WHAT EINSTEIN WANTED

Nicholas RESCHER

ABSTRACT: Einstein envisioned a clear difference between a bottom-up physics that moves from observations to the conjecture of explanatory generalizations, and a top-down physics that deploys intuitively natural principles (especially of economy and elegance) to explain the observations. Einstein's doubts regarding standard quantum mechanics thus did not simply lie in this theory's use of probabilities. Rather, what he objected to was their status as merely phenomenological quantities configured to accommodate observation, and thereby lacking any basis of derivation from considerations of general principle.

KEYWORDS: quantum theory, probability, phenomena, principles, rationalization

I. Einstein's Discontent

Albert Einstein always thought that the quantum theory in its then-standard formulation offered no more than a phenomenological observation-descriptive account of reality, bereft of any grounding rationale on the basis of fundamental principles.[1] And Einstein disdained as scientifically insufficient and inadequate any theory which (as one recent expositor puts it) "owes its original to [mere] 'facts of experience'… [since] however compelling these may be, physicists then still did not have a 'general theoretic basis' capable of providing a logical foundation for the phenomenology at issue."[2] Einstein was intent upon explanatory understanding and therefore steadfastly rejected any observationality

[1] See Jeroen van Dongen, *Einstein's Unification* (Cambridge: Cambridge University Press, 2010), 177-78. It may be of incidental interest that the writer can himself claim a somewhat curious family connection with Einstein. For there once lived in Adingen, in the Neckar valley in the Swabian region of Germany, one Salomon Pappenheimer (1794-ca. 1870) – a merchant and the richest man in town. He married three times. His first wife died in childbirth. His second wife was Sarah Rescher (1805-1834) of my family, who died enroute to a visit in North America when her ship foundered in a storm. He thereupon married his third and last wife. She was Margot Einstein (1806-1868) of the family of the great Albert.

[2] Van Dongen, *Einstein's Unification*, 125.

bottom-up, merely phenomenological empiricism. As that just-cited expositor puts it:

> He remained convinced that his program – his top-down approach, based on maxims of simplicity and naturalness … was a promising alternative that in the end would carry the day.[3]

On this basis Einstein was deeply discontent with quantum theory in its Bohr/Copenhagen version by having what has been characterized as "a methodological discomfort with the nature of its recourse to probabilities."[4] He resisted the introduction of underived probabilities into quantum physics because – as he himself put it – "I still believe in the possibility of a model of reality – that is to say, of a theory which represents things themselves and not merely the probability of their occurrence."[5] He thus viewed the probabilistic description of quantum phenomena as not so much incorrect as incomplete because in admitting probabilities as basic given facts in physics, quantum theory failed to do justice to reality's descriptive definiteness of condition.

As Einstein affirmed in a 1929 address:

> I admire in the highest degree the achievement of the younger generation of physicists which goes by the name of quantum mechanics, and I believe in the deep level of truth of that theory, but I believe that its restriction to statistical laws will be a passing one.[6]

Maintaining that "God does not play dice with his universe," Einstein insisted that probabilities ought not to be introduced into physical theory as underived givens – or, perhaps better, *takens* – but should be accounted for in nonprobabilistic terms. Accordingly, Einstein told Peter Bergmann in 1949 that "I am convinced that the probability concept must not be introduced into the description of physical reality as primary [i.e. without derivation from plausible nonprobabilistic conditions]."[7] As he saw it, probabilities as such are never basic, and his battle-cry was: *ad*

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[3] Van Dongen, *Einstein's Unification*, 174.

[4] Van Dongen, *Einstein's Unification*, 177-78.

[5] Cited in Van Dongen, *Einstein's Unification*, 177.

[6] Alice Calaprice (ed.), *The Expanded Quotable Einstein* (Princeton: Princeton University Press, 2000), 246. The original edition (drop "Expanded") appeared in 1996 and a later revision (change "Expanded" to "New") in 2005.

[7] See van Dongen, *Einstein's Unification*, 154-55.

probabilitatem esse deducendam: probability always is – or should be – something derivative. But how derivative, and deducible from what?

To answer this question it is – strange to say! – expedient and instructive to go back to the very origin of modern physics in the 17th century, albeit not to Newton but to Leibniz.

II. The Leibnizian Project

Leibniz regarded physics as an applied mathematics – or perhaps better, an enriched mathematics – one that is enlivened by its enmeshment with matters of existence in the real world. He writes: "There is nothing which is not subordinate to number; Number is thus like a metaphysical figure (*numerus quasi figura metaphysica est*) and arithmetic is a kind of statics of the universe by which the powers of things are discovered."[8] And as Leibniz saw it, the mathematicizing of nature is subject to certain basic principles. Nature has a vast host of problems to solve in the determination of her *modus operandi*. And this determination will have to align with an array of fundamental parameters of rational merit as encapsulated in certain basic principles of rational systematization.[9] Like Einstein long after him, Leibniz envisioned a rational universe.

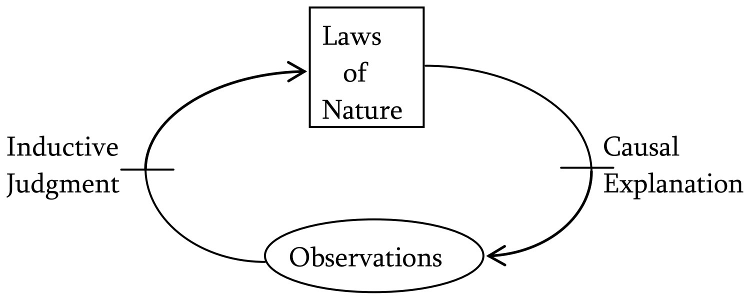
The Leibnizian program in physics accordingly sought to dig through to a stratum deeper than that of the Newtonian synthesis. For Newton's own program in physics was essentially that of the ancient Greek mechanicians and astronomers. With Archimedes and Ptolemy, it asks "What laws of nature can we stipulate to 'save the phenomena' by providing an adequate accounting for why

[8] GP VII 184. Citations in this style refer to C. I. Gerhardt, ed., *Die philosophischen Schriften von G. W. Leibniz*, 7 vol.'s (Berlin: Wiedmann, 1875-90).

[9] The principal secondary sources bearing upon Leibniz's physics include: Martial Gueroult, *Dynamique et métaphysique leibniziennes* (Paris: Les Belles Lettres, 1934); George Gale "The Physical Theory of Leibniz," *Studia Leibnitiana* 2 (1970): 114-127; Diogenes Allen, "Mechanical Explanations and the Ultimate Origin of the Universe Accordingly to Leibniz," *Studia Leibnitiana*, Sonderheft 11 (Wiesbaden: Franz Steiner, 1983); Hans Poser, "Apriorismus der Prinzipien und Kontingenz der Naturgesetze: Das Leibniz-Paradigma der Naturwissenschaft," in *Leibniz' Dynamica*, ed. Albert Heinekamp (Stuttgart: Franz Steiner, 1984; *Studia Leibnitiana* Sonderheft 13), 164-79; Herbert Breger, "Symmetry in Leibnizian Physics," in *The Leibniz Renaissance* (Firenze: Leo S. Olschki, 1989), 23-42; and Francois Duschesneau, *Leibniz et la méthode de la science* (Paris: Presses Universitaires de France, 1993).

our observations are as they are?" And it addresses this question as per the pattern of Display 1.[10]

Display 1
CLASSICAL SCIENTIFIC SYSTEMATIZATION



There is an elegant equilibrium here. The phenomena instantiate and illustrate the operation of the laws, the laws determine and account for the phenomena. And in this neat arrangement there is both ontological and epistemological closure. However, Leibniz sought to go even further, taking a more ambitious line, one which in effect says: "Fine. Let's give this program our efforts. But let us then suppose we are successful in getting a grasp on nature's laws. Then there still remains the question: "Now viewing these laws themselves as our 'phenomena' how can we best 'save' *them* – how can we account for these laws themselves?"

And so even as standard physics studies nature's phenomena via observation and experimentation to discern the laws governing nature's phenomenal modus operandi, so Leibnizian physics studies nature's laws in thought-experimental deliberation to discern the "archi-tectonic" principles of rational economy and factual efficacy governing nature's lawful modus operandi. As Leibniz himself put it:

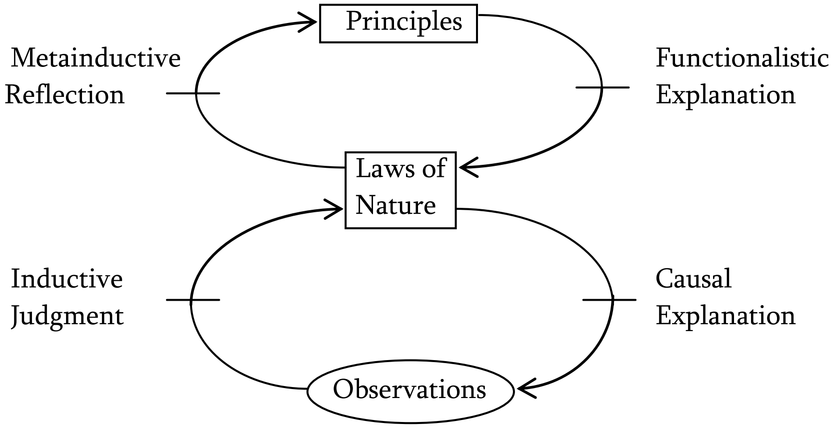
> We can see the wonderful way in which metaphysical laws of cause, power, and action are present throughout all nature and how they pre dominate over the

[10] The given schematic enfolds, sight unseen, the crucial stage of applicative testing of the laws leading either to confirmation or replacement/revision.

> purely geometric laws of matter themselves, as I found to my astonishment (*admiration*) when I was explaining the laws of motion.[11]

And so as Display 2 shows, Leibnizian physics augments classical physics by superimposing upon it an added cycle of systematization consisting in a meta-inductive step to a set of explanatory principles that make it possible to account for the laws of nature. Even as classical physics seeks to 'save the phenomena' by addressing the question of why the observations are as they are, so Leibnizian

Display 2
LEIBNIZIAN SCIENTIFIC SYSTEMATIZATION



physics seeks to provide a scientifically cogent and rationally plausible answer to the question of why the laws of nature are as they are.[12]

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[11] GP VII 305. Trans. in L. E. Loemker, ed., *Leibniz: Philosophical Papers and Letters*, 2 vol.'s (Chicago: University of Chicago Press, 1956); 2nd edition in one volume (Amsterdam: Reidel, 1970), 488-89. (Henceforth cited as simply Loemker.)

[12] Leibniz himself then took the further step of adding yet another cycle of systematization that proceeds in theological terms to provide a rational explanation of the explanatory principles themselves. As he put it in a 1679 letter to Christian Philip:

For my part I believe that the laws of mechanics which serve as foundation for the whole system [of physics] depend upon final causes, that is to say, on the will of God determined to do what is most perfect ... (GP IV 281-82 (Loemker 273).)

As Leibniz saw it, the world exists as is because God has chosen to create it that way. And God has so chosen it because that particular world design is optimal. Now here one could, in theory eliminate the middle man and move directly from optimality to existence. In a post-Kantian, not to say post-Nietzschean world, such a sidelining the deity may have a certain

As Leibniz saw it, such principles of rational design as those of continuity, of conservation, and of least effort can both guide our researches into nature's laws and provide a framework for understanding and explaining the results of our investigations: they both serve to explain nature's mode of operation and provides evidential quality-control for our investigative hypotheses. It was on this basis that Leibniz said such things as:

> All natural phenomena could be explained mechanically [i.e., scientifically] if we understood them well enough, but the principles of mechanics themselves cannot be so explained … since they depend on more substantive [i.e. deeper] principles. (*Tentamen anagogicum*, GP VII 271 (Loemker 478).)

Leibnizian physics is thus a two-tier affair. It sees the world's phenomena as explicable by the laws of nature, but has it that these laws themselves are to be explained with reference to fundamental principles of rational coherence. As Leibniz himself put it:

> All the particular phenomena in nature could be explained mechanically if we were capable enough… But I hold, nevertheless, that we must also consider how these mechanical principles and general laws of nature themselves arise from higher principles and cannot be explained by quantitative and geometrical considerations alone.[13]

What Leibniz ardently wanted was a functional account showing the physical laws of nature as we have them to be the optimal means of satisfying basic principle of operational economy – and so for classic physics to be exhibited as the best solution of a problem of rational design.

Considerations of rational intelligibility ('sufficient reason') – broadly understood to encompass such factors of rational economy at large, conservation, and symmetry [e.g., of action and reaction) – provide the driving impetus of Leibnizian physics. And here, as Leibniz saw it, the prime principles are those listed in Display 3. For what Leibniz emphasized in his physics was not just the lawfulness of nature, but the lawfulness of nature's laws – their systemic

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appeal. But this view of the matter just was not Leibniz's – no matter how insistently Bertrand Russell thought it should have been. To be sure, a purely naturalistic Leibnizianism would of course refrain from taking this further, theological step, but for Leibniz himself it was crucial. In any case, for Einstein's version of exactly this selfsame picture see van Dongen, *Einstein's Unification*, 51-57.

[13] GP IV 391 (Loemker 409).

harmonization within a systemic order as geared to principles of rational intelligibility. The salient and characteristic goal of Leibnizian physics is accordingly oriented to the discovery of deeper physical – or, rather, *metaphysical* – principles for grounding Nature's laws. Its key aim is not just the *discovery* of laws via *phenomena* but preeminently the *explanation* of laws via *principles*. And he set out to deploy such eco nomic and aesthetic principles to account for the explanation of laws. For in Leibnizian physics, the situation is that, first, the laws as best we can discover them be used as a launching-platform for discerning the appropriate principles, and thereupon that these principles can and should be deployed to explain how and why it is that those laws are what they are.[14] To be sure, there is circularity here, but it is supportive and substantive, and not vicious.

Display 3
LEIBNIZIAN PRINCIPLES

- *Fertility* (variety, abundance, diversity, complexity)[15]
- *Economy and Simplicity* (least effort, ease of operation, greatest efficiency, least time, least action)
- *Continuity* (gaplessness, amplitude)
- *Definiteness* (specificity, precision, mini-max determinacy)
- *Uniformity* (regularity)
- *Consonance* (simplicity, uniformity, consistency, regularity)
- *Conservation* (equivalence of action and reaction and generally of the *causa plena* and *effectus integer*)[16]
- *Elegance* (symmetry, harmony, balance)

Accordingly, Leibniz has it that:

> Although all the particular phenomena of nature can be explained mathematically or mechanically… it becomes increasingly apparent that

[14] Although Leibniz holds that it lies in our power to see how the fundamental principles of natural philosophy can, at least in principle, account for the laws of physics, it is beyond our power to see how they account for nature's particular detail. This insight is reserved for God alone. On this issue see Hans Poser, "Apriorismus."

[15] The duly balanced combination of all of these factors is what Leibniz calls *harmony*, which is for him, the hallmark of perfection.

[16] On this principle see especially Leibniz's letter to de l'Hôpital of 15 January 1696 (GM II 308).

> nevertheless the general principles of corporeal nature and of mechanics are themselves of metaphysical rather than merely geometrical form.[17]

The insistence not just on the lawfulness of nature but on the higher-order lawfulness of nature's laws is the hallmark of Leibnizian physics.

Leibniz insisted that the natural world is designed to function efficiently and economically, and for this reason its investigation must proceed on the principle that "the best hypothesis is that which plans the most phenomena in the simplest way."[18] Rational economy lies at the core: even sufficient reason has its economic dimension. (Why have something be so if one can losslessly dispense with it – i.e., if there is no good reason for its being so?) Leibniz thus envisioned such principles as formative constraints on the laws of nature. For they are not merely or only matters of mathematical elegance but manifest the pressure of rational economy on nature's modus operandi. Given this gearing to the modus operandi of intelligence, the metaphysics of optimality and the epistemics of rational intelligibility stand coordinate with one another in Leibniz's thought.[19]

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[17] "Discourse of Metaphysics," §18; GP IV 444 (Loemker 315).

[18] See the preface to Leibniz's edition of *Nizolius* and compare Massimo Mugnai, *Introduzione alla filosofia di Leibniz* (Torino: G. Einaudi, 2001), esp. 152-63.

[19] Many thoughtful people have over the years taken much the same line. Thus in addressing a university convocation in the late 1800's Joshua L. Chamberlain (Civil War hero, Governor of Maine, and Bowdoin University president) said:

Sooner or later … they [our men of science] will see and confess that these laws along whose line they are following, are not forces, are not principles. They are only methods … Laws cannot rightly be comprehended except in the light of principles … Laws show how only *certain* [limited] ends are to be reached; it is by insight into Principles that we discover the great, the integral ends … Now the *knowledge of these Laws* I would call *Science* but the *apprehension of Principles* I would call *Philosophy*, and our men of science may be quite right in their science and altogether wrong in their philosophy. (Quoted in W. M. Wallace, *Soul of the Lion: A Biography of General Joshua L. Chamberlain* (Edinburgh: Thomas Nelson & Sons, 1960), 232-33.)

The perspective at issue here is in much the same spirit as the more profoundly developed ideas of Leibniz, who did, however, see Principles as still belonging to *natural* philosophy and thus to science itself.

III. Leibniz's Implementation of his Program

The Mechanics of Rebound

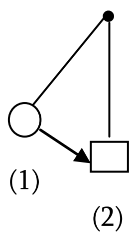
Consider the issue of ball-bouncing in mechanics. And let us start with a billiard-table cushion here. Nature faces the following problem:

> To propel a ball from point *X* to point *Z* by bouncing it off the cushion. Which path is Nature to choose? What impact-point *Y* is to be appropriate here?

The most "convenient" path is of course the shortest – which is also the fastest when the ball moves at a constant velocity. And it is exactly this path – the one which, as it were, maximized the economy of effort that Nature in fact chooses, with its characteristic feature that the angle of incidence equals the angle of rebound.

Again, let it be that a suspended moving elastic object meets a suspended standing one as per the diagram of Display 4. First let it be that the moving object (1) has greater mass then the standing one (2). Then on Cartesian principles (i) they will both move in the direction of the heavier, and (ii) if the moving object has less mass then the standing one, then the later will remain in place while the former bounces back in the direction from which it came. But there are problems here.

Display 4
IMPACT INTERACTION



For so reasons Leibniz, if the difference in masses be only a minuscule amount (∈) in object (1)'s favor then the motion of object (1) after impact will be →, but if object (2) is even minimally the more massive object (1)'s motion after impact will be ←. An infinitesimal difference in input will have a substantial difference in result. This violates Leibniz's principle of continuity thereby also violates simplicity in specifying a significantly different modus operandi in fundamentally analogous cases. For Leibniz the Principle of Continuity provided for a uniformity of result that insists on the same outcome coming from different directions of approach. Accordingly, this principle was the Archimedean fulcrum that he used to dislodge the principles of Cartesian physics.[20]

The Optics of Reflection and Refraction

As Leibniz saw it, the principle of processual efficiency also governs laws that describe the motion of light. He put the matter as follows in his *Discourse on Metaphysics*:

> Snell, who first discovered the rules of refraction, would have waited a long time before discovering them if he first had to find out how light is formed. But he apparently followed the method which the ancients used for catoptrics, which is in fact that of final causes … For when, in the same media, rays observe the same proportion between sines (which is proportional to the resistances of the media), this happens to be the easiest or, at least, the most determinate way to pass from a given point in a medium to a given point in another. And the demonstration Descartes attempted to give of this same theorem by way of efficient causes is not nearly as good.[21]

And the same efficiency principle of time minimization obtains in refraction when rays of light travel from one medium into another – say from air to water. Here nature's modus operandi obeys 'Snell's Law' which proportions the angles of reflection resistance and refraction to the density of the medium at issue, a relationship that once again maximizes efficacy by minimizing transit time.[22]

Leibniz ardently espoused this extremal, efficiency-oriented perspective, and he reproached Descartes with having used (in accordance with the Cartesian program) a more clumsy mechanical method in the derivation of Snell's law, instead of the more elegant *a priori* principle of least time or distance.[23] As he saw it, those Newtonian process-descriptive phenomenological laws of physics are to be derived from deeper, rationally cogent principles.

But how did this work out? Here some historical background is relevant.

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[20] See in particular his *Critical Thoughts on the "Principles" of Descartes*, GP IV 354-92, esp. 375 (Loemker 397-98).

[21] "Discourse of Metaphysics," §22, G IV 447-48 (Loemker 317-18).

[22] The law in question was stated by Willebrord Snell in 1621.

[23] "*Tentamen anagogicum*," GP VII 274 (Loemker 478).

IV. The Leibnizian Heritage: Rational Mechanics

In the 1740s P.L.M. de Maupertuis enunciated the principle of least action and used it to ground Fermat's principle and derive Snell's law in optics. His discussion was soon extended and generalized by Leonard Euler, who thereupon represented the principle as fundamental and applicable to all physical systems and not merely to light. In 1751 Maupertuis' claims to priority were challenged by J. S. Koenig who cited a 1707 letter from Leibniz to – describing results tantamount to those in Euler's 1744 paper. This publication created an intense priority dispute. Maupertuis and his supporters demanded that Koenig produce the original of the Leibniz letter, and when Koenig could only produce copies of this and related letters there was a sharp reaction. As president of the Berlin Academy, Euler himself accused Koenig of forgery. And the Academy declared the letter spurious and sustained Maupertuis' claim to priority for the principle of least action. Koenig however, continued to defend Leibniz's claim and various eminent figures – including Voltaire and Frederic II of Prussia – took sides in the quarrel, the former defending Koenig and the latter Maupertuis. The matter stood on an indecisive footing for some 150 years until it was settled by modern Leibniz scholars who discovered contemporary copies of those Leibniz letters cited by Koenig in various archives.[24]

Leibniz's vision of a physics based on principles certainly found traction. The value of the principle of least action lies in its unifying effect; it provides a basis for the axiomatic development of large sections of physical theory. Here Leibniz's insights were extended by Maupertuis, and in Lagrange's *Méchanique analytique* the principle of least action was shown to be a sufficient basis for the deduction of the laws of mechanics, and the work of Hamilton extended this result to optics and dynamics. Some idea of the power of this principle can be gained from the following except from a paper in which Hamilton presented his results on optics to the Royal Irish Academy in 1824:

> Those who have meditated on the beauty and utility, in theoretical mechanics, of the general method of Lagrange, who have felt the power and dignity of that central dynamical theorem which he deduced in the *Méchanique analytique* …, must feel that mathematical optics can only then attain a coordinate rank with mathematical mechanics…, when it shall possess an appropriate method and become the unfolding of a central ide… It appears that if a general method in

[24] On the historical issues see Philip E. B. Jourdain, *The Principle of Least Action* (Chicago: Carus, 1913). See also Carnetius Lanczos, *The Variational Principle of Mechanics* (New York: Dover, 1986).

> deductive optics can be attained at all, it must follow from some law of principle, itself of highest generality, and among the highest results of induction…, (This) must be the principle, or law, called usually the Law of Least Action.[25]

In the hands of the great masters of classical mathematical physics – Euler, Lagrange, Laplace, Gauss, and Hamilton – the Principle of Least Action became the mainstay of rational mechanics. And the work of Gibbs and Mach further amplified its role.[26] But from the very outset, Leibniz had already envisioned its significance and that of the general minimax principle from which it derived. However, as the 19th century moved along, other ideas and other paradigms came into prominence and by its end principles like minimax, economy, simplicity, and least action were not greatly in vogue.

Moreover, a surprising revival has transpired in the later years of the 20th century. Various capable scientists have found their way back into a Leibnizian state of mind. Simplicity, fertility, and lawful order are back in vogue. Einstein wrote that "experience justifies one belief that nature is the realization of the simplest mathematical ideas that are reasonable."[27] The astronomer Mario Livio proposes a "cosmological aesthetic principle" encompassing such functions as simplicity, symmetry, continuity. The physicist Anthony Zee has the universe continuing in creative terms such functions as "unity and diversity, absolute perfection and boisterous dynamism, symmetry and lack of regularity."[28] And the physicist Freeman Dyson maintains that nature's simple laws appear to be designed to "make the universe as interesting as possible."[29] Cosmologists Julian Barbour and Lee Smolin see the universe as exhibiting order amidst "extremal

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[25] Quoted from the article "Light," *Encyclopedia Britannica*, eleventh edition.

[26] For an overview of this historical development see Ernst Mach, *Die Mechanik in ihrer Entwicklung* (Leipzig: Brockhaus, 1901), and also Jourdain, *The Principle of Least Action*.

[27] Quoted in Mario Livio, *The Accelerating Universe* (New York: John Wilem, 2000), 34. Einstein speculates that considerations of simplicity alone may determine the laws of nature: "What really intrigues me is whether God could have created the world any differently; in other words; whether the demand for logical simplicity leaves any freedom at all." Calaprice, *The Expanded Quotable Einstein*, 221.

[28] Anthony Zee, *Fearful Symmetry* (Princeton: Princeton University Press, 1999), 211.

[29] Quoted in John Horgan, *Rational Mysticism: Spirituality Meets Science in the Search for Enlightenment* (New York: Haughton Mifflin, 2003), 172.

variety."[30] The idea of a physical domain subject to the rational efficacy and economy at work in Leibnizian physics is still alive and stirring.[31]

V. Einstein's Penchant for Principles

But let us now return to Einstein. The Leibnizian distinction between descriptively empirical phenomenological laws and the underlying rational principles that they instantiate and implement actually played a key role in Einstein's thought. In his oft-cited London *Times* note of 28 November 1919 he discussed the epistemology of physical theories and emphasized the distinction between "constructive" or merely empirical theories based only on observation and "principle theories" that have a cogent rationale for being as is. And he insisted that those principle theories "have greater logical perfection and security in their foundations."[32] And Einstein went on to maintain:

> My interest in science was always essentially limited to the study of principles … That I have published so little is due to this very circumstance, as the need to grasp principles has caused me to spend most of my time on fruitless pursuits.[33]

Writing to Paul Ehrenfest in 1925, Einstein described himself as a "principle-fanatic" (*Prinzipienfuchser*").[34] Einstein's principles went beyond anything that constitutes a physical "law" as ordinarily construes (i.e., as a mathematical relationship between physical parameters of some sort, like $F = ma$ or action = reaction). As early as 1919 he wrote:

> Along with this most important class of theories there exists a second, which I will call "principle-theories." These employ the analytic, not the synthetic, method. The elements which form their basis and starting-point are not hypothetically constructed but empirically discovered ones, general characteristics of natural processes, principles that give rise to mathematically formulated criteria which the separate processes or the theoretical representations of them have to satisfy. Thus the science of thermodynamics seeks by analytical means to deduce necessary conditions, which separate events have to satisfy, from the universally experienced fact that perpetual motion is impossible.

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30 Julian Barbour and Lee Smolin, "Extremal Variety as the Foundation of a Cosmological Quantum Theory," published on the web at http: arxiv.org/hep-th/9203041.

31 I owe some of these references to William C. Lane.

32 Cited in van Dongen, *Einstein's Unification*, 50.

33 To Maurice Solomon in 1924. See Calaprice, *The Expanded Quotable Einstein*, 245.

34 See van Dongen, *Einstein's Unification*, 162-63.

Among the fundamental principles of physics at work in Einstein's thought were "simplicity" and the "economy" of process which harked back to Ernest Mach's conception of physics, and beyond him to the tradition of rational mechanics.[35] As he saw it, "nature is the realization of the simplest conceivable mathematical ideas [that serve for an explanation of certain fundamental facts]."[36] And he accordingly affirmed that:

> I believe that [nature's] laws are *logically simple* [his italics] and that trust in this logical simplicity is our best guide, so that it suffices to proceed from only a few empirical data. If nature were not arranged correspondingly to this belief, then we would have no hope at all of achieving any deeper understanding.[37]

In conversations with Valentin Bargmann, Einstein repeatedly insisted that his efforts in unified field theory were attempts to find the simplest theory in a given class.[38] Rational economy via what Einstein himself termed the "logical simplicity" of theories was his guiding star. In his 1933 Herbert Spencer lecture at Oxford, "On the Methods of Theoretical Physics," Einstein declared "Our experience hitherto justified us in believing that nature is the realization of the simplest conceivable mathematical ideas. I am convinced that we can discover by means of purely mathematical construction the concepts and laws connecting them with each other which furnish the key to the understanding of natural phenomenon."[39]

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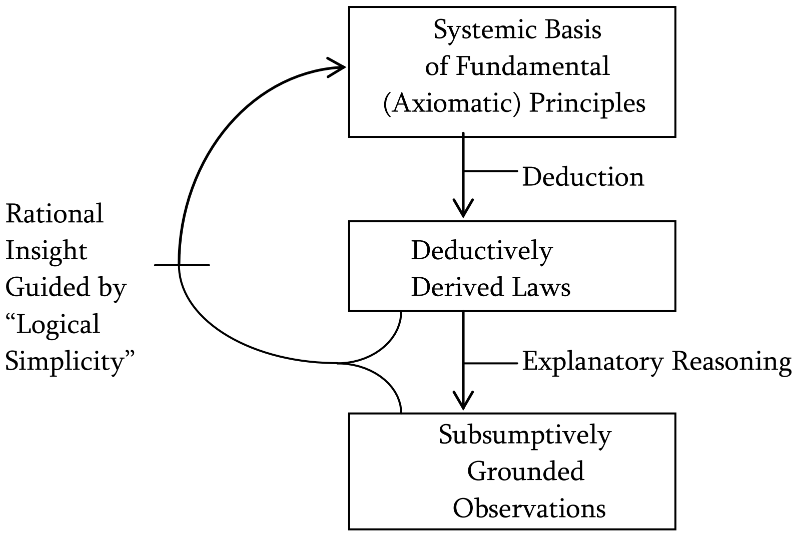
[35] See Einstein's "On Generalized Theory of Gravitation," *Scientific American* 182 (1950): 13-17.
[36] Van Dongen, *Einstein's Unification*, 52. Compare the ampler discussion of this passage in John Norton "Nature is the Realization of the Simplest Conceivable Mathematical Ideas: Einstein and the Canon of Mathematical Simplicity," in *Studies in the History and Philosophy of Modern Physics* 31 (2000): 135-70; see esp. 136-37.
[37] Letter to Bohm of 24 November 1954. See Van Dongen, *Einstein's Unification*, 181-82.
[38] See Van Dongen, *Einstein's Unification*, 147.
[39] A. Einstein, *Ideas and Opinions* (New York: Bonanza, 1954), 270-76. On the relevant issues see John D. Norton, "Nature is the Realization of the Simplest Conceivable Mathematical Ideas: Einstein and the Canon of Mathematical Simplicity," *Studies in the History and Philosophy of Modern Physics* 31 (2000): 135-70.

Display 5
EINSTEINEAN SCIENTIFIC SYSTEMATIZATION



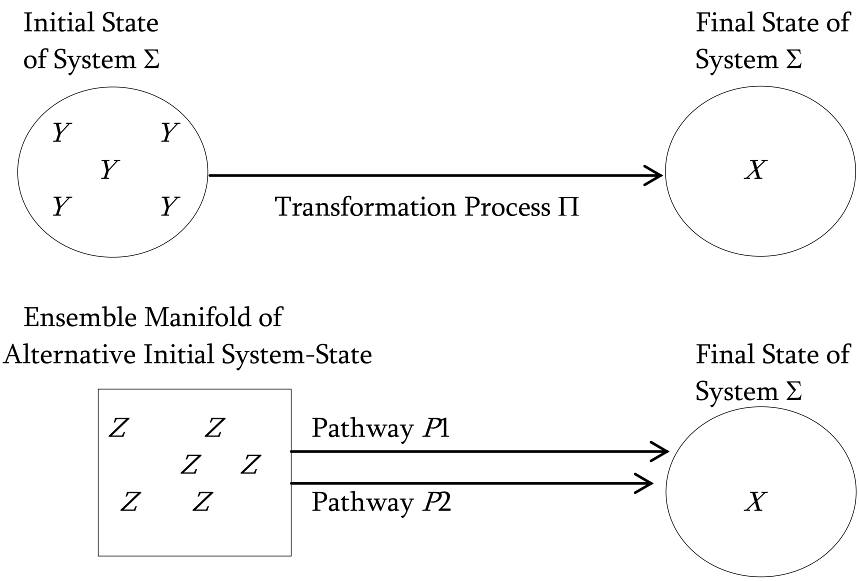
NOTE: The diagram is adapted from Einstein's own 1952 depiction as presented and analyzed in Van Dongen, *Einstein's Unification*, 51-55.

In a 1952 letter to Maurice Solovine, Einstein gave a diagrammatic sketch of the methodology he advocated for the physical sciences, which in its structure is closely analogous to the Leibnizian systematization of Display 2. (See Display 5). The fundamental kinship between Einstein's vision of the methodology of systematization in physical science and that of Leibniz becomes readily apparent when one compares the tripartite structure of Displays 5 and 2. And the kin ship at work is all the more strikingly notable when one acknowledges that consideration of economy and simplicity is in each case the driving force of the process of systematization that is at work.

VI. Einstein's Approach Illustrated

But how is one to obtain probabilities from nonprobabilistic processes via considerations of simplicity and rational economy? The general idea is implicit in what Einstein wrote to Bohm: “I do not believe in micro- or macro-laws, but only in structure laws that lay claim to a universally binding validity.”[40] And the pivotal fact is that when such laws are to serve the interests of simplicity across the entire ensemble of possible state-conditions, a recourse to probabilities can become derivatively necessary. For once one poses a problem to nature – or indeed once nature sets a problem to itself – the economic factors of the effectiveness and efficiency of a given solution come upon the agenda. And just here it becomes possible for probabilities to enter in, seeing that there are some such optimization problems that are best addressed by probabilistic machinery.

Display 6
SYSTEMIC EVOLUTION

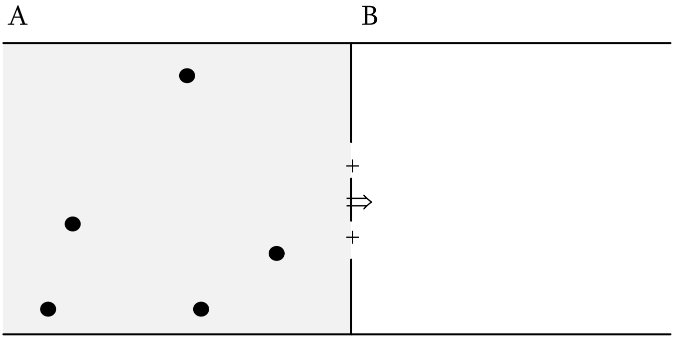


To convey a general idea of such a pathway to probability let us consider a simple illustration of a solution of the type familiar from classical rational mechanics which endeavored to show how various laws of nature are as is because conformity to them provides for maximal efficiency-effectiveness-economy of operation. Consider a process Π that takes all constituents of a physical system Σ

[40] Letter to Bohm of 24 November 1954. See Van Dongen, *Einstein's Unification*, 181.

from an initial state to an end-state as per the top of Display 6. But now let it be that this can be accomplished by one of two pathways P_1, and P_2, where that initial state can be any one of an ensemble of alternatives *Z*. (See the bottom half of Display 6).

Display 7



Two lawful modes of transition can be contemplated here:

(1) One based on a deterministic law to the effect that every Type 1 constituent of the system effects its state-transit by pathway P_1, and every Type 2 constituent of the system effects its state transit by pathway P_2.

(2) One based on a non-deterministic law that says that any given constituent effects its transit stochastically by P_1 with probability p_1 and by P_2 with probability p_2.

Now such a transition in the condition of the system can be deemed efficient to the extent that it effects the transition at issue more smoothly – more rapidly or economically – when considered on average across the whole spectrum of the initial-state ensembles. And on this basis, there will be some state-transitions that will operate more efficiently by (2)-style randomness than by (1)-style strict lawfulness.

For an example here consider the set-up depicted in Display 7. At issue here is a hypothetical transmission process where there is to be a transfer of the five 'units' distributed on side *A* of a barrier to side *B*. There are two revolving-door turnstile considerations between the two sides, each of which can allow the passage of one 'unit' per second. Now consider two possible and plausible lawful rules for unit transit:

I. Effect transit via the nearest passageway.

II. Effect transit via a passageway selected 50:50 at random.

The rule to be adopted is to be general, covering the entire spectrum of alternatives – the 'ensemble' range of alternative possibilities for distributing units or the *A* side of the barrier. It is clear that, in these conditions, rule II would make the transfer of units from such to side *B* no-one efficient (i.e. faster). For if efficiency to be achieved throughout the entire ensemble of possible initial conditions, then the behaviour of individual constituents may well have to be governed by laws geared to probabilities. It would obviously be more efficient and speedy to have those units pick a gate at random to minimize a traffic jam than to follow a uniformly fixed strict rule.

Further, consider also the prospect that those two connective turnstiles rotate at different speeds, say one at twice the rate of the other. Then the optimizing rule for those individual units would not be to effect a transit with one-to-one-randomness as between the two turnstiles but to head for the faster at a two-to-one ratio of probability. For maximum efficiency the operative probability would then have to be adjusted to the mechanical mode of turnstile operation. Probability would thus become derivative from nonprobabilistic features of the *modus operandi* of the physical set-up at issue via considerations of efficiency and economy.

What we have here is the realization of a mode of operation which, while indeed allowing the individual subunits of a system "to throw the dice" as it were in line with probabilistic variation, this so functions as to realize a process which overall achieves its product in a way that is optimally effective, efficient, and economical.

As such illustrational indicate, it can readily prove to the advantage of a system in point of economy, stability, or viability that its components should behave randomly. For rigid regularity involves overload, and randomness helps to keep things on an even keel. Take the analogy of human affairs. Not every passenger should go to the same side of the boat. In evacuating an unevenly occupied building the universalized instruction "Go to the nearest exit" may not be as effective as "Just leave" (by whatever exit you may wish).

The salient point of such a condition of things lies in its showing that if certain definite global conditions are to be realized with maximal efficacy in the comportment of a physical system, then its constituent elements may have to conform to probabilistic laws of behavior. On such an approach, probabilities need not enter by unexplained fiat, but can prove to have an explanatory rationale in terms of fundamental principles. And it was apparently just this sort of thing that Einstein had in view.

The fact of it is that Einstein had nothing against probabilities as such: it is only *elemental* probabilities that have no rationale in considerations of principle that he finds objectionable. "That there should be statistical laws that require God to throw dice in each individual case, I find highly disagreeable."[41] Accordingly, probabilities should not just spring into being *ex nihilo,* but should emerge as part of a solution to a problem of optimization under plausible constraints.[42] As he saw it, those physical processes – probabilistic and improbabilistic alike – should have a cogent rationale. He did not hesitate to decline that "When I am judging a theory I ask myself whether, if I were God, I would have arranged the world in such a way."[43]

Conclusion

The definitive task of Leibnizian Physics – and of the rational mechanics to which it gave rise – was to show that the laws of nature themselves represent solutions to problems of optimization under constraint mediated by considerations of economy and efficiency: in sum, to equip those laws with a rationally cogent explanation for being as is. As this approach developed from Maupertuis to Hamilton, rational mechanics was a realization and elaboration of the Leibnizian vision of physics with its prospect of grounding the laws of nature in underlying principles of economy and efficiency. And Einstein's position with respect to quantum theory ran along just these lines. For what Einstein wanted was a functional account showing the physical laws of nature as we have them to be the optimal means of satisfying basic principles of rational economy – and so for quantum theory to be exhibited as the best solution of a problem of rational design. In short, Einstein's great pragmatic desideratum in physics was isomorphic with that of Leibniz. Einstein too was committed to the quest for a Leibnizian physics.

The idea of probing behind the laws of nature to consider why they should be what they certainly fascinated Leibniz and impelled his thought in a

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[41] Calaprice, *The Expanded Quotable Einstein*, 260.

[42] John Norton has reminded me that in other contexts too search problems such as that of the travelling salesman will often be solved most efficiently by probabilistically geared processes.

[43] Calaprice, *The Expanded Quotable Einstein*, 259. Given this perspective on the matter it should be clear that (despite Peter Pesic, *Labyrinth: A Search for the Hidden Meaning of Science* (Cambridge: MIT Press, 2000), 149-50) Einstein did not flatly object to having randomness as such play a role in nature. He objected, rather, to having this transpire without a cogent justificatory rationale.

theological direction. And even Einstein himself was on board here – at least in his more ruminative moments. For he expressed surprise that "despite such harmony of the cosmos as I, with my humble human mind, am able to recognize, there yet are people who say that there is no God."[44] To be sure, Einstein's God was certainly not personal and anthropomorphic but rather something along the lines of a governing force or power endowing the universe with a harmonious rational order – something akin rather to the cosmic *nous* of Plato's *Timaeus* than to the Judeo-Christian God.

But the fact remains that when Einstein made his oft-quoted remark "I believe in Spinoza's God who reveals himself in the orderly harmony of all that exists"[45] he was far from being on target. For his position with regard to the rational methodology of physics was in fact much closer to the optimalism of Leibniz than to the absolute necessitarianism of Spinoza.[46]

The crux of the matter is that Einstein wanted quantum probabilities to be obtained by derivation under the aegis of rationally cogent basic principles. In specific he was seeking for a higher-level perspective of physical principles that would engender the probabilistic detail of quantum theory as the demonstrably adequate resolution of a problem of optimization under constraints – a projection of the classic standpoint of rational mechanics into the latter-day realm of quantum mechanics.[47] And there really seems to be no ultimately compelling reason of fundamental principle why he cannot have his way here.[48]

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[44] Calaprice, *The Expanded Quotable Einstein*, 214.

[45] Calaprice, *The Expanded Quotable Einstein*, 204. Also quoted in Rebecca Goldstein, *Incompleteness: The Proof and Paradox of Kurt Gödel* (New York: Norton, 2005), 259. Of course, Einstein rejected the idea of a personal God. See Calaprice, *The Expanded Quotable Einstein*, 146-53. Einstein felt a spiritual kinship with Spinoza as a fellow Jew (see Pesic, *Labyrinth*, 144-45). And he lacked Gödel's familiarity with Leibniz's thought.

[46] Spinoza's necessity was absolute and unconditional; Leibniz's necessity was axiological and pivoted on an optimality geared to harmony, economy, and elegance to design. And just here Einstein actually took the Leibnizian route: "What really interests me is whether God could have created the word differently; in other words *whether the demand for logical simplicity* leaves and freedom at all." (Calaprice, *The Expanded Quotable Einstein*, 221: my italics.) Spinoza's necessity is unconstrained; Leibniz's is constrained by conditions of harmony, economy, simplicity, that is, by just those value considerations that Spinoza eschews.

[47] Actually, a way of developing *relativity* theory within the framework of rational mechanics is developed in Arnold Sommerfeld's *Electrodynamics: Lectures in Theoretical Physics*, Vol. III, trans. E. G. Ramberg (New York: Academic Press 1964); German original: *Vorlesungen über theoretische Physik* (Wiesbaden: Klemm Verlag, 1945). I owe this reference to my colleague Kenneth Schaffner.

[48] This chapter was presented as a Luncheon Lecture at the Center for Philosophy of Science at the University of Pittsburgh in September of 2010.