Chapter 6
The Vienna Experiments

Quantum Randomness & Logical Independence

Summary This chapter describes the Vienna Experiments, sets out the reasoning used, and then locates the point where logical independence enters the mathematics. It also explains the loss of information during collapse.

6.1 Logical Independence Demonstrated in Experiments

In 2008, Tomasz Paterek et al published experiments, proving that the origin of quantum randomness lies in *mathematical information* [14, 18, 19, 20]. This was research carried out in Vienna by teams at the *Institut für Quantenoptik und Quanteninformation* and *Fakultät für Physik, Universität Wien,* headed by Anton Zeilinger and Časlav Brukner.

In experiments measuring photon polarisation, statistics demonstrate a correlation linking *predictable* outcomes with *logical dependence*; and *random* outcomes with *logical independen*ce. This dependence, or independence, are alternative logical connectives between certain Boolean propositions, found to encode whether experiment hardware configuration is deducible from measurement outcomes. And so, by way of dependence or independence, these Boolean propositions relate the prior-to-measurement epistemology, for polarisation.

The Vienna Team prove the bare-bones fact, that quantum randomness: correlates with logical independence in mathematics. And so logical independence must be taken seriously as an important influence in physical processes. But even without this result, independent of the Vienna findings, there are compelling reasons from within Quantum Mathematics for believing logical independence is key.

The job of this book is to derive implications for Wave/Matrix Mechanics and deduce philosophical implications for the Foundations of Physics.

6.2 The Experiment Setup

The Paterek et al research concerns polarised photons as information carriers through measurement experiments. The experiment hardware comprises a sequence of three segments, which in accordance with Paterek, I denote: Preparation, Blackbox and Measurement. These *prepare*, then *transform*, then *measure* polarisation states. Informationally, the experiment apparatus can be thought of as hardware being fed with hard input data, in the form of the hardware configuration; and expressing output data, in the form of measurement outcome. The hardware configuration is the experiment's orientational alignment of interchangeable hardware filters, read from an X–Y–Z reference system fixed to the hardware. The Y axis is aligned along the direction of photon propagation. Measured states of polarisation are the experiment's output data. Experiments were performed very many times and statistics accumulated. Finally, correlations were found evident, relating configuration input with experiments' output, being either random or predictable. Details of the experiments' setups are taken from Johannes Kofler's Dissertation [14].

1. Preparation
   Photons prepared alternatively as: $|z+\rangle$, $|x+\rangle$ or $|y+\rangle$ eigenstates, by filtering through one of these three alternative polarisers:

   $|z+\rangle$ Linear polariser aligned at 0° to the Z axis.
   $|x+\rangle$ Linear polariser aligned at 45° to the Z axis.
   $|y+\rangle$ Linear polariser aligned at 0° to the Z axis ~ *followed by*
   ~ Quarter wave plate aligned at 45° to the Z axis.

2. Blackbox
   The previously prepared eigenstates are altered through one of these four alternative Pauli transformations:

   $\mathbb{1}$ no waveplate
   σ_z Half wave plate aligned at 45° to the Z axis.,
   σ_x Half wave plate aligned at 0° to the Z axis.,
   $\sigma_x\sigma_z$ Half wave plate aligned at 45° to the Z axis ~ *followed by*
   ~ Half wave plate aligned at 0° to the Z axis.

3. Measurement
   Measurement is performed, by detecting photon capture, directly after one of these three alternative Pauli transformations:

   σ_z no waveplate
   σ_x Half wave plate aligned at 22.5° to the Z axis.
   σ_y Quarter wave plate aligned at 45° to the Z axis.

6.3 The Boolean Representation of Experiments

Use shall now be made of the Boolean propositions discussed in section 4.4. I repeat them here:

$$\begin{array}{lll} f(0) = 0 & f(1) = 0 & f(0) = f(1) \\ f(0) = 1 & f(1) = 1 & f(0) \neq f(1) \end{array} \tag{6.1}$$

Notation: These propositions are shown using notation just as the Vienna Team wrote them. In sections that follow, I make a slight adjustment to their notation, by writing $\overset{\square}{f}(0)$ and $\overset{\square}{f}(1)$ to denote deterministic-definite information written by the Blackbox; and $\overset{\diamond}{f}(0)$ and $\overset{\diamond}{f}(1)$ to denote information, as read by Measurement. The $\diamond$ and $\square$ notation is borrowed from Modal Logic, respectively meaning *necessary* and *possible.*

The Vienna Team represent their experiment configurations using the *Boolean pairs* $(0, 1)$, $(1, 0)$, $(1, 1)$. Information held in these pairs is taken directly from indices in the product $\sigma_{\mathsf{x}}^i \sigma_{\mathsf{z}}^j$; where i and j are interpreted as integers, modulo 2; thus:

$$\sigma_{\mathsf{z}} = \sigma_{\mathsf{x}}^0 \sigma_{\mathsf{z}}^1 \mapsto (0, 1) \qquad \sigma_{\mathsf{x}} = \sigma_{\mathsf{x}}^1 \sigma_{\mathsf{z}}^0 \mapsto (1, 0) \qquad -i\sigma_{\mathsf{y}} = \sigma_{\mathsf{x}}^1 \sigma_{\mathsf{z}}^1 \mapsto (1, 1) \tag{6.2}$$

By way of these three mappings, the Boolean pairs $(0, 1)$, $(1, 0)$, $(1, 1)$ are *linked* respectively to the operators: σ_{z}, σ_{x}, σ_{y}. The action (configuration) of each individual segment: Preparation, Blackbox and Measurement, is each represented by its own Boolean pair. Action of the Preparation is written thus:

$$\sigma_{\mathsf{x}}^m \sigma_{\mathsf{z}}^n \mapsto (m, n)$$

Action of the Blackbox is written thus:

$$\sigma_{\mathsf{x}}^{\overset{\square}{f}(0)} \sigma_{\mathsf{z}}^{\overset{\square}{f}(1)} \mapsto \left(\overset{\square}{f}(0), \overset{\square}{f}(1) \right) \tag{6.3}$$

where $\overset{\square}{f}(0)$ and $\overset{\square}{f}(1)$ are deterministic-definite, axiomatic versions of the Boolean functions (6.1). And action of the Measurement is written thus:

$$\sigma_{\mathsf{x}}^p \sigma_{\mathsf{z}}^q \mapsto (p, q)$$

Remark 3. Variables p and q are not used by The Vienna Team. Instead they copy values m and n from Preparation and repeat them for Measurement. I introduce p and q to avoid confusion between the Preparation and Measurement variables.

By comparing the three mappings in (6.2) against functions in (6.3) we get three propositions, each Pauli operator uniquely specific to one:

$$\boxed{\sigma_{\mathsf{z}} \Rightarrow \overset{\square}{f}(0) = 0 \qquad \sigma_{\mathsf{x}} \Rightarrow \overset{\square}{f}(1) = 0 \qquad \sigma_{\mathsf{y}} \Rightarrow \overset{\square}{f}(0) + \overset{\square}{f}(1) = 0} \tag{6.4}$$

Remark 4. The converse of implications in (6.4) would not be valid, because any of these three propositions could imply $\sigma_{\mathsf{x}}^0 \sigma_{\mathsf{z}}^0 = \mathbb{1}$ the unit operator.

Critically, depending on which Pauli configuration is elected, the Blackbox sets precisely one of these formulae as an axiom. During the run of an experiment, the Blackbox writes that axiom, onto the photon's density matrix. The density matrix holds the whole of that information, *complete* — deterministically. Subsequently, Measurement attempts to read that information, and depending on its own configuration, Measurement's reading will **either** 'agree or disagree' with the Blackbox axiom — **or** — 'do neither'. 'Agree or disagree' demonstrates Measurement's outcome as logically dependent on the Blackbox configuration; 'do neither' demonstrates Measurement's outcome as logically independent.

6.4 Locating Logical Independence in the Experiments

The Paterek research is concerned with the *fact* of logical independence, and not the question of its origins. In this book the direction is different; here, focus is on *tracing lines of dependency and implication,* flowing through experiments — with the aim of locating the point where events depart from dependency and logical independence enters. That is of interest because, whatever 'anomaly' occurs at that specific point will shed light on the workings and machinery of indeterminacy, explaining the *uncausedness* and *indefiniteness.*

What follows charts the progress of logical dependence through the experiment hardware, in order to reveal the origin and generation of logical independence, wheresoever it may arise. The flow of dependency is considered in two stages. I designate these stages: Blackbox-Processes and Measurement-Processes. Blackbox-Processes entail the ingress and egress of information passing through the Blackbox; this is the account from the Blackbox viewpoint. Measurement-Processes entail the reading of that information, by the Measurement hardware; this is the account from the Measurement viewpoint.

Blackbox-Processes and Measurement-Processes are outlined in Subsections 6.4.1 and 6.4.2. They are then shown schematically in Figure 6.1. Chapter 11 expands on this, covering the detail from the Pauli algebraic viewpoint, rather than that of the Boolean.

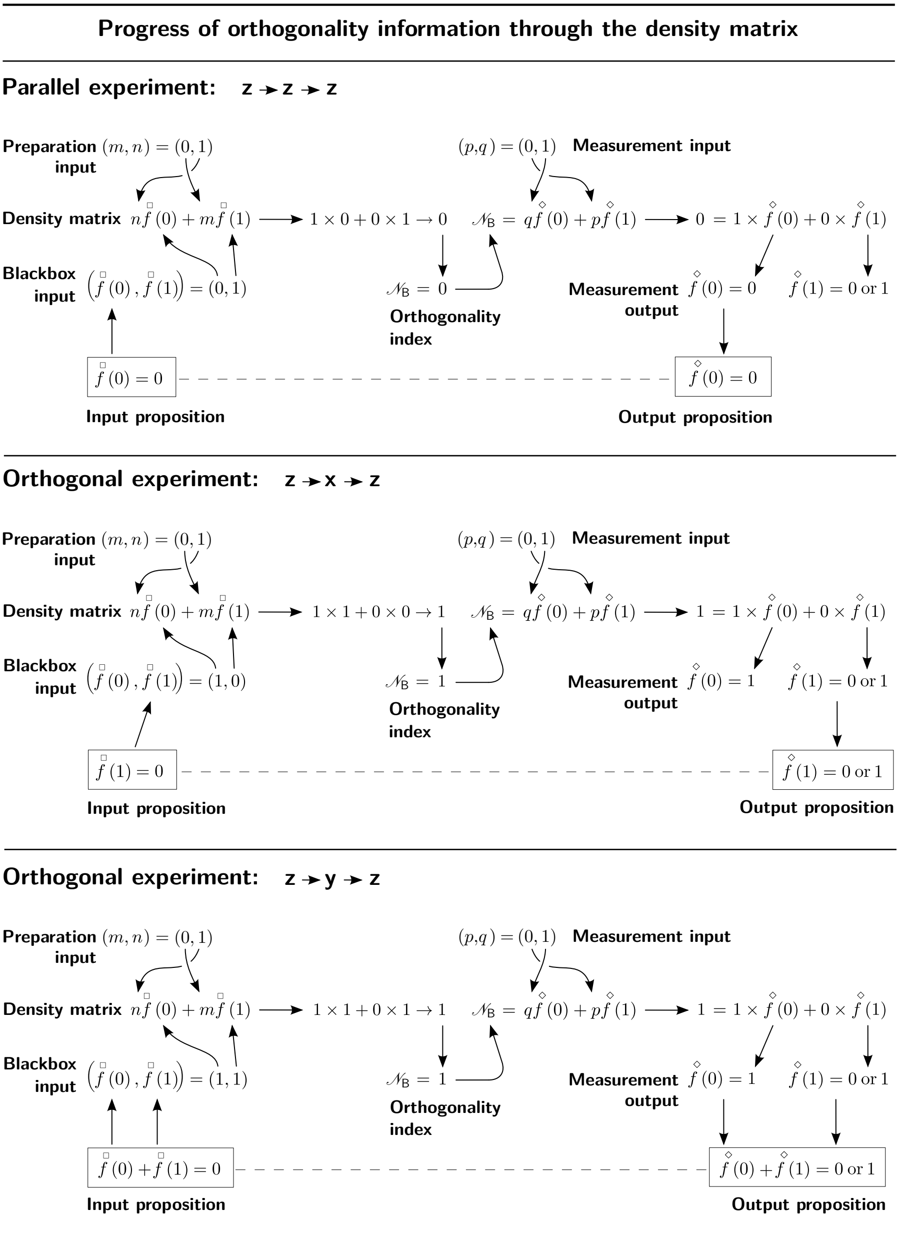

Fig. 6.1: The Vienna Experiments involve polarised photons as information carriers. Polarisation information prepared upstream is conveyed in the density matrix, and taken as input by the measurement hardware. Pivotal in this conveyance is the role of the Orthogonality Index $\mathscr{N}_{\mathsf{B}}$. In experiments on mixed states, processing of $\mathscr{N}_{\mathsf{B}}$ is irreversible. The three scenarios above depict information input feeding into $\mathscr{N}_{\mathsf{B}}$, and the subsequent attempted recovery of information from $\mathscr{N}_{\mathsf{B}}$. Comparison of propositions shown in boxes reveals the overall dependency or independency in each of the three experiments depicted.