Tychism

Key Words: Chance, indeterminism, statistics, probability, law.

Abstract: *Tychism is the thesis that chance has a real (non-subjective) presence in the workings of the world, and that physical laws are statistical regularities or dispositions always short of the limiting state of perfect regularity. Consequently, the world contains real possibilities left undetermined by mechanical laws and initial conditions, these being decided by chance and thereby explaining the emergence of genuine novelty and variety in the universe. Tychism has important roots in developments of nineteenth-century science and mathematics, specifically the mathematical theory of probability and statistics, statistical mechanics, and Darwin's theory of organic evolution. Peirce proposed the thesis as an alternative to the attitude of deterministic physicalism prevalent in the nineteenth century, according to which all natural phenomena must ultimately be explicable by or reducible to the action of invariant mechanical laws of motion upon eternal and immutable material particles.*

Tychism is the name given by Peirce to his thesis of indeterminism, according to which there is in nature an objective feature of spontaneous chance activity free from the exact and necessary dictates of mechanical law (from the Greek *tyche* for chance). More specifically, it is the claim that laws of nature are at best statistical regularities, that causation is essentially probabilistic, and that the natural properties of things always fall short of the ideal state of perfect precision and determinateness. The fullest, if not the first, published expression of this doctrine was in the 1892 *Monist* essay "The Doctrine of Necessity Examined." (For earlier hints of the doctrine see the articles "Design and Chance" and "A Guess at the Riddle" in Houser and Kloesel eds. (1992).) The term "tychism" was introduced in a later essay of the same series and journal (the essay "The Law of Mind").

Peirce's motives for invoking the thesis were of at least two distinct sorts. One was observational in nature, the other more speculative. The first derived from his experience as a laboratory scientist in the making of precise measurements of natural constants and other physical quantities. A standard tool in this activity is the statistical method of errors or least squares, whereby a best estimate of a quantity is derived from numerous repeated observations. As described by the law of large numbers or central limit theorem, repeated measurements of a quantity, for example the length of a rigid rod or the acceleration due to gravity (*g*), are found to exhibit an approximately regular pattern of dispersion about a central or average value. Represented graphically this pattern assumes the familiar bell-shaped or normal curve of frequency distribution. [See figure 1] It is found that a continuous bell-shaped curve is a closer approximation to the distribution of actual data the more numerous are the measurements or observations. Assuming that the central peak or tendency represents the true or real objective value, those values departing from this mean in either direction are referred to as "errors."[1] Such errors are typically ascribed to human error, due to the crudity and coarseness of our neurophysiology and our measuring instruments, in comparison with the level of precision required to make fine determinations of exact quantities which may shade off beneath the limit of our capabilities. By increasing the number of observations or improving the precision of the instrumentation, the range of error or dispersion can be diminished, but never entirely eliminated.

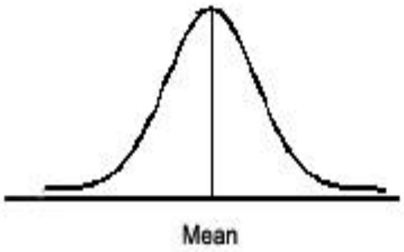

Figure 1. Normal Probability Curve

In light of this Peirce proposed that the evidence is at least equally supportive of the supposition that physical quantities have no truly invariant and precise values. In fact, he argued, this opinion is better supported by the observed evidence than the default assumption that there are such truly exact and constant values. On the tychistic supposition, natural quantities actually undergo a range of random fluctuation about an overall mean value, and all physical regularities or natural laws are mere statistical approximates.

It struck Peirce as more plausible that physical quantities would be slightly inexact than that they would assume a unique, precise and discontinuous value from among a continuous (and hence uncountably infinite) range of alternative possible values. This interpretation of natural quantities permitted him to propose that in reality all physical laws are imperfect statistical regularities, which we observe as relatively stable averages over segments of time and space. As Peirce noted, the more precise we attempt to measure some quantity in the laboratory, the more noticeable the variance or fluctuations in our measurements become. This statistical interpretation of physical laws was consistent with contemporary developments in the kinetic theory of gases and statistical thermodynamics, forwarded by such researchers as Rudolf Clausius, James Clerk Maxwell, Ludwig Boltzmann, and Josiah Willard Gibbs, among others. These researchers explained certain observable regularities in the properties of gases, such as temperature and pressure, as the macroscopic average effect of the “random” or independent motions of multitudinous microscopic molecules. Although this regularity at the level of the population of molecules was considered to be a statistical result, it was still believed that the individual molecules each obeyed necessary laws of mechanics in their separate motions. Talk of the “chance” or “random” motion of a gas’s component molecules was assumed to arise from the human inability to follow the dynamically determined motions of each separate molecule. Peirce’s more speculative extension of the idea of a subjective statistical regularity to that of an objective stochastic or chance activity at the level of individual molecules and atoms showed him to be more philosophically daring than his scientific peers.

The second motive for introducing the tychistic thesis was to provide an alternative to the widely popular philosophy of determinism. The opinion that every fact is precisely determined by law (or more roughly that every event has a cause) Peirce called necessitarianism. In its modern dynamical form it supposes that every physical state of the universe is the direct and necessary consequence of the laws of mechanics in conjunction with the instantaneous state of each material particle in the previous instant. The epistemic reading of this doctrine, popularized by the eighteenth century French physicist Laplace, states that a sufficiently intelligent being knowing all the mechanical properties of each particle in the universe and the laws of mechanics could predict the entire future (and past) states of the universe. This deterministic thesis Peirce called the mechanical philosophy. Peirce opposed the mechanical philosophy and proposed his own thesis of tychism on the grounds that otherwise a whole range of phenomena would be rendered inexplicable.

As he understood it the mechanical philosophy involved the assumption that all natural phenomena (including mental and organic phenomena) must ultimately be explicable by or at least consistent with the materialistic principles of physical science. Central to the physical sciences at the time were the exact mathematical laws of motion. One feature of the mathematical expression of Newton’s laws (in terms of differential equations describing the rate of change of physical quantities as a function of time) is their invariance under what amounts to a reversal of the direction of the “flow” of time. For example, acceleration, (the rate of change of velocity, or the rate of change of the rate of change of spatial position), is expressed as a second order differential equation like so: $d^2s/dt^2 = F/m$, where F is an external force and m the mass of the object whose motion is under consideration. To solve such an equation is to find the changed spatial position of the object, and requires integrating the above equation twice. (We must also know how the force in question acts as a result of change in position and/or time). Each integration results in the placement of a negative sign at the front of the solution, and so ultimately the two negative signs cancel one another out. Hence, changing the sign for the time in the original second order differential equation from ‘t’ to ‘$-t$’, which is in effect to “reverse the flow of time,” leaves the final solution unchanged, i.e. $d^2s/dt^2=d^2s/d(-t)^2$. (So long as the laws of motion involve differential equations of an even powered order this will hold true.)

For this reason the laws of motion are said to be time-reversal invariant. In other words, so far as the laws themselves dictate, physical events might just as well occur in a reverse sequence running from the future to the past as the more familiar “forward” sequence from past to future. There is nothing in the laws themselves, that is, that specifies that a cold cup of coffee with cream mixed in uniformly might not, on its own accord, absorb heat from the surrounding environment to become a hot cup of coffee; nor do the laws forbid that the cream should spontaneously separate itself from the coffee and leap “backward” into the cream dispenser from which it came. Of course either of these transitions would be considered an astonishing reversal of normal events. In any real application the mechanical laws are employed in conjunction with some initially specified state of the system in question in order to transform that system into a new state of (possibly) different conditions. Which state we choose as the initial one (cold coffee, cream mixed; or hot coffee, cream unmixed) is an entirely arbitrary decision from the standpoint of the laws. Moreover, the mechanical laws carry one completely specified state of the system continuously and deterministically into another completely specified state. (In fact this is an oversimplification even for ‘classicial’, i.e. pre-quantum, mechanics; for details see Earman 1986). But why we should begin with one state rather than another, or why we find that only one of two conceivable sequences of events is ever actualized (those we recognize as proceeding from past to future and not vice versa), are questions to which the laws on their own can provide us no answer.

It is a consequence of the mechanical philosophy, therefore, as Peirce pointed out, that it can provide no explanation of why we seem to experience the vast majority of events in just one irreversible order from past to future. (The incessant swinging of a pendulum back and forth in a vacuum void of all air resistance and drag is one of the very few reversible phenomena met with in real life.) What this shows is that the mathematical laws of matter in motion are not on their own sufficient to explain in any satisfactory way the most basic of ordinary physical experiences. Peirce’s chief target in raising this objection was the popular evolutionary philosophy of Herbert Spencer. Spencer declared (via his “developmental hypothesis” or “law of progress”) that the irreversible evolution of matter from a state of undifferentiated uniformity to one of increased complexity and diversity was a direct result of the law of the conservation of energy (or the “law of persistence of force” as Spencer called it). This cannot be so, Peirce repeatedly argued, since the law of energy conservation is also time reversible and so equally consistent with the development of a chicken into an egg as with the more familiar process leading from egg to chicken. All evolutionary processes with which we are familiar, Peirce pointed out, appear to be irreversible and so cannot be the direct result of reversible mechanical laws alone. Apart from Spencer and some others advocating systems of philosophical materialism (e.g. Ludwig Büchner, Ernst Haeckel) it is not clear that any physicist of Peirce’s time actually held the laws of mechanics to be sufficient to explain all natural phenomena, although Boltzmann did attempt to reduce the second law of thermodynamics–which is often described as “time’s arrow” due to its description of irreversible energy dissipation or increase in entropy–to the reversible laws of mechanical motion. Peirce was among the first to note the deficiency of the mechanical philosophy using these sorts of arguments.

The four basic features of the world which Peirce claimed are inexplicable on supposition of the mechanical philosophy (see CP 6.58-6.61) are the following (expressed here in my own terms so as to provide more elaboration than originally given by Peirce):

1. The general prevalence of irreversible physical behaviour, especially that which appears to move from an originally unordered or primitive state toward a

more complex one. (Peirce has in mind here teleological phenomena of both an inorganic and organic nature, both of which he described as kinds of “growth” or “evolution.”) This, as we have noted above, is in obvious tension with the time-reversibility of mechanical laws.

2. The sheer variety of the world, which would be unexpected were exact mechanical laws the only causally relevant agent at work in the universe. For it is the essence of an exact law that the same causes always produce the same effects. How then did there come to be so much variety of form and character in the universe? To say that there has been no real increase in the amount of variety and complexity in the universe goes against all the evidence of the modern historical sciences, e.g. astronomy, biology, geology. To say that all this variety is merely combinatorial, i.e. the result of novel combinations of original particles, is to leave the existence of those original particles and their properties unaccounted for. It is akin to supposing that the world is constructed from an original store of various shaped lego-like building blocks, but offering no suggestions as to how these blocks and their particular properties came about. To declare any positive matter of fact ultimately inexplicable is in violation of what Peirce called the first rule of logic: “do not block the path of inquiry.” Causation, then, must be probabilistic. The same causes are supposed only to have a general tendency toward the same effects. In this way a range of genuine novelty is admitted into the world. [See figure 2]

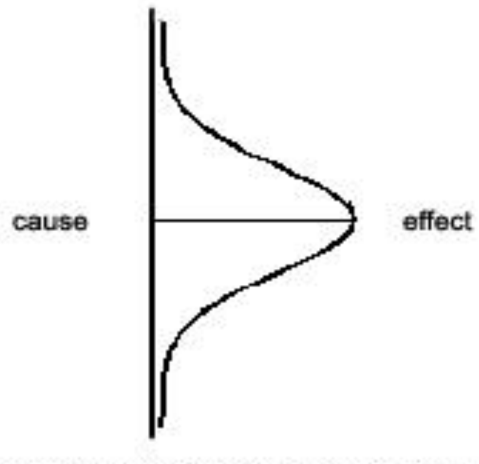

Figure 2. Tychistic causation: the same cause results in a range of effects normally distributed about a mean or average effect

3. The very existence of lawful behaviour itself, which, as we saw above, is

> presupposed by the mechanical philosophy and so is left unexplained. Why do particles exhibit the specific laws/regularities that they do? Have they always done so for eternity? Again, to insist that the laws have been in existence from the very beginning (or eternally) is to violate the first rule of inquiry. The only legitimate reason for maintaining a hypothesis, Peirce insisted, is that it provides some explanation of things; and to declare the laws beyond all understanding is to give them no explanation at all.
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> 4. Feeling, sensation, and other mental phenomena, which are difficult to square with the activity of supposedly dead insensate matter acting in accordance with blind and reversible mechanical law. In addition most, if not all, mental properties appear to be irreversible (to the extent that they are goal-directed toward specific ends or outcomes). How could teleological behaviour result from reversible mechanical laws?

With the assistance of the hypothesis of tychism Peirce proposed that all of these features of the universe would be rendered explicable. In truth the thesis of tychism on its own is insufficient to explain all these things, but in conjunction with two other theses a highly speculative explanation is obtainable. These two additional theses are (i) objective idealism, and (ii) a law of self-organization (which he called in various contexts the law of habit, the law of habit-taking, the law of mind). The first Peirce adopts from the tradition of German *Naturphilosophie*. According to the thesis of objective idealism the laws of mind and matter are identical. Matter is to be construed as an evolved state of a more fundamental mind-like substance. Matter’s remaining mind-like qualities are identified in a rudimentary form of “sensation” or reactiveness to external stimulation, this behaviour supposed to be originally haphazard or random in nature. It is through the gradual emergence of a self-organizing tendency to become less random and more habitual or regular that this mind substance is supposed to take on the features of law-governed matter. In Peirce’s words, “Matter is mind hide-bound with habit.” This law of self-organization was alternatively called by Peirce the law of habit-taking and the law of mind. It is to be contrasted with the mechanical laws of material physics in that it is neither exact nor deterministic. Rather it describes a propensity or objective probability of behaviour. Its effect is to make the activity of the primordial mind-stuff more regular, orderly, and habitual, in a fashion analogous to the formation of habits in rudimentary organic protoplasm. It should be noted that Peirce did not intend that the primordial mind-stuff be understood to partake of any kind of self-consciousness, which Peirce regarded as an evolved property of the complex molecular systems constituting certain higher organisms. (Although Peirce did speculate within his semeiotic researches that in a sense every general idea or system of signs partook of the property of consciousness.) For present purposes it is perhaps helpful to think of this primitive mind-stuff of the original chaos as a kind of undifferentiated plasma reminiscent of the early moments of the universe as described by the current big bang cosmological model. This proto-plasmic material substance has the capacity to react (and so exhibits a kind of sensation), but as yet has not organized itself into any coherent and differentiated systems, nor can we suppose that individual, regular-behaving particles have yet emerged at this point. The universe's evolution consists in an ever increasing tendency on the part of its constituent components (particles?) to become more regular and law-like in their interactions with one another, so that in the end they become constrained (but for a very minute amount of spontaneity within fine limits) to obey the recognized laws of motion. According to Peirce's triadic system of universal categories, three distinct elements are active in the world: "first, chance; second, law; and third, habit-taking" (1.409).

It is important to keep in mind the analogy between Peirce's proposed law of habit-taking and the law of large numbers. Like the law of large numbers, the law of habit-taking is a probabilistic or statistical regularity. In both cases the strength of the regularity is in direct proportion to the number of events or trials involved. The law of habit provides a central role for the non-deterministic activity of chance events. But in contrast, while the individual events described by the law of large numbers may themselves be the outcomes of deterministic forces (e.g. coin tosses), the law of habit must include a real objective form of spontaneous chance free from law in order to account for the diversity of the world.

In this way we see how Peirce proposed to account for the four general features listed above. (i) The law of habit, like the law of large numbers, results in an aggregative effect which is distinctly irreversible and goal-directed. This is in both cases the emergence of a cumulative statistical regularity. (Consider for instance that as the number of coin tosses is extended, the emergence of a distinct ratio of heads to tails becomes more and more pronounced and stable.) (ii) Because the law of habit involves an objectively indeterministic agency, (the influence of laws upon events is never totally complete), qualitatively novel results may occur, which serve to increase the diversity and variety of the world. (iii) The law of habit provides an explanation of the existence of lawful behaviour, such as physical laws – these are, however, to be understood as statistical regularities; and the self-organizing, auto-catalytic nature of the habit-taking tendency permits it to act as its own explanation. It first arose in a very imperfect form, Peirce suggests, as a mere chance and very weak disposition from an otherwise incoherent and irregular proto-cosmos, but became more and more pronounced thereafter through its recursive application to itself. (iv) Lastly, via the thesis of objective idealism, which is in effect the supposition that mental phenomena such as sensation and volition are ubiquitous throughout the world, even to a very limited extent in "dead" matter, the primitive phenomena of mind are accounted for. A key component of Peirce's version of idealism was his identification of spontaneous "chance" activity as a defining feature of life and mind. The key merit of this idealist proposal, according to Peirce (and others), is that whereas a reduction of mind to matter seems in principle ill-fated, a reduction of matter to mind via the law of habit- taking seems more promising.

Peirce distinguished between two notions of chance: (a) quasi or relative chance, and (b) absolute chance. Both notions involve a certain freedom from being necessitated by any law, but of differing degrees. For instance, quasi or relative chance refers to the existence of coincidences. There are many relations between separate facts that fall under the domain of no overriding law. To suppose otherwise would be to believe that, not only does everything happen for a reason, but that for every and any two facts one can imagine, a real and general law can be found that would make their relationship to one another an inevitable outcome. For instance, suppose that the Queen of England should sneeze at precisely the moment that I take a sip of coffee. Should we suppose that coincidence of events to be the necessary result of some overriding law? To allow for the existence of quasi chance is, as Peirce himself said, to recognize “that diversity in the universe which the laws leave room for, instead of a violation of law, or lawlessness” (6.602). Turley (1969) and Cosculluela (1993) have suggested that quasi chance refers to the fortuitous (i.e. uncaused) crossing of independent causal chains. This would seem to cover the occurrence of coincidences. Peirce noted that even this quasi notion of chance is an objective feature of the world in the sense that it reflects more than a subjective ignorance on our part to know all the details of the universe. The insurance business, he remarked, could hardly be as profitable as it is, were the statistical facts upon which it relies merely subjective descriptions of human ignorance.

While this first notion of chance primarily concerns relations between facts or events, absolute chance concerns the outcome of individual facts or events. When an event occurs without a prior cause, or is not precisely predetermined by an exact covering law, then we have an instance of absolute chance. Because Peirce proposed that absolute chance and the emergence of law are coexistent (in an inverse relationship) throughout the evolution of the universe, it is rather natural to understand absolute chance as a kind of violation of previously existing law. Until the cosmic process of “habit-taking” reaches its final ideal limit of exact necessary law, the influence of all laws will continue to be imperfect. It is not, therefore, that perfectly established laws are at times violated by a chance interruption (to suppose they are, Peirce objected, would be to believe in miracles, which are interventions of perfectly established law); rather, because the laws are only imperfectly established, they do not perfectly “shape” the outcomes. All laws at this stage of universal evolution are inexact stochastic dispositions toward regular behaviour, and so display the features of absolute chance. It is helpful to think once again of the normal probability curve as representing the less than exact results of some law involving a natural constant (consider for instance the gravitational constant G in Newton’s formula for universal gravitation, $G = 6.6732 \pm 0.0031 \times 10^{-11}\ \mathrm{N\ m^{2}\ kg^{-2}}$). The greatest bulk of the curve will be symmetrically situated about the mean observable result, showing that the most probable outcomes will be close to the mean or average result. Slight departures from the overall mean, therefore, will be frequently observed, while more extreme departures are the less probable the greater they are from the mean. In terms of the growth of law or habit, a relatively new and imperfect law will exhibit a relatively large variance about the central or mean tendency; while in the ideal limit of exact law all variation will have vanished, leaving a spike with zero breadth perfectly centered on an invariant natural constant. [See figure 3] In this sense absolute chance refers to the amount of spread or variation in the mean effect of the law or cause in question. For anything less than ideal law, there will always be a certain amount of “swerving” of events, a certain looseness of play, from precise regularity.

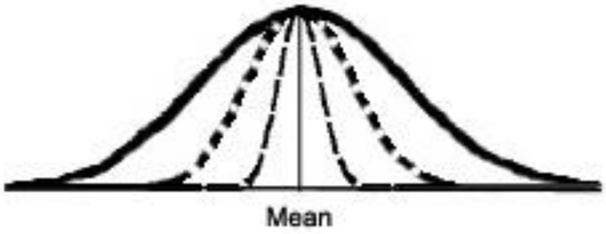

Figure 3. Four curves showing the evolution of a law over time. As the law or 'habit' becomes more perfect, the amount of chance variation shrinks until reaching the final limiting case represented by the line centered exactly on the mean.

This discussion has, to this point, dealt principally with what might be called the “dynamical” aspect of Peirce’s thesis of tychism. It has focused on the implications of the objective presence of absolute chance in the laws of nature, stating that no law is more exact than can be illustrated by a statistical regularity on the average and in the long run of continued experience. But this dynamical interpretation of tychism or absolute chance is compatible with the idea that while the *behaviour* of a particle, for instance, fluctuates in a random but vanishingly small fashion over time, the values of the physical properties of each particle *at any given instant* are mathematically precise. (Imagine an extremely fine indicator needle on some measuring device pointing to mathematically precise values, but fluctuating randomly about a mean value.) But Peirce’s notion of absolute chance suggests something even deeper and more radical than this. For one way of interpreting his thesis of tychism is that at any given instant, the actual micro-properties of any particle are in fact imprecise, inexact, indeterminate.[2] If we could observe Nature at its deepest and most fundamental level, in other words, we would find that it has no truly sharp points and edges, but rather is objectively “smudgy” and indeterminate. If we contrast this tychistic picture of the world with that which William James called the “block universe,” we might say that according to the tychistic blueprint the universe is found, upon close inspection, to be “drawn” with a blunt and soft leaded pencil; whereas according to the blueprint required by the block universe, in which the world is a system of perfectly determined clockwork, the plans are found to have been drawn with the ideally exact and precise instruments of a divine geometer/artisan.[3]

We can distinguish, then, three separate readings of Peirce's thesis of tychism with respect to the question of determining through measurement the value of some physical quantity. Ranging from the weakest to the strongest these are as follows:

(i) Humans are incapable of surpassing certain limits of precision when it comes to determining mathematically exact values of physical quantities, because our measuring instruments are coarser than the things we wish to measure with them. For instance, at some point any device with which we attempt to make an absolutely precise measurement is going to prove as useless as measuring the length of a grain of sand with a yard stick, because the available gradations are simply not fine enough. One reading of the Heisenberg uncertainty principle is suggestive of this type of epistemic limitation: namely, that any attempt to measure one of a complementary pair of physical properties of a sub-atomic particle (either the position or the momentum of an individual particle say), requires our interacting with the particle, and this will necessarily disturb the value of the other quantity. This was Heisenberg's initial interpretation of the uncertainty relations bearing his name; he eventually abandoned it for a stronger reading due to Bohr to be discussed below.

(ii) Physical quantities do not admit of *constant* or *invariant* mathematically precise values, but display a fluctuation about some mean value. This reading would be consistent with the observation that the length of a table fluctuates on the micro-level due to the agitated thermal motion of the table's constituent molecules. Although this reading allows that at any particular instant physical quantities have precise values, the best we can do on this reading is to gauge a statistically average value over some segment of time.

(iii) Physical quantities simply do not admit of absolute mathematically precise values even in principle. Nature is, on this reading – especially at the microlevel – inherently 'smudgy,' imprecise, indeterminate. This reading is suggestive of the stronger reading of the Heisenberg principle (sometimes referred to as the *indeterminacy* principle to distinguish it from the epistemically construed *uncertainty* principle). According to this more radical interpretation due to Bohr, it is not just that our attempts to measure a particle's velocity, for instance, interfere with its position, but that particles do not have both velocities and positions in simultaneously determinate degrees. If this third option is Peirce's intended reading of tychism, of course – given that he did not live to see the formal presentation of quantum physics (he died in 1914) – it is only reasonable to assume that his proposal was that all physical properties are indeterminate at the micro-level, not just complementary pairs as is the case in quantum mechanics.

It is this third reading of tychism which provides the most distinct alternative to the deterministic picture of the world as a piece of perfect clockwork. And it is this reading that fits best with Karl Popper's (1972, 213) remark that, "So far as I know Peirce was the first post-Newtonian physicist and philosopher who thus dared to adopt the view that to some degree *all clocks are clouds*; or in other words, that *only clouds exist*, though clouds of very different degrees of cloudiness."

There is indeed a striking resemblance between the cloudy indeterminism of tychism and the quantum fuzziness or indeterminacy of the later quantum theory of atomic physics. This should not be entirely surprising, since Peirce was led to develop his metaphysical theories from an interest in the cutting-edge atomic and molecular research of the last decade of the nineteenth century. He was well aware of the peculiar phenomena of radioactivity and saw perhaps sooner than most that it would ultimately prove incompatible with the mechanical philosophy so popular among the majority of his scientific peers. Peirce also drew inspiration for the thesis of tychism from the random molecular (thermal) motion posited by the kinetic theory of gases, and from Darwin's notion of random spontaneous "sports," or mutations, from rigid hereditary law. In addition he noted the historical precedence for the thesis of tychism in Epicurus's idea of the *clinamen* or random swerving of atoms as they fall through the void.

Tychism and Modern (Post-Classical) Science

The tychistic picture of a fundamentally indeterminate reality was made mainstream scientific opinion through the Copenhagen interpretation of quantum physics (due in large extent to Niels Bohr and Werner Heisenberg). According to this interpretation of the theory and highly successful results of quantum mechanics nature is, most noticeably at the atomic and subatomic levels, intrinsically probabilistic in its properties. Although the Schrödinger equation, the differential equation which describes the time evolution of the physical quantities of a quantum system, is deterministic, the process of measurement, whereby the results of this deterministic evolution of the system's quantum properties are discerned, is irreducibly probabilistic. This tension between the deterministic and probabilistic elements of quantum theory is the source of what is known as the "measurement problem." Attempts to replace this probabilistic formulation of quantum physics with a fully deterministic theory (so called "hidden variable" theories) have not met with much success.

Another tychistic feature of quantum mechanics is expressed in the curious wave-particle duality of matter. All matter shares to some extent, dependent upon the nature of the observational conditions in question, both discrete particle-like and fuzzy wave-like properties. At the scale of macroscopic objects with which we are most familiar, matter typically displays discrete and determinate properties. Yet there is always a vanishingly small theoretical probability that, to use Popper's example, clocks might appear as clouds. At the atomic and subatomic levels, however, the wave-like fuzziness of matter predominates, and the best that we can obtain are probabilistic predictions of how it is likely to behave on average and in the long run. There are certain complementary pairs of sub-atomic properties of which we cannot have simultaneously precise knowledge (for example, the momentum and the position of a particle). The Heisenberg Indeterminacy Principle states that it is not possible to know both properties of such complementary pairs to an unlimited degree of precision. As we make our knowledge of the particle's momentum more exact, for instance, our knowledge of its position must become correspondingly less precise. This, as explained above, is not merely due to limitations in our measuring techniques (according to the orthodox Copenhagen interpretation), but arises because matter at this fundamental level simply does not have both properties to indefinitely determinate degrees.

There are important differences, however, between Peirce's tychistic vision of a world incorporating real absolute chance and the objective indeterminacy revealed by quantum mechanics. For instance, it is typically assumed in the standard expressions of quantum mechanics that, while some of the basic physical laws are of an objectively probabilistic nature, there is no reason to suppose that they or any others have an evolutionary history of the kind supposed by Peirce. For the purposes of modeling and predicting the behaviour of quantum systems in the laboratory there is no need to speculate whether the fundamental laws have always been as they are now or have changed over time. There are those (e.g. Wheeler 1973 and 1979, Thirring 1995, Smolin 1999), on the other hand, with an interest in cosmological questions who have mooted the possibility of a kind of evolutionary development in the basic laws of the universe. (For a discussion of Peirce's tychism in comparison with modern quantum theory and cosmology see Finkelstein 1996.)

Ilya Prigogine, winner of the Nobel Prize in physics for his work on the thermodynamics of non-equilibrium systems, has also argued for an objectively tychistic interpretation of the fundamental laws of chemical thermodynamics. According to Prigogine, chance and law work together to produce an irreversible growth in complexity, in a way reminiscent of Peirce's idea of the chance-dependent law of habit-taking. In this regard Prigogine has written of Peirce that "today [his] work appears to be a pioneering step toward the understanding of the pluralism [of necessity and chance] involved in physical laws" (Prigogine 1984: 303).

A list of others who have seen modern physics as an empirical refutation of determinism and have attempted to articulate a philosophical system of objective indeterminism would include Mellor 1990, von Mises 1981, Popper 1972 and 1982, Suppes 1970 and 1984, and Shimony 1993.

Propensities and Probabilities

Popper (1959, 1982) and others (e.g. Giere 1973 and 1979, Hacking 1965, Mellor 1971) have also followed Peirce's lead in attempting to articulate a rigorous and consistent propensity interpretation of the probability calculus. On this reading the concept of probability refers to an objective tendency in events or certain types of chance systems (such as dice, radioactive decay of an atom etc.) to exhibit roughly regular behaviour. The approximately regular behaviour of such stochastic systems may be expressed in the form of statistical frequencies or probabilities which are expected to be more or less experimentally adequate on average and in the long run. For example, a fair coin may be said to have an objective propensity of 0.5 or ½ for landing head side up. Unlike frequency interpretations, which construe probabilities as the actual relative frequency of some event type within a series of trial outcomes or as the limiting value toward which a finite series would converge if extended indefinitely without end, propensities are supposed to be applicable to a single case scenario. This is considered to be an advantage over the frequency interpretations, because without a series of repeated trials we cannot speak of the frequency of a particular type of event, and hence there can be no way of talking about the probability of a particular single case.

However, propensities are considered by some (nominalist) philosophers to have a troubling ontological status, since they seem to commit us to the reality of pure (that is non-instantiated or non-actualized) possibilities. This was no problem for a Scotistic realist like Peirce, for whom all realities – thirds according to his theory of categories – have the quality of transcending what is actual or second. To put the difficulty with propensities in another way, there would seem to be no way of falsifying any claim about the objective chance of an event taking a particular value, say of ½. The same objection can be raised against interpreting probabilities as limiting relative frequencies (a position Peirce held prior to adopting the propensity interpretation). This is because *any* observed relative frequency of heads whatsoever obtained from a finite series of events, 0.95 say, is consistent with the ideal limiting value of 0.5, since it can always be maintained that the ideal limit value is what is to be expected for an infinite series of tosses, and that what is needed is lots more trials to permit the observed relative frequency to converge to the limit value. The formal result known as the law of large numbers states (in rough terms) that the observed frequency of an event will with great probability converge to the objective chance (or limit value) of that event on a single trial. But it provides no guarantee that in any finite sequence of trials the actual frequency will be close to the objective chance. Even if the objective chance of tossing a head with a fair coin is ½ we can't really expect that ½ or close to ½ of the tosses in any finite series of trials will result in heads. What the law of large numbers (a theorem of the probability calculus really, not an empirical law) does say is that of an infinite set of infinite series of repeated tosses with an ideally fair coin, the overwhelming majority of these series of repeated tosses will have relative frequencies of ½ heads or at least very close, (just how close can be arbitrarily specified in advance). The fundamental problem about chance, as Bas van Fraassen (1991, 81ff) has stated it, is to explain just how and why our beliefs about the objective chance of an event should be a reliable guide to what will in fact happen in the future.

The consequences of these objections to a propensity interpretation of probability for Peirce's more general notion of objective chance or tychism are uncertain. The fact is that it is orthodoxy today to maintain that nature is intrinsically chancy and that mechanical determinism is an exploded metaphysical thesis. Peirce's larger vision of an open-ended and indeterminate universe evolving on many levels has spread itself into nearly every discipline and field of inquiry. In the words of the philosopher of science Abner Shimony, "It is honorable to be an epigone of Peirce" (Shimony 1993: 245).[4]

Endnotes:

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1. For a discussion of the connection between the theory of errors and Peirce's pragmatic account of truth see Reynolds (2000).
2. I am grateful to Richard Keshen for making me see this point clearly.
3. In fact, Peirce's idea of god is equally unorthodox. God, according to Peirce, is also in a continuous process of evolution toward greater perfection and determinacy.
4. Many thanks to Kellie White for generating the figures using Minitab and Adobe Photoshop.

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