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TRAUTMAN A.: EINSTEIN AND THE GEOMETRIZATION OF PHYSICS.

Summary

1. The search for a geometric and unified theory of physical fields occupied a major place in the scientific activity of Albert Einstein. Shortly after the general theory of relativity had been formulated /1915/, Hermann Weyl put forward a geometric model of gravitational and electromagnetic forces /1918/. Einstein criticized /1921/ the extension of Riemannian geometry proposed by Weyl, but he became fascinated with the idea of building a unified theory, providing a description of electromagnetic and gravitational fields in terms of differential geometry.

2. Einstein's programme of constructing a unified theory has been often, and sometimes sharply, criticized by physicists. Einstein was accused of having ignored the growth of physics after 1935, when it became clear that there exist in nature fundamental interactions other than gravitational and electromagnetic forces.

3. The development of physics in recent years throws a new light on the idea of geometrizing physics. It seems that all fundamental interactions exhibit similarities that are most easily perceived and described in the language of differential geometry. There is a prospect for achieving a unification of weak and electromagnetic interactions /the Weinberg-Salam theory/.

4. The original "Einstein Programme" of unifying physics can be summarized as follows:

- construct a theory of a classical geometric field without sources;
- unify the basic variables of gravitation and electromagnetism into one geometric object;
- obtain unified field equations from a variational principle;
- describe charged particles as sourceless solutions and derive their motion from the field equations.

Einstein hoped that fundamental properties of elementary particles and their apparent quantum behaviour could also be somehow explained on the bassis of a geometric, classical and unified theory.

5. The relativistic theory of gravitation is based on two fundamental geometric objects: a metric tensor and a linear connection. The metric is needed to measure distances, time intervals, relative velocities and angles. Based on the notion of parallel transport, due to Levi-Civita, the connection is a somewhat subtler concept needed to compare directions, forces and fields at points separated in space and time.

6. It turns out that the idea of a connection has a significance which goes well beyond the theory of gravitation. The potential of an electromagnetic field plays a role in comparing the phases of wave functions of charged particles at different points. This leads to the important idea of a gauge field. Generalized by Yang and Mills to more complicated "phase factors" which can change by means of transformations belonging to a non-Abelian group, gauge fields have become the most promising candidate to provide a geometric description of physics. From the point of view of mathematics, they are connections on principal fibre bundles.

7. Gauge theories attract much attention because they are renormalizable. Moreover, the non-Abelian theories allow a spontaneous breaking of symmetries that leads to massive vector particles, needed to describe the short-range character of nuclear forces.

8. If the current views are confirmed, then the four fundamental interactions that /probably/ underly all physical phenomena will allow a description by means of gauge fields - - or, equivalently, connections - associated with Lie groups. In the case of gravitation, the Lorentz group plays the fundamental role, the Weinberg-Salam theory is based on U (1) x SU (2), whereas the current model of strong interactions /quantum chromodynamics/ is based on SU (3).

9. If the future development of physics confirms the hopes physicists now associate with gauge fields, then connections on principal bundles will provide the key to a geometrization of physics close in spirit, if not in detail, to Einstein's dream.