An Angle on the New Physics

Seeking unity in physics is an exercise in geometry

BY DIETRICK E. THOMSEN

Modern physics without geometry is like Pythagoras without triangles — and for approximately the same reason. Indeed, an excursion into that most successful of modern theories, the Weinberg-Salam model of the weak and electromagnetic interactions, is like a return to trigonometry class: sines, cosines and tangents all over the place. They all refer to a particular angle, the Weinberg mixing angle.

As it happened, the annual meeting of the Division of Particles and Fields of the American Physical Society (held at Montreal and co-sponsored by the Canadian Association of Physicists) took place on the last weekend in October shortly after the announcement of the Nobel awards. When it came to a series of papers on Weinberg-Salam theory, a certain satisfaction was evident, and the speakers dwelt more on history than they might otherwise have done, but the major concern was the present status of the theory and its future significance for the rest of physics. That brought the speakers back again and again to the Weinberg mixing angle.

This angle is a measure of the way of putting together two kinds of interaction, two mathematical varieties of force field. W-S theory is an attempt at a partially unified theory — most physicists now seem to agree that it works — and as such it ought to form a part of more ambitious attempts that hope to explain everything in physics, known colloquially as GUTS, Grand Unification Theories.

Physics is faced with four different varieties of "interaction" that exert forces on particles or change their identities by seemingly different rules and with apparently different strengths. Most physicists' instinct is to try to unify this mishmosh, and there are common threads that justify the hope. The interactions called electromagnetic and weak looked particularly close, and that is where W-S theory began. It picked up on an exercise in field theory that had been going on for years.

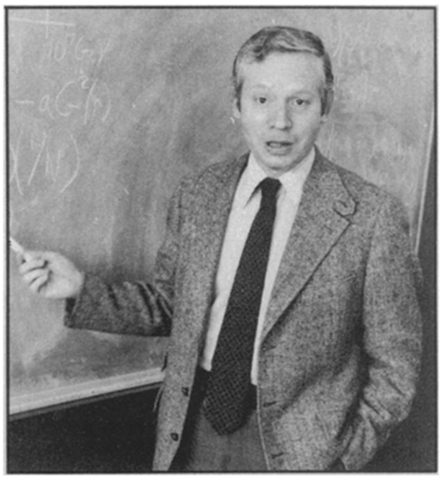
A field is a mathematical way of describing a condition of space by labeling each point in the space with a number. Take its temperature. There might be a field equation from which the temperature at any point can be calculated, the movement of heat followed, and other things predicted. Life is seldom so simple, however, as to require only one number per point. In a force field at least two data, strength and direction, must be specified. Things can get much more complicated than that. To specify the curvature of space at any point in Einsteinian general relativity requires a sizable matrix array of numbers. Fields are classified by the complexity involved in labeling the points. The technical names of the classes go scalar, pseudoscalar, vector, axial vector and tensor.

A long history has shown that electromagnetic fields are purely of the vector class. People had believed that the weak interaction fields ought to involve a mixture of the vector and axial vector classes, but exactly how the mix should be done had been a problem up to the time the unified theories of weak and electromagnetic interactions were essayed. The W-S model gives a rule for mixing the two kinds of field. The critical parameter in that rule is this Weinberg mixing angle. The geometric qualities of fields make it reasonable that this should be an angle.

The W-S model predicted more phenomena than anybody needed at the time. "We used to think that the weak interaction was only charged current," says Charles Baltay of Columbia University. "The W-S model removed infinities [which had plagued previous attempts], but it predicts neutral currents." "Charged current" is a way of describing an interaction between two particles, say a collision, during which they exchange a unit of electric charge and thereby alter their identities. "Neutral current" describes such an occurrence in which charge is not exchanged, and the identities of the particles can remain the same. All observed weak interactions had always been of the charged current variety.

Experimenters had never seen a neutral current weak interaction, and they reacted with more than a little skepticism. But eventually the weak neutral currents had to be searched for; they came from the basis of the unification.

Behind the geometrical world of the fields is a more abstract sort of geometrical thought, that of the symmetry groups and the transformations they encompass. Suppose there is some geometric pattern, say a plane covered with interlocked equilateral triangles. (This example is stolen from the French mathematician Jean Dieudonné, writing in the Sept. RECHERCHE.) An invisible hand may do something to one of the triangles: move it sideways, rotate it, etc. Group theory is the study of ensembles of such "transformations" according to their nature (translations in space, rotations, etc.), what they do to the pattern, how they can be combined. It can be a dangerous craft. Gerard t'Hooft, the Dutch physicist who pulled W-S theory out of what looked like a fatal jam, once nearly dislocated an arm trying to show the effect on a glass of water of a succession of rotations adding up to 720°. (Nearly spilled the water, too.)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The particular groups that are most associated with particle physics are the so-called gauge groups. "Gauge" has several meanings, but in this context, to use Weinberg's own studiedly vague description, it has to do with the identities of the subatomic particles. And so gauge transformations are transformations affecting the identities of the particles. (The interactions on which physicists are using group theory affect the identities of the particles.) For the record, it was found that a combination of two groups, written SU(2) x U(1), could contain all the transformations necessary to a unification of the weak and electromagnetic interactions.

For the intermediary particles of the unified interaction it predicted a set of four, designated W^+, W^-, W^0 and B^0. The intermediary particles are the ones that "carry" the interaction. One of them is exchanged whenever something happens, the exertion of a force between particles, for example. In this bunch the electrically charged W's were all right. They mediate the familiar charged current weak interactions. The neutral ones presented a problem. Electromagnetic effects need a neutral intermediary, but even after a further action of mixing and redividing the W^0 and B^0 (so to speak) brought out the recognizable photon or gamma particle of electromagnetics, the weak interaction per se was still left with a neutral intermediary, now called Z^0, which is a definite prediction of neutral current interactions.

Physicists went out and looked for neutral current weak interactions. They found more than one variety. When they did, they

Continued on page 412

strong emphasis on prevention. Westberg and others from the centers are helping to set up similar clinics with other groups around the country.

At the University of Wisconsin at Stevens Point, University Health Service director Bill Hettler started a similar "Wellness" program in 1976. Students fill out a questionnaire about their past medical history, their strengths and the things about themselves that they'd like to change. Their answers are analyzed by a computer that provides information about health risks, both short and long term. It also tells students where to get information to help them solve their problems. The University of Colorado also has a "whole person" health care program, this one based on three principles: individual responsibility for health, prevention through education and a person-centered approach to health care delivery. These programs are popular with students, and one study carried out by Hettler suggests higher rates of compliance and change than with traditional methods.

It is relatively easy to sort out those holistic therapies that have little value from those that have the potential to be of great use. Between them, however, there is a large grey area and many holistic therapies dwell here; there may be some evidence that they work, but not enough to be certain or to use them in clinical practice. Herbal medicine, for example, has yielded many valuable drugs and will undoubtedly produce more, but it is difficult to control dosages when a medication is in the form of a plant. Such therapies need to be refined and better documented. Negative ion therapy, another example, sounds strange, but researchers — Felix Sulman of Hebrew University in Jerusalem and Albert P. Krueger of the University of California at Berkeley, among others — have documented that increases of positive air ions lead to an increase in production of the powerful neurohormone serotonin. This leads to a "serotonin irritation syndrome," common in areas of the world where certain weather fronts bring on abnormally high concentrations of positive air ions. The sharav in the Near East, the foehn, the sirocco, the santa ana — all of these ill winds do cause physiological changes, and negative ion therapy may have a place in treating them.

In the end, the medical consumer can judge holistic medicine only by looking at each holistic practitioner, and therapy system individually. As research into the effectiveness of various systems continues, it may become easier to separate the useful from the useless and the benign from the harmful. Until then, however, the medical consumer can't be entirely certain of what the "holistic" label means. If seeking holistic care, it is probably more circumspect to choose a holistic clinic run by an M.D. or D.O. In medicine as elsewhere: caveat emptor. Let the buyer beware. ☐

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referred the findings to the W-S theory.' That's the way things are usually done in such cases. The theory was why they had looked in the first place. They didn't have enough data to analyze independently of any model, and says Baltay, "The W-S model gave clear predictions and this mixing angle." Since 1978, he says, they have had enough data to do an independent analysis of the experimental results to see whether this is truly the theory they support and to better determine the value of the mixing angle.

Experimenters sort out effects identifiably dependent on one or more of the four intermediaries, W^+ , W^- , Z^0, and gamma, but especially Z^0 and gamma, and compare the probabilities or rates at which they happen. Since the mixing angle is involved in determining how much of each is involved in the total, its trigonometric functions are involved in the analysis of those ratios, as well as the relationships between the masses of the intermediaries, and among the strengths of the different forces generated by the unified interaction. The two neutral intermediate particles are of particular interest because neutral current weak interactions are something new and because the relationship between them and the electromagnetic interactions demonstrates the unifying character of the theory.

The classic experiment for determining that there are in fact weak current neutral interactions is electron-neutrino scattering, collisions of electrons and neutrinos in which the participants come away with their identities unchanged. In the past six years a good number of such investigations have been done. Al Abashian of the National Science Foundation described an experiment just finished at the Fermi National Accelerator Laboratory, in which he is collaborating with a large number of colleagues, that is a rather rare variation on this technique, the scattering of muon neutrinos off electrons. This is an event that doesn't happen often, but they chose it, Abashian says, because "it needs W-S only." That is, no assumptions from other theories. It is therefore a very good test. After scanning 80,000 pictures they come up with 46 events attributed to scattering of muon neutrinos and electrons. Throwing away some dubious ones yields a "net signal" of 36. From this, nevertheless, they deduce that the square of the sine of Weinberg's angle is 0.25, but with a sizable uncertainty.

Baltay reviewed the more usual sorts of neutrino-electron scattering. Then he considered scattering of electrons off deuterium nuclei. This measures the interference, the ratio and competition, between forces mediated by weak neutral currents and by electromagnetic effects. The same relationship is tested by studies of certain energy transitions in bismuth and thallium atoms, except that the atomic case probes the interference between forces on an electron in an atom.

Considering experiments of various kinds from all over (Novosibirsk, Hamburg, Aachen, Geneva, Oxford, Batavia, Berkeley, Stanford), Baltay comes to the conclusion that W-S theory is well supported by all of them. This is a difference from the recent past when anomalies were suspected in some, especially the bismuth atom work. He also concludes that the value of the square of the sine of the Weinberg angle is 0.23, but 0.20 or 0.21 cannot be ruled out at the present time, "and that is what supersymmetry theorists would like to know."

Supersymmetry is one way of trying to reunite all of physics into a single framework. The Grand Unification Theories are another, sometimes different, sometimes a part of supersymmetry. They want to know the value of the Weinberg angle because it affects the balance of forces and the existence of a large class of particles. It tells you how many different kinds of fermions there are. Or putting it the other way, in the words of William J. Marciano of Rockefeller University, "If you know all the fermions that exist in the world, you know $\sin^2 \Theta_w$." Fermions are particles with half-integral amounts of spin. They include neutrons, protons, electrons — and quarks. The operative question is whether new families of fermions need to be added to theory, superquarks, ultraquarks, technicolor quarks, beyond the plain quarks that already cause so much trouble. The Weinberg angle may tell.

Another thing the Weinberg angle brings to GUTS is a measure of the proton lifetime. "Almost all GUTS predict proton decay," says Marciano. Radioactive decay of the proton is a revolution in physics. The proton was always supposed to be *the* stable particle. The attempt to connect the domain of the strong interaction, where the proton mostly lives, with the Weinberg-Salam unified interaction has changed all that. Now expensive experiments are being set up to look for proton decay (see p. 405).

The lifetime of the proton depends on the value of the Weinberg angle, and Marciano sets out to calculate whether these experiments are likely to see proton decay, given the present range of values for the square of the sine of the angle. All predictions give a very long lifetime, figures upwards of 10^{30} seconds. Very little proton decay is likely to be seen in any case. If the sine squared is less than .20, the proton lifetime is too long in comparison to that of the universe for much to be seen. Above .23, and proton decay should have been seen already.

Maybe they'll see it and maybe they won't. And then maybe somebody will change something in the theory, and maybe somebody won't. The only absolutely valid theory may be the domino theory: When anybody makes waves, they're likely to shake everything. ☐