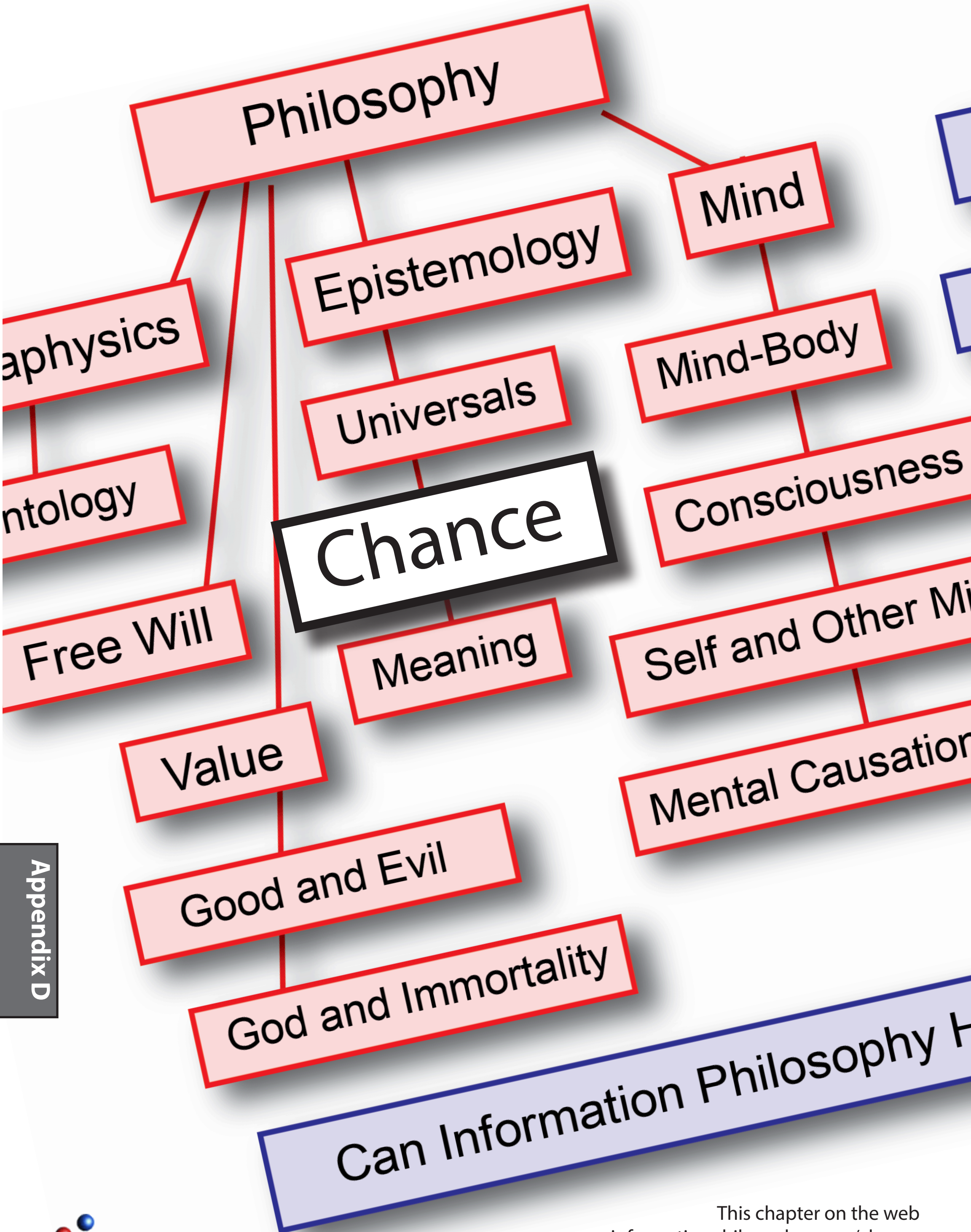


Appendix D

This chapter on the web
informationphilosopher.com/chance

# Chance

Is chance *ontological* and real or *epistemic* and the result of human ignorance. Information philosophy answers this question.

For most of the history of philosophy, ontological chance has been strictly denied. Leucippus (440 BCE) stated the first dogma of determinism, an absolute necessity.

> "Nothing occurs by chance (*maton*), but there is a reason (*logos*) and necessity (*ananke*) for everything."

Chance is regarded as inconsistent with causal determinism and with physical or mechanical determinism.

The first thinker to suggest a physical explanation for chance in the universe was Epicurus. Epicurus was influenced strongly by Aristotle, who regarded chance as a fifth cause. Epicurus said there must be cases in which the normally straight paths of atoms in the universe occasionally bend a little and the atoms "swerve" to prevent the universe and ourselves from being completely determined by the mechanical laws of Democritus.

For Epicurus, the chance in his atomic swerve was simply a means to deny the fatalistic future implied by determinism (and necessity). As the Epicurean Roman Lucretius explained the idea,

> "...if all motion is always one long chain, and new motion arises out of the old in order invariable, and if the first-beginnings do not make by swerving a beginning of motion such as to break the decrees of fate, that cause may not follow cause from infinity, whence comes this freedom in living creatures all over the earth."[1]

Epicurus did not say the swerve was directly involved in decisions so as to make them random. His critics, ancient and modern, have claimed mistakenly that Epicurus did assume "one swerve - one decision." Some recent philosophers call this the "traditional interpretation" of Epicurean free will, an unfortunate error.

On the contrary, following Aristotle, Epicurus thought human agents have an autonomous ability to transcend the necessity and chance of some events. He stated clearly that this special ability makes us morally responsible for our actions.

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1 *De Rerum Natura*, Book 2, lines 251-256

Epicurus, again following Aristotle, finds a *tertium quid*, between and beyond the other two options, necessity (Democritus' determinism) and chance (Epicurus' swerve).

The *tertium quid* is agent autonomy. Epicurus wrote:

> "...some things happen of necessity (ἀνάγκη), others by chance (τύχη), others through our own agency (παρ' ἡμᾶς)...necessity destroys responsibility and chance is uncertain; whereas our own actions are autonomous, and it is to them that praise and blame naturally attach."[2]

Despite abundant evidence, many philosophers deny that real chance exists. If a single event is determined by chance, then indeterminism would be "true," they say, and undermine the very possibility of certain knowledge. Some go to the extreme of saying that chance makes the state of the world totally independent of any earlier states,[3] which is nonsense, but it shows how anxious they are about chance.

The Stoic Chrysippus (200 BCE) said that a single uncaused cause could destroy the universe (cosmos), a concern shared by some modern philosophers, for whom reason itself would fail. He wrote:

> "Everything that happens is followed by something else which depends on it by causal necessity. Likewise, everything that happens is preceded by something with which it is causally connected. For nothing exists or has come into being in the cosmos without a cause. The universe will be disrupted and disintegrate into pieces and cease to be a unity functioning as a single system, if any uncaused movement is introduced into it."

The core idea of chance and indeterminism is closely related to the idea of causality. Indeterminism for some is simply an event without a cause, an uncaused cause or *causa sui* that starts a new causal chain. If we admit some uncaused causes, we can have an adequate (statistical) causality without the physical necessity of strict determinism - which implies complete predictability of events and only one possible future.

Appendix D

2 Letter to Menoeceus, §133
3 Compare perdurantism on p.40

An example of an event that is not strictly caused is one that depends on chance, like the flip of a coin. If the outcome is only probable, not certain, then the event can be said to have been caused by the coin flip, but the head or tails result itself was not predictable. So this "soft" causality, which recognizes prior uncaused events as causes, is undetermined and the result of chance alone.

## The Calculus of Probabilities

The great mathematical theorists of games of chance found ways to argue that the chance they described was somehow necessary, that chance outcomes were actually determined by "laws." The greatest of these, Pierre-Simon Laplace, preferred to call his theory the "calculus of probabilities." With its connotation of approbation, *probability* is a more respectable term than chance, which has associations of gambling and lawlessness. For Laplace, the random outcomes were not predictable only because we lack the detailed information needed to predict. As did the ancient Stoics, Laplace explained the appearance of chance as the result of human ignorance. He said,

> "The word 'chance,' then expresses only our ignorance of the causes of the phenomena that we observe to occur and to succeed one another in no apparent order."

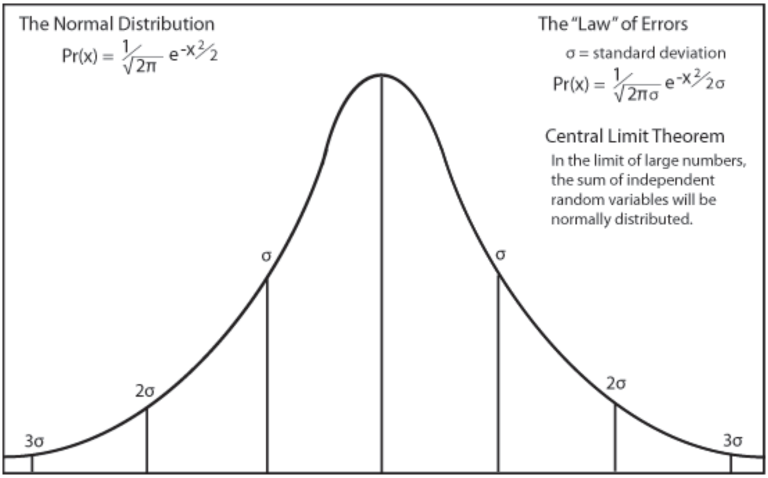


**Figure 32-1. C.S.Peirce called the distribution of random events "normal."**

Decades before Laplace, Abraham de Moivre discovered the normal distribution (the bell curve) of outcomes for ideal random processes, like the throw of dice. Perfectly random processes produce a *regular* distribution pattern for many trials (the law of large numbers). Inexplicably, the discovery of these regularities in various social phenomena led the great thinkers to conclude that the phenomena were determined, not random. They simply denied the existence of chance in the world.

In 1718 De Moivre wrote a book called *The Doctrine of Chances*. It was very popular among gamblers. In the second edition (1738) he derived the mathematical form of the normal distribution of probabilities, but he denied the reality of chance. Because it implied events that God could not know, he labeled it *atheistic*.

> "Chance, in atheistical writings or discourse, is a sound utterly insignificant: It imports no determination to any mode of existence; nor indeed to existence itself, more than to non existence; it can neither be defined nor understood."

As early as 1784, Immanuel Kant had argued that the regularities in social events from year to year showed that they must be the consequence of underlying deterministic laws.

> "Thus marriages, the consequent births and the deaths, since the free will seems to have such a great influence on them, do not seem to be subject to any law according to which one could calculate their number beforehand. Yet the annual (statistical) tables about them in the major countries show that they occur according to stable natural laws."

In the early 1800's Adolphe Quételet and Henry Thomas Buckle argued that these regularities in "social physics" proved that individual acts like marriage and suicide were not "free," but determined by an unknown natural law.

The possibility that chance is more than human ignorance entered physics when Ludwig Boltzmann showed in 1877 that random collisions between atomic particles in a gas could explain the increase in entropy that is the Second Law of Thermodynamics.

In 1866, when Boltzmann first derived Maxwell's velocity distribution of gas particles, he did it assuming that the physical motion of each particle (or atom) was *determined* exactly by Newton's laws. And in 1872, when he attempted to show how his kinetic theory of gases could explain the increase in entropy, he again used strictly deterministic physics. But Boltzmann's former teacher JOSEF LOSCHMIDT objected to this derivation of the second law. Loschmidt said that if time was reversed, the deterministic laws of classical mechanics require that the entropy would then go down, not up.[4]

So in 1877 Boltzmann reformulated his derivation, assuming that each collision of gas particles was not determined, but statistical and random. He assumed that the directions and velocities of particles after a collision depended on chance, as long as energy and momentum were conserved. He could then argue that the particles would be located randomly in "phase space" based on the statistical assumption that individual cells of phase space were equally probable. His *H*-Theorem produced a quantity which would go only up, independent of the time direction. Laws of nature became statistical.

Boltzmann's student FRANZ S. EXNER defended the idea of absolute chance and indeterminism as a hypothesis that could not be ruled out on the basis of observational evidence. Exner did this in his 1908 inaugural lecture at Vienna University as rector (two years after Boltzmann's death), and ten years later in a book written during World War I. But Exner's view was not the standard view. Ever since the eighteenth-century development of the calculus of probabilities, scientists and philosophers assumed that probabilities and statistical phenomena, including social statistics, were completely determined. They thought that our inability to predict individual events was due simply to our ignorance of the details.

In his own 1922 inaugural address at the University of Zurich, *What Is a Law of Nature?*, ERWIN SCHRÖDINGER said about his favorite teacher,

> "It was the experimental physicist, Franz Exner, who for the first time, in 1919, launched a very acute philosophical criticism against the taken-for-granted manner in which the absolute determinism of molecular processes was accepted by everybody. He came to the conclusion that

4 See chapter 25.

> the assertion of determinism was certainly possible, yet by no means necessary, and when more closely examined not at all very probable.
>
> "Exner's assertion amounts to this: It is quite possible that Nature's laws are of thoroughly statistical character. The demand for an absolute law in the background of the statistical law — a demand which at the present day almost everybody considers imperative — goes beyond the reach of experience."

Ironically, just four years later, after developing his continuous and deterministic wave theory of quantum mechanics, Schrödinger would himself "go beyond the reach of experience." He searched for deterministic laws underlying the discontinuous, discrete, statistical and probabilistic indeterminism of the Bohr-Heisenberg school, to avoid the implications of absolute chance in quantum mechanics. Planck and Einstein too were repulsed by randomness and chance. "God does not play dice," was Einstein's famous remark.

A major achievement of the Ages of Reason and Enlightenment was to banish absolute chance as *unintelligible* and *atheistic*. Newton's Laws provided a powerful example of deterministic laws governing the motions of everything. Surely Leucippus' and Democritus' original insights had been confirmed?

Franz Exner was not alone in defending chance before quantum physics. In the nineteenth century in America, Charles Sanders Peirce coined the term "tychism" for his idea that absolute chance was the first step in three steps to "synechism" or continuity.

Peirce was influenced by the social statisticians, Buckle and Quételet, by French philosophers Charles Renouvier and Alfred Fouillée, who also argued for some absolute chance, by the physicists Maxwell and Boltzmann, but most importantly Peirce was influenced by the philosophers Kant and Hegel, who saw things arranged in the *triads* that Peirce so loved.

Quételet and Buckle thought they had established an absolute deterministic law behind all statistical laws. Buckle went so far as to claim it established the lack of free will.

Renouvier and Fouillée introduced chance or indeterminism simply to contrast it with determinism, and to discover some way, usually a dialectical argument like that of Hegel, to reconcile the opposites. Renouvier argues for human freedom, but nowhere explains exactly how chance might contribute to that freedom, other than negating determinism.

Maxwell may have used the normal distribution of Quételet and Buckle's social physics as his model for the distribution of molecular velocities in a gas. Boltzmann also was impressed with the distribution of social statistics, and was initially convinced that individual particles obeyed strict and deterministic Newtonian laws of motion.

Peirce does not explain much with his tychism. And, with his view that continuity and evolutionary love is supreme, may have had doubts about the importance of chance. He did not propose chance as directly or indirectly providing free will. He never mentions the ancient criticisms that we cannot accept responsibility for chance decisions. And he does not really care for chance as the origin of species, preferring a more deterministic and continuous lawful development, under the guidance of evolutionary love. He called Darwinism "greedy? But Peirce does say clearly, well before Boltzmann and Exner, that the observational evidence simply does not establish strict determinism.

It remained for William James, Peirce's close friend, to assert that chance can provide random unpredictable alternatives from which the will can choose or "determine" one alternative. James was the first thinker to enunciate clearly a two-stage decision process, with chance in a *present* time of random alternatives, leading to a choice which selects one alternative and transforms an equivocal ambiguous *future* into an unalterable determined *past*.

Free will consists of undetermined alternatives followed by adequately but statistically determined choices.

> "The stronghold of the determinist argument is the antipathy to the idea of chance...This notion of alternative possibility, this admission that any one of several things may come to pass is, after all, only a roundabout name for chance...

> "What is meant by saying that my choice of which way to walk home after the lecture is ambiguous and matter of chance?...It means that both Divinity Avenue and Oxford Street are called but only one, and that one either one, shall be chosen."[5]

Chance is critically important for the question of free will because strict necessity implies just one possible future. Absolute chance means that the future is fundamentally unpredictable at the levels where chance is dominant. Chance allows alternative futures and the question becomes how the one actual present is realized from these potential alternative futures.

The amount of chance and the departure from strict causality required for free will is very slight compared to the miraculous ideas often associated with the "causa sui" (self-caused cause) of the ancients. For medieval philosophers, only God could produce a *causa sui*, a miracle. Modern quantal randomness, unless amplified to the macroscopic world, is often insignificant, not a miracle at all.

Despite David Hume's critical attack on causality, many philosophers embrace causality strongly, including Hume himself in his other writings, where he dogmatically asserts "*'tis impossible to admit of any medium betwixt chance and an absolute necessity.*"

Since Chrysippus twenty-two centuries ago, philosophers still connect causality to the very possibility of logic and reason.

Bertrand Russell said "The law of causation, according to which later events can theoretically be predicted by means of earlier events, has often been held to be *a priori*, a necessity of thought, a category without which science would not be possible."[6] Although he felt some claims for causality might be excessive, Russell was unwilling to give up strict determinism, saying "Where determinism fails, science fails."[7] And, "what science cannot discover, mankind cannot know."



The great polymath Henri Poincaré said

> "Every phenomenon, however trifling it be, has a cause, and a mind infinitely powerful and infinitely well-informed concerning the laws of

5 "The Dilemma of Determinism," in *The Will to Believe*, 1897, p.155
6 *Our Knowledge of the External World*, p.179
7 *Determinism and Physics*, p.18

nature could have foreseen it from the beginning of the ages. If a being with such a mind existed, we could play no game of chance with him; we should always lose. For him, in fact, the word chance would have no meaning, or rather there would be no such thing as chance."

Max Planck, along with Einstein, Schrödinger and others, opposed indeterminism. Einstein called chance a "weakness in the theory." Planck remained convinced that determinism and strict causality are essential requirements for physical science and so must be true.

"Just as no physicist will in the last resort acknowledge the play of chance in human nature, so no physiologist will admit the play of chance in the absolute sense."

"the assumption of chance in inorganic nature is incompatible with the working principle of natural science."

"We must admit that the mind of each one of our greatest geniuses — Aristotle, Kant or Leonardo, Goethe or Beethoven, Dante or Shakespeare — even at the moment of its highest flights of thought or in the most profound inner workings of the soul, was subject to the causal fiat and was an instrument in the hands of an almighty law which governs the world."[8]

Ernest Rutherford studied the emission of particles from decaying radioactive atoms. He called them α and β rays. The alpha particles are helium nuclei stripped of electrons. The beta particles are electrons. It was Niels Bohr who told Rutherford that the α and β rays were coming from the central nucleus that Rutherford had discovered in 1911, not from the surrounding electron cloud as had been thought.

Rutherford said the emission of rays is a chance process. There seemed to be no way to predict the time or direction of such events. He could only discover a characteristic time or "half-life" after which 50% of the original radioactive elements would be left.

When Bohr showed two years later that the electron cloud could be organized into circular orbits, and the electrons were jumping from one orbit to another with the emission or absorption of light quanta, Rutherford's question to Bohr was, "How do the electrons know which orbit they are going to jump to?"Bohr did not know.

8 *Where Is Science Going?*, pp.147, 154, 156

Einstein answered that question in 1916 when he showed it is purely a matter of chance. Einstein derived A and B coefficients describing the absorption, spontaneous emission, and (his newly predicted) stimulated emission of radiation. In two papers, "Emission and Absorption of Radiation in Quantum Theory," and "On the Quantum Theory of Radiation," he derived the Planck law (for Planck it was mostly a heuristic guess at the formula), he derived Planck's postulate $E = hv$, and he derived Bohr's second postulate $E_m - E_n = hv$. Einstein did this by exploiting the obvious relationship between the Maxwell-Boltzmann distribution of gas particle velocities and the distribution of radiation in Planck's law. He wrote:

> "The formal similarity between the chromatic distribution curve for thermal radiation and the Maxwell velocity-distribution law is too striking to have remained hidden for long. In fact, it was this similarity which led W. Wien, some time ago, to an extension of the radiation formula in his important theoretical paper, in which he derived his displacement law...Not long ago I discovered a derivation of Planck's formula which was closely related to Wien's original argument and which was based on the fundamental assumption of quantum theory. This derivation displays the relationship between Maxwell's curve and the chromatic distribution curve and deserves attention not only because of its simplicity, but especially because it seems to throw some light on the mechanism of emission and absorption of radiation by matter, a process which is still obscure to us."[9]

But the introduction of Maxwell-Boltzmann statistical mechanical thinking to electromagnetic theory produced what Einstein called a "weakness in the theory." It introduces the reality of irreducible objective chance!

If light quanta are particles with energy $E = hv$ traveling at the velocity of light $c$, then they should have a momentum $p = E/c = hv/c$. When light is absorbed by material particles, this momentum will clearly be transferred to the particle. But when light is emitted by an atom or molecule, a problem appears.

9 "On the Quantum Theory of Radiation," Sources of Quantum Mechanics, B. L. van der Waerden, Dover, 1967, p.63

The "statistical interpretation" of Max Born ("Born rule") tells us the outgoing wave is the probability amplitude wave function $\Psi$, whose absolute square is the probability of finding a light particle in an arbitrary direction.

Conservation of momentum requires that the momentum of the emitted particle will cause an atom to recoil with momentum $h\nu/c$ in the opposite direction. However, the standard theory of spontaneous emission of radiation is that it produces a spherical wave going out in all directions. A spherically symmetric wave has no preferred direction. In which direction does the atom recoil?, Einstein asked:

> "Does the molecule receive an impulse when it absorbs or emits the energy $\varepsilon$? For example, let us look at emission from the point of view of classical electrodynamics. When a body emits the radiation $\varepsilon$ it suffers a recoil (momentum) $\varepsilon/c$ if the entire amount of radiation energy is emitted in the same direction. If, however, the emission is a spatially symmetric process, e.g., a spherical wave, no recoil at all occurs. This alternative also plays a role in the quantum theory of radiation. When a molecule absorbs or emits the energy ε in the form of radiation during the transition between quantum theoretically possible states, then this elementary process can be viewed either as a completely or partially directed one in space, or also as a symmetrical (nondirected) one. It turns out that we arrive at a theory that is free of contradictions, only if we interpret those elementary processes as completely directed processes."[10]

An outgoing light particle must impart momentum $h\nu/c$ to the atom or molecule, but the direction of the momentum can not be predicted! Neither can the theory predict the time when the light quantum will be emitted. Einstein called this weakness by its German name - *Zufall* (chance).

He recalled that Rutherford's law for radioactive decay of unstable atomic nuclei could only give the probability of decay time. Einstein saw the connection with radiation emission:

> "It speaks in favor of the theory that the statistical law assumed for [spontaneous] emission is nothing but the Rutherford law of radioactive decay."[11]

Appendix D

10 On the Quantum Theory of Radiation, p.65
11 "Subtle is the Lord...", A. Pais, p.411

But the inability to predict both the time and direction of light particle emissions, said Einstein in 1917, is "*a weakness in the theory..., that it leaves time and direction of elementary processes to chance* (*Zufall*, ibid.)." It is only a weakness for Einstein, of course, because his God does not play dice.

Einstein clearly saw, as none of his contemporaries did, that since spontaneous emission is a statistical process, it cannot possibly be described with classical physics. Einstein had probably known this since 1905, but he deeply disliked the idea of chance in physics. But Einstein's dislike of quantum physics did not prevent him from seeing its necessity.

> "The properties of elementary processes required...make it seem almost inevitable to formulate a truly quantized theory of radiation."[12]

Einstein may not have liked this conceptual crisis, but his insights into the indeterminism involved in quantizing matter and energy were known, if largely ignored, over a decade before Heisenberg's quantum theory introduced his famous uncertainty principle in 1927. Heisenberg states that the exact position and momentum of an atomic particle can only be known within certain (sic) limits. The product of the position error and the momentum error is greater than or equal to Planck's constant $h/2\pi$.

$$\Delta p \Delta x \geq h/2\pi$$

Indeterminacy (*Unbestimmtheit*) was Heisenberg's original name for his principle. It is a better name than the more popular uncertainty, which connotes lack of knowledge. Quantum indeterminacy is ontological as well as epistemic lack of information.

Heisenberg declared that the new quantum theory disproved causality, using facts that were first described by Einstein years earlier. But Heisenberg did not reference Einstein's landmark 1916 work on the breakdown of causality.

12 Pais, ibid.

Heisenberg simply says:

> "We cannot - and here is where the causal law breaks down - explain why a particular atom will decay at one moment and not the next, or what causes it to emit an electron in this direction rather than that."

Indeed, Heisenberg (and possibly Bohr) were still not convinced about Einstein's light quanta as late this remark in 1926!

He told Einstein directly in a personal meeting,

> "Whether or not I should believe in light quanta, I cannot say at this stage. Radiation quite obviously involves the discontinuous elements to which you refer as light quanta. On the other hand, there is a continuous element, which appears, for instance, in interference phenomena, and which is much more simply described by the wave theory of light. But you are of course quite right to ask whether quantum mechanics has anything new to say on these terribly difficult problems. I believe that we may at least hope that it will one day."[13]

It is important to note that Einstein's indeterminism of time and direction is an intrinsic property of the interaction of radiation with matter. It does not depend on limits put on measurements, as Heisenberg's "uncertainty" suggested, nor on the presence of a conscious observer, as Bohr's Copenhagen Interpretation seems to imply. Where Bohr and Heisenberg describe *epistemic* limits to knowledge, Einstein's light quanta shows us an ontologically indeterministic world, independent of any observation or measurement. Einstein says:

> "If the molecule suffers a loss of energy in the amount of *hν* without external stimulation, i.e., by emitting the energy in the form of radiation (spontaneous emission), then this process too is a directional one. There is no emission of radiation in the form of spherical waves. The molecule suffers a recoil in the amount of *hν/c* during this elementary process of emission of radiation; the direction of the recoil is, at the present state of theory, determined by "chance"...
>
> "The weakness of the theory is, on the one hand, that it does not bring us closer to a link-up with the undulation theory; on the other hand, it also leaves time of occurrence and direction of the elementary processes a matter of "chance." Nevertheless, I fully trust in the reliability of the road taken."[14]

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13 "Quantum Mechanics and a Talk with Einstein," *Physics and Beyond*, p.67

14 On the Quantum Theory of Radiation, p.76

## Chance and Free Will

Our two-stage model for free will[15] sees a role for chance in the brain in the form of quantum level noise (as well as pre-quantal thermal noise). Noise can introduce random errors into stored memories. Noise can create random associations of ideas during memory recall. Many scientists have speculated that randomness in the brain may be driven by microscopic fluctuations that are amplified to the macroscopic level. This would not happen in some specific location in the brain. It is most likely a general property of all neurons.

We can distinguish seven increasingly sophisticated ideas about the role of chance and indeterminism in the question of free will. Many libertarians have accepted the first two. Determinist and compatibilist critics of free will make the third their central attack on chance, claiming that it denies moral responsibility. But very few thinkers appear to have considered all seven essential requirements for chance to contribute to libertarian free will.

• Chance exists in the universe. Quantum mechanics is correct. Indeterminism is true, etc.

• Chance is important for free will because it breaks the causal chain of determinism.

• But chance cannot directly cause our actions. We cannot be responsible for random actions.

• Chance can only generate random (unpredictable) alternative possibilities for action or thought. The choice or selection of one action must be adequately determined, so that we can take responsibility. And once we choose, the connection between mind/brain and motor control must be adequately determined to see that "our will be done."

• Chance, in the form of noise, both quantum and thermal noise, must always be present. The naive model of a single random microscopic event, amplified to affect the macroscopic brain, never made sense. Under what ad hoc circumstances, at what time, at what place in the brain, would it occur to affect a decision?

15 See chapter 4 for details.

• Chance must be overcome or suppressed by the adequately determined will when it decides to act, de-liberating the prior free options that "one could have done."

• To the extent that chance is not completely suppressed by the will, the resulting choice can be considered to have an element of randomness. The agent can still take responsibility for allowing the choice to be partially or completely random, the equivalent of flipping a mental coin, if no available option is clearly best.

Of those thinkers who have considered most of these aspects of chance, a small fraction have also seen the obvious parallel with biological evolution and natural selection, with its microscopic quantum accidents causing variations in the gene pool and macroscopic natural selection of fit genes by their reproductive success.

Our two-stage model of free will needs chance for the free generation of action items and thoughts in an agenda of alternative possibilities to be de-liberated by the will. Chance is the "free" in the first stage of free will and the source of human creativity. The adequately determined second stage is the "will" in free will that de-liberates, choosing actions for which we can be morally responsible.