International Journal of Theoretical Physics, Vol. 32, No. 9, 1993

The Myth of Cosmic Symmetry Breaking

Joe Rosen[1]

Received November 15, 1992

General considerations are presented concerning symmetry and reference frames. It is shown that the Universe as a whole cannot possess perfect symmetry and that there was no cosmic symmetry breaking at cosmic phase transitions between cosmological eras. Cosmological schemes that assume perfect symmetry for the Universe are meaningless, but that can be circumvented. Assuming discontinuous evolution, high-energy physics does not reconstruct earlier eras. Specifically, any symmetry emerging at high energies cannot be a feature of earlier eras and is not a restoration of symmetry (that never was). The quantum era is considered and can reasonably be assumed to have been nontemporal, nonspatial, and extremely quantal. The Beginning can reasonably be identified with the quantum era or with the cosmic transition to space-time.

1. INTRODUCTION

We have attained excellent understanding of the world in which we live on the ordinary, human scale of distances, durations, masses, speeds, and so on. And nature has equipped us with intuitions that generally serve us well on that scale. In our attempt to understand the world on scales more and more different from the ordinary scale, we push that understanding and those intuitions as far as they will go. When we find we have surpassed the domain of validity of our understanding, we try to develop new, more general understanding to comprehend extended domains of reality. Our intuitions, however, lag behind our intellect. The formalism of quantum theory, for example, seems adequately to describe a certain aspect of nature, and we have accomplished much with that formalism. Yet our understanding of quantum phenomena beyond the application of the formalism suffers from the counterintuitive character of those phenomena.

[1]Department of Physics, Catholic University of America, Washington, D.C. 20064. On leave from the School of Physics and Astronomy, Tel-Aviv University, 69978 Tel-Aviv, Israel.

0020-7748/93/0900-1585$07.00/0

True, we have managed to improve our intuition to some extent, but well-known difficulties, such as quantum nonlocality, remain.

In our attempt to understand the world on the extra large scale and on the cosmic scale, we naturally extrapolate from the ordinary scale as far as we can. When we cannot push any farther, we exploit relativity and quantum theories to come up with what appears to be a satisfactory theoretical framework for comprehending the Universe on those scales. Of course, we try to apply our ordinary-scale intuitions to those scales as well. And, with a boost from what we have intuitionally internalized from relativity and quantum theories, we generally have the feeling that we do have a satisfactory intuitive grasp of the situation.

Yet strange findings, such as the non-Keplerian dependence of rotational velocity on radius in galaxies and the extra-large-scale structure in the spatial distribution of galaxies, hint that perhaps we are running into counterintuitive phenomena on those scales. I would venture to propose that although we seemingly facilely extrapolate from the ordinary scale to the extra large and cosmic scales, the extra large is probably every bit as counterintuitive as the extra small. As we expand our observational horizons, I expect it will become more and more necessary to face up to the fact that our understanding of the Universe in the extra large is as poor as our understanding of it in the extra small.

Our need for explanation and for a feeling of coherence drives us to devise cosmological schemes, such as the presently standard big-bang-type models, that are amenable to our intuition. As such they are most certainly very wrong, as marvelous and as useful as they might be. As I stated above, I believe that our intuition, at least in its present state, is as inadequate to cope with the extra large as it is to grasp the extra small. Thus any intuitionally graspable cosmological scheme cannot but be light years off the mark, perhaps as far off as Newtonian mechanics is from a description of the atomic nucleus.

We must humbly realize that we are not on the verge of discovering a Theory of Everything, and, by my understanding, we never will be (Rosen, 1991, Chapter 4). We are not finally, after centuries, even millennia, of conceptual groping, about to grasp The Real Thing (Rosen, 1991, Chapter 8). Our cosmological schemes are but the latest additions to the respectable series of such schemes that have been devised by humankind throughout its history, in order to satisfy its need for explanation and for a feeling of coherence (Park, 1988). They are just as true for us now as ancient schemes, as absurd as they seem to us today, were for their inventors then. And our cosmological schemes will certainly seem just as absurd to our descendants. Yet, as Edward Harrison (1985, Chapter 1) puts it, each such scheme, each such "mask of the Universe," is an aspect of reality.

All such schemes "are real, and the Universe is patient of many interpretations.... Ultimately, beyond all systems, stands the Universe in a cloud of unknowing."

In this article I show that unwarranted extrapolation from the physics of the present cosmological era has led to correspondingly unwarranted conclusions about previous eras in the big-bang-type cosmological schemes currently under consideration. The essence of my claims is that each era must be referred to its own reference frame, not to that of any other era, specifically not to the reference frame of the present era. Since it is the whole Universe that is being considered, no externally imposed reference frame can be applicable, not even that of another era. The result is that there was no cosmic symmetry breaking at cosmic phase transitions between eras. Thus the higher-energy physics of the present era, although it might indeed exhibit a higher degree of symmetry than lower-energy physics, will not thus be restoring broken symmetries that in fact never were. The quantum era is considered in that light, and some discussion is devoted to The Beginning.

2. SYMMETRY AND ASYMMETRY

In its essence symmetry is the possibility of making a change that leaves some aspect of the situation unchanged, or, most succinctly, symmetry is immunity to a possible change (Rosen, 1990). That is the conceptual formulation of symmetry. It can also be called the qualitative formulation of symmetry, in contrast to the group-theoretic formulation, which can accordingly be called the quantitative formulation of symmetry.

Approximate symmetry is approximate immunity to a possible change (Rosen, 1983, Chapter 5). The approximation is in the immunity, not in the change.

Asymmetry is lack of immunity to a possible change. For asymmetry there must be the possibility of a change.

If there is no possibility of change, the very concept of symmetry is inapplicable, and we have neither symmetry nor asymmetry. [It is tempting to suggest revising conventional terminology by using the term "dissymmetry" [from Pierre Curie's (1894) "dissymétrie"] for what we call asymmetry, while reserving the latter term for situations to which the concept of symmetry is inapplicable, i.e., for situations in which there is no possibility of change.]

The conceptual/qualitative formulation of symmetry is expressed in terms of changes and immunities, in terms of what in the situation is immune to what possible change. The group-theoretic/quantitative formulation is expressed in terms of transformations (or operations), transformation groups, equivalence relations, equivalence classes, symmetry transformations (or symmetry operations), and symmetry groups, and can be developed from the conceptual formulation (Rosen, 1983, Chapter 3). While for the description and treatment of many derivative applications of symmetry in physics the group-theoretic formulation is the appropriate one, it is the conceptual formulation that is the more suitable for the understanding of the fundamentals of physics.

As an example of symmetry, consider the long- and well-known phenomenon of nuclear physics called charge symmetry: Nuclei possessing almost the same nucleonic composition, with their sole difference being a single proton in one replaced by a neutron in the other (and vice versa, of course), often have very similar properties (such as energy levels). The possible change here is the replacement of a proton with a neutron (or a neutron with a proton). What are approximately immune to that change in many cases are certain nuclear properties such as energy levels. Thus charge symmetry, actually an approximate symmetry, involves *both* the possibility of proton–neutron replacement *and* the (approximate) invariance of nuclear properties under such a replacement.

Nuclear charge symmetry is explained by assuming that the strong nuclear interaction is blind to the difference between proton and neutron, while the deviations from exact symmetry are explained by the Pauli exclusion principle and the electromagnetic and weak interactions.

For the purpose of our subsequent discussion it is important to note that the proton–neutron replacement change is possible precisely because there *is* a difference between proton and neutron. Although the blindness of the strong nuclear interaction to the proton–neutron difference is an aspect of nature, so, too, is the difference between the proton and the neutron an aspect of nature. And it is *both* the proton–neutron difference *and* the blindness of the strong nuclear interaction to the difference that bring about the symmetry.

Imagine a hypothetical world in which there is no difference between proton and neutron. Then they would be identical, and there would be no protons and no neutrons, only nucleons. That world would not be more symmetric than the real world; it would not possess exact charge symmetry, while in reality we have only approximate charge symmetry. On the contrary, it would have no charge symmetry at all! In that world there would be no possibility of a change to which the strong nuclear interaction would be immune. Replacing a hypothetical nucleon with another hypothetical nucleon would be no change at all. That would be as much a change as replacing a proton with a proton in the real world.

The point here is that a physical change inherently involves a frame of reference by which the change acquires meaning, a standard to which the change is referred. Indeed, it is a reference frame that makes a change possible. And the reference frame cannot itself be immune to the change under consideration, otherwise it could not serve its purpose.

As a simple example, consider the change of spatial displacement by any distance in some direction. An infinite ruler laid out in that direction could be an appropriate reference frame. But the ruler must not be homogeneous (uniform and unmarked). Position cannot be referred to a homogeneous ruler. Neither can it be merely periodic (with equally spaced, unnumbered marks). In fact, it must in principle have a continuum of numbered marks; it must serve as a one-dimensional coordinate system. It must itself possess no immunity to spatial displacement. So even though nature possesses spatial displacement *symmetry* in that the laws of nature seem to be immune to possible spatial displacement, nature must concomitantly also possess spatial displacement *asymmetry* in that some aspect of it is *not* immune to possible spatial displacement, in order to allow the very possibility of spatial displacement. And indeed the distribution of matter in the Universe is inhomogeneous, and coordinate systems can be set up.

For nuclear charge symmetry there are plenty of protons and neutrons around to serve as a frame of reference for the change of proton–neutron replacement. The change of replacing a proton with a neutron (or vice versa) is meaningful because there is a difference between them, and the many protons and neutrons in the environment serve as a standard by which the ones in a nucleus are differentiated.

So symmetry and asymmetry, antithetic as they might be thought of in certain respects, are also intrinsically involved with each other in that symmetry implies asymmetry. (That relation is not symmetric, however, since asymmetry does not seem to imply symmetry, although it does imply the conceptual possibility of symmetry. Asymmetry involves an aspect of the situation that is not immune to a possible change, and that implies the conceptual possibility of that aspect's immunity.) If any aspect of the Universe possesses some symmetry, then there *must* be another aspect of the Universe that is asymmetric under the change involved in the symmetry.

The relations among symmetry, asymmetry, change, immunity, and reference frame can be expressed by the following diagram, where arrows denote implication.

$$\begin{tikzcd} & \text{Possibility of a change} \arrow[r] & \text{Reference for the change} \arrow[r] & \text{Asymmetry under the change} \\ \text{Symmetry} \arrow[ur] \arrow[dr] & & & \\ & \text{Immunity to the change} & & \end{tikzcd}$$

Thus a hypothetical perfectly homogeneous universe cannot be said to possess perfect spatial displacement symmetry (while the real Universe does have spatial displacement variant aspects); it would indeed possess no spatial displacement symmetry (or asymmetry) at all. It would not possess the possibility of spatial displacement, so the notion of immunity (or lack of immunity) to such change would be irrelevant to it. We can go even farther and declare that it would have no spatial dimensionality at all; "location" or "position" would be irrelevant to such a universe, since it would possess nothing that could serve as a coordinate system. (Recall that the Universe, or a universe, is everything, so no externally imposed coordinate system is meaningful.)

And from here we reach the conclusion that a perfectly homogeneous universe is an oxymoron. Homogeneity means the possession of identical properties at all locations. Perfect homogeneity means that all locations are absolutely indistinguishable and are thus identical. So there are no different locations at which properties can be compared. All locations are identical and thus conceptually merge into a single location, which makes the very concept of location redundant. And hence no spatial dimensionality.

How did we ever come up with the silly idea of a perfectly homogeneous universe then? By extrapolating from the real, inhomogeneous Universe, by trying to imagine the limit of vanishing inhomogeneity. A perfectly homogeneous three-dimensional mathematical space may serve as an approximate model of the real world in certain respects. And we have no difficulty conceptually and meaningfully imposing coordinate systems on it. But as a thing-in-itself, there can be no such animal.

Symmetry requires a reference frame, which is necessarily asymmetric. The absence of a reference frame implies identity, hence no possibility of change, and hence the inapplicability of the concept of symmetry.

3. SYMMETRY OF THE UNIVERSE

As we saw in the preceding section, symmetry implies asymmetry, or asymmetry is inherent to symmetry. So if any aspect of the Universe possesses some symmetry, then there *must* be another aspect of the Universe that is asymmetric under the change involved in the symmetry. And from here follows:

Exact symmetry of the Universe as a whole is an empty concept.

We saw this for perfect spatial displacement symmetry in the example of a hypothetical perfectly homogeneous universe. Since the Universe, or a universe, is everything, no external reference frames can be imposed on it.

Our example, due to its hypothetical perfect homogeneity, would possess no coordinate system (frame of reference) of its own. (A coordinate system would be an inhomogeneity.) Thus there would be no possibility of spatial displacement, so the very concept of spatial displacement symmetry would be inapplicable to that universe.

And for the nuclear charge symmetry example, in a hypothetical perfectly symmetric world there would be no reference frame for differentiating protons from neutrons. (Such a reference frame would be an asymmetry.) Thus there would be no possibility of proton–neutron replacement, and the very concept of charge symmetry would be inapplicable to such a world.

[For a discussion of symmetries of the Universe, some of which are thought to be "exact," see, for instance, Lee (1981), Chapter 9.]

Degrees of freedom of the Universe that are undifferentiable within the Universe are physically identical and are but a single degree of freedom. Any conceptual differentiation involving external reference frames conceptually imposed on the Universe is of no physical significance. In short:

For the Universe as a whole undifferentiability of degrees of freedom means their physical identity.

In paraphrase: If it makes no difference to the Universe, then there is nothing else for it to make a difference to.

In the homogeneous universe example, all locations would be undifferentiable and would therefore be identical. As mentioned above, such a universe would possess no spatial dimensionality at all. We can consider 3-dimensional homogeneous spaces as mathematical models, but only by externally imposing coordinate systems on them. That cannot be done for a universe.

For the charge-symmetric-world example, protons and neutrons would be undifferentiable and would thus be identical.

4. NO COSMIC SYMMETRY BREAKING

The big-bang-type cosmological schemes currently in vogue generally have the Universe evolve through a number of distinct eras, where during each era the Universe evolves in a continuous manner, while the transition from one era to the next is supposed to have the character of a (discontinuous) phase transition. One such scheme is (for example, Narlikar, 1988, Chapters 4 and 5; Turner, 1988):

1. Quantum (or Planck) era: ??? (the less said the better).
2. GUT era: space-time, gravitation, quantum microscopic behavior,

a single interaction (single set of force particles/fields) among a single set of matter particles/fields.

3. Electroweak era: space-time, gravitation, quantum microscopic behavior, strong interaction (gluons) among quarks, electroweak interaction (set of electroweak force particles/fields) among leptons and quarks.

4. Present era: space-time, gravitation, quantum microscopic behavior, strong interaction (gluons) among quarks, weak interaction (W, Z) among leptons and quarks, electromagnetic interaction (photon) among all (electrically charged) particles/fields.

During eras 2–4 the interactions are all describable by quantum gauge field theories on space-time.

The details and fine structures of the eras and even their number are unimportant for our discussion. So if my list does not fit your favorite scheme, or even if you do not like the names I used, please feel free to make corrections. All we need for our present purpose is a number of temporally ordered eras of continuous evolution preceded by a practically unmentionable era, where each era is the result of a (discontinuous) phase transition from the preceding era.

Now, what do we mean by phase transition? Two well-used examples are crystallization and spontaneous magnetization. As a material in liquid state is cooled, its properties change continuously until (under suitable conditions) it spontaneously and discontinuously crystallizes to a solid state. Or, as a ferromagnet in an unmagnetized state is cooled, its properties change continuously until it spontaneously and discontinuously goes into a magnetized state.

In each of the examples the phase transition is, and other phase transitions might be, accompanied by spontaneous symmetry breaking, whereby equivalent degrees of freedom suddenly become inequivalent (and the symmetry group becomes a subgroup of the former one). In crystallization the system jumps from a state of no distinguished positions and directions to a state of distinguished positions and directions, whose choice is extremely sensitive to conditions and is thus effectively random. The symmetry of an effectively homogeneous and isotropic medium (the three-dimensional Euclidean group, possibly with reflections) is broken to that of a crystal lattice (one of the crystallographic space groups). In magnetization the system jumps from a state of no distinguished direction to one of a single distinguished direction, whose choice is extremely sensitive to conditions and is thus effectively random. The symmetry of an effectively isotropic chiral medium (the three-dimensional rotation group) is broken to that of an axial vector (the one-dimensional rotation group).

In each example and in general at a symmetry-breaking phase transition the volume of the system might divide into domains, whereby the symmetry breaking takes different directions in different domains. In crystallization the resulting solid might be composed of crystalline domains, in which the crystal axes are differently oriented in each one. And in spontaneous magnetization the ferromagnetic medium might divide up into magnetic domains, in which the direction of magnetization is different in different domains. Adjacent domains are separated by relatively thin transition surfaces called domain walls.

That is what can happen at ordinary-scale phase transitions during the present cosmological era here on Earth (and presumably elsewhere in the Universe). But what happened at the assumed *cosmic* phase transitions, when the *whole Universe* is assumed to have jumped from its state at the end of one era to its state at the beginning of the next? Consider, for example, the transition from the GUT era (2) to the electroweak era (3). The major change seems to have been that the single interaction (single set of force particles/fields) among a single set of matter particles/fields became the strong interaction (gluons) among quarks along with the electroweak interaction (set of electroweak force particles/fields) among leptons and quarks. Does that mean the gluons evolved from an equal number of pregluons, the ew-bosons evolved from an equal number of pre-ew-bosons, and the pregluons and pre-ew-bosons were somehow equivalent in era 2 but became inequivalent at the beginning of era 3? Does that mean the quarks evolved from an equal number of prequarks, the leptons evolved from an equal number of preleptons, and the prequarks and preleptons were somehow equivalent in era 2 but became inequivalent at the beginning of era 3? (Does that mean the symmetry group of era 3 was a subgroup of the GUT symmetry group of era 2?)

No! Our discussion in the preceding sections taught us that cosmic equivalence means identity. In era 2 there simply was no reference frame by which pregluon–pre-ew-boson and prequark–prelepton distinctions could have been possible, so there was no distinction. And that means *identity*, not equivalence. Thus there were no equivalent pregluons and pre-ew-bosons that at the phase transition became inequivalent gluons and ew-bosons. There was only a set of GUT-bosons, which at the phase transition transformed into a set of gluons and a set of ew-bosons. And similarly there was only a set of GUT-fermions, which at the phase transition transformed into a set of quarks and a set of leptons. The number of members of each GUT set of era 2 was not simply the sum of the numbers of members of the two respectively resulting sets of era 3. The particle menagerie of era 2 is open for speculation, although it seems reasonable to me to assume that the numbers of particle kinds were less than the just-mentioned sums. Indeed, the particle zoo of the electroweak era (3) is similarly open for speculation, and I would similarly assume that the numbers of particle kinds then were less than their numbers in the present era (4).

The questions at the end of the paragraph preceding the previous one are the result of extrapolating backward in time from the reference frame of era 3. Such extrapolation gives meaning to the terms used in those questions. However, such conceptual extrapolation on our part in no way obliges era 2 to conform. The transition from era 2 to era 3 is supposed to have been discontinuous, so a continuous conceptual limiting process from era 3 back to era 2 is in principle useless.

In what sense, then, can the transitions from era to era be viewed as phase transitions? Clearly not in the sense of the equivalent becoming inequivalent, i.e., not in the sense of symmetry breaking. Symmetry change—yes. Each era had and has its own characteristic symmetry expressed in terms of the degrees of freedom of that era. But the change in symmetry at a transition was not symmetry breaking (was not a change from a group to one of its subgroups). At least not if we want to keep the discontinuity of the transitions. If we choose to give up discontinuity, the cosmological scheme will have an altogether different character, and the concept of phase transition will be irrelevant. If, however, we keep discontinuity, then the only sense in which the transitions might be considered phase transitions is in their discontinuous character itself. Yet as a compensating factor we have the appearance of *new degrees of freedom.*

A by-product of discontinuous transition and the appearance of new degrees of freedom is, in analogy to what happens in laboratory phase transitions, the possibility of domaining. Space might become divided into domains, in which the "orientation" of physics in the abstract space of the new degrees of freedom is different in different domains. Such domains would be separated by relatively thin domain walls, which might be of importance for the formation of galaxy clusters. It is hard to see how thin domain walls could form as a result of continuous cosmic evolution.

Physics involves the devising of metaphors to describe reality. Our metaphors are often mathematical, but still they are metaphors. "Phase transition" is a metaphor for describing the transitions between the eras of big-bang-type cosmological schemes. In order not to be misled we are well warned not to take that metaphor (or any metaphor, for that matter) too literally. As we just saw, the "phase transition" metaphor is appropriate only in that discontinuity and the possibility of domaining are common to both cosmic transitions and ordinary-scale phase transitions. It is inappropriate in that, while ordinary-scale phase transitions might involve the equivalent becoming inequivalent, i.e., they might involve symmetry breaking, cosmic transitions cannot involve the equivalent becoming inequivalent and thus cannot involve symmetry breaking.

The reasoning of this and the preceding sections leads to the following interrelated conclusions:

Cosmological schemes cannot involve perfect symmetry for the Universe as a whole.

Thus no symmetry we consider for the present cosmic era (4), be it color-$SU(3)$ of the strong interaction or any other, can be assumed to be a perfect symmetry. Some aspect of the Universe must violate it. And the same for previous cosmic eras.

Cosmological schemes cannot involve fundamentally undifferentiable, yet still somehow different, degrees of freedom of the Universe.

We might try to imagine such degrees of freedom for previous cosmic eras by conceptually imposing upon those eras the reference frame of the present era. But that is physically meaningless, since the reference frame of the present era was not part of the Universe then. For an additional example, it is assumed that during era 3 the present electromagnetic and weak interactions were unified as a single interaction, the electroweak interaction. Then, it is assumed, the precursors of the Z weak vector boson and the photon, as different as the latter two are in the present era (4), were somehow undifferentiable while still comprising two degrees of freedom. That is meaningless.

Cosmological schemes with phase transitions between eras cannot involve symmetry breaking.

If a transition was continuous, then a perfect symmetry could not have become an approximate symmetry. And according to our conclusion there could not have been a perfect symmetry anyway. However, an approximate symmetry could have changed its approximation at a continuous cosmic transition. Thus at a continuous cosmic transition a good approximation could have worsened, perhaps *in imitation* of symmetry breaking.

If a transition was discontinuous (a "phase transition"), the character and number of degrees of freedom could have changed. Thus one (approximate) symmetry could have changed to another. But undifferentiable degrees of freedom becoming differentiable could not have occurred, since there could not have been undifferentiable degrees of freedom to begin with. So no symmetry breaking. Thus at a discontinuous cosmic transition ("cosmic phase transition") there could have occurred symmetry change, but no symmetry breaking.

It then follows that cosmological schemes that assume perfect symmetry of, or equivalently, indistinguishable degrees of freedom for, the Universe are meaningless. I am not claiming that such schemes cannot be perfectly valid schemes by the criteria of consistency with experimental data and self-consistency. Neither am I claiming that such schemes cannot be very useful and valuable in addition to their being beautiful and amazing intellectual achievements. Nevertheless, to the extent cosmological schemes assume perfect symmetry of the Universe they are indeed meaningless.

One possibility of circumventing that meaninglessness is to take such schemes as *approximate* descriptions of a situation that is not perfectly symmetric, just as a spatially homogeneous Robertson–Walker model is taken as an approximation to describe the Universe. A price to pay for that is giving up the idea, if in fact one held the idea, that such schemes could be final and exact descriptions of the Universe.

5. NO SYMMETRY RESTORATION EITHER

It is commonly taken for granted that by raising particle accelerator energies higher and ever higher, thus probing physics at higher temperatures, at shorter distances, and at shorter time intervals, we are actually investigating the conditions prevailing during previous cosmic eras. Indeed, it is assumed that if we managed to produce energies and momentum transfers high enough to probe time intervals and distances at the Planck scale (about 10^{-43} sec and 10^{-35} m), we would even be investigating the quantum era (1) itself. However, the idea that we can reconstruct past cosmological eras by investigations performed in the present era is a fallacy, as long as we are assuming discontinuous cosmic transitions.

The problem can be expressed thus: Why should the high-energy physics in the present era reflect the physics of previous eras? For a model of continuous cosmic evolution that would indeed be a reasonable assumption. We might then very well assume that by raising accelerator energies we would be reconstructing previous cosmic conditions in our laboratories. But discontinuous transitions are barriers to such "time travel." The reconstruction idea is reasonable only as far back as the beginning of the present era. Beyond that it just does not hold water.

The essence of the matter is that the physics of the present era, however high the energy might be, is still a characteristic of the present era. It is occurring in the context of the reference frame of the present era. For example, no matter how similar the photon and the Z become at higher and higher energies, they never become identical and are always distinguishable in principle. However, in the electroweak era (3) the situation was *qualitatively* different from that, as we have learned above. "Indistinguishable" as the limit of "barely distinguishable" is very different from "identical."

The reconstruction assumption is carrying the "phase transition" metaphor too far. It is true that by reheating a crystalline solid or magnetized ferromagnet we restore the symmetry that was broken at the phase transition induced by cooling. The cosmic analog would be the reheating of the whole Universe. And that is an extremely far cry from the high-energy physics of the present era, in which an infinitesimal part of the whole Universe, merely a few particles within an infinitesimal volume of space, are heated infinitesimally briefly within a cold environment.

It is not unreasonable to expect that as we go to higher energies new symmetries will turn up, so that higher-energy physics will be characterized by a higher degree of symmetry than lower-energy physics (and the symmetry group of the latter will be a subgroup of the symmetry group of the former). It is not unreasonable to hope that at sufficiently high accelerator energies the weak and electromagnetic interactions will be found to merge into a unified electroweak interaction, whose symmetry subsumes that of the distinct interactions. But it is completely baseless to assume that we are thus reconstructing past eras and thus restoring the symmetries that were assumed broken at the cosmic phase transitions. (In fact, as we saw above, there can be no symmetry breaking at discontinuous cosmic transitions.) Specifically, there is no reason whatsoever to expect that the electroweak interaction and its symmetry that we might discover at sufficiently high energies should reflect the actual situation during era 3.

Yet in order to construct *some* cosmological scheme rather than simply giving up in despair, we might, not unreasonably, assume that high-energy physics does give us some indication, however imperfect, of the situations in previous cosmic eras. We know we cannot count degrees of freedom. But perhaps we can deduce the general character of the situation. Indeed, that is how the eras presented at the beginning of Section 4 were proposed. For example, it is not unreasonable to assume that the era preceding the present one was characterized by, among its other characteristics, an interaction additional to and weaker than the strong interaction, a set of intermediate bosons (distinct from gluons) that interacted via that interaction both with quarks and with another set of matter particles that were lighter than quarks. That interaction is assumed to have transformed into the weak and electromagnetic interactions at the cosmic phase transition between the preceding era (3) and the present one (4), and so it is reasonable to call the interaction "electroweak" and the additional set of matter particles "leptons." However, that interaction is *not* the expected high-energy merger of the weak and electromagnetic interactions. It is altogether another animal. That interaction is assumed to have been a characteristic of the preceding cosmic era, while the latter is expected to be a characteristic of the present era.

High-energy physics cannot be expected to reflect precisely the situations that prevailed during earlier cosmic eras that evolved into the present era via phase transitions, although it might be indicative. Specifically, any symmetry emerging at high energies cannot have been a feature of such earlier eras.

6. THE QUANTUM ERA AND THE BEGINNING

As mentioned in the previous section, it is commonly assumed that if we succeeded in probing the Planck scale, we would be investigating the quantum era (1). Nevertheless, as we saw in the previous section, that assumption is fallacious. Yet, can anything, however general and qualitative, be reasonably deduced concerning the quantum era? What can reasonably be thought to have preceded the GUT era (2), assuming, of course, that there was indeed a GUT era and that it was the result of a discontinuous cosmic transition?

So let us assume there was a GUT era characterized by space-time, gravitation, quantum microscopic behavior, and, say (the details are not important), a single interaction (a single set of force particles/fields) among a single set of matter particles/fields. And let us consider what the high-energy physics of the present era tells us. What? We have not reached the Planck scale yet? What shirkers those experimentalists are! Never mind. Let us consider what we *think* we would find at the Planck scale. We think that at the Planck scale we would discover the fundamental quantum character of space-time, also called quantum gravity. We expect to find quantum fluctuations of the space-time metric itself, a situation suggestively called "space-time foam" (Misner *et al.*, 1973, Section 43.4). We expect to find some of the metric fluctuations leading to the "pinching off" of Planck-size regions, which become disconnected from the Universe and form "baby universes" (Linde, 1990, Chapter 3, Section 8). What those picturesque, vaguely meaningful metaphors indicate is that we think known physics, including the concept of space-time itself, utterly breaks down at the Planck scale.

Now, the assumed transitions from era 2 to era 3 and from era 3 to era 4 had the property of carrying a situation that can be considered simpler into one we might consider more complex. A single interaction in era 2 became two interactions in era 3, which then became three in the present era (4). Using that as a guide, we expect that the quantum era (1) was somehow simpler than the GUT era (2). In what way simpler? One interaction less than a single interaction is no interaction. Perhaps some protogravitation in era 1 can be viewed as splitting into gravitation and the single interaction of era 2. But gravitation is intimately connected with space-time. And the assumed results of our *gedanken* Planck-scale high-energy investigations point to the irrelevance of space-time, as we are macroscopically familiar with space and time, to the quantum era. So then macroscopic gravitation appears to be out as well.

It looks as if our surest guesses about the character of the quantum era are negative: no space, no time, no gravitation. How, then, can we conceive of *anything* about the quantum era, if we cannot do so in terms of space and time, in terms of being and becoming? (Our metaphoric description of the Planck-scale breakdown of known physics was couched in terms of space and time, of being and becoming.) One might try something like this: "The quantum era was a situation of highly quantum character, strongly fluctuating. It was unstable to fluctuations and thus underwent a transition to era 2 and space-time." But the idea of instability leading to transition implies becoming and time.

In the cosmological scheme of eras 1–4 certain properties of certain eras are supposed to have carried over, fully or partially, into the subsequent eras. For example, space-time is assumed to have carried over from era 2 to era 3 and on to the present era (4). And something of the electroweak interaction of era 3 is supposed to the reflected in the present weak and electromagnetic interactions, especially in their high-energy behavior. Furthermore, something of the assumed grand unified interaction of era 2 is supposed to be reflected in the present strong, weak, and electromagnetic interactions. The assumed describability of the era 2 interaction by a quantum gauge field theory on space-time seems to have carried over fully into the present era, since all three present interactions appear to possess that character. And presumably the very high-energy physics of the present era should reflect other relic properties of the GUT era interaction.

Now, the quantum era, too, presumably bequeathed properties to its descendants. The moderate quantum character of the present era—moderate, because it is not dominant at all scales but mostly only at the submicroscopic scale—might be thought of as a relic of an extreme quantum character of era 1. And the assumed nonspatiality and nontemporality of the quantum era might be considered to be the source of present quantum spatial and temporal nonlocality. The idea here is that according to quantum theory all locations and all times, separately, are in a certain sense equivalent. In the quantum sense all locations can be thought of as *the same location* and all times as *the same time*. Thus, for example, the fact that a measurement at one place instantaneously "affects" other places can be understood, rather than as faster-than-light propagation, better as *no propagation at all*. The "effect" of the measurement does not have to go anywhere; it is already there, since there and here are in a sense the same. But if all locations are the same location and all times the same time, the situation is reduced, in the relevant quantum sense, to zero spatiotemporal dimensionality. In other words, to nonspatiality and nontemporality.

On the other hand, as we saw above, it is reasonable not to consider space-time to be a property of the quantum era, so the spatiotemporal character of subsequent eras cannot be thought of as a quantum-era relic. The origin of space-time should then be understood to be the spontaneous appearance of new degrees of freedom at the transition from the quantum era to era 2. And those degrees of freedom are assumed to have survived the transitions from era 2 to the present.

What else can be said about the quantum era? Very little of any physical significance, it seems to me. I have emphasized elsewhere (Rosen, 1991, Chapter 4) that cosmological schemes, dealing as they do with a unique phenomenon *par excellence*, the Universe as a whole, have exceeded the domain of physics and have ventured into the domain of metaphysics. That is true *a fortiori* for considerations involving the quantum era. I do not intend to imply that cosmological schemes do not involve physics nor that they are not very useful for physics. Indeed, a successful cosmological scheme would be a marvelous achievement and would offer physicists important and useful insight and guidance. Yet given the inaccessibility of the quantum era from the present era and the current status of our cosmological understanding, it seems reasonable that the more detailed any statement about the quantum era is, the more suspect that statement should be held to be. For example, specific equations have been proposed to describe the quantum era (Casher and Englert, 1981, as an example). Such considerations actually belong to the domain of metaphysics, and, although expressed in the language of physics, they really have little, if any, physics content (Rosen, 1991, Chapter 4).

That brings us to the subject of The Beginning, as an apt ending for this article. It seems to be a common misconception that cosmological schemes of the general type of that presented in Section 4 imply the chronological sequence: (a) The Beginning, followed by (b) the quantum era, which had a duration of about 10^{-43} sec, which in turn was followed by (c) era 2, and so on. However, as we saw above, the quantum era seems best considered nontemporal. Thus it should not be thought of as having been characterized by any duration at all. The Planck time of about 10^{-43} sec is considered to be characteristic of the quantum nature of space-time in the present era. But the quantum era is neither the present era nor is reasonably considered to have possessed the property of time. The assignment of a duration to the quantum era is an unwarranted extrapolation from the present era to the quantum era. It is a conceptual imposition of a reference frame of our era on an era inherently possessing no such reference frame.

It also follows from the nontemporality of the quantum era that it cannot be thought of as having been preceded nor as having been followed by anything. From its own, nontemporal point of view the very concepts of precession and succession are meaningless for the quantum era. However, the quantum era can still be considered to have been followed by era 2 in the following carefully construed sense. Era 2 is assumed to have been characterized by time. Thus *from the temporal reference frame of era 2* the quantum era can legitimately be though of as having preceded era 2, just as era 3 is thought of as having followed era 2. Then by verbal manipulation we replace the expression "the quantum era preceded era 2" with the expression "era 2 followed the quantum era." But in both cases the temporal ordering is with respect to the reference frame of era 2.

Thus the quantum era, by its reasonably assumed nontemporality, forms a barrier to the flight of our imagination back in time in search of The Beginning. Although it can be thought of as having preceded era 2, it itself cannot be considered as having had duration. Nor are the concepts of "the beginning of the quantum era" or "before the quantum era" anything but vacuous. So The Beginning, as the beginning of the quantum era or as whatever preceded the quantum era, is utterly meaningless.

A reasonable alternative for The Beginning is "the beginning of time," in whatever sense the latter can be assigned meaning. Now, since the quantum era can be thought of as having preceded era 2, and since era 2 is thought of as having been characterized by time, the quantum era itself, or the transition from the quantum era to era 2, the transition to space-time, might be thought of as the beginning of time. The idea is that the quantum era and the transition to space-time are considered to precede any time. As far back in time as we imagine, and, using a suitable time variable, we can imagine going back in time "forever" (Rosen, 1987), the quantum era and the transition to space-time will still be considered earlier. That is the meaning we can assign to "the beginning of time." So if any need for The Beginning is felt, the quantum era, or perhaps the transition to space-time, can reasonably fulfill that need.

The quantum era can reasonably be assumed to have been nontemporal, nonspatial, and extremely quantal. The Beginning can reasonably be identified with the quantum era or with the transition to space-time.

REFERENCES

Casher, A., and Englert, F. (1981). *Physics Letters*, **104B**, 117–120.

Curie, P. (1894). *Journal de Physique* (Paris) *3 Ser.*, **3**, 393–415 [English translation, On symmetry in physical phenomena, symmetry of an electric field and of a magnetic field, in *Symmetry in Physics*, J. Rosen, ed., American Association of Physics Teachers, College Park, Maryland, 1982, pp. 17–25].

Harrison, E. (1985). *Masks of the Universe*, Macmillan, New York.

Lee, T. D. (1981). *Particle Physics and Introduction to Field Theory*, Harwood, Chur.

Linde, A. D. (1990). *Inflation and Quantum Cosmology*, Academic Press, Boston.

Misner, C. W., Thorne, K. S., and Wheeler, J. A. (1973). *Gravitation*, Freeman, San Francisco.

Narlikar, J. V. (1988). *The Primeval Universe*, Oxford University Press, Oxford.

Park, D. (1988). *The How and the Why*, Princeton University Press, Princeton, New Jersey.

Rosen, J. (1983). *A Symmetry Primer for Scientists*, Wiley, New York.

Rosen, J. (1987). *American Journal of Physics*, **55**, 498–499.

Rosen, J. (1990). *Foundations of Physics*, **20**, 283–307.

Rosen, J. (1991). *The Capricious Cosmos: Universe Beyond Law*, Macmillan, New York.

Turner, M. S. (1988). Cosmology and particle physics, in *The Early Universe*, W. G. Unruh and G. W. Semenoff, eds., Reidel, Dordrecht.