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PARTICLE PHYSICS

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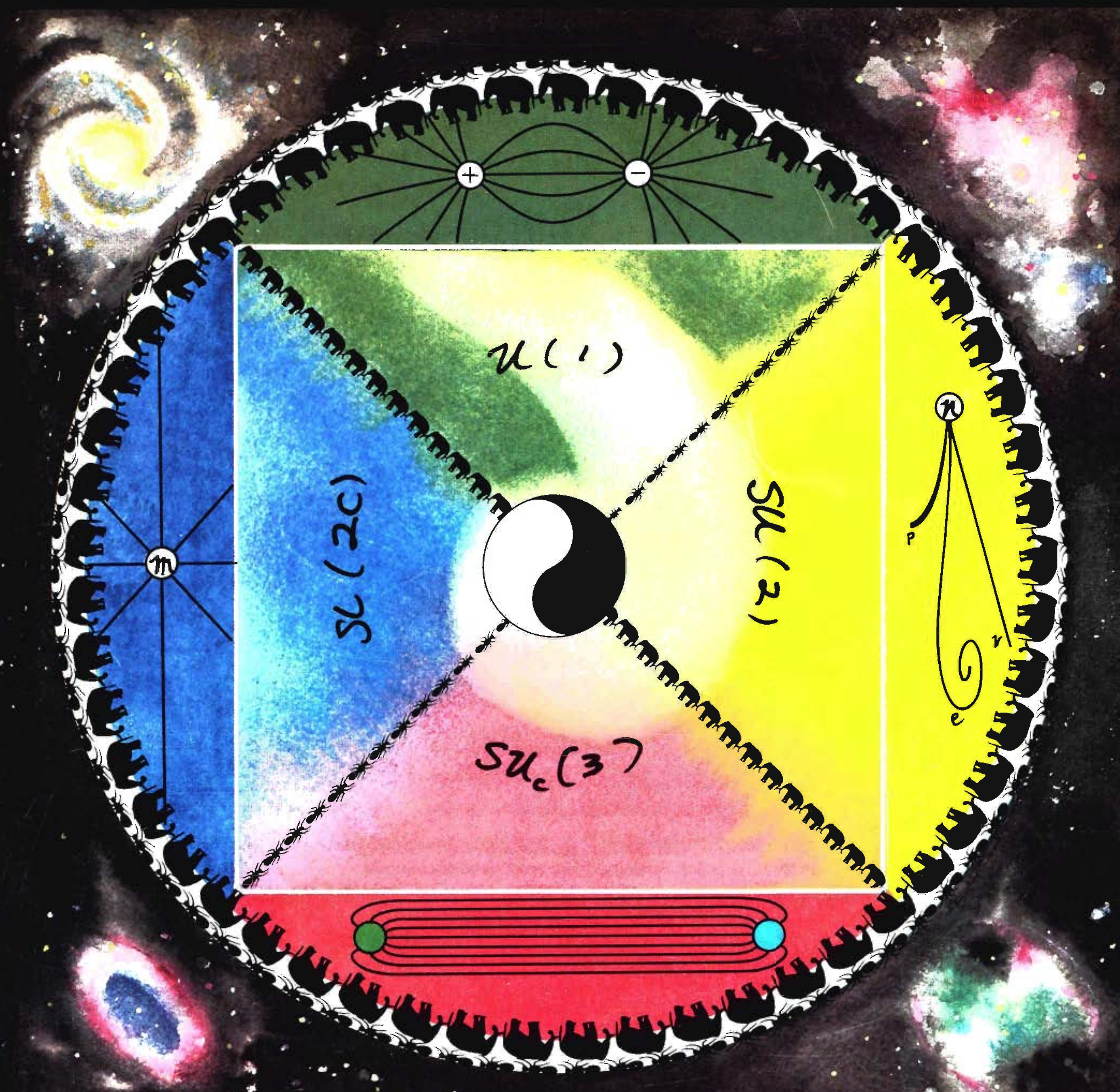

EDITOR'S NOTE

On the cover a mandala of the laws of physics floats in the cosmos of reality. It symbolizes the interplay between the inner world of abstract creation and the outer realms of measurable truth. The tension between these two is the magic and the challenge of fundamental physics.

According to Jung, the "squaring of the circle" (the mandala) is the archetype of wholeness, the totality of the self. Such images are sometimes created spontaneously by individuals attempting to integrate what seem to be irreconcilable differences within themselves. Here the mandala displays the modern attempt by particle physicists to bring together the basic forces of nature in one theoretical framework.

The content of this so-called standard model is summarized by the mysterious-looking symbols labeling each force: U(1) for electromagnetism, SU(2) for weak interactions, $SU(3)_C$ for strong interactions, and SL(2C) for gravity; each symbol stands for an invariance, or symmetry, of nature. Symmetries tell us what remains constant through the changing universe. They are what give order to the world. There are many in nature, but those listed on the mandala are special. Each is a *local* symmetry, that is, it manifests independently at every space-time point and therefore implies the existence of a separate force. In other words, local symmetries determine all the forces of nature. This discovery is the culmination of physics over the last century. It is a simple idea, and it turns out to describe *all* phenomena so far observed.

Where does particle physics go from here? The major direction of present research (and a major theme of this issue) is represented by the spiral that starts at electromagnetism and turns into the center at gravity. It suggests that the separate symmetries may be encompassed in one larger symmetry that governs the entire universe—one symmetry, one principle, one theory. The spiral also suggests that including gravity in such a theory involves understanding the structure of space-time at unimaginably small distance scales.

Julian Schwinger, whose seminal idea led to the modern unification of electromagnetic and weak interactions, regards the present emphasis on unification with skepticism: "It's nothing more than another symptom of the urge that afflicts every generation of physicists—the itch to have all the fundamental questions answered in their own lifetime."* To others the goal seems tantalizingly close, an achievement that may be reached, if not this year—then maybe the next . . . .

The hope of unification depends on a second theme of this issue, symbolized by the ants and elephants walking round the mandala. These creatures are our symbol of scaling, the sizing up and sizing down of physical systems. Strength (or any other quality, for that matter) may look different on different scales. But if we look hard enough, we can find certain invariances to changes in scale that define the correct variables for describing a problem. Why do ants appear stronger than elephants? Why does the strong force look weak at high energies? How could all the forces of nature be manifestations of a single theory? These are the questions explored in "Scale and Dimension—from animals to quarks," a seductively playful article that leads us to one of the most important contributions to modern physics, the renormalization group equations of quantum field theory. The insights about scaling gained from these equations are important not only to elementary particle physics but also to phase transition theory and the dynamics of complex systems.

All the articles in this issue were written by scientists who care to tell not only about their own research but about the whole field of particle physics, its stunning achievements and its probing questions. Outsiders to this field hear the names of the latest new particles, the buzz words such as grand unification or supersymmetry, and the plans for the United States to regain its leadership in this glamorous, high tech area of big science. But what is the real progress? Why does this field continue to attract the best minds in science? Why is it a major achievement of human thought? From a distance it may be hard to tell—except that it satisfies some deep urge to understand how the world works. But if one could be given a closer look at the technical content of this field, its depth and richness would become apparent. That is the aim of the present issue.

The hardest job was defining the technical level. How could the framework of the standard model be appreciated by someone unfamiliar with symmetry principles? How could modern particle physics research, all of which builds on the standard model, be understood by someone unfamiliar with what everyone in the field takes for granted? We hope we have solved this problem by presenting some of the major concepts on several levels and in several different places. We even include our own reference material, a remarkably clear and friendly set of lecture notes prepared especially for this issue.

As one who was trained in this field, I returned to it with some trepidation—to deal with the subject matter, which had been so difficult, and with the personalitites competing in the field, who sometimes ride roughshod over each other as they battle these unruly abstractions. Much to my delight and the delight of the *Los Alamos Science* staff, the experience of preparing this issue was immensely enjoyable and rewarding. The authors were enthusiastic about explaining and re-explaining, about considering the essence of each point one more time to make sure that the readers too would be able to grasp it. Their generosity and interest made it fun for us to learn. May this presentation also be a treat for you.

Necia Grant Cooper

This quote appeared in "How the Universe Works" by Robert P. Crease and Charles C. Mann (**The Atlantic Monthly**, August, 1984), a fast-paced article about the history of the electoweak theory.

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CONTENTS

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

RESEARCH AND REVIEW

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