Relativistic Theories of GRAVITATION

The international conference on relativity which is reviewed in these pages was held from July 25 to 31, 1962, in Warsaw, Poland, under the sponsorship of the International Union of Pure and Applied Physics and the Polish Academy of Sciences.

*By **I. Robinson, A. Schild, and E. Schucking***

IT was already past midnight when the Penroses' Peugeot reached the outskirts of Warsaw. Unable to find our way to the Grand Hotel, where relativists from many countries were to stay, we searched the deserted streets for a pilot who could give us directions in some western language. A lone student of Warsaw University on his way home was the man we had been looking for. He pointed to the gigantic building in the dark, illuminated by red lights: "You go this way to the Palace of Culture," and then added thoughtfully: "By the way, do you know the answer to this: Why does one have the finest view of Warsaw from the top of the Palace of Culture?" He paused for a moment, got no reaction, and went on: "It's easy, that is the only point in Warsaw where you don't see the Palace of Culture."

This is an old joke, but behind the curtain that now divides the world it was an amiable critical reflection of the keen international spirit of Warsaw. The open-minded atmosphere of a great European capital gave us its first charming touch.

The next morning, July 25th, theoreticians from many countries squeezed into the rows of narrow seats of the Sala Lustrzana of Warsaw's Pałac Staszica for the opening session. Leopold Infeld, former collaborator of Einstein, now director of one of the world's foremost centers for research in relativity theory, was the organizer of this meeting. With the help of his many excellent coworkers, including the brilliant Andrzej Trautman, he opened a conference which turned out to be extremely well organized. Many new faces have appeared among the experts since the first of the relativity conferences began seven years ago in Berne. Dirac, Feynman, Mandelstam, Møller, Wheeler, and others known for their work in quantum mechanics and in field theory, showed by their presence that research in gravitation has gained new momentum and is beginning to attract some of the most fertile minds in physics. Ginzburg, the distinguished astrophysicist, was the only representative of the famous school of Landau and Lifshitz.

It was no coincidence that physicists whose excellent English had a slight Polish accent predominated in the crowd. They were the students of Leopold Infeld, who returned to Poland in 1950 to lead a renaissance of physics unparalleled since the days of Copernicus. Many have had part of their postdoctoral education in the US or England and have returned to Poland to fill the gap created by the Nazi murders.

The problems discussed at the Warsaw conference can be loosely classified into three groups: experimental verification, quantization, and the study of the classical theory of general relativity.

Since 1919, when Eddington's and Crommelin's solar-eclipse expeditions to Principe and Sobral verified the bending of light predicted by Einstein's theory of general relativity of 1915, this theory has been the accepted theory of gravitation, superseding Newton's theory of 1687. Now, general relativity is the only complete theory of gravitation which agrees with all the facts known today—yet it occupies a peculiar position in our knowledge of the physical world. This is due to

The authors of this report are I. Robinson of the Southwest Center for Advanced Studies in Dallas, Texas, and A. Schild and E. Schucking of the University of Texas, Austin.

J. L. Synge (Dublin)

two facts: the weakness of gravitational interactions on the one hand, and, on the other, the qualitative difference between general relativity theory and other field theories.

On the scale of elementary particles, the gravitational force between the masses of two electrons is about 10^{-40} times the electrostatic force between their charges. On the astronomical scale, ranging from stellar to galactic dimensions, Newtonian theory gives an excellent approximation, and the specific new effects of general relativity are very small and difficult to measure. Even special relativity is unnecessary.

Gravitation is a universal force. To the best of our knowledge, every system of matter and energy is affected by gravitation and affected the same way in the sense that, loosely speaking, all gravitational effects can be eliminated locally by going into free fall. Einstein's theory of general relativity builds this fact of universal gravitation into its very foundation by eliminating the gravitational field altogether and replacing it by the geometry of space and time, the theory of physical measurements of length and time. It is this abrupt qualitative change in our picture of nature which suggests the possibility that general relativity need not be relegated to the role of merely providing small corrections to Newtonian gravitational theory.

The theory of general relativity is very poorly confirmed by experiment and observation, especially when contrasted with the large number of accurate confirmations of the two other new physical theories of this century, special relativity and quantum mechanics. However, the situation has improved over the past few years. Dicke is repeating the important Eötvös experiments and already has achieved an improvement in accuracy of some two orders of magnitude. Pound and Rebka have confirmed the gravitational red shift in a terrestrial laboratory experiment; they have achieved an accuracy of a few percent and hope to improve this considerably. Other experiments, using satellites and perhaps astronomical observations from outside our atmosphere, are on the verge of becoming technologically feasible.

V. L. Ginzburg gave a lucid review of the present state of the experimental verification of general relativity theory and a discussion of other possible experiments, including the effects of the

D. Ivanenko (Moscow) and I. Robinson (Dallas)

Seated in the front row during a session of the conference are, left to right: Leopold Infeld (Warsaw), A. Lichnerowicz (Paris), S. Deser and R. Arnowitt (Waltham), V. A. Fock (Leningrad), and P. A. M. Dirac (Cambridge).

rotation of the sun and the earth on the orbits of planets and satellites. L. I. Schiff discussed a proposed satellite experiment in which the precession of a torque-free gyroscope is measured; both special relativity (Thomas precession) and general relativity (curvature of space-time) contribute to this effect. Nordsiek and Fairbank are considering performing the gyroscope experiment; there are great technical difficulties, but it seems to be on the verge of the possible. J. Weber described a detector which he has built to observe gravitational radiation, provided such radiation is present in a suitable frequency range and in sufficiently high intensity.

A field which interacts with a quantized field should be itself quantized; otherwise the description of the combined system may not be self-consistent. Therefore, the gravitational field should be quantized in principle. The question arises why gravitation need be quantized in practice, since on the small scale where quantum effects become important, gravitational effects are numerically negligible. It is here that the qualitative difference between gravitation and other fields comes in. A quantum state of a system can be roughly visualized as a smeared-out classical configuration, a superposition of many sharp configurations with a probability amplitude attached to each. When the gravitational field is quantized, it is the metric structure of space-time that becomes smeared out, and with it the light cone. This smearing out of the light cone may well play an important role in quantum field theory in spite of the numerical weakness of the gravitational forces. In the past ten years, work on the quantization of gravitation has been carried out, notably by Bergmann and his coworkers and by Dirac.

R. P. Feynman reported the present state of a vigorous attack on the problem of quantization by means of the standard methods of perturbation the-

V. L. Ginzburg (Moscow)

J. A. Wheeler (Princeton) and R. Penrose (Austin)

ory. S. Mandelstam proposed an interesting scheme for the coordinate-independent quantization of the gravitational field by using field variables which are functionals of paths rather than functions of points in space-time. B. DeWitt and A. Lichnerowicz discussed the technical problems of dealing with propagators or Green's functions in curved space-time.

In the opening paper of the conference, J. L. Synge described the relativistic interpretation and modification of Newtonian models. The ideas of energy and momentum, which are so well understood in most parts of physics that we tend to regard them as features of reality itself rather than theoretical constructs, are by no means so simple in general relativity. Papers on this subject were presented by V. A. Fock, C. Møller, J. Plebański, and N. Rosen. At Berne, seven years ago, gravitational radiation would have been neglected entirely but for the contribution of Einstein's collaborator Nathan Rosen. At this conference, H. Bondi, C. Misner, I. Robinson, R. K. Sachs, and A. Trautman gave some account of the current state of the art. Even these talks, however, could not reflect adequately the tremendous progress made in this field during the past six years. Felix Pirani, one of the pioneers, was greatly missed both at this session and at the concluding banquet.

The largest number of papers were classical. Apart from the topics already mentioned, P. G. Bergmann reported on the asymptotic properties of gravitating systems, P. A. M. Dirac on the motion of an extended particle in a gravitational field, and J. A. Wheeler on Mach's principle.

It is remarkable that, among the many short papers, there was only one on unified field theory, which for so many years had first place in Einstein's thoughts. Interest in this approach has declined steadily over the years. Another important subject hardly touched at the conference was the theory of motion. Infeld and his pupils, who are the world's leaders in this field, had, with a modesty uncommon among savants, omitted their own specialty from the agenda. Cosmology too was poorly represented, but this was due to lack of time. The omission may be rectified by the conference planned for the coming winter at the Southwest Center for Advanced Studies in Dallas, Texas.

Peter Bergmann, benign father-figure of the American relativists, presented the concluding report. After a masterly summary of the scientific proceedings, he went on to say: "I believe that I speak in the name of all participants from outside Poland, if I express our gratitude for having been shown a country that is beautiful by nature and which has been the seat of a culture that has left its mark over the centuries. I myself am a native of Europe, though I have spent more than half of my life in the United States; every time I come to a really beautiful old European city, it is a new emotional experience, and Warsaw is no exception; it is a very beautiful city, and so are the surroundings that we were shown on some of the excursions. Warsaw is different from many other cities in that it has become ravaged by war, not in what might legitimately be called military action, but in a wanton and calculated destruction of people and of cultural values. It would be an insult to earlier epochs of humanity to call that barbarism. This is bestiality, and it is not a very reassuring experience to see what can be done, but I believe it is an experience that we must go through, and we have to thank our hosts also for having given us this experience, even if it was not enjoyable."