(*Reprinted from Nature, Vol. 252, No. 5478, pp. 15–17, November 1, 1974*)

Development of general relativity

S. Chandrasekhar*

This article is based on an invited talk given at the 1974 annual meeting of the American Physical Society in Chicago on the occasion of the award of the Dannie Heineman Prize for Mathematical Physics, February 5, 1974. (The substance of this lecture has been published for private circulation in the Summer 1974 issue of The University of Chicago Magazine.)

In an invited talk at a meeting of this society which Freeman Dyson gave nine years ago[1], he described the history of the development of the general theory of relativity in the following terms:

"Einstein's theory of gravitation took the world by storm in 1919 for two reasons. In the first place, there was the dramatic prediction of the displacement of star-images by the Sun's gravitational field, the organisation of eclipse expeditions to Brazil and Africa to make the very difficult observations that could test the theory, and the clearly positive outcome of the test. In the second place, there was the appealing philosophical character of the Einstein theory, starting with the postulate of a space-time continuum without any special framework of coordinates to label points of space-time with numbers, so that all the laws of physics should be statements which are true in any possible coordinate system.

To Einstein himself and to many other physicists of the 1920s, including Hermann Weyl and the youthful Pauli, it appeared that this beautiful and successful gravitation theory must be the model for the future development of physics. They expected that further extension of the two principles of Einstein, firstly the representation of physical reality as geometrical in nature, and secondly the insistence on general coordinate invariance, would lead to understanding of electromagnetism and of matter, the chief phenomena that remained outside Einstein's original theory. As is well known, these expectations proved false. The theory of matter and electromagnetism took a totally different direction with the advent of quantum mechanics in 1925. Everybody involved in the development of quantum mechanics forgot rather quickly about gravitation and assumed special coordinate systems without apology. Meanwhile the study of gravitation itself lost interest for physicists because nobody could think of any new observations or experiments. So the theory of gravitation gradually became detached from the rest of physics and was studied only by specialists."

Complementary to Dyson's last statement that the general theory of relativity lost its interest to the physicist because "one could not think of any new observations or experiments" is the statement, which one often hears now, that the renewed interest in general relativity during the 1960s is due to the emergence of new astronomical observations and new planned experiments bearing on the theory. I shall not presume to disagree with these statements. But I must confess that it is not clear to me why some very obvious questions were not asked of general relativity until fairly recently: questions whose answers could well have contributed to an understanding of the theory itself as distinct from its bearing on possible observations or experiments.

I shall illustrate by some examples the kinds of questions that might have been asked.

Orbit of Mercury

One of the first accomplishments of the general theory of relativity was to show that the trajectory of a test particle in the gravitational field of a central mass is a Kepler ellipse which precesses. The agreement of this predicted precession with that observed for the planet Mercury demonstrated that the theory had successfully met one of Einstein's three crucial tests. The comparison that was made is proper since the approximation of considering Mercury as an infinitesimal test particle in the gravitational field solely of the Sun is an extremely good one. It is well known, however, that in the framework of the Newtonian theory, two finite spherical masses will also describe Kepler ellipses, exactly, about their common centre of mass. On this account, it would be natural to expect that in the framework of general relativity these Kepler ellipses will, in a first non-trivial approximation to the theory, also precess; and, further, that the precession will be given by the same formula that is applicable to the case of an infinitesimal test particle except for the difference that the mass of the central body is replaced by some reduced mass. If these expectations should be justified, then their establishment in the framework of the theory cannot be very difficult. Nevertheless, only twenty years after the founding of the theory was the question asked and its solution attempted by Eddington and Clark, Einstein, Infeld, and Hoffmann, and Fock, independently.

Gravitational radiation

Let me consider a second example. The principal reason why Einstein felt compelled to develop his general theory was, of course, the fact that the Newtonian theory is based on instantaneous action at a distance—a proposition that is contrary to the tenets of special relativity. On the general theory, gravitational forces are propagated with the velocity of light, and as a consequence it would be natural if the theory predicted the emission and propagation of gravitational waves by systems that are nonstationary. Simple considerations of a semi-heuristic nature show, as Einstein in fact showed in 1918, that on a linearised version of the theory, gravitational radiation will be emitted by systems that are nonstationary; that such radiation will have a quadrupole character; and finally that the flux of such radiation will be proportional to the square of the third time derivative of the quadrupole moment of the system. Nevertheless, for some forty years serious theoretical doubts were entertained with regard to the reality of the predicted radiation. For example, in the Born–Einstein letters that have recently been published[2] there is an undated letter

*Enrico Fermi Institute, University of Chicago, 933 East 56th Street, Chicago, Illinois 60637.