<u>Comments on Quantum Ontology</u>

Dave, 4/2/21- 4/9/21…

<u>Book:</u> "Cosmo" book reading group topic: Peter Lewis, <u>Quantum Ontology, A Guide to the Metaphysics of Quantum Mechanics,"</u> Oxford, 2016, 207 pages [pg. ___].

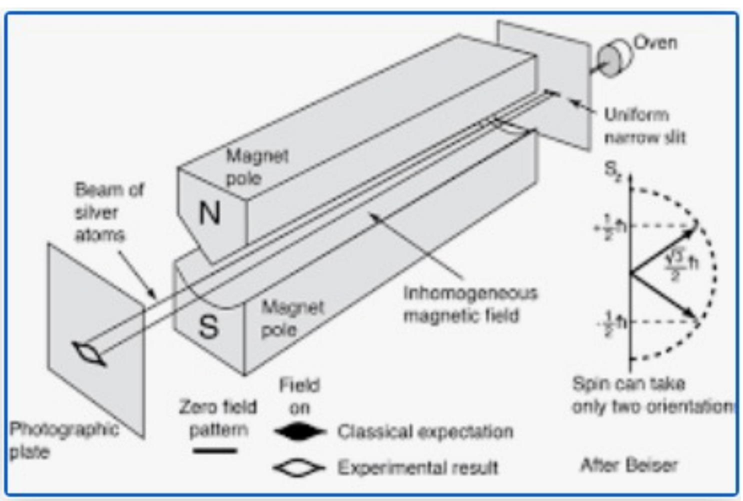
"The physicist E. T. Jaynes famously made the following comment about quantum theory:

"But our present QM formalism is not purely epistemological; it is a peculiar mixture describing in part realities of Nature, in part incomplete human information about Nature --- all scrambled up by Heisenberg and Bohr into an ***omelette*** *that nobody has seen how to unscramble. Yet we think that the unscrambling is a prerequisite for any further advance in basic physical theory. For, if we cannot separate the subjective and objective aspects of the formalism, <u>we cannot know what we are talking about</u>; it is just that simple."*

This is not an easy book. It takes concentration, patience, some struggle and outside reading to get a feeling for the basic terms and ideas. And like much of the study of quantum interpretation, it often strains credulity. What is meant by a realistic interpretation and "quantum reality," non-locality, independence, collapse, quantum "**state**," "**<u>system</u>**," retro-causality, and "measurement?" Electron spin is a primary example with state-vectors for spin-up and spin-down. That is the simplest example of a "state space." But understanding quantum spin isn't that easy. To me, this book led to a lot more time trying to find clarity by reading Google leads than reading the book itself.

Since the book mainly uses electron spin in its discussions, it is best to elaborate on that first:

<u>Spin-Up Spin-Down {A tangible example} Stern-Gerlach</u> Electron Spin Experiment of 1922 (SG). Relevant Terms:



Electron spin
hyperphysics.phy-astr.gsu.edu

<u>Parts of the Experiment:</u>

Preparation : Outer silver valence electrons are carried along with a beam of hot speeding electrically-neutral silver atoms from an oven (~1000 ^oC) after passing through an arrangement of slits. The net angular momentum and magnetic moment of a silver atom is determined by the single spin of its valence electron.
Deflector-Separator-Apparatus: diverging magnetic field from different shaped electromagnetic poles with beam between them through center *{magnetic moment $\mu = \gamma S$ (for spin), electron magnetic energy **H** (for "Hamiltonian") = $-\mu \cdot B$, and deflecting force $F_z = \mu\, dB_z/dz$ }.*

Detector: accumulated metal atoms on a screen form a "lips" pattern.
Observation: 'Bad-cigar breath' containing impurities made silver atoms become black and clearly visible { https://physicstoday.scitation.org/doi/10.1063/1.1650229 }. The presence of human observation enabled the results to be gathered and published. But did human "consciousness" affect the physical collapse? *I don't believe that.* Note that the experimenters had no idea that they had discovered electron spin but rather that magnetic moments led to "space quantization."

Mathematical Description:
Its "**State Space"** can be based on just two "vectors" called up and down in a "z direction".

Then the set of all possible spin "vectors" in all possible directions can be the **state** $|\psi\rangle = a|\uparrow\rangle + b|\downarrow\rangle$ {the coefficients a and b can be any complex numbers such that $|a|^2+|b|^2 = 100\%$}. *This is the simplest example of a "Hilbert Space," but it is not conceptually simple since these aren't vectors in our usual sense: up + down $\neq$ 0 (spin is **not** a Euclidean vector, [p 11]).* Here we can have examples of spin-sideways in the x-direction as the superposition $|\rightarrow\rangle_x = (|\uparrow\rangle + |\downarrow\rangle)/\sqrt{2}$, and spin-y as $|\odot\rangle_y = 0.707|\uparrow\rangle + i\, 0.707|\downarrow\rangle$

{The reason this can make sense is that spin is described by a "spinor" operated on by 2×2 "Pauli matrices." This stuff lives in the realm of hypercomplex space.}.

Before the deflector, the beam has spins in all directions (isotropic, *but some would say the spins are "undefined").* Exposure to the B_z magnetic field gradient locks-in or "**projects**" the spins onto the z-direction and pushes up-spins $|\uparrow\rangle$ upwards and down-spins $|\downarrow\rangle$ downwards. So, after the deflector, there are two beams with individual "eigen-states" $|\uparrow\rangle$ and $|\downarrow\rangle$. "Many-Worlds" would call these "branches" for each electron event {the German word "eigen" means 'its "own" property' }.

The "**System**" is the atomic beam with states $|\Psi\rangle$ of **possible** spins;
Its **observables** are spin operators S_x, S_y, S_z that can operate on $|\Psi\rangle$ to yield their "eigenvalue" spins. And the "dynamical law" is the Schrodinger equation $H|\Psi\rangle = E|\Psi\rangle$ describing energies for spin up and spin down electrons in a magnetic field. Forces are derived from knowing energy. The relevant observable here is the particular spin operator S_z.

The "**Measurement**" consists of both the deflector and the screen (and methods of observing the results). The deflector "collapses" $|\Psi\rangle$ onto its individual spin-eigenstates with eigenvalues $+\hbar/2$ and $-\hbar/2$ in two new beams. "One particular potentiality is actualized" in each beam. The pattern on the screen is the final physical collapse and tells the observer that half the spins were up and half were down {observer's statistical knowledge over many random events}.

<u>REALITY</u>: The term "real" is most often used to mean something "objective and <u>independent</u> of the observer" {Independent of Observation – *too restrictive for quantum mechanics I think*}. In a realist interpretation, observations are claimed to be a "consequence of properties carried by physical systems." Some say real means "classical," perhaps if hidden variables are added; and then they also add that the system should be deterministic. But <u>quantum mechanics is clearly non-classical</u>. Sometimes ψ-real means <u>"pre-assigned"</u> state properties prior to measurement. "Several writers have proposed that the **<u>world of the possible</u>** has to be included as part of reality—because in quantum physics the possible influences the future of the actual" *(e.g., Lee Smolin, Stuart Kauffman, Ruth Kastner, Michael Epperson, Abner Shimony).*

I think the term "Real" should mean something even broader: whatever physical mechanisms are actually used by Nature in the quantum world to transfer information or energy from an emitter to an absorber. The processes might be unobservable and very strange with waves in configuration space (p 51+, 154+) or have extra dimensions or hypercompex variables, or waves going backwards in time while still allowing the mechanism to be called "physical." In a "transactional interpretation [p 123]," this process depends very much on the end absorber and type of measurement and hence is **<u>not</u>** **<u>independent</u>** from it {contextual or environmental [pg. 32] }. It was Mach's positivism that insisted that only classically "observable magnitudes should be considered within a theory," and that guided the "Copenhagen interpretation."

<u>Eigenvector</u>: is a real scalar number value such that an operator on a state = value × state (the "eigenvector–eigenvalue" connection or "link").

<u>Examples</u>: a) If the state is a wave ψ(x) ~ $e^{2\pi ix/\lambda}$, then the derivative operation (-iℏ d/dx)ψ = -iℏi2πψ /λ= +ψ h/λ = p ψ (the wave yields its momentum, p, if '–iℏ d/dx' is an operator for momentum {"ℏ " = h/2π }.

b) Or suppose there is an operator **N** = -i d/dφ , ψ = exp[imφ] /$(2\pi)^{½}$, $\int_o^{2\pi}$ ψ*ψ dφ = 1 (normalized to yield a total of 100% probability), **<u>Nψ = mψ</u>** . For m= 3 standing waves around a Bohr orbit, $e^{i3\varphi}$ gives **Nψ = 3ψ** So, ψ is an eigenfunction of the number operator and m is the eigenvalue}. *{Most other examples use matrices}.*

<u>Epistemic Wave Function:</u>

{The dictionary says, "epistemology is the theory of knowledge, especially with regard to its methods, validity, and scope. It is the investigation of what distinguishes justified belief from opinion." }

An observer who gathers large statistics for the results of a given experiment can obtain an outcome profile as a probability distribution of events. That knowledge can also be calculated from an appropriate wave function squared: P = Ψ*Ψ according to the basic "Born Rule" {discussed below}. So amplitude Ψ contains **<u>our knowledge</u>** of the experiment. Copenhagen would say that is the only purpose of Ψ, and it has no reality beyond that. But that is not the case with some of the other interpretations of quantum mechanics: e.g., Bohmian mechanics, de Broglie "double solution," Cramer's Transactional Interpretation, …. These also have a clear ontology. Also, Ψ is not something deduced from observations, it is derived as a solution of the Schrodinger wave equation expressing conservation of energy (*sounds very physical*).

De Broglie's "double solution" interpretation is similar to Bohmian mechanics except that the Bohmian particle is instead a fundamental wave soliton whose wavelength matches and causes its matter field wavelength Ψ [source arXiv.com :1703.06158] .

"The Born Rule" :

It is the Born Rule that allows superpositions of amplitudes to become interferences for output probabilities. The fundamental but mysterious Born Rule of 1926 was initially a guess about the meaning of the quantum wave function, ψ(x,t), based on an analogy to electric fields, E(x,t). In Einstein's photoelectric effect, a quanta of energy, $\mathcal{E} = hf$, is transferred to an electron. But electric energy density goes as $u_E = ½\ \epsilon_o E^2$ – the "square" of the electric field amplitude. Max Born assumed that ψ was a complex scalar amplitude that also needed "squaring" to be applicable, $|\psi|^2 = \psi^*\psi$. If e_i is an eigenvalue of ψ, he assumed that the "probability" of e_i was $P(e_i) = |\langle e_i|\psi\rangle|^2$ – so right up front, it is postulated that ψ is a strange thing called a **"probability amplitude."** This proposal has always appeared to agree with experimental facts.

But, the rule is an added postulate and "cannot be derived from the other standard postulates of quantum theory without some additional assumptions"

[Vaidman] Lev Vaidman, "Derivations of the Born Rule," Chapter 26, {https://www.tau.ac.il/~vaidman/lvhp/m162.pdf} Tel-Aviv.

In the unitary evolution of the quantum state, it is a virtue that the product $P=\psi^*\psi$ is conserved; but a utility is not a derivation. A plausible physical derivation is desired for understanding.

Retrocausality – Backwards-in-time influences:

It is interesting that the idea called "retrocausality" seems not to be encouraged in our book. And yet it is very frequently mentioned as an alternative or escape from puzzles throughout. There are many of these "backwards-in-time" interpretations with the dominant "Transactional interpretation of Quantum Mechanics" or "TIQM" of John Cramer and Ruth Kastner – which together only take up about three pages {pgs. 123-125 with backward causation mentioned on p 116+}.

Ruth "Kastner claims that the 'transactional interpretation' is unique in giving a physical explanation for the Born rule [Wikipedia]" – a handshaking agreement between an emitter's offer wave ψ and the absorber acknowledgement wave ψ* incorporating "retrocausality" backwards in time. But, as yet, there is no fully worked-out retrocausal interpretation. On the other hand, there aren't any acceptable fully worked-out interpretations at all for quantum mechanics. One nice feature of a "transaction" is that "collapse" doesn't occur far away but rather back at the emitter at time equals zero after it decides its future {a particle knows what it is going to do and where it is going to go because *it has already been there*}. Bohm also has a way of justifying the stability of the Born rule (p 56).

Retrocausality has the virtue of showing that "there is no need for a violation of locality or relativity to explain the Bell correlations." The "dependence of the present on the future" deviates "significantly from the classical ideal" [Lewis p 125]. "Independence" is no longer valid. We know that quantum mechanics isn't classical anyway and that we need very unconventional ideas to make progress.

Quantum mechanics is contextual. The kinds of measurements we make affect "the system" – the processes that may take place before the final observation. Retrocausality is one explanation. For two correlated particles, it isn't important that one measurement might occur well after the other. They both make mutual decisions at the location of their past mutual origin at time equals zero based on their knowledge and reconciliation of their futures. Often that reconciliation is the enforcement of conservation laws regardless of spatial separations between particles. Forget all the "faster than light" talk for non-local influences. Correlating is effectively instantaneous !

COMMENTS:

1. It is interesting that the historically dominant **"Copenhagen Interpretation**" of Heisenberg and Bohr is sparsely mentioned in the book (e.g., p 107, 126). All of our quantum classes and books have been based on this interpretation. Some big names in quantum physics still like this view (e.g., Zeilinger and the "Vienna Group": "the quantum state is a mathematical representation of our knowledge"). But, Adam Becker's book "What is Real" {2018, p 271-277} says: "there is no single Copenhagen interpretation and never really was. It is slippery. Philosophers of physics today almost unanimously reject it. Albert says that Copenhagen is not just weird, "it's gibberish, it's unintelligible." Non-Copenhagen interpreters agree that Copenhagen is the worst of the lot." Sean Carroll commented on the " double slit wave versus particle": if we don't collect which-way information, the photon behaves like a wave; if we do, it behaves like a particle" -- "all that is complete nonsense."

2. **An electron or photon interferes only with itself** -- a simple well-validated sentence. But if you go to a lake on a breezy day, the surface of the water is filled with waves that superimpose on each other with impressive complexity. Matter waves seem not to do this – How do they keep their separate identities? The ψ wave is attached or radiated from the particle it represents. One exception to this is that photons are bosons; and many identical photons close enough in space-time will behave as a single "quanton."

3. I had trouble understanding the word "**supervene**" in the book. Its definition seems to be: "X is said to supervene on Y if and only if some difference in Y is necessary for any difference in X to be possible. A-properties supervene on B-properties if and only if all things that are B-indiscernible are A-indiscernible. [A reference is: https://plato.stanford.edu/entries/lewis-metaphysics/humean-supervenience.html

4. **The world is all-quantum.** Lewis talks about quantum states for marbles, coffee cups, human observers, and human brains! – maybe so, but I suspect they are all way too big. And experimental validations are still much much smaller and well below a Planck Mass {10 μg or 10^{19} GeV energy which I suspect is an ultimate upper size limit}. Tests include ultra cold 30 μm long vibrating paddles and interference demonstrated with beams of big 2000-atom molecules. In addition, constituents of small objects have to be 'coherent:' "The more coherent an object, the more it acts like a wave overall." But large scale coherent states are improbable. Very cold superconductivity is an example of large scale coherent wave states.

5. **Wave function over the Universe** with ~10^{80} particles (e.g., p 154, 161). Again, there are many physicists who accept this, but it is way-beyond testability. Entanglement between two objects has been demonstrated over a thousand kilometers distance (which by itself is mind boggling!). And quantum computers use perhaps 5 to 50 qubits and show incredible computing power. But what could couple many particles and how could they retain coherence?

Revealing Correlations out of Configuration Space:

Two entangled particles move in a 6-dimensional space with 3d x,y,z for each particle.

Suppose we have ultraviolet laser beam photons passing through a non-linear crystal and producing two diverging but entangled red photons of wavelength $\lambda_{red} = 2\ \lambda_{uv}$. Then let these red photons pass through two sets of separate double slits and form interference patterns on each separate test screen {say in a direction z perpendicular to the slits -- see Picture in reference}.

*[**Biphoton**] Ananya Paul 1 & Tabish Qureshi 2, " Biphoton Interference in a Double-Slit Experiment," 67-390-1-PB.pdf http://quanta.ws/ojs/index.php/quanta/article/view/67/102,*

Let mobile detectors sample hits while moving through the screen pattern with the same z at each given time . Accumulated coincidence counts between z_1 and z_2 will reveal **twice** the number of interference peaks --implying a joint coincidence wavelength $\lambda_{red}/2$ -- **like the original λ_{uv} !** The two-red photons act as an emergent "quasi-particle" that could be called a "biphoton"

Similarly, two electrons doubly photoionized by 400 eV photons on H_2 molecules are entangled. If each is passed through a double slit, their joint coincidence count reveal a bi-electron effective wavelength near $\lambda/2$. {ArXiv.com : 1607.07275, 2016}.

SUMMARY

(Lewis's three most prominent solutions to the measurement problem).

Bohmian Mechanics

"Bohm's theory presents us with a clear, dual ontology: There are particles, and there is a wave-like field that pushes them around [p 180]." They follow continuous deterministic trajectories (p145). This means that collapse isn't needed. It is called a non-local hidden variable theory (Lewis doesn't like non-locality). Position X is the hidden variable and Key property, but it resides in "Configuration Space" with 3N dimensions (p 159). Bohmian theory has "counterfactual definiteness" -- the ability to speak "meaningfully" of the definiteness of the results of measurements that have not been performed. "Processes that are entirely local in configuration space can be nonlocal in three-dimensional space."

GRW is the first spontaneous collapse theory that was devised. Physical collapse definitely occurs (p 146) but is random over space and time and has a collapse radius near 100 nm size. A collapse rate is small enough so that microscopic objects are rarely localized (so ordinary QM still applies), but large objects are nearly classical. It is still indeterministic, holistic, and nonlocal with a 3d ontology (p 181). A macro-measurement on particle 1 instantly causes determinant particle 2. Evolution is still by the Schrodinger equation but with a bell-shaped-profile "collapse operator."

Many Worlds fails to produce the Born Rule and has largely undefined probability. Ψ obeys the same local deterministic, reversible laws at all times, and strict collapse never occurs ("everything happens"). Decoherence results in something like an "effective collapse" [p 99]. The concept of branches versus observers seems unclear to me. But Sean Carroll and many others appreciate it and understand it better.

QM in general claims "widespread indeterminancy at the microscopic level that disappears at the macroscopic level" a concrete ontological consequence -- Indeterminancy exists in the world [p 103] -- *unless there is retrocausality.* It has genuine randomness so that probabilities apply. "Does God play dice? The evidence from quantum mechanics is equivocal; and this is a clear case of **underdetermination** at work." [p 149]

Pure Randomness – Intrinsic Indetermenancy – IDEA:

If we could propose a mechanism that seems to produce randomness, QM would still be probabilistic because an observer would not be able to unscramble that randomness. But the underlying physics might be more deterministic.

Here is one idea for the mechanism. **Phase** Matching:

We ignore individual phase because it is just a gauge term that could never be measured – not an observable. But suppose that, at the quantum level, it did exist uniquely for a given interaction. That is, when a photon or electron encounters a coherent object (say an atom or molecule), it has a particular phase. And the object also has its particular phase. If the two are in synch, let that be an enhancement for choosing that event over all other possible events. A candidate selection mechanism.

Atoms get together in molecules by **entraining** their phases into special superimposed orbital bonds. They agree on very precise particular relative phases for constructive interferences. In a retrocausal model, an offer wave would match phases with an optimal absorber's pre-existing phase over all other candidates.

If a simple S^1 circular phase isn't rich enough to do semi-unique matching (one out of 2π radian angles), imagine unseen extra dimensions for more discriminating phases (θ,ϕ) on the sphere S^2 or (χ,θ,ϕ) on S^3. So, an offer wave might have to encompass extra dimensions to carry some sphere phase along with it. And each tiny object would also have to have more complex phase sets.

Some Possible Books ? : It seems to be harder now to find good group books. But we should try to select ones that at least one of us has read and recommended.
One secondary possibility is a little off track for us: Sharon Bertsch McGrayne, **Nobel Prize Women in Science,** 2nd Ed., 1998. Updated information is provided at: https://stacker.com/stories/1709/48-women-who-have-won-nobel-prize#:~:text=With%202020%20Nobel%20prizes%20going,the%20more%20than%20900%20recipients. This added 12 More women up to 2020: Physics includes Donna Strickland & Andrea Ghez.
{I'm now reading Code Breaker by Isaacson on the life and work of Jennifer Doudna – Nobel 2020 for CRISPR. }.
Subtle is the Lord, by Pais on Einstein, is still a great book.