the example of an electric field produced by equal and opposite charges. In a typical such configuration, we see the field lines, the so-called lines of force, emerging out of one charge and converging onto the other. Even if we had no means of seeing the charges, we could deduce their existence by looking at where the field lines begin to converge and hence crowd together. The lines would have infinite density at the point charges, which can be identified as singular points. The bunching of field lines in a small region would indicate that a charge is located there. A good analogy is of the flight paths of aircrafts and how they bunch closer near an airport.

Wheeler was a great admirer of Michael Faraday, who had invented the concept of lines of force and the notion of fields built out of them. The above example led him to argue that *we need not have separate existence of charges*. The singularities in the fields would indicate where the charges are. Hence he coined the phrase *charge without charge*. Likewise, when talking about gravitation, solutions like the Schwarzschild solution would indicate the location of the source mass at the spacetime singularity. Thus when one talks of gravitational interaction moving masses around, one could talk of a changing geometry of spacetime in which

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singularities move. Thus we do away with particles acting as sources.

It is debatable if this interpretation simplifies the job of a scientist trying to solve an explicit problem in classical or quantum gravity. However, I cannot but see an ironical transformation of attitude of a great mind behind this nomenclature. For this, a historical flashback is necessary.

In the early 1940s, when John Wheeler was established in Princeton, he had an exceptionally bright graduate student, Richard Feynman. To Feynman he suggested looking at the notion of action at a distance in electrodynamics. The full background of this notion having been discussed by Vasant Natarajan in this issue, I will not repeat the exercise. It was clear that both Wheeler and Feynman were attracted by the Fokker action described by electrically charged particles. This description does away with the notion of fields altogether. Thus the uncountably infinite degrees of freedom of fields are absent in this formalism. As an alternative description of electromagnetic phenomena, this version, *provided it worked well*, could be considered logically more superior since it worked with fewer degrees of freedom. The absorber theory of radiation that Wheeler and Feynman came up with was an intellectual exercise *par excellence*. Indeed, Feynman's PhD thesis contains a persuasive defence of this approach in preference to the normal field theory. On the question of whether light is quantized, he writes:

"…When one attempts to list these phenomena which seem to indicate that light is quantized, the first type of phenomenon which comes to mind are like the photoelectric effect or the Compton effect... . "
– Feynman

> "··· When one attempts to list these phenomena which seem to indicate that light is quantized, the first type of phenomenon which comes to mind are like the photoelectric effect or the Com- pton effect. One is however, struck by the fact that since these phenomena deal with the interaction of light with matter their explanation may lie in the quantum aspects of matter, rather than requiring photons of light··· ."

The Wheeler–Feynman theory as it is called was worked out in 1941 but published in two papers [4,5], numbered II and III which appeared respectively in 1949 and 1945. (In case this numbering does not seem chronological, this may be justified by the acausal spirit behind the theory!) For, as seen in Natarajan's article, advanced as well as retarded interactions play an important role in this theory. Nevertheless, as Feynman tried to manage with particles only, he encountered conceptual and technical difficulties to the extent that he had to abandon the programme of quantizing action at a distance. Rather, he found that the techniques he had developed as alternatives to the formalisms based on Hamiltonians that were available, enabled electrodynamics to be quantized *but only as a field theory*. Thus he felt that the direct particle interaction theory could not be taken any further. This was also a possible reason for his erstwhile mentor Wheeler to talk of mass without mass.

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When I was working with Fred Hoyle in Cambridge, our attention was drawn by Hermann Bondi to the work by Jack Hogarth from Canada then working under the guidance of Bill McCrea in London. Hogarth had found an important lead: namely, the time asymmetry of an expanding universe. By restricting themselves to a static Minkowski universe, which is time symmetric, Wheeler and Feynman had missed the cosmological time asymmetry. He showed that using cosmological models of the big bang type the net effect locally felt is of advanced solutions [6]. The correct retarded effect is found in the steady state model.

Although elegant in concept, Feynman noted that Hogarth's work had some technical defects. To eliminate them and to express action at a distance in an expanding universe, Hoyle and I followed the route that Hogarth had taken. Eventually we managed to satisfy Feynman at the classical level [7]. At a colloquium I gave at Caltech, he agreed that we had a satisfactory resolution of

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the time asymmetry but expressed pessimism that at the quantum level we would have insurmountable difficulties.

Fred and I persisted and in a couple of papers in *Annals of Physics* [8,9] did complete the quantum problem, including such subtle effects as the Lamb shift and the anomalous magnetic moment of the neutron.

Nevertheless Fred and I persisted and in a couple of papers in *Annals of Physics* [8,9] did complete the quantum problem, including such subtle effects as the Lamb shift and the anomalous magnetic moment of the neutron. In 1977 I happened to spend a semester at the University of Texas at Austin at Wheeler's invitation. When I described the details of our work on the Wheeler–Feynman theory, he was impressed. When I asked him if he would now regard fields as redundant, he gave one of his rare smiles and said: "My attitude towards direct particle theory is like that of a converted alcoholic (who hates alcohol more than a normal person). So I continue to believe in fields despite my earlier work against them."

And so I consider the direct particle theory as a case of 'Wheeler without Wheeler'.

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Suggested Reading

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