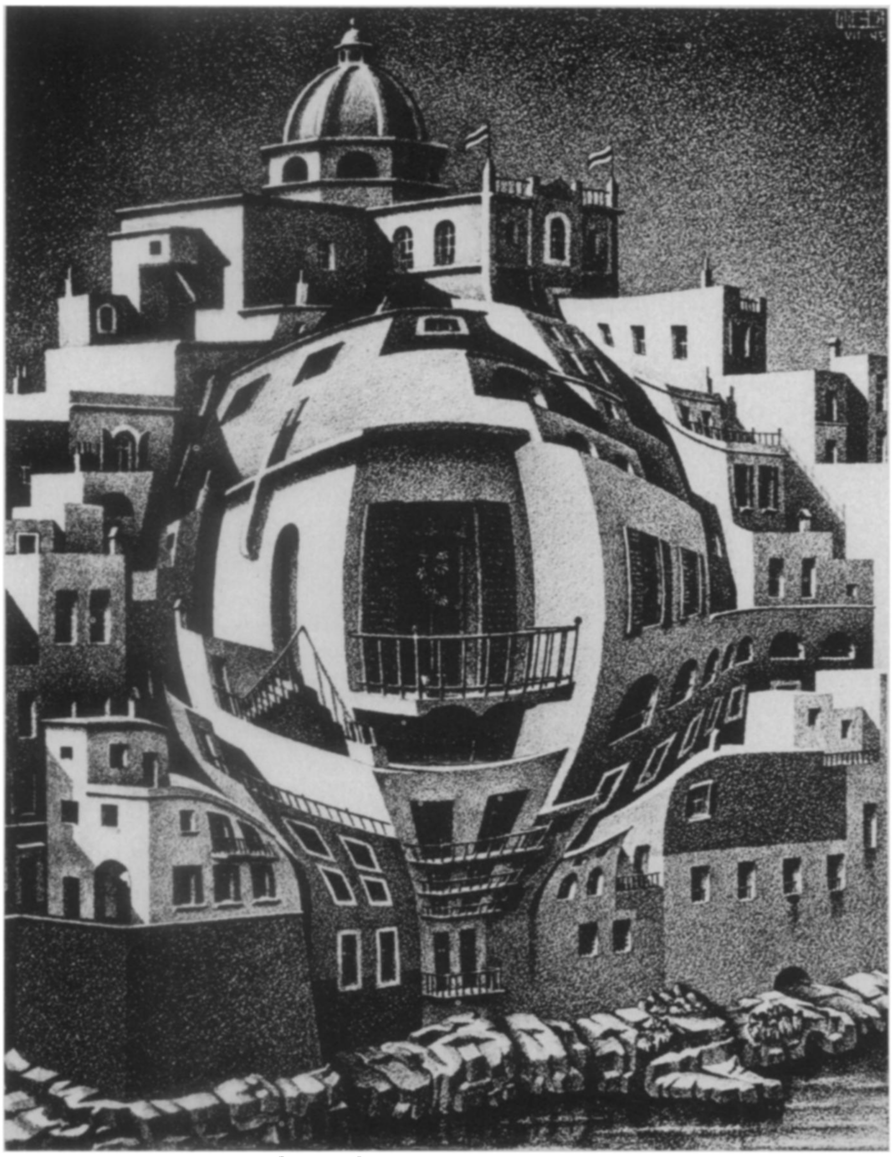

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A varying standard of length can produce a very strange looking universe.

Dirac's new field

In which the Nobel Prize winner and theorist of the relativistic electron takes up the question of uniting gravity and electromagnetism and comes up with a theory having novel cosmological consequences

by Dietrick E. Thomsen

After some decades in the doldrums of physicists' attention, unified field theory is again becoming a fashionable topic. What it means is the attempt to unite the theories of the different kinds of natural force (of which physicists recognize four: the gravitational, electromagnetic, strong nuclear and weak) in such a way that they can all be derived from a single basic principle and be seen as aspects of a single thing.

The theorists of particle physics have been having an interesting and somewhat successful time in an endeavor to unite the weak force, which comes into play in certain processes such as beta decay, with the electromagnetic (SN: 9/15/73, p. 164), and their work is mostly what has brought unified field theory into the news lately. But there is another approach. It was begun by Albert Einstein with his theory of general relativity, and it might be called the geometrization of physics. Usually it seeks to start by unifying gravity and electromagnetism. In recent years one of its most prominent practitioners has been P. A. M. Dirac of Florida State University at Tallahassee. He described his latest work at the *Orbis Scientiae* meeting in January at the University of Miami.

Einstein succeeded in geometrizing gravity. He made the gravitational forces into effects of the curvature of space. The question then arises: If gravity comes from changes in the curvature of space, what aspect of space can be the source of electromagnetism? Dirac, who has probably the longest memory in physics, goes back to an old abandoned idea of Hermann Weyl: that electromagnetism comes from changes in the gauge of the space, its local standard of length.

To apply this idea it is necessary to imagine a space in which the standard of length can be different from point to point. As Dirac illustrates, if you take a string and move it in a closed path in such a space, it will return to its starting point a different length from the one with which it left. Such a space seems absurd, but then so did Einstein's curved space at first. It is possible to devise mathematical equations that impose some order on the arbitrariness of such a space and tell how the gauge varies from point to point. When this is done, the proper derivation yields the equations for the electromagnetic field.

But there is a big hitch in Weyl's program, one that caused it to be abandoned. Weyl's derivations worked on the macroscopic scale. In macroscopic physics there is no naturally

theory—A strange, variable-gauge universe

given standard of length. Any standard we use is arbitrary, and there is no philosophical objection to having it vary from point to point according to whether there is a stronger or weaker electromagnetic field at the point.

On the atomic scale, however, we have a naturally given standard of length. The wavelength of the light emitted when atomic electrons jump from one energy state to another is fixed and certain for each case, and there is no evidence (in the laboratory at least) that it varies from point to point. "The whole basis of Weyl's theory dropped away," says Dirac.

But Dirac insists, "We still need a connection between the gravitational and electromagnetic fields." To get it, he goes by way of another favorite topic of his, the astronomical numbers that come up when the ratios of certain fundamental quantities are taken.

One such number is the ratio between the gravitational and electromagnetic forces between the proton and the electron in a hydrogen atom. It comes to 10^{39}. How to explain such a huge number? Obviously it has something to say about the relationship between the two forces.

There is another number, the age of the universe, which Dirac takes as 18 billion years (a few billion more than most cosmologists would estimate). If this is expressed in atomic units similar to those used for the ratio of the two forces, it too comes out to 10^{39}. "It is hard to believe this is just a coincidence," says Dirac. "Numbers of this order of magnitude are connected by theories not well understood." But the connection, whatever it is, leads to the suggestion that if one number (the age of the universe) increases with time, the other ought to do so to.

For the ratio of the two forces to increase with time, one of the forces must change. Dirac picks gravity. As the universe ages, gravity gets weaker. Newton's universal gravitational constant is not really a constant, but decreases in value. The idea of a gradually weakening gravity is not unique with Dirac. It is taken up in more than one current cosmological theory, and it has a long history, going back at least to the work of Ernst Mach in the 1890's. But the other theories don't generally make it a consequence of a relationship between gravity and electromagnetism. "[Weakening gravity] is an assumption unproved that needs experimental confirmation," says Dirac.

The decrease that he would like to have amounts to about one part in 20 billion per year. "It is not hopeless to try to measure," he says. He refers to the work of I. I. Shapiro of Massachusetts Institute of Technology, who has been trying for years to measure possible changes in the gravitational constant and other general relativistic data by bouncing radar beams off planets. In five years he might reach the requisite accuracy. "We really have to wait for Shapiro to complete his observations," Dirac concludes.

But Einstein assumed that gravity does not vary. Einstein's theory has been so successful that we do not want to throw it away, says Dirac, but we must modify it. The modification that he makes allows him to pick up Weyl's hypothesis and use it again.

Dirac proposes the somewhat unusual course of considering a space with two metrics. The metric of a space is a way of defining how to measure the distance between two adjacent points in that space. It is related to the gauge, the curvature and the nature of the dimensions of the space. In the space in which Einstein wrote down his general relativity, gravitational forces are closely connected to the metric. It is this Einsteinian metric that Dirac next takes up in his argument.

Suppose, he says, that the Einsteinian metric is not the same as the metric one might derive by measurement, a metric that would depend on the fixed gauge given to us by atomic processes, and which Dirac calls the atomic metric. If the Einsteinian metric is not the atomic metric, then Weyl's ideas of a variable gauge from which the electromagnetic field is derived can apply to it, and the geometrization of electromagnetism can be accomplished. We can never measure the Einsteinian metric; everything we measure in the lab always gives us the atomic metric. But the Einsteinian metric does appear as a mathematical factor in the equations that govern the motions of bodies under the influence of the forces we are considering. The ratio between the two metrics varies with the age of the universe, and fitting this variation to the variation in the strength of gravitation is the mathematical key to exactly how the Weyl theory comes back in.

The dual-metric theory has consequences in different parts of physics. Its cosmological consequences are not only striking; some of them may be measurable.

The theory leads Dirac to postulate a universe in which there is continual creation of new matter. If this is granted, the important question that follows is: Where is the new mass created? Is it created uniformly throughout space or is it created preferentially where matter already exists, a kind of matter-begetting-matter situation. Dirac calls the first case additive creation and the second multiplicative. With the work that has been so far done, he says, "We don't know which to prefer. We get a model with either one." One thing that falls out of both models is any bouncing-universe theory. The universe must continue to expand forever with no change in the law of expansion.

One place where the two models give divergent predictions is the motions of the bodies in the solar system. These will be affected by the appearance of new matter and by where it appears. The result is that with additive creation planetary orbits get smaller and the solar system is generally contracting. With multiplicative creation the solar system expands. Shapiro's observations may show some of this.

Meanwhile the cosmological consequences of the two metrics and the necessity for keeping Einstein's equations are rather strange. In both cases the necessity of keeping the law of conservation of mass—that the total amount of mass in the universe remains constant—requires some kind of compensation for the creation of new matter. In the additive case it turns out that the masses of bodies already in the universe diminish as time goes on. The atomic standards change with time. The atomic clocks—the frequencies of the emitted radiation—are continually speeding up with respect to the Einsteinian standard of length. This means that the redshifts we see in the light of distant galaxies really represent the change in the ratio between the atomic and the Einsteinian standards of length in the time since the radiation was emitted. The universe is closed with a finite size.

In the multiplicative case, mass can be conserved only by postulating the creation of negative mass in equal amounts with the positive. Negative mass is something new and unusual, but it gives us a universe with a net creation of zero, which we need to save Einstein's equations. The creation of negative mass is unobservable, and postulating an invisible uniform distribution of it seems contrived, but "we are driven to it," Dirac says.

He continues to work on the theory, especially such questions as the quantization of mass and a better understanding of the relationship between the two standards of length. It remains to be seen whether other physicists will pick up his lead and a school of neo-Weylian field theory will develop. □