KALUZA-KLEIN: THE KOENIGSBERG CONNECTION

By DIETRICK E. THOMSEN

Kaluza and Klein had no idea what they were starting when they worked on a theory of electromagnetism as the fifth dimension. But how could they have? That was 60 years ago and it is now, in the 1980s, that Kaluza-Klein theories have become the Gucci and Pucci of theoretical physics, the latest thing among those who are trying to relate particle physics to cosmological questions.

Such rediscoveries of old ideas are not new in theoretical physics. In the 1880s and 1890s Marius Sophus Lie, a Norwegian mathematician, worked out the characteristics of the transformation groups that bear his name. They deal with the possible permutations of geometric figures and were of interest mainly to geometers and topologists. In the 1960s they began to explain all sorts of things in particle physics. Part of being a model of a modern mathematical physicist seems to be browsing in the archives.

More to the present point, an Israeli professor who studied under Kaluza in the 1920s at the University of Koenigsberg in East Prussia (now Kaliningrad in the USSR) remembers that he was the only student in the class Kaluza gave on tensor analysis. Today tensor analysis is basic to all kinds of physics; then it was still pretty much abstract mathematical analysis. What must have been more important to Kaluza is that he was then a *Privat-Dozent*, a tutor paid according to the fees paid by his students, not a professor on regular salary.

Poor Theodor Kaluza! He was something of a "failed" mathematician. Commentators are not sure whether he was Polish or German. If Polish, the name is pronounced Kah-luh'-za; if German, Kah-lu'-tsa. Both pronounciations are heard. The most memorable thing he seems to have done is to take Einstein's theory of general relativity, which showed so neatly that gravity is an artifact of the geometry of spacetime, and add a fifth dimension by which he could show that electromagnetism, the other kind of force known to physicists in those days, was likewise an artifact of geometry. However, there doesn't seem to be a fifth dimension, so the idea became one of those clever mathematical things that is published and put away on a shelf.

Oskar Klein, a Swedish physicist, was famous for a number of important contributions and so will not get equal space here. He solved the difficulty of nonperception of the extra dimension by saying: Suppose there is a fifth dimension, only it is curved so tightly that anything that moved in that direction would return to its starting point after traveling only a microscopic distance. We are much too big to perceive anything like that. But the idea doesn't seem to have gone very far at the time (1926). Unified field theory, the attempt to unify all of physics in a single connected theory, which had inspired Kaluza to propose the fifth dimension, had become dormant.

Today unified field theory is all the rage, and Kaluza's name (evermore coupled with Klein's) is heard wherever advanced theoretical physicists gather. Probably the first to pick up on Kaluza-Klein in recent years were the people involved in trying to quantize general relativity. Einstein gave us a theory that takes no notice of the quantization characteristic of the subatomic world. For atoms and smaller things, energy and other important quantities change in finite increments rather than continuously and infinitesimally as they do (or seem to do) in the macroscopic world. General relativity works well in the macrocosm, but to be valid for all of physics it has to be quantized somehow. Those working on the problem began to find that Kaluza-Klein theories, extended beyond five dimensions to eight, 10, or 12, were quite helpful. In fact it turns out that in the earliest moments of the cosmos the extra dimensions attain a crucial and very weird-looking importance (SN: 7/23/83, p. 60; 9/3/83, p. 152).

Meanwhile, particle physicists were pursuing the unification of all of their branch of physics into one theory (in preparation for uniting it with all the rest). As they did so, they came in theory to realms of higher and higher energy. Such energies are beyond what can ever be supplied by accelerating machines in laboratories. They exist or existed only in astrophysics and cosmology. So particle physicists became cosmologists.

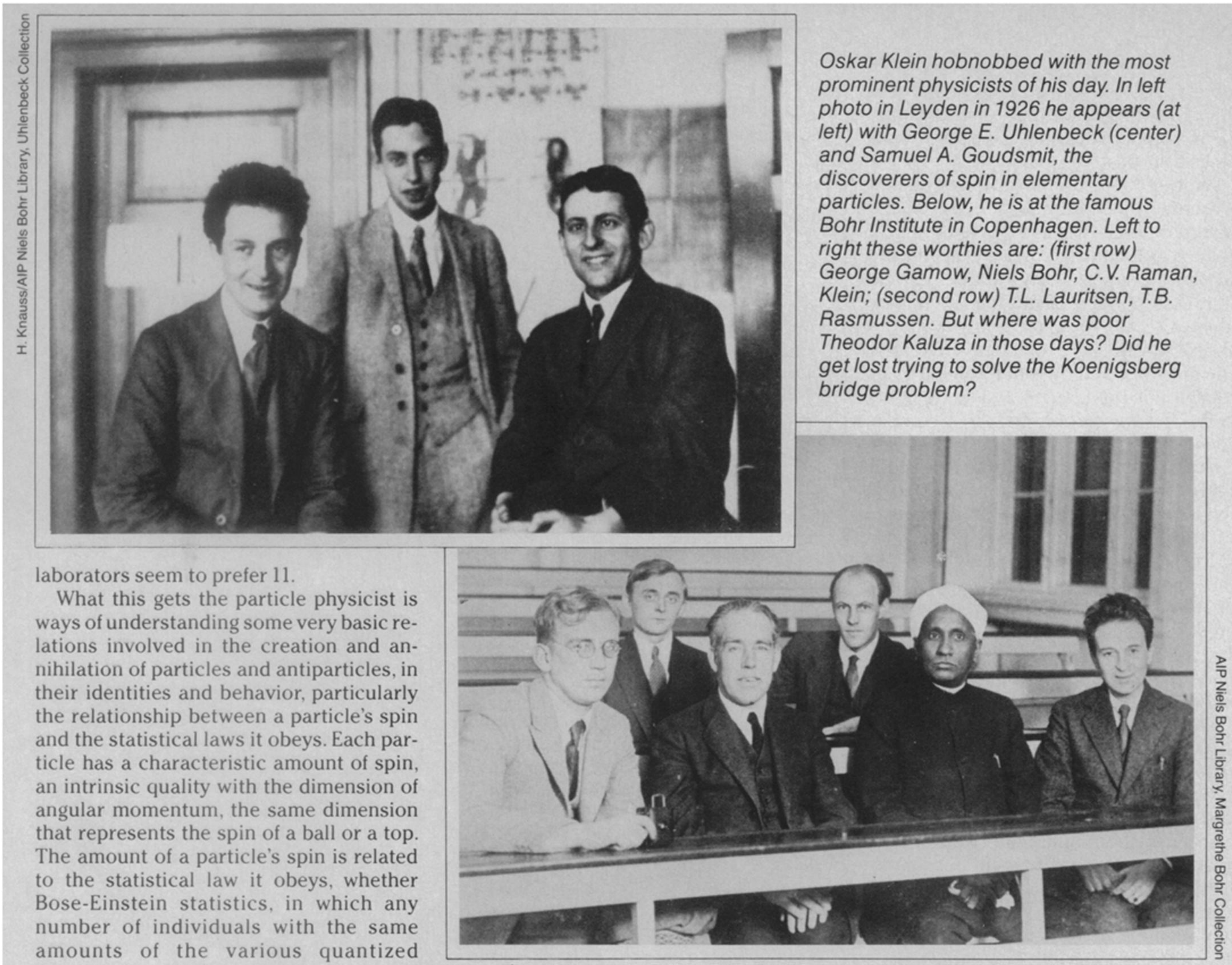
One part of this movement was to pick up on Kaluza-Klein theories for reasons partly their own and partly the same as those of the gravity quantizers, who, of course, had always been interested in cosmology.

Physicists who come to Kaluza-Klein from both directions spoke at the recent Inner Space/Outer Space meeting held at Fermilab in Batavia, Ill. In an invited paper that in fact was the ceremonial close of the conference, Steven Weinberg of the University of Texas at Austin summarized what Kaluza-Klein can do for particle physics. Weinberg shared a Nobel prize for his contribution to the present state of unification of particle physics, an effort that was based on finding Lie groups that can contain larger and larger collections of phenomena and relate them all to one another in a satisfyingly consistent way. Now he and those who collaborate with him and follow him are taking their Lie groups into the many dimensioned world of Kaluza-Klein, where they are sure to meet the gravity quantizers coming around from the opposite direction with many of the same Lie groups.

Weinberg's first reason why Kaluza-Klein is useful to particle physicists is that it helps them to make sense of the basic properties of the particles and of the coupling constants that measure the relative strengths of the different kinds of forces found in nature. That means there is a possibility of explaining basic facts of particle physics that previously had to be considered as givens that Mother Nature just threw in.

To get such neat results, one must of course face the problem common to all users of Kaluza-Klein: How many dimensions are best? Several of the gravity quantizers have opted for even numbers for reasons related to their purposes. Indeed at the meeting Peter Freund of the University of Chicago may have won whatever prize there may be for most dimensions by proposing 950. (Due to geometric identities of one kind and another, the 950 can be reduced to 26, but this is still a formidable number.) For particle physics purposes it seems an odd number is needed. Weinberg and col-

A concept of compactified curved dimensions confronts cosmologists and particle physicists who consider it convenient for quantification



Oskar Klein hobnobbed with the most prominent physicists of his day. In left photo in Leyden in 1926 he appears (at left) with George E. Uhlenbeck (center) and Samuel A. Goudsmit, the discoverers of spin in elementary particles. Below, he is at the famous Bohr Institute in Copenhagen. Left to right these worthies are: (first row) George Gamow, Niels Bohr, C.V. Raman, Klein; (second row) T.L. Lauritsen, T.B. Rasmussen. But where was poor Theodor Kaluza in those days? Did he get lost trying to solve the Koenigsberg bridge problem?

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laborators seem to prefer 11.

What this gets the particle physicist is ways of understanding some very basic relations involved in the creation and annihilation of particles and antiparticles, in their identities and behavior, particularly the relationship between a particle's spin and the statistical laws it obeys. Each particle has a characteristic amount of spin, an intrinsic quality with the dimension of angular momentum, the same dimension that represents the spin of a ball or a top. The amount of a particle's spin is related to the statistical law it obeys, whether Bose-Einstein statistics, in which any number of individuals with the same amounts of the various quantized properties can be in the same place at the same time, or Fermi-Dirac statistics, in which there are limits to the number of individuals with the same amounts that can be in the same place at the same time. As an example of the importance of such questions, Fermi-Dirac statistics make possible atoms and all larger structures, as they force electrons to stay in their appointed shells. If electrons obeyed Bose-Einstein statistics, atoms would collapse.

The reason for these spin-statistics relationships and their connection to the identities of particles and antiparticles and the behavior permitted to the different varieties have often seemed mysterious. Weinberg says the extra dimensions of Kaluza-Klein can provide ways of understanding how they come about. But he points out already a surprise: In more than four dimensions, particle and antiparticle do not always have the same spin, as they always do in four dimensions. That will take some understanding in itself.

Also, Weinberg says, Kaluza-Klein may give means for calculating "from first principles" certain fundamental constants that it has seemed up to now that Nature just threw in. For example, electric charge is quantized. The amount of charge on the electron is the least there can be, and all other charges are integral multiples of that amount. Why is charge quantized and why in that amount? The compactification of the extra dimensions gives physicists a geometric reason why things are quantized — the rolling up of the dimensions into a ball of a particular size implies that various properties of matter will be quantized — and the size of that ball, the compactification length or compactification parameter, gives a measure for calculating the sizes of the quanta and of the gauge coupling constants, the numbers that relate the strengths of different kinds of force to each other.

We see in nature four different kinds of force: gravitational, electromagnetic, strong or chromodynamic, and weak. They do not all attract the same objects, and each obeys a different dynamical law from the others. One of the goals of unification is to show that all four are manifestations of a single underlying principle (and the geometry of spacetime, incidentally, has always seemed a good place to look for that principle). The four kinds of force have different relative strengths (when they happen to be pulling on the same object). The gauge coupling constants measure these differences, and they have seemed up to now to be things Nature just hit upon. Now there may be a way of understanding why they are what they are.

Weinberg's second reason for liking Kaluza-Klein is that maybe we do really live in a world of more than four dimensions. As he remarks, people who use Kaluza-Klein theories are usually noncommittal about whether the extra dimensions are physically real or merely mathematical artifacts useful for understanding what is physically real. However, several of the others who spoke about Kaluza-Klein theories at the meeting tended to talk as if the dimensions were real.

In this view the universe would have started out multidimensional. At some point early in history, a spontaneous compactification would have occurred, a rolling up of the extra dimensions that abruptly takes place because it is in the nature of the universe for it to happen just then. This procedure would determine the nature and values of all the quantized things that Weinberg and others are so interested in, and it could do a couple of other things.

According to Malcolm S. Perry of Princeton University, it could make magnetic monopoles. Monopoles are bodies that carry either a north or south magnetic pole alone, not both together as all ordinary magnets do. Monopoles have been much discussed lately, but usually they are the ones predicted in the so-called grand unified theories (GUTs) (SN: 11/27/82, p. 348). Kaluza-Klein monopoles could be distinguished from GUT monopoles, Perry says, so maybe someday, if we ever find monopoles, we will be able to tell from their properties whether such a Kaluza-Klein compactification happened sometime in the past.

Another Kaluza-Klein curiosity, this one presented by Edward W. "Rocky" Kolb of Fermilab and Richard Slansky of Los Alamos National Laboratory, is the production of supermassive stable particles known as pyrgons (from the Greek word "pyrgos" [πυργος], meaning ladder or tower) at the time of compactification. The mass of a pyrgon is determined by the compactification length and the temperature of the universe at the time of compactification.

Unfortunately in many theories of this kind, the number of pyrgons in the universe comes out equal to the number of photons. This would be acceptable in the universe as now observed only if the pyrgon mass was very small, less than 100 electron-volts. Otherwise the universe would have suffered a pyrgon catastrophe; the total mass of pyrgons would have made the universe curl up and die a premature death.

The universe has manifestly not done so, yet the mass of a pyrgon is more likely to be something like a million billion electron-volts (or a million times that of a proton). The only way to get rid of the pyrgons is to have them annihilate with antipyrgons. Kolb and Slansky point out that the details of Kaluza-Klein theories must be adjusted to permit the proper number of annihilations to get out of the dilemma. Nevertheless some pyrgons would remain, and they could become another candidate for the dark matter that astrophysicists believe dominates the universe (SN: 6/23/84, p.396).

Motohiko Yoshimura of the KEK laboratory in Tsukuba, Japan, proposes a bouncing universe as a result of Kaluza-Klein beginnings. The universe expands, contracts, expands again, contracts again, etc. Like a bouncing ball, however, each expansion is less than the previous, so that over eons, the universe dribbles away to... whatever.

As Weinberg reminded his audience, solving one problem in physics usually opens others. With Kaluza-Klein theories physicists still have the problem of finding just the relationships and hierarchies of particles and all the relationships and particles that the actual universe seems to hold. It may be necessary to meld other theoretical approaches together with Kaluza-Klein to get them. Problems come and problems go.

Perhaps Kaluza was neither a Pole nor a German, but of the Slavic people known as Kashubians. In that case it might be apropos to quote the old Kashubian grandmother in Günter Grass's novel *The Tin Drum*. She said something to the effect that the Germans come and the Germans go, the Poles come and the Poles go, but we Kashubians just stay. □

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