Fundamental Requirements in Building Physical Theories

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As mentioned in some of my previous essays,[1] the philosophy of science requires that any physical theory worth its salt must be built around at least *potential observability* and must obey the *reduction principle*, i.e., be capable of being shown to rest on established theories. These are logical requirements based on the *consistency of Nature.* However, if one approaches theory-building in physics from the physical rather than the philosophical side, there are some other principles to obey; and these principles are *sine qua non* requirements of proper physical theories, in the sense of transcending any particular theory. Collectively, they may be called *symmetry* and *conservation laws*; and they directly rest upon *invariances*, which are independent of time and space and which are also based on the consistency of Nature. The difference is that while the philosophical requirements are *a priori*—that is, "dictated" by induction and synthesis—the physical requirements are *a posteriori*—that is "dictated" by deduction and analysis of actual data. For the present heuristic purposes, let us concentrate on the latter kinds.[2]

Symmetry in Nature has been dealt with by some very famous authors,[3] and, likewise, *conservation laws* have also been extensively discussed.[4] Instrumentalism and its extreme form, solipsism, would proclaim that as "beauty is in the eye of the beholder," symmetry is a figment of human imagination, based on the basic human need for esthetic experiences. Scientific realism in general, and quantum realism in particular, on the other hand, would maintain that symmetry is *inherent* in Nature; and this whole disagreement in philosophical perspectives between instrumentalism and realism represents, in fact, the difference between *epistemic* and *ontic* viewpoints and orientation emphases. While there are certain difficulties with both vantage points, especially in their extreme forms, most of the data from recent research in physics seems to tilt the balance in favor of quantum realism and against instrumentalism, especially in its earlier (Copenhagen School) form.[5] Let's now briefly review, first, the theory of the basic symmetry and conservation laws, as they represent broad generalizations whereby physical theories may transcend time and space, and then list the most important principles and laws.

Based on concepts from classical geometry, the word *symmetry* implies divisibility into two or more even parts of any regular shape in 1-, 2-, or 3-dimensional ordinary (Euclidean) space. However, in physics, "symmetry" has a more precise, albeit more general, meaning than in geometry. Reversible balance is implied; that is, something has a particular type of symmetry if a specific operation is performed on it yet it remains essentially unchanged. For example, if two sides of a symmetrical figure can be interchanged, the figure itself remains basically invariant. A triangle may be moved any distance; if there is neither rotation nor expansion/contraction involved, then the triangle remains symmetrical under the operation of translation in space. This means little in (projective) geometry; but, in actual physical situations, it can be far from trivial. If we imagine an initially symmetrical shape with some weight attached to it as being moved to a different gravitational field, symmetry will not be conserved. Yet, the basic laws of physics are supposed to be independent of locations in space. And they are. What may be different are those aspects which are variable, but their interrelationships do not change. Symmetry will be conserved not relative to a fixed observer, but relative to the form in which the basic laws are expressed, i.e., their mathematical descriptions.

The inevitable conclusion is that the mathematical expressions of physical laws are responsible for ensuring that *the form of the basic laws of physics is symmetrical under the operation of translation in space.* For example, the law of conservation of momentum is a mathematical consequence of the fact that the basic laws have this property of assuming the same form at all points in space. The conservation law is a consequence of the symmetry principle, and there is reason to believe that the symmetry principle is more fundamental than the detailed form of the conservation law. A general theory, thanks to its mathematical armory in which tensor analysis and differentiable manifolds assume great importance, is able to formulate basic equations which have the property of assuming the same form at all points in space.

Therefore, when "indulging" in theory building, the theoretical physicist is well-advised to try to formulate his basic laws so that they become *and* remain symmetrical under any and all fundamental transformations. Fortunately, there are several well-known and well-established guidelines, and these are what we may subsume under the general heading of *symmetry principles* and *conservation laws.* It is important to keep in mind that conservation laws are mathematical consequences of various symmetries; thus, as long as the theorist ensures that his formulations do not violate basic principles of symmetry, he stands a good chance of being subsequently able to deduce the appropriate conservation laws and prove, at least to the satisfaction of the requirements of mathematical logic, the soundness of his conceptualizations. By contrast, failure to observe this guideline may result in heaps of impressive-looking pseudoscientific *rubbish*, as, for example, in various airy, grandiose schemes, trendy New Age fads, and hasty oversimplifications *ad nauseam.*[6] While it is true that a few symmetry principles and conservation laws are still controversial—and it is not always clear which conservation law is necessarily a (mathematical) consequence of which symmetry principle—the fact is that most of the relationships are well established, and repeated mathematical testing of various new theoretical models is not only always helpful but perhaps even *mandatory* as well. That is, before making predictions, deducing testable hypotheses, and subjecting them to observations and experiments, it is best to play the devil's advocate, trying as hard as one can to make a "liar" of oneself. This grueling task will pay grateful dividends later, by saving the theorist from self-discreditation and its inevitable consequence, death by ridicule.

Following Einstein and his postulates of special relativity, we accept that the form of the basic laws of physics is the same at all points in space. This is called *symmetry under translation in space*, and (mathematically) it leads to the *law of conservation of linear momentum.* This is one of the most fundamental principles of modern physics. Next, in a similar vein, we also accept that the basic laws of physics describing a system apply in the same form under fixed-angle rotations, i.e., the laws have the same form in all directions. We may call this the *principle of symmetry under rotation in space*, and again, (mathematically) it gives rise to the *law of conservation of angular momentum.* Now comes time—i.e., the form of the basic laws of physics does not change with the passage of time. Once a fundamental invariance is successfully identified, it can be assumed with great confidence that what was the case many millions of years ago will still be the case indefinitely into the future. This principle is called s*ymmetry under translation in time*, and (mathematically) it yields the *law of conservation of energy* (also known as the First Law of Thermodynamics). However, the next principle, that of *symmetry under reversal of time*, is somewhat controversial, because, although it is theoretically possible, it is practically never observed. The principle leads to the great Second Law of Thermodynamics through a series of steps which would be a bit too technical for the present purposes. Symmetry under time reversal maintains that a time-reversal process can occur, but it does not say that it does occur or that it ever will occur. This is a rather subtle and, thus, a much-misunderstood and disputed point, as discussed in my paper, "Conceptual Skepticism in Irreversible Energetics" (cited in Note no.1). It is precisely because symmetry under time reversal is never observed in practice, but the opposite (i.e., asymmetry and irreversibility) are always observed, that the Second Law of Thermodynamics is still one of the most controversial of the basic laws of physics. Disregarding mathematics for the moment, how theoretical reversibility gives rise to practical irreversibility in Nature remains somewhat nebulous. It is possible that irreversibility is a special case of reversibility due to a hitherto unexplained intervening construct or variable, rather than the other way around. Future research will tell, we hope.

Still another consequence of Einstein's special relativity theory is that the basic laws of physics have the same form for all observers, regardless of the observers' motions. In other words, the basic laws have the same form in all inertial frames of reference and, thus, do not depend on the velocity or momentum of the observer. In Einstein's general theory of relativity, which is not as well substantiated as the special theory, the basic laws are assumed to have the same form for all observers, no matter how complicated their motions might be. Altogether, this is the *principle of relativistic symmetry*.

Turning to microphysics, it must be considered that fundamental particles have no individual differences in the sense of "identities," i.e., if we interchange two particles of the same class or category (*vide infra*), such action does not influence the physical process as a whole. This indistinguishability of similar particles gives rise to the *principle of symmetry under interchange of similar particles.* An electron is no different from any other electron. Furthermore, if negative charge cancels an equal amount of positive charge, then there is no known physical process which can change the net amount of electric charge. This is known as the *law of conservation of electric charge*, and it is thought to be a (mathematical) consequence of certain symmetry properties of the quantum mechanical wave function psi (ψ). Similarly, if a particle cancels its antiparticle, there is no known physical process which changes the net number of leptons (light particles); this is known as the *law of conservation of leptons*, although an underlying symmetry principle has not been unequivocally established. In a similar vein, also in particle-antiparticle cancellations, the net number of baryons (heavy particles) remains the same; this is the *law of conservation of baryons*, and similarly to leptons, no underlying symmetry principle has been properly established. It is noteworthy that, while there are conservation laws for fermions, there are no such laws for bosons, photons, pions, kaons, etas, and gravitons.

There are also *imperfect symmetries*, which may or may not be intrinsic to Nature. That is, it is possible that Nature is "constructed" according to a scheme of partial or imperfect symmetry, whereby irreversibility would be the rule and reversibility the exception. It is more probable, however, that things are the other way around (reversibility is the rule and irreversibility is the exception), and the fault lies within our own machinery, as mentioned in some of my other writings (see Notes). One such imperfect symmetry is *charge independence.* There is a *principle of symmetry of isotopic spin*, whose (mathematical) correspondent is a *law of conservation of isotopic spin*. This law applies to strong nuclear interactions but is broken by electromagnetic and weak interactions. Also, there are then processes which involve what have come to be called the *strange* particles; and to each particle, an integral number has been assigned, known as its strangeness. The *law of conservation of strangeness* is also an imperfect symmetry, inasmuch as strangeness is conserved in strong interactions but not in weak interactions. However, the very *particle-antiparticle symmetry* turns out to be a broken or imperfect symmetry, because all weak interactions violate it; and there is no fully satisfactory explanation for this imperfect charge conjugation.

The *principle of mirror symmetry* maintains that for every known physical process, there is another possible process which is identical with the mirror image of the first. Yet, this can also be a broken or imperfect symmetry, depending on "handedness"—inasmuch as one cannot put a left-hand glove on the right hand, no matter how much one glove may seem like the mirror image of the other. Mirror symmetry can be expressed mathematically in terms of a quantity called parity, and there is a corresponding *law of conservation of parity*. However, weak interactions do not conserve parity, even though all other types of interactions do. One example is that, although the neutrino and the antineutrino are mirror images of one another, the neutrino is like a left-hand glove and the antineutrino is like a right-hand glove. Generally speaking, all weak interactions violate the symmetry principle of mirror reflection. All weak interactions violate the symmetry principle of particle-antiparticle interchange. All interactions, including weak interactions, are symmetrical under the combined operation of mirror reflection plus particle-antiparticle interchange.[7]

Despite such "violations" and "broken symmetries," when the universal "big picture" is contemplated, symmetries outweigh asymmetries sufficiently to restore one's faith in the esthetic beauty and efficient elegance of Nature. Although asymmetries are cosmological in origin, recent advances in cosmology[8] somehow seem to fit integrally into the overall scheme of things and, thus, represent no violations of any great law. Rather, they help to give rise to them and to maintain them in a sort of dynamic equilibrium, however unbalanced certain parts of the whole seem to be from time to time or even all the time. Therefore, it seems reasonable to conclude that the more we come to understand the fundamental nature and ways of the Universe, the more we may become enchanted by its intrinsic beauty and harmony on the grandest, as well as the minutest, scales, whereby we may even catch an occasional glimpse of Eternity.

NOTES

1. Frank Luger, "The Futility of Lambasting Balaam's Ass," *Telicom* 14, no. 2 (September 2000): 12-22; Frank Luger, "Conceptual Skepticism in Irreversible Energetics," *Telicom* 15, no. 2 (December 2000): 46-56.

2. The philosophical requirements of potential observability and the reduction principle will be dealt with in another essay, which will examine the connection between the philosophy of quantum mechanics and that of modern interactional psychology, more or less within the framework of General Systems Theory.

3. Hermann Weyl, *Symmetry* (Princeton University Press, 1952); E. P. Wigner, "The Unreasonable Effectiveness of Mathematics in the Natural Sciences," in *Symmetries and Reflections: Scientific Essays of Eugene P. Wigner* (Bloomington: Indiana University Press, 1978); John Ziman, *Reliable Knowledge: An Explanation of the Grounds for Belief in Science* (Cambridge: Cambridge University Press, 1978).

4. Richard Feynman, *The Character of Physical Law* (Cambridge, MA: The M.I.T. Press, 1965); Max Jammer, *The Philosophy of Quantum Mechanics: The Interpretations of Quantum Mechanics in Historical Perspective* (New York: Wiley, 1974); Victor F. Weisskopf, *Knowledge and Wonder: The Natural World as Man Knows It* (Cambridge, MA: The M.I.T. Press, 1979); John Ziman, *Reliable Knowledge: An Explanation of the Grounds for Belief in Science* (Cambridge: Cambridge University Press, 1978).

5. Sir Alan H. Cook, *The Observational Foundations of Physics* (Cambridge: Cambridge University Press, 1994); Bernard d'Espagnat, *Reality and the Physicist*, trans. J. C. Whitehouse (Cambridge: Cambridge University Press, 1989); Stephen Hawking, *A Brief History of Time: From the Big Bang to Black Holes* (New York: Bantam, 1988); Rudolf Peierls, *More Surprises in Theoretical Physics* (Princeton, NJ: Princeton University Press, 1991); Fritz Rohrlich, *From Paradox to Reality: Our Basic Concepts of the Physical World* (Cambridge: Cambridge University Press, 1989); Steven Weinberg, *The Quantum Theory of Fields*, Vols. 1-3 (Cambridge: Cambridge University Press, 1995, 1996, 2000).

6. Fritjof Capra, *The Tao of Physics* (New York: Bantam, 1975); Paul A. LaViolette, *Beyond the Big Bang: Ancient Myth and the Science of Continuous Creation* (Rochester, VT: Park Street Press, 1995); Gary Zukav, *The Dancing Wu Li Masters: An Overview of the New Physics* (New York: Bantam, 1980).

7. D. I. Blokhintsev, *Questions of Principle in Quantum Mechanics and Measure Theory in Quantum Mechanics* (Moscow: Science, 1981); Robert Eisberg and Robert Resnick, *Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles*, 2nd ed. (New York: Wiley, 1985); Peter R. Holland, *The Quantum Theory of Motion: An Account of the de Broglie-Bohm Causal Interpretation of Quantum Mechanics* (Cambridge: Cambridge University Press, 1993); Cesar Gómez, Marti Ruiz-Altaba, and German Sierra, *Quantum Groups in Two-Dimensional Physics* (Cambridge: Cambridge University Press, 1996); Donald A. McQuarrie, *Quantum Chemistry* (Mill Valley, CA: University Science Books, 1983).

8. John D. Barrow, *The Origin of the Universe: Science Masters Series* (New York: Basic Books, 1994); James Binney and Scott Tremaine, *Galactic Dynamics* (Princeton, NJ: Princeton University Press, 1987); Stephen Hawking, *A Brief History of Time: From the Big Bang to Black Holes* (New York: Bantam, 1988); Stephen Hawking, *Black Holes and Baby Universes and Other Essays* (New York; Bantam, 1993); Stephen Hawking and Roger Penrose, *The Nature of Space and Time* (Princeton, NJ: Princeton University Press, 1996); William J. Kaufmann III, *Relativity and Cosmology*, 2nd ed. (New York: Harper & Row, 1985); Roger Penrose and Wolfgang Rindler, *Spinors and Space-Time, Volume 2: Spinor and Twistor Methods in Space-Time Geometry* (Cambridge: Cambridge University Press, 1993); W. Rindler, *Essential Relativity: Special, General, and Cosmological* (New York: McGraw-Hill, 1977); Robert M. Wald, *Space, Time, and Gravity: The Theory of the Big Bang and Black Holes* (Chicago: Chicago Press, 1977).