Ontogenesis, Part 2

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For the mind of man is far from the nature of a clear and equal glass, wherein the beams of things should reflect according to their true incidence; nay, it is rather like an enchanted glass, full of superstition and imposture, if it be not delivered and reduced.

Francis Bacon, Novum Organum, Book I, Aphorism XLI

Physics concerns itself with relations between variables, generally in a form of equation. For both sides of an equation to simultaneously have definite values, let alone these values be equal, they must represent commuting observables. QM formalism is grounded in ephemeral entity called *quantum state*[1], identified by values of a complete set of commuting observables (CSCO) [1]. Consequently, an equation does not merely relate numeric values of the observables; it asserts the existence of the specific state those observables denote. This “fact of existence” and the numeric values of observables constitute classical information, which emerges only through the act of measurement. Thus, any equation involving definite values of observables implies measurement. Quantum state, as an entity, arises from measurement, as *output state* of measuring device [2]. There is no state before measurement[2], as demonstrated by Alain Aspect’s [3] Nobel prize-winning experiments. Contrary to a common belief [1] rooted in *dogmatic realism*[3], quantum state does not impart the knowledge of an insinuated external system, but the configuration of measuring device, as explicated in Appendix A. From this premise, I expound on QM formalism, to reach conclusions on several topics of interest, and answer some questions:

1. What is the amount of information in measuring device output?
2. What determines the output of measuring device, aka *quantum state*?
3. What is the amount of information required to set device to a certain configuration?
4. What is the relation between preparation and measuring device?
5. What is the relation between quantum state and quantum ensemble?
6. Is there a boundary between measuring device and measured entity?
7. Does quantum state (aka wave function) collapse upon measurement?
8. Are event outcomes truly probabilistic as commonly believed?
9. What is the significance of global phase?
10. What is the boundary between measuring device and observer?
11. What is the role of observer, debated [4, 5, 6] since very inception of quantum mechanics?

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[1] *Quantum state* is a mathematical entity that embodies the knowledge of a quantum system – Wikipedia, 2025

[2] This straightforward argument obliterates a number of paradoxes rooted in falsehoods permeating the field of quantum physics. One infamous example is the so-called Schrödinger's cat paradox [4], premised on false assumption that there exists a *state* of the cat before the cat is observed

[3] There is *realism*, and there is *dogmatic realism*. Realism is the restatement of objective facts and nothing but facts, even if no finite set of objective facts can explain itself [13]. *Dogmatic realism* (expression coined by Heisenberg [35] for the likes of Einstein and Schrödinger) builds on a subset of facts with added speculative assumptions (dogmas), such as *a priori* assumption of existence of an entity to be measured, external to measuring device

A device of cardinality M is represented by a Hermitian operator $\boldsymbol{X}$, in its eigenbasis, as:

$$\boldsymbol{X} = \sum_{k=1}^{M} x_k \cdot |\boldsymbol{x}_k\rangle\langle\boldsymbol{x}_k| \tag{1}$$

, where $\boldsymbol{x}_k$ is the outcome of measurement event, corresponding to obtained device reading x_k. Outcomes $\{\boldsymbol{x}_k\}$ are called *eigenstates*, and corresponding device readings $\{x_k\}$ are called *eigenvalues*. Throughout this paper M is the device cardinality in fundamental representation [7].

A measurement consists of *quantum ensemble* [8] of $N = \sum_{k=1}^{M} n_k$ events; n_k being the number of occurrences[4] of outcome $\boldsymbol{x}_k$. Output state $\boldsymbol{\psi}$ is deemed a superposition[5] of outcomes $\{\boldsymbol{x}_k\}$:

$$|\boldsymbol{\psi}\rangle = \sum_{k=1}^{M} X_k \cdot |\boldsymbol{x}_k\rangle = \sum_{\{x\}} X(x) \cdot |\boldsymbol{x}\rangle \tag{2}$$

, where $\{X_k\}$ are complex amplitudes. $P_k = |X_k|^2$ is the probability of outcome $\boldsymbol{x}_k$ by Born rule [9], with total probability $P = \langle\boldsymbol{\psi}|\boldsymbol{\psi}\rangle = \sum_{k=1}^{M} P_k = 1$. Instead of using index k to mark eigenvalues and eigenstates, the right side of (2) uses eigenvalues $\{x\}$ as unique index, to express output state $\boldsymbol{\psi}$ in terms of *wave function* $X(x)$.

The standard expression (2) for quantum state pertains to neither an ensemble of systems, nor an individual system, as it contains no attributes specific to either. Even if (2), misleadingly, has adjective *quantum* attached, it represents classical information made accessible by measurement. It is this information, that materializes as *object*, by *observation*[6]/registration, not a speculative *system* or *ensemble of systems*, which, in various models[7] [11, 12], presumably exist "out there", extraneous to obtained information [13]. The assumption of information only "representing" real physical system[8], instead of being one and the same, leads to predictions contradicting those of quantum theory[9] [14]. The very notion of a *system*, as an entity external to materialized information, is a fallacy, equivalent to an assumption of hidden variables. This conclusion makes the discourse [15] on ontic vs. epistemic nature of wave function meaningless.

The information in output state (2), is encoded in complex amplitudes $X_k = |X_k| \cdot exp(i\varphi_k)$. I shall obtain expressions for the amount of information encoded in probabilities $\{P_k\}$, and in phases $\{\varphi_k\}$, and show that in the limit $N \to \infty$ all information is contained in phases $\{\varphi_k\}$, not in probabilities $\{P_k\}$.

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[4] E.g., n_k may be the number of photons of polarization $\boldsymbol{x}_k$ registered by photodetector in a single shot (measurement)
[5] This disposition does away with absurd idea of *wave function collapse*, and with associated measurement "paradox" [17], simply because wave function $X(x)$ in (2) being classical information, does not even exist prior to measurement
[6] The process of observation/registration is described in Appendix C
[7] All QM "interpretations" are rife with falsehoods, as exemplified by the following quote from [11]: "*a momentum eigenstate ... represents the ensemble whose members are single electrons each having the same momentum, but distributed uniformly over all positions*". Momentum and position are conjugate observables. Assuming an individual particle possesses both a specific momentum and a specific (albeit statistically distributed) position implies classicality
[8] All models wherein wave function "represents" physical reality, otherwise described by something, e.g., by some [hidden] variables, other than solely by wave function itself, have been discredited [40, 13]
[9] The assumptions, used in referenced PBR theorem's [14] proof, are equivalent to an assumption of hidden variables, as attributes of insinuated "real physical system"

I first consider finite ensemble $\{n_k\}$, and then take the limit $N \to \infty$. As events with the same outcome are indistinguishable[10], there are Ω ways to arrange events in $\{n_k\}$ sample:

$$\Omega = \frac{N!}{\prod_{k=1}^{M} n_k!} \tag{3}$$

If $\{n_k\}$ is a classical ensemble, then each of N events is a separate, distinct measurement, with no event correlation. The amount of information, carried by classical ensemble of N measurements, is Boltzmann's entropy: $H_B = \ln \Omega$ (*nats*). The amount of information per measurement is $\ln(\Omega)/N$. In quantum ensemble, where event outcomes are correlated, all N events constitute one measurement. Therefore, for quantum ensemble, $\ln(\Omega)/N$ gives the amount of information carried in events correlation of the whole $\{n_k\}$ event sample. For quantum ensemble with given $\{n_k\}$, output states (2) only differ in phases $\{\varphi_k\}$ of amplitudes $\{X_k\}$. Given fixed $\{n_k\}$, different sets of phases $\{\varphi_k\}$ can only correspond to different event correlations in $\{n_k\}$ sample.

Taking the limit $N \to \infty$, I obtain the amount of information in device output, per measurement, encoded in phases $\{\varphi_k\}$. It comes out equal to Shannon's entropy H_S [16]:

$$\left.\frac{H_B}{N}\right|_{N\to\infty} = -\left(\frac{(M-1)}{2N}\ln 2\pi N + \sum_{k=1}^{M}\frac{\left(n_k + \frac{1}{2}\right)}{N}\ln\frac{n_k}{N}\right)_{N\to\infty} =$$

$$= -\sum_{k=1}^{M} P_k \cdot \ln P_k \equiv H_S \ \ (nats) \qquad , where\ \ P_k = \left.\frac{n_k}{N}\right|_{N\to\infty} \tag{4}$$

To evaluate the amount of information encoded in probabilities $\{P_k\}$, I note, the number of different event samples $\{n_k\}$ with no distinction for event correlation, is

$$\Theta = \frac{(N+M-1)!}{N! \cdot (M-1)!} \tag{5}$$

The amount of information encoded in population numbers $\{n_k\}$ of classical ensemble is $H_\Theta = \ln(\Theta)\ nats$. The amount of information carried by population numbers in quantum ensemble is H_Θ/N. The amount of information H_P encoded in probabilities $\{P_k\}$ is then:

$$H_P = \left.\frac{H_\Theta}{N}\right|_{N\to\infty} \to (M-1)\left.\frac{\ln N}{N}\right|_{N\to\infty} \to 0 \tag{6}$$

Thus, the amount of information carried by output state (2), in the limit $N \to \infty$ equals Shannon's entropy (4). Information is encoded in phases $\{\varphi_k\}$ of complex amplitudes. Probabilities $\{P_k\}$ only convey the amount of information (4) in output state, not the information itself. The bandwidth (6), taken by $\{P_k\}$ values, is the protocol overhead [16], vanishingly small for large event samples.

More general formalism, which covers correlated, and uncorrelated event samples, is that of a density matrix $\boldsymbol{\rho}$. Loss of correlation is associated with extraction[11] of information from device output, in amount given by von Neumann entropy [17] $H_N = -Tr(\boldsymbol{\rho}\ln\boldsymbol{\rho})\ nats/measurement$.

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[10] Events can only be distinguished by the outcome of measurement, i.e., by device reading, and by no other parameter or hidden variable. Thus, n_k events corresponding to the same device reading x_k are indistinguishable

[11] The extraction of information from device output is done via process of observation/registration (Appendix C)

The amount of available information H_A in device output, also called *knowledge* [13, 18], is the difference: $H_A = H_S - H_N$. It matches the so-called *Holevo bound* [19, 20] for the amount of accessible information. From (4), the maximum amount of information in measuring device output is $H_M = \ln(M)\ nats$, corresponding to output state (2) with equal probabilities $\{P_k = 1/M\}$. The actual amount of information H_A in device output may vary from 0 to $\ln(M)$ $nats$, depending on $\{P_k\}$ distribution in (4) and depending on if $\boldsymbol{\rho}$ is a pure state, or a mixture. For a mixture, $H_N > 0$. In a mixture, all or part of information contained in phases $\{\varphi_k\}$ is lost, signified by reduction of off-diagonal terms of $\boldsymbol{\rho}$. There is the following relation:

$$(H_A = H_S - H_N) \le H_S \le H_M \tag{7}$$

I have thus derived the amount of information H_A in device output. The related challenge is to find the amount of information in device itself. In presented paradigm, information in device output is part of total information contained in device configuration.

The max amount of information an entity, such as device, may carry is $\ln(K)\ nats$, where K is the number of orthogonal base elements of entity's algebra. Base elements are information-encoding operators. Normalized coefficients of decomposition of an entity into base elements are amplitudes. The squares of amplitudes' absolute values are the probabilities to which formula (4) for quantifying information applies [21]. A device Hermitian operator decomposes into $K = M^2$ base operators of $\boldsymbol{U}(M)$ Lie algebra (Gell-Mann decomposition), where M is device cardinality in fundamental representation. Therefore, a device may contain maximum $\ln(M^2)\ nats$ of information, associated with M^2 base elements, and M^2 real parameters of decomposition.

Out of M^2 real parameters defining device operator, M are eigenvalues, invariant under device unitary transformation. The rest $M^2 - M$ parameters define device internal state, i.e. configuration. Thus, setting device configuration, by $SU(M)$ process $\boldsymbol{X} \to \boldsymbol{V}^\dagger \boldsymbol{X} \boldsymbol{V}$, which I call *preparation*, takes $\ln(M^2 - M)\ nats$ of information. The reverse process $\boldsymbol{V}\boldsymbol{X}\boldsymbol{V}^\dagger \to \boldsymbol{X}$ diagonalizes device operator into form (1). For a device with non-degenerate eigenvalues $\{x_k\}$, transformation $\boldsymbol{V}$, which diagonalizes device operator, is unique up to M global phases of eigenvectors $\{\boldsymbol{\psi}_n\}$ of $\boldsymbol{V}$. I call eigenvectors $\{\boldsymbol{\psi}_n\}$ the *state basis* in Hilbert space of device $\boldsymbol{X}$ output, vs. device eigenbasis $\{\boldsymbol{x}_k\}$. For $SU(M)$ transformation $\boldsymbol{V}$, the sum of global phases of its eigenvectors must be 0. Thus, the number of parameters defining global phases of $\{\boldsymbol{\psi}_n\}$ is $M - 1$. The global phases of $\{\boldsymbol{\psi}_n\}$ account for $\ln(M - 1)\ nats$, which are not converted into classical information, out of total $\ln(M^2 - M)$ $nats$ in device configuration. The $\ln(M)\ nats$, which are converted into classical information, determine which $\{\boldsymbol{\psi}_n\}$ vector is the output state (2). Thus, the configuration of measuring device solely determines output state (2), as one of $\{\boldsymbol{\psi}_n\}$ basis states.

The output state (2) corresponds to a certain event correlation in quantum ensemble $\{n_k\}$. This conclusion defies common view that event outcomes are strictly probabilistic[12]. Truly probabilistic event outcomes correspond to a statistical mixture, i.e. classical ensemble, that has no event correlation. The event correlation information is carried by phases $\{\varphi_k\}$ of complex amplitudes.

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[12] It would be wrong to assume events form a sequence. The word "sequence" implies some ordering parameter (hidden variable) for event outcomes. Eigenvalue is the only parameter which identifies event outcome

[Appendix B](#) describes how event correlation may define phases $\{\varphi_k\}$. The reference phase with respect to which $\{\varphi_k\}$ phases and corresponding event correlation are defined, is the global phase.

The above consideration resolves the problem of randomness in event outcomes of quantum measurement: *He* indeed does not play dice [22]. Instead, *Old Man* makes up *the mind* [2] of measuring device, by setting device internal state, which ultimately determines[13] event correlation.

I call device (1) configuration *optimal* if measurement output contains maximum possible $H_A = H_M = \ln(M)$ *nats* of information. From (4), a device with optimal configuration has eigenbasis $\{\boldsymbol{x}_k\}$ such that $P_k \equiv |X_k|^2 = |\langle \boldsymbol{x}_k|\boldsymbol{\psi}\rangle|^2 = 1/M \;\; \forall k$. Transformation $\boldsymbol{V}$ from state basis $\{\boldsymbol{\psi}_n\}$ to optimal eigenbasis $\{\boldsymbol{x}_k\}$ is:

$$V_{k,n} = \langle \boldsymbol{x}_k|\boldsymbol{\psi}_n\rangle = M^{-1/2} exp(i\pi(n-1)(2k-1-M)/M + i\varphi_k - i\varphi_0); \;\; k,n = 1,2,\ldots M \quad (8)$$

, where $\{\varphi_k\}$ are phases of amplitudes $X_k = |X_k| \cdot exp(i\varphi_k)$; global phase $\varphi_0 = \pi S_M/2M$, where S_M is OEIS cyclic sequence A111951: $S_{(M=1,2,3,4,5,6,7,8,\ldots)} = 0,3,1,2,2,1,3,0,\ldots$ The global phase φ_0 is subtracted to ensure $det(\boldsymbol{V}) = 1$, for $SU(M)$ compliance.

Columns of matrix $\boldsymbol{V}$ are M orthogonal output states $\{\boldsymbol{\psi}_n\}$, represented in optimal device eigenbasis $\{\boldsymbol{x}_k\}$. Introducing eigenvalues $\{y_n = n-1\}$, marking states $\{\boldsymbol{\psi}_n\}$, I write $\{\boldsymbol{\psi}_n\}$ as:

$$|\boldsymbol{\psi}_n\rangle = M^{-1/2}\sum_{k=1}^{M} exp(iy_n x_k + i\varphi_k - i\varphi_0)|\boldsymbol{x}_k\rangle \;\; ; \;\; \{y_n = n-1\} \;\; ; \;\; n = 1,2\ldots M \quad (9)$$

Prior to measurement, state (2) does not exist. State $\boldsymbol{\psi}$ can only be expressed in standard form (2) after measurement has been completed and amplitudes $\{X_k\}$ acquired values $X_k = \langle \boldsymbol{x}_k|\boldsymbol{\psi}\rangle$. Expression (2) is the *hindsight* of pre-measurement state $\boldsymbol{\psi}$ in the context of post-measurement information.

In *hindsight*, measurement generates transition from pre-measurement state $\boldsymbol{\psi}$ to post-measurement state $\boldsymbol{\psi}'$ via $SU(M)$ transformation $\boldsymbol{U} = exp(i\boldsymbol{X}) = \sum_{k=1}^{M} exp(ix_k) \cdot |\boldsymbol{x}_k\rangle\langle \boldsymbol{x}_k|$:

$$\boldsymbol{\psi}' = \boldsymbol{U}\boldsymbol{\psi} = \sum_{k=1}^{M} exp(ix_k)\,|\boldsymbol{x}_k\rangle\langle \boldsymbol{x}_k|\boldsymbol{\psi}\rangle = \sum_{k=1}^{M} X_k exp(ix_k)\,|\boldsymbol{x}_k\rangle \;\; ; \;\; X_k = \langle \boldsymbol{x}_k|\boldsymbol{\psi}\rangle \quad (10)$$

The distinctness of $\boldsymbol{\psi}$ and $\boldsymbol{\psi}'$, i.e. orthogonality $\langle \boldsymbol{\psi}|\boldsymbol{\psi}'\rangle = 0$, signifies the fact of completed measurement. From (10), the orthogonality $\langle \boldsymbol{\psi}|\boldsymbol{\psi}'\rangle = 0$ is expressed by $\sum_{k=1}^{M} P_k exp(ix_k) = 0$. With optimal device configuration, $\boldsymbol{\psi}$ and $\boldsymbol{\psi}'$ are two of $\{\boldsymbol{\psi}_n\}$ states, and $\boldsymbol{V}^\dagger\boldsymbol{U}\boldsymbol{V}$ is a permutation matrix between $\{\boldsymbol{\psi}_n\}$ vectors. The complete set of orthogonality conditions: $\langle \boldsymbol{\psi}_n|\boldsymbol{\psi}_{n+m}\rangle = \langle \boldsymbol{\psi}_n|\boldsymbol{U}^m|\boldsymbol{\psi}_n\rangle = 0$ leads to equations for M device eigenvalues $\{x_k\}$ and M probabilities $\{P_k\}$:

$$\sum_{k=1}^{M} x_k = 0 \;\; ; \;\; \sum_{k=1}^{M} P_k = 1 \;\; ; \;\; \sum_{k=1}^{M} P_k exp(imx_k) = \delta_{m,M} \;\; ; \;\; m = 1,2,\ldots,M \quad (11)$$

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[13] *The heart of man plans his way, but the Lord establishes his steps* [Proverbs, 16:9]

Equations (11) resolve to:

$$x_k = \pi(2k - 1 - M)/M \quad ; \quad P_k = 1/M \quad ; \quad k = 1,2, \ldots M \tag{12}$$

E.g., $\{x_k\} = \pm\pi/2 \ (radians)$, for spin-$1/2$ particle. With (12) transformation $\boldsymbol{U} = exp(i\boldsymbol{X})$ is cyclic. The period is M for odd M, and $2M$ for even M: $\boldsymbol{U}^M \boldsymbol{\psi}_n = (-1)^{M-1}\boldsymbol{\psi}_n$, which ensures $det(\boldsymbol{U}) = 1$.

An arbitrary output state (2) can be expressed in state basis $\{\boldsymbol{\psi}_n\}$ or device eigenbasis $\{\boldsymbol{x}_k\}$:

$$|\boldsymbol{\psi}\rangle = \sum_{k=1}^{M} X_k |\boldsymbol{x}_k\rangle = \sum_{n=1}^{M} Y_n |\boldsymbol{\psi}_n\rangle \quad ; \quad where \quad Y_n = \sum_{k=1}^{M} X_k \langle \boldsymbol{\psi}_n | \boldsymbol{x}_k \rangle =$$

$$= M^{-1/2} \sum_{k=1}^{M} X_k exp(-iy_n x_k - i\varphi_k + i\varphi_0) \quad ; \quad \{y_n = n - 1\}\,;\ n = 1,2 \ldots M \tag{13}$$

Definite values of amplitudes $\{X_k\}$, $\{Y_n\}$ in (2),(13) would not exist unless measurement is completed. It is a fallacy to consider values of amplitudes to be unknown, rather than non-existent. It equates to an assumption of infamous *hidden variables*, with a slew of paradoxes [23, 24, 25] which follow any falsehood. What is viewed as *the past*, i.e. the pre-measurement state $\boldsymbol{\psi}$, is based solely on information contained in post-measurement state (10). The past is *inferred* from the present, via reverse transformation $\boldsymbol{\psi} = \boldsymbol{U}^\dagger \boldsymbol{\psi}'$. The "unitary evolution of quantum state"[14] is unmitigated fallacy if referring to some physical process with continuously varying observables. Unitary transformation is a mathematical interpolation of otherwise indeterminate transition from inferred pre-measurement, to realized post-measurement device output state carrying information which materializes as object by observation/registration[15].

Transformation (8) applied to (1) $\boldsymbol{X} \to \boldsymbol{V}^\dagger \boldsymbol{X} \boldsymbol{V}$ sets device $\boldsymbol{X}$ internal state to optimal configuration. Unitary transformation has to be generated by a device. Transformation $\boldsymbol{V}$ is generated by device $\boldsymbol{Z}$: $\boldsymbol{V} = exp(-i\boldsymbol{Z})$. I call device $\boldsymbol{Z}$ the *preparation device*, vs. measuring device $\boldsymbol{X}$. It takes $\ln(M^2 - M)\ nats$ of information to set device (1) with given eigenvalues $\{x_k\}$ to optimal configuration. It takes full $\ln(M^2)\ nats$ to specify preparation device. Preparation device does not pass all its information to measuring device via $\boldsymbol{X} \to \boldsymbol{V}^\dagger \boldsymbol{X} \boldsymbol{V}$ unitary process.

For $M > 2$, eigenvalues $\{z_k\}$ of preparation device, generally, are not equidistant. It implies that setting cardinality $M > 2$ measuring device to a certain configuration cannot be achieved by $(M - 1)$-qubit preparation device[16] whose eigenvalues are quantized according to (12).

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[14] The word "evolution" is loaded with falsehood in practically every scientific discipline

[15] *If we want to describe what happens in an atomic event, we have to realize that the word `happens' can apply only to the observation, not to the state of affairs between two observations*. – Heisenberg [34]

[16] To expand on this conclusion, considering cardinality $M > 2$ device represents living organism [2], it means a living organism cannot be created from non-live matter. This is the principle of *biogenesis* [41], vs. *archebiosis*. No matter how much a notorious *Victor.Frankenstein* would try to mix various materials and subject them to all kind of conditions, he would not be able to create a living man, or even a single living cell.
And God said, Let the Earth bring forth living creatures according to their kinds – Genesis 1:24
Only the internal state of a qubit can be set using output of another qubit, as they are defined by the same number of parameters, as shown in Appendix D

No matter the internal state of measuring device, eigenvalues (12) are preordained. If device measures electron spin, it registers either $x_1 = +\pi/2$ or $x_2 = -\pi/2$ $radians$. If device is of cardinality $M = 3$, it registers $\{x_k\} = (+2\pi/3\,, 0, -2\pi/3)$ $radians$, the sum of commuting measurements of *isospin* $\{I_3\}_k = (+1/2\,, -1/2, 0)$, and *hypercharge* $\{Y\}_k = (1/3\,, 1/3\,, -2/3)$: $\{x_k\} = \pi(Y + 2\,I_3/3)$. In isolated, i.e. optimal, measurement, the probabilities $\{P_k\}$ of measurement outcomes are fixed at $P_k = 1/M\ \forall k$, as mandated by equations (11). Yet in real-life experiments $0 \leq P_k \leq 1$. It is because real-life situations involve participation by an observer/registrar.

Appendix C shows that involvement of registrar in the measurement leads to:

1. reduction of device output state (2)
2. decrease in amount of information in device output
3. variation in probabilities $\{P_k\}$
4. variation in expectation value, aligned with variation in probabilities $\{P_k\}$

- all manifested by expressions $(C4)$-$(C6)$ in Appendix C.

These conclusions continue to evade physicists, as considerable efforts are being made with multitude of experiments [26] on confirming what should have been by now mundane textbook knowledge.

Appendix A

A number of no-go theorems stipulate an arbitrary quantum state cannot be cloned [27], deleted [28], teleported [29], broadcast [30], hidden [31], communicated [32], or signaled [33] via quantum channel, i.e., via unitary transformation. A deeper look reveals these theorems reduce to the same disposition: apart from trivial case, the underlying process would increase[17] the amount of information, signifying a completed measurement. Yet unitarity ought to conserve information. It makes the mentioned no-go theorems rather self-evident. To add to the no-go list, here is the "no-external entity" theorem. It obviates common, among dogmatic realists[3], belief that measuring device retrieves information about entity, external to the device.

Let $\boldsymbol{x}$ be the initial state of measuring device $\boldsymbol{X}$, and $\boldsymbol{s}$ the initial state of an external entity device is to measure. As expected, before measurement, the separable initial state $|\boldsymbol{\psi}_0\rangle = |\boldsymbol{x}, \boldsymbol{s}\rangle$ contains no information, since states $\boldsymbol{x}$ and $\boldsymbol{s}$ are unknown, i.e., not expressed via bits of classical information: amplitudes, phases.

In "external entity" paradigm, measurement involves interaction between measuring device and external entity. Interaction effectuates global, i.e., involving both the device and entity, transformation from initial $\boldsymbol{\psi}_0$ to entangled interaction state

$$|\boldsymbol{\psi}\rangle = \alpha|\boldsymbol{x}_1, \boldsymbol{s}_1\rangle + \beta|\boldsymbol{x}_2, \boldsymbol{s}_2\rangle \qquad (A1)$$

, with standard normalization[18]:

$$\alpha\alpha^\dagger + \beta\beta^\dagger = 1 \ ; \ \langle\boldsymbol{x}_1|\boldsymbol{x}_1\rangle = 1 \ ; \ \langle\boldsymbol{x}_2|\boldsymbol{x}_2\rangle = 1 \ ; \ \langle\boldsymbol{s}_1|\boldsymbol{s}_1\rangle = 1 \ ; \ \langle\boldsymbol{s}_2|\boldsymbol{s}_2\rangle = 1$$

The above corresponds to the simplest case of measurement in cardinality $M = 2$ basis, with device represented by operator $\boldsymbol{X} = x_1|\boldsymbol{x}_1\rangle\langle\boldsymbol{x}_1| + x_2|\boldsymbol{x}_2\rangle\langle\boldsymbol{x}_2|$. Here $\boldsymbol{x}_1$, $\boldsymbol{x}_2$ are orthogonal $\langle\boldsymbol{x}_1|\boldsymbol{x}_2\rangle = 0$ device eigenstates, marked by eigenvalues x_1, x_2; $|\boldsymbol{x}_1, \boldsymbol{s}_1\rangle$ and $|\boldsymbol{x}_2, \boldsymbol{s}_2\rangle$ are orthogonal states in device + entity Hilbert space. The expression $(A1)$ indicates the measurement outcome $\boldsymbol{x}_1$ correlates with state $\boldsymbol{s}_1$ of insinuated external entity, and outcome $\boldsymbol{x}_2$ correlates with state $\boldsymbol{s}_2$.

The expectation value of the measurement by device $\boldsymbol{X}$ is:

$$\langle\boldsymbol{\psi}|\boldsymbol{X}|\boldsymbol{\psi}\rangle = |\alpha|^2\langle\boldsymbol{x}_1|\boldsymbol{X}|\boldsymbol{x}_1\rangle + |\beta|^2\langle\boldsymbol{x}_2|\boldsymbol{X}|\boldsymbol{x}_2\rangle = P_a x_1 + P_b x_2 \qquad (A2)$$

, where $P_a = |\alpha|^2$; $P_b = |\beta|^2$; with amount of information (4) in device output:

$$H_A = -P_a \ln(P_a) - P_b \ln(P_b)$$

Even though measurement by device $\boldsymbol{X}$ implicitly includes measurement on external entity [34], the output of measurement on external entity is not converted into classical information. Device $\boldsymbol{X}$ does not detect entity. To measure "external" entity, one has to use global device:

$$\boldsymbol{G} = x_1|\boldsymbol{x}_1, \boldsymbol{e}_1\rangle\langle\boldsymbol{x}_1, \boldsymbol{e}_1| + x_2|\boldsymbol{x}_1, \boldsymbol{e}_2\rangle\langle\boldsymbol{x}_1, \boldsymbol{e}_2| + x_3|\boldsymbol{x}_2, \boldsymbol{e}_1\rangle\langle\boldsymbol{x}_2, \boldsymbol{e}_1| + x_4|\boldsymbol{x}_2, \boldsymbol{e}_2\rangle\langle\boldsymbol{x}_2, \boldsymbol{e}_2| \qquad (A3)$$

, where $\boldsymbol{e}_1$, $\boldsymbol{e}_2$ is measurement basis in entity's Hilbert space.

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[17] Which would also forbid deletion process, in manifestation of the second law of thermodynamics

[18] Scalar product $\langle\boldsymbol{\psi}_1|\boldsymbol{\psi}_2\rangle$ is the correlation coefficient between two measurement outputs. The self-correlation coefficient $\langle\boldsymbol{\psi}|\boldsymbol{\psi}\rangle$ is always 1, thus providing underlying reason for normalization of quantum state to 1

The amount of information in device $\boldsymbol{G}$ output state $(A1)$ includes, in the last two terms, the weighted sum of information carried by entity states $\boldsymbol{s}_1, \boldsymbol{s}_2$:

$$H_A = -P_a \ln(P_a) - P_b \ln(P_b)$$
$$-P_a(|\langle \boldsymbol{s}_1|\boldsymbol{e}_1\rangle|^2 \ln(|\langle \boldsymbol{s}_1|\boldsymbol{e}_1\rangle|^2) + |\langle \boldsymbol{s}_1|\boldsymbol{e}_2\rangle|^2 \ln(|\langle \boldsymbol{s}_1|\boldsymbol{e}_2\rangle|^2))$$
$$-P_b(|\langle \boldsymbol{s}_2|\boldsymbol{e}_1\rangle|^2 \ln(|\langle \boldsymbol{s}_2|\boldsymbol{e}_1\rangle|^2) + |\langle \boldsymbol{s}_2|\boldsymbol{e}_2\rangle|^2 \ln(|\langle \boldsymbol{s}_2|\boldsymbol{e}_2\rangle|^2))$$

Unlike $(A2)$, measurement by device $\boldsymbol{G}$ detects entity, which also shows in expectation value:

$$\langle \boldsymbol{\psi}|\boldsymbol{G}|\boldsymbol{\psi}\rangle = P_a(x_1|\langle \boldsymbol{s}_1|\boldsymbol{e}_1\rangle|^2 + x_2|\langle \boldsymbol{s}_1|\boldsymbol{e}_2\rangle|^2) + P_b(x_3|\langle \boldsymbol{s}_2|\boldsymbol{e}_1\rangle|^2 + x_4|\langle \boldsymbol{s}_2|\boldsymbol{e}_2\rangle|^2)$$

Since entity measurement basis $\boldsymbol{e}_1, \boldsymbol{e}_2$ is part of device $(A3)$ operator, the entity is part of $\boldsymbol{G}$, not something external to the device. The conclusion is, if device is to detect a thing, the thing has to be part of the device, not an external entity. Therefore, any boundary between measuring device and measured entity is arbitrary and superfluous. It was noted by Heisenberg [35]:

It has been said that we always start with a division of the world into an object, which we are going to study, and the rest of the world, and that this division is to some extent arbitrary. It should indeed not make any difference in the final result if we, e.g., add some part of the measuring device or the whole device to the object and apply the laws of quantum theory to this more complicated object. It can be shown that such an alteration of the theoretical treatment would not alter the predictions concerning a given experiment.

This conclusion may seem counter-intuitive, as everyone is used to thinking that measuring device measures something external to the device. For example, voltmeter measures voltage in electric outlet. Yet setting up voltmeter, a circuit, and other preparations prior to measurement, amount to creation of device $\boldsymbol{G}$, with no-information initial state $\boldsymbol{\psi}_0$ of device output interface. Once the voltmeter is connected to the circuit, it is impossible to draw the boundary between voltmeter and the circuit it is measuring, as they effectively merge into one device.

One can contemplate a voltmeter which is separated into two parts by wireless connection over arbitrary distance, with no change to its functionality. Then, instead of voltmeter, call it a photon detector. It shows there is only one entity, besides observer, involved in extraction of classical information: the measuring device. In case of voltmeter, it encompasses the whole circuit. In case of photon detector, it includes the photon source. There are no measured "systems" or "objects". The classical information extracted from output of measuring device is *the object*. This realization had escaped many renown physicists, who dwell in dogma about objects existing "out there", independent of and outside of measurement, and possessing some "pre-existing properties", i.e. hidden variables. As exemplified by the quote from [36]:

It would seem that the [QM] *theory is exclusively concerned about results of measurement, and has nothing to say about anything else. ... When it is said that something is measured it is difficult not to think of the result as referring to some pre-existing property of the object in question.*

The generator of unitary transformation $\boldsymbol{U}$, interpolating transition from initial no-information state $|\boldsymbol{\psi}_0\rangle = |\boldsymbol{x}, \boldsymbol{s}\rangle$ to information-carrying interaction state $(A1)$ is the measuring device itself. If device is $\boldsymbol{X}$, then:

$$\boldsymbol{\psi} = \boldsymbol{U}\boldsymbol{\psi}_0 = \alpha|\boldsymbol{x}_1, \boldsymbol{s}_1\rangle + \beta|\boldsymbol{x}_2, \boldsymbol{s}_2\rangle$$

, where:

$$\boldsymbol{U} = exp(i\boldsymbol{X}) = exp(ix_1)|\boldsymbol{x}_1\rangle\langle\boldsymbol{x}_1| + exp(ix_2)|\boldsymbol{x}_2\rangle\langle\boldsymbol{x}_2|$$

$$\alpha = \langle\boldsymbol{x}_1|\boldsymbol{x}\rangle \ ; \ \beta = \langle\boldsymbol{x}_2|\boldsymbol{x}\rangle \ ; \ \ |\boldsymbol{s}_1\rangle = exp(ix_1)|\boldsymbol{s}\rangle \ ; \ |\boldsymbol{s}_2\rangle = exp(ix_2)|\boldsymbol{s}\rangle$$

As above shows, the entity states $\boldsymbol{s}_1$, $\boldsymbol{s}_2$ are not distinguishable by device $\boldsymbol{X}$, i.e., $\langle\boldsymbol{s}_2|\boldsymbol{s}_1\rangle \neq 0$.

If measuring device is $\boldsymbol{G}$ $(A3)$, then:

$$\boldsymbol{\psi} = \boldsymbol{U}\boldsymbol{\psi}_0 = \alpha|\boldsymbol{x}_1, \boldsymbol{s}_1\rangle + \beta|\boldsymbol{x}_2, \boldsymbol{s}_2\rangle$$

, where:

$$\boldsymbol{U} = exp(i\boldsymbol{G}) =$$
$$exp(ix_1)|\boldsymbol{x}_1, \boldsymbol{e}_1\rangle\langle\boldsymbol{x}_1, \boldsymbol{e}_1| + exp(ix_2)|\boldsymbol{x}_1, \boldsymbol{e}_2\rangle\langle\boldsymbol{x}_1, \boldsymbol{e}_2| +$$
$$exp(ix_3)|\boldsymbol{x}_2, \boldsymbol{e}_1\rangle\langle\boldsymbol{x}_2, \boldsymbol{e}_1| + exp(ix_4)|\boldsymbol{x}_2, \boldsymbol{e}_2\rangle\langle\boldsymbol{x}_2, \boldsymbol{e}_2|$$

$$\alpha = \langle\boldsymbol{x}_1|\boldsymbol{x}\rangle \ ; \ \beta = \langle\boldsymbol{x}_2|\boldsymbol{x}\rangle$$
$$|\boldsymbol{s}_1\rangle = exp(ix_1)|\boldsymbol{e}_1\rangle\langle\boldsymbol{e}_1|\boldsymbol{s}\rangle + exp(ix_2)|\boldsymbol{e}_2\rangle\langle\boldsymbol{e}_2|\boldsymbol{s}\rangle$$
$$|\boldsymbol{s}_2\rangle = exp(ix_3)|\boldsymbol{e}_1\rangle\langle\boldsymbol{e}_1|\boldsymbol{s}\rangle + exp(ix_4)|\boldsymbol{e}_2\rangle\langle\boldsymbol{e}_2|\boldsymbol{s}\rangle$$

The entity states $\boldsymbol{s}_1, \boldsymbol{s}_2$ are distinguishable by device $\boldsymbol{G}$ with appropriate choice of measurement basis $\boldsymbol{e}_1$, $\boldsymbol{e}_2$ and device eigenvalues x_1, x_2, x_3, x_4, so that $\langle\boldsymbol{s}_2|\boldsymbol{s}_1\rangle = exp(ix_1 - ix_3)|\langle\boldsymbol{e}_1|\boldsymbol{s}\rangle|^2 + exp(ix_2 - ix_4)|\langle\boldsymbol{e}_2|\boldsymbol{s}\rangle|^2 = 0$.

Since $\boldsymbol{G}$ is the generator of $\boldsymbol{U}$, they commute. The expectation value does not change upon transformation $\boldsymbol{U}$, i.e., measurement does not lead to observable wave function "collapse":

$$\langle\boldsymbol{\psi}|\boldsymbol{G}|\boldsymbol{\psi}\rangle = \langle\boldsymbol{\psi}_0|\boldsymbol{G}|\boldsymbol{\psi}_0\rangle =$$
$$(P_a x_1 + P_b x_3)|\langle\boldsymbol{s}|\boldsymbol{e_1}\rangle|^2 + (P_a x_2 + P_b x_4)|\langle\boldsymbol{s}|\boldsymbol{e_2}\rangle|^2$$

Appendix B

The relation of quantum state (2) to event sample $\{n_k\}$, i.e. to so-called quantum ensemble, is manifested by formula (4) for the amount of information carried by quantum state (2), where set of phases $\{\varphi_k\}$ corresponds to a certain correlation of events in $\{n_k\}$ sample.

For event sample with population numbers $\{n_k\}$, the number of ways to correlate N events, is Ω, given by (3). Hence, Ω should be the number of distinct combinations of phases $\{\varphi_k\}$ in (2).

The number Ω_1 of possible ways to correlate n_1 indistinguishable events having outcome $\boldsymbol{x}_1$, with the rest of $N - n_1$ events, out of a sample of N events is:

$$\Omega_1 = \frac{N!}{n_1! \cdot (N - n_1)!}$$

Phase φ_1 of amplitude X_1 in (2) acquires one of Ω_1 distinct values quantized by $2\pi/\Omega_1$ over $[-\pi, \pi]$ domain: $\varphi_1 = -\pi(\Omega_1 - 1)/\Omega_1, -\pi(\Omega_1 - 3)/\Omega_1, \dots, \pi(\Omega_1 - 1)/\Omega_1$

With the given correlation of n_1 event $\boldsymbol{x}_1$ outcomes, there are

$$\Omega_2 = \frac{(N - n_1)!}{n_2! \cdot (N - n_1 - n_2)!}$$

possible ways to correlate n_2 events having outcome $\boldsymbol{x}_2$, with the rest of $N - n_1 - n_2$ events. It results in phase φ_2 taking one of Ω_2 distinct values:

$$\varphi_2 = -\pi(\Omega_2 - 1)/\Omega_2, -\pi(\Omega_2 - 3)/\Omega_2, \dots, \pi(\Omega_2 - 1)/\Omega_2$$

One step further:

$$\Omega_3 = \frac{(N - n_1 - n_2)!}{n_3! \cdot (N - n_1 - n_2 - n_3)!}$$

$$\varphi_3 = -\pi(\Omega_3 - 1)/\Omega_3, -\pi(\Omega_3 - 3)/\Omega_3, \dots, \pi(\Omega_3 - 1)/\Omega_3$$

Continuing with this logic for the rest of $\{\varphi_k\}$, I end up with: $\Omega_M = 1$; $\varphi_M = 0$. It means the global phase has been eliminated from $\{\varphi_k\}$, leaving φ_M as the reference phase with respect to which other $\{\varphi_k\}$ are defined, and $\boldsymbol{x}_M$ as the reference outcome with respect to which the correlation is defined for other $\{\boldsymbol{x}_k\}$. As expected, the number of distinct combinations of phases $\{\varphi_k\}$ is (3):

$$\prod_{k=1}^{M} \Omega_k = \frac{N!}{\prod_{k=1}^{M} n_k!} = \Omega$$

For absolute values of amplitudes $\{X_k\}$ in (2), it begs for the conjecture: $|X_k| = \sqrt{n_k/N}$, satisfying $|X_k|^2 = P_k$ limit when $N \to \infty$.

I have thus provided the likely scheme of how quantum ensemble of $\{n_k\}$ event outcomes having certain event correlation translates into expression (2) for quantum state.

Appendix C

Output state (2) of measuring device transforms under $SU(M)$ group, in effectuated by measurement transition $\boldsymbol{\psi} \rightarrow (\boldsymbol{\psi}' = \boldsymbol{U}\boldsymbol{\psi})$. To appear as $3D$ *object of observation*, the extracted information has to embody an entity which collectively transforms under $SU(2)$ group, homomorphic to $SO(3)$ transformations in observation space [38]. Such entity is multi-qubit [2]. It materializes by correlation with output states of measuring device:

$$|\boldsymbol{\chi}\rangle = \sum_{n=1}^{M} C_n |\boldsymbol{\psi}_n\rangle |\boldsymbol{q}_n\rangle \qquad (C1)$$

, where $\{\boldsymbol{q}_n\}$ are multi-qubit states; $\{\boldsymbol{\psi}_n\}$ is device state basis (9), $\{C_n\}$ are amplitudes of decomposition of device output in state basis. Multi-qubit states $\{\boldsymbol{q}_n\}$ are the states of observer sensory organs, which object of observation projects onto. States $\{\boldsymbol{q}_n\}$ are normalized, but not necessarily orthogonal: $\langle \boldsymbol{q}_n | \boldsymbol{q}_n \rangle = 1;\ |\langle \boldsymbol{q}_m | \boldsymbol{q}_n \rangle| \geq 0$.

The above disposition facilitates answering old question: is there a boundary between measuring device and observer? The question, as put forward by John von Neumann [17]:

> *That is, we are obliged always to divide the world into two parts, the one being the observed system, the other the observer. In the former we can follow all physical processes (in principle at least) arbitrarily precisely. In the latter, this is meaningless. The boundary between the two is arbitrary to a very large extent. […] That this boundary can be pushed arbitrarily far into the interior of the body of the actual observer is the content of the principle of psycho-physical parallelism. But this does not change the fact that in every account the boundary must be put somewhere if the principle is not to be rendered vacuous; i.e., if a comparison with experience is to be possible.*

The presented here and elsewhere [13, 2] arguments provide the answer: the boundary between observer and measuring device is at the device output interface, which converts device output into classical information by correlation with the states $\{\boldsymbol{q}_n\}$ of observer receptors. The actual location of this boundary may well be inside the body of observer, e.g., at the eye retina, skin, or other sensory organ whose state can be described in terms of classical information. In this context, any multi-qubit device having its states correlated $(C1)$ with output states of measuring device, would qualify as observer. The *registrar* could be the right term to use.

Appendix A demonstrates how entangled state arises as output of a measurement by global device. Any entangled state is the output state of a global device.

As was pointed out in [37], the information extracted by one party in entanglement is not shared with other parties (no-communication [32]). The effect of measurement by a party is the reduction of shared state. The act of measurement traces out measuring device from shared state $(C1)$:

$$\boldsymbol{\rho}_q = Tr_X(|\boldsymbol{\chi}\rangle\langle\boldsymbol{\chi}|) = \sum_{n=1}^{M} C_n C_n^{\dagger} |\boldsymbol{q}_n\rangle\langle\boldsymbol{q}_n| \qquad (C2)$$

The reduced state $(C2)$ is the state of observer receptors. From the point of view of observer, it is the *object of observation*, a multi-qubit, which collectively transforms under a rep of $SU(2)$.

Another way to see this, is through measurement-effectuated transition $\boldsymbol{\chi} \rightarrow (\boldsymbol{\chi}' = \boldsymbol{U}_{\psi}\boldsymbol{\chi})$, where $\boldsymbol{U}_{\psi} = \boldsymbol{V}^{\dagger}\boldsymbol{U}_{x}\boldsymbol{V}$ and $\boldsymbol{U}_{x} = exp(i\boldsymbol{X})$, with $\boldsymbol{X}$ and $\boldsymbol{V}$ given by (1) and (8). $\boldsymbol{U}_{\psi}$ is a permutation matrix between $\{\boldsymbol{\psi}_n\}$ basis states, satisfying $det(\boldsymbol{U}_{\psi}) = 1$:

$$\boldsymbol{U}_{\psi}\big|_{M=2} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}; \quad \boldsymbol{U}_{\psi}\big|_{M=3} = \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}; \quad \boldsymbol{U}_{\psi}\big|_{M=4} = \begin{pmatrix} 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

Due to the same set of eigenvalues (12), transformation $\boldsymbol{U}_{\psi}$ is unitarily equivalent to $spin-(M-1)/2$ transformation of the fully symmetric state of $(M-1)$-qubit [2].

The act of observation, tracing out observer from $(C1)$, reduces shared state $(C1)$ to state $\boldsymbol{\rho}_x$, unitarily equivalent to $(C2)$:

$$\boldsymbol{\rho}_x = Tr_q(|\boldsymbol{\chi}\rangle\langle\boldsymbol{\chi}|) = \sum_{n,m=1}^{M} C_n C_m^{\dagger} \langle \boldsymbol{q}_m | \boldsymbol{q}_n \rangle |\boldsymbol{\psi}_n\rangle\langle\boldsymbol{\psi}_m| \qquad (C3)$$

With registrar involvement, the probabilities of measurement outcomes by device (1) are:

$$P_k = \langle \boldsymbol{x}_k | \boldsymbol{\chi} \rangle \langle \boldsymbol{\chi} | \boldsymbol{x}_k \rangle = \langle \boldsymbol{x}_k | \boldsymbol{\rho}_x | \boldsymbol{x}_k \rangle = \frac{1}{M} \sum_{n,m=1}^{M} C_n C_m^{\dagger} \langle \boldsymbol{q}_m | \boldsymbol{q}_n \rangle exp(i(y_n - y_m)x_k) \qquad (C4)$$

The expectation value of the measurement by device (1) is:

$$\langle \boldsymbol{\chi} | \boldsymbol{X} | \boldsymbol{\chi} \rangle = Tr(\boldsymbol{X}\boldsymbol{\rho}_x) = \frac{1}{M} \sum_{n,m=1}^{M} C_n C_m^{\dagger} \langle \boldsymbol{q}_m | \boldsymbol{q}_n \rangle \sum_{k=1}^{M} x_k exp(i(y_n - y_m)x_k) \qquad (C5)$$

The amount of extracted information $H_N = -Tr(\boldsymbol{\rho}_x \ln \boldsymbol{\rho}_x) = -Tr(\boldsymbol{\rho}_q \ln \boldsymbol{\rho}_q)$. Information H_A in device output is:

$$H_A = H_S - H_N = Tr(\boldsymbol{\rho}_x \ln \boldsymbol{\rho}_x) - \sum_{n=1}^{M} |C_n|^2 \ln|C_n|^2 \quad nats \qquad (C6)$$

The quantities $(C4)$-$(C6)$ exhibit dependence on observer receptors via factors $\langle \boldsymbol{q}_m | \boldsymbol{q}_n \rangle$. The dependency of $(C4)$-$(C6)$ on observer does not violate objectivity[19], because values $\langle \boldsymbol{q}_m | \boldsymbol{q}_n \rangle$ are invariant of observer basis.

The non-equal probabilities $(C4)$ of measurement outcomes, and the decrease in information $(C6)$ in device output, are due to registrar involvement. The information H_A in output of measurement device, and information H_N recorded by the registrar are two complementary [5] quantities. It underscores the participatory nature of physical phenomena.

[19] Objectivity is defined as independence of extracted information (objective facts) on observer [basis] [38]

Appendix D

Unlike cardinality $M > 2$ device, the classical information in output of a qubit uniquely identifies its internal state. If we know $|\boldsymbol{\psi}_1\rangle = \alpha|\boldsymbol{x}_1\rangle + \beta|\boldsymbol{x}_2\rangle$, with $\alpha = \langle\boldsymbol{x}_1|\boldsymbol{\psi}_1\rangle,\ \beta = \langle\boldsymbol{x}_2|\boldsymbol{\psi}_1\rangle$, we also know output state $|\boldsymbol{\psi}_2\rangle = \beta^\dagger|\boldsymbol{x}_1\rangle - \alpha^\dagger|\boldsymbol{x}_2\rangle$, orthogonal to $\boldsymbol{\psi}_1$: $\langle\boldsymbol{\psi}_2|\boldsymbol{\psi}_1\rangle = 0$. Thus, we have a complete state basis $\{\boldsymbol{\psi}_n\}$ in qubit Hilbert space.

The qubit operator in its own eigenbasis is $\boldsymbol{X} = x_1|\boldsymbol{x}_1\rangle\langle\boldsymbol{x}_1| + x_2|\boldsymbol{x}_2\rangle\langle\boldsymbol{x}_2|$. The qubit operator in state basis is $\boldsymbol{V}^\dagger\boldsymbol{X}\boldsymbol{V}$, where:

$$\boldsymbol{V} = \begin{pmatrix}\alpha & \beta^\dagger \\ \beta & -\alpha^\dagger\end{pmatrix} = \alpha|\boldsymbol{x}_1\rangle\langle\boldsymbol{\psi}_1| + \beta^\dagger|\boldsymbol{x}_1\rangle\langle\boldsymbol{\psi}_2| + \beta|\boldsymbol{x}_2\rangle\langle\boldsymbol{\psi}_1| - \alpha^\dagger|\boldsymbol{x}_2\rangle\langle\boldsymbol{\psi}_2|$$

$$\boldsymbol{V}^\dagger = \begin{vmatrix}\alpha^\dagger & \beta^\dagger \\ \beta & -\alpha\end{vmatrix} = \alpha^\dagger|\boldsymbol{\psi}_1\rangle\langle\boldsymbol{x}_1| + \beta^\dagger|\boldsymbol{\psi}_1\rangle\langle\boldsymbol{x}_2| + \beta|\boldsymbol{\psi}_2\rangle\langle\boldsymbol{x}_1| - \alpha|\boldsymbol{\psi}_2\rangle\langle\boldsymbol{x}_2|$$

From above, the qubit operator in state basis, which represents qubit internal state, is:

$$\boldsymbol{V}^\dagger\boldsymbol{X}\boldsymbol{V} = \begin{pmatrix}|\alpha|^2x_1 + |\beta|^2x_2 & \alpha^\dagger\beta^\dagger(x_1 - x_2) \\ \alpha\beta(x_1 - x_2) & |\alpha|^2x_2 + |\beta|^2x_1\end{pmatrix} \qquad (D1)$$

Determining device internal state from device output is only possible for cardinality $M = 2$ device, i.e., qubit. For cardinality $M > 2$ devices, the output state would not contain enough information to uniquely identify device configuration. Measurement cannot extract all information from $M > 2$ device. This fact prompted me to associate $M > 2$ devices with living organisms [2].

As emphasized by N. Bohr [39], a complete measurement of living organism is incompatible with the state of living. Upon such measurement the amount of information in device output would equal the amount of information in device internal state, signifying it is not a live matter.

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