Chapter 1
The Question of Quantum Indeterminacy

Summary This first chapter introduces the concepts of quantum randomness and quantum indeterminacy. An example of indeterminacy is given, along with questions it raises. The book's argument strategy is outlined, and some terminology is clarified.

1.1 Is Quantum Indeterminacy Irreducible?

Quantum Theory is staggeringly accurate and hugely reliable. Yet, it offers little insight into the workings of the Quantum World. For ten decades now, facts witnessed in quantum experiments have defied understanding. The difficulties they present have become the most intractable of conundrums in science. Two perplexing problems stand out: *Quantum Indeterminacy* and *The Measurement Problem.* The chapters of this book resolve the former, and point the way forward toward resolving the latter.

A fundamental question for the Philosophy and Foundations of Physics is whether *Quantum Indeterminacy* is an *irreducible* feature of Nature, to which there can *never* be any deeper understanding; or whether there is reason and process from which indeterminacy originates and stems.

The historical tradition in Physics has been to explain phenomena in terms of factors that *cause* them. This has meant looking for Postulates and Principles which imply physical consequences; along with mathematical framework that conveys those implications. This expectation of *cause & effect* is deeply rooted in experience. *That* is the Classical World. However, in the Quantum World there is phenomenology for which no determining cause can be found. Indeed, there is good science supporting the view that there is *none*. But that lack of *cause* does not mean there is lack of *reason;* there are reasons for the occurrence of effects or phenomena which are not causative.

This book lays down machinery, providing mechanism for quantum indeterminacy; removing the question of irreducibility, as any kind of answer. That machinery will be most unusual to physicists; being afforded by mathematical *freedoms* that *permit* — rather than what might be expected — implications that *cause*. The machinery exposes indeterminacy as an association of *uncausedness* and *indefiniteness*, whose fundamentals lay in: *freedom* that permits perfect symmetries; *stability* that maintains them; and *epistemology* that ambiguates their reference-frame information.

This machinery is not an invented contrivance; it has axioms deriving from the Vienna Experiments [19]; has basis in Mathematical Logic; and reliance on the distinction between *true* and *provable* statements, made famous through the work of Kurt Gödel.

1.2 Concepts of Cause

It is important I make clear the meaning I intend when using the term '*cause*'. There are two meanings that might apply. One is often known as *ontological cause* or *reductionist cause*. This meaning is in use when saying that the motions of planets, and apples, are *caused* by Newton's Laws of Motion and Gravitation.

Reductionism offers insight by explaining the World's workings in terms of fundamental Principles, Axioms or Postulates. These are concise statements which we then accept as *a priori*[1] rules or foundations: at least until better theory comes along. The idea is that these *a priori* rules ***imply***, and so ***cause*** what we witness, as logical consequence. As with both planets and apples, reductionism tends to unify separate theories, previously thought to be unrelated.

The second meaning is *temporal cause*. This entails events in spacetime, where one event follows deterministically from one previous[2]. An example that emphasises the difference between temporal and ontological cause is the question: What Principles, Axioms or Postulates *cause* the existence of spacetime? Or the questions: Is spacetime irreducible? Does spacetime exist without cause? Is spacetime an *a priori* entity?

Where I use the term *'cause'* in this book, I am referring to the reductionist, ontological meaning.

[1] An *a priori* fact is one assumed to be a fundamental truth, for the sake of developing an argument.

[2] The term previous is in dubious usage here, considering, according to Feynman, time runs backwards for antiparticles.

1.3 Quantum Randomness

In *classical physics*, experiments of chance, such as coin-tossing and dice-throwing are *not* truly random, but are *deterministic* — in the sense that — perfect knowledge of the initial conditions would render outcomes perfectly predictable. Put another way; if initial conditions are guaranteed perfectly identical, outcomes of different throws shall be identical also. The degree of randomness relates to the degree of ignorance in the detail of the initial toss or throw. Accordingly, *classical randomness* stems from the ignorance of *physical information.*

In diametrical contrast, in the case of *quantum physics*, the theorems of Kochen and Specker [13], the inequalities of John Bell [4], and experimental evidence of Alain Aspect [2, 1], all indicate that *quantum randomness* does not stem from any such *physical information*, often referred to as *'hidden variables'* or *'predeterminated properties'.*

Motivated by that negatory evidence, in 2008, experiments were conducted in Vienna by Tomasz Paterek et al, designed to demonstrate that quantum randomness originates in *mathematical information* [14, 18, 19, 20]. Their research revealed that quantum randomness results only in experiments where *logical independence* is involved. This is a logical disconnect that stands between items of information which neither prove nor disprove one another.

The inference we can make is that quantum randomness is a matter of *conveyance processes* and *communication* of physical information, rather than the substance-content of physical information itself.

1.4 A Simple Example of Indeterminacy

Randomness refers to statistical distribution in *large* samples; doing statistics on a sample of *one* is meaningless and can never tell us about randomness. Yet, each single sample of *one* must convey an 'intrinsic randomness' — We call this *indeterminacy.* The following is a simple example illustrating quantum indeterminacy, given by Richard Feynman in his book: *QED The Strange Theory of Light and Matter* [8].

Quantum Indeterminacy is illustrated in light reflected by a glass sheet. The experiment concerns a beam of red light. Blue light would do just as well; the important point is that all the light is the same colour.

A very sensitive detector produces 'noise' when hit by this beam. As the beam intensity is lowered the noise becomes discernible as *separate* clicks. The separate clicks are explained as registering discrete *photons.* As the beam intensity is lowered further, to something of the order of weak starlight, the clicks happen less and less often, but their loudness never weakens. The clear separation of clicks indicates that one photon at a time is present in the experiment.

The stream of photons is now aimed at a glass sheet, with detectors placed in front and behind, facing it. Clicks from the different detectors are found to be never simultaneous. Counting clicks reveals the ratio of photons *reflected*, to those *transmitted*. Out of every 100 clicks, those reflected average some definite number, in the range $0 - 16$: dependent on the glass thickness. For a particular thickness glass sheet the reflected clicks might average 5, say. This average remains constant as beam intensity is varied.

For the thinnest of glass sheets, the number reflected is almost always zero. As thicknesses are increased, the reflections go up to average 16 and then fall back to zero. This pattern repeats in cycles over and over again as thicknesses are gradually increased. Newton knew of these cycles. Modern experiments using monochromatic lasers reveal them to continue past 100,000,000 repetitions, corresponding to 50 metres of glass.

Irrespective of all that, we can never predict whether the *next* photon will reflect or transmit.

The detectors demonstrate *discrete decisions*[3] made by *discrete* objects. But the ratios and cycles are perfectly explained by interference in a *wave continuum* — expressing no decision. The waves are viewed as expressing *probability* for decisions individual photons *will* make. But they do not determine, predict, imply or cause the decision of any individual photon.

And so, the question of *Quantum Indeterminacy* is this: prior to encounter with the glass plate, if photons are all understood to be perfectly identical, by what mechanism does any individual photon have the freedom, either to transmit, or reflect? And *The Measurement Problem*: by what mechanism is that freedom lost, as the decision is made?

1.5 The Thesis

1. **Known Science**

   - The Vienna Experiments tell us that quantum randomness has mathematical origins, in *logical independence*.
   - Well-known to Mathematical Logicians: The imaginary unit is *logically independent* of the Axioms of Elementary Algebra — bedrock algebra underlying Quantum Mathematics.

[3] My use of the term decision indicates an *option* — not an information based choice.

2. **Premise**

   - Studying the circumstances of the imaginary unit's *logical independence* in relation to Quantum Mathematics shall lead to a Physical Theory for quantum randomness and quantum indeterminacy.

3. **Investigation**

   - Derive axiomatic consequences demanded by the Vienna Experiments.
   - Trace through Quantum Mathematics to establish:
     - † precisely what items of information drive necessity for requirement of the imaginary unit.
     - † the true *a posteriori* logical status of unitary|Hermicity in Quantum Mathematics — as opposed to the textbook *a priori* status, given as standard.
   - Propose a formal treatment of Quantum Mathematics that acknowledges the logical Independence; and show how it explains the uncaused and indefinite behaviour of indeterminacy.

4. **Findings**

   - Quantum Mathematics of standard theory is demanded by mixed states only; pure states are representable by a rational theory.
   - What connects these is a step-transition, permitted by self-reference, allowing new mathematical freedoms, concerning cause and ambiguity.
   - Complementarity is a mixed state requirement, needed to maintain self-consistency in mixed state systems.
   - Pure states are representable by rational mathematics. For pure states, complex, unitary|Hermitian, Hilbert space, orthogonal, complementary mathematics is redundant.
   - Complementarity is redundant in representation of pure states.
   - There is a step-transition in logic, lying between pure states and mixed, where mixed states are open to mathematical freedoms, concerning cause and ambiguity, not open to pure states.
   - There is a step-transition in logic, lying between pure states and mixed; the transition being furnished by self-reference.
   - Mathematical machinery is derived in which: imaginary unit, unitary symmetry and Hilbert space spontaneously establish and stabilise through self-reference; and in doing so, present referential ambiguities — typically exemplified by left|right handedness in vector spaces.
   - Quantum mixed states do not exist through such cause; but through being: *not preventially denied.* And instead exist by being stably consistent with that axiom set, by not contradicting any of its axioms. This, neither caused, nor prevented world of phenomena, is permitted by *logical independence.*

5. **Conclusions**

- Quantum phenomena are there through consistent stability, not though cause.
- In the Classical World, the path followed by a planet is determined by the influences on it; but equally, every other path is *denied* by those influences. The path *caused* and the singular path *not prevented* are the same. But to deduce the converse, that all phenomena *not prevented* must also be *caused* would be baseless. I propose, therefore, that the Quantum World is filled with uncaused, unprevented phenomena; neither implied nor denied; *consistent* with the underlying ontology, but not a consequence of it. This is freedom allowed by *logical independence.*