2

Questions and Answers

2.1 What Is Physics?

Throughout this book we shall be concerned greatly with *questions* and *answers*. The *subject* that an *observer* asks a question of will be denoted by a bold symbol such as $\boldsymbol{\Psi}$. On the other hand, the *question* that is asked of a subject will be denoted by a barred bold symbol such as $\overline{\boldsymbol{Q}}$. Then the *answer* A that is obtained when that question is asked of that subject will be denoted by $A \equiv \overline{\boldsymbol{Q}}\boldsymbol{\Psi}$. This notation will be used to explain what quantized detector networks (QDN) is all about and in its mathematical implementation. Note that the left-right ordering here is significant: $\boldsymbol{\Psi}\overline{\boldsymbol{Q}}$ will mean something very different.

If $\mathbf{I}$, the author, were asked the question $\overline{\boldsymbol{Q}} \equiv$ **What is physics?**, my answer $\overline{\boldsymbol{Q}}\mathbf{I}$ would be

$$\overline{\boldsymbol{Q}}\mathbf{I} = \textit{Physics is the process whereby observers first formulate,}$$
$$\textit{then ask, and then answer, empirical questions.}$$

We need to clarify some points about this answer. By *empirical*, we mean according to the established principles of science, whereby theorists make propositions or assertions and then establish the truth values of those propositions relative to experiments carried out by unbiased experimentalists. This is done to acquire information about systems under observation (SUOs) in order to add to our knowledge about the relative physical Universe (that part of the Universe empirically accessible to us). We are motivated to do all this for numerous reasons, not the least of which is basic curiosity. This is the view of physics taken in this book.

Physics is emphatically *not* a discipline that philosophers and metaphysicists can meaningfully contribute to, because without empirical testing, any proposition has to be regarded as scientifically vacuous (empirically meaningless).

The questions relevant to physicists are posed through experiments and consequently will be referred to as empirical questions. Other sorts of questions will be referred to as theoretical questions.

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Matters are never as simple as that. We will clarify presently what we mean by observers, SUOs, and so on. At this point, we observe that the above answer $\overline{\boldsymbol{Q}}$**I** begs a number of questions that should have been asked and answered first. Specifically, we should also ask the questions

$$\begin{aligned}\overline{\boldsymbol{A}} &\equiv \textbf{Who is asking this question?}\\ \overline{\boldsymbol{B}} &\equiv \textbf{Why is this question being asked?}\\ \overline{\boldsymbol{C}} &\equiv \textbf{Who or what is being asked?}\\ \overline{\boldsymbol{D}} &\equiv \textbf{What will be done with the answer?}\end{aligned}$$

and perhaps more. It is the failure to ask questions $\overline{\boldsymbol{A}}$, $\overline{\boldsymbol{B}}$, and so on, that seems to us to be the root cause of many if not all of the conceptual problems people have in the interpretation of quantum mechanics (QM).

We could go further. The *context*, or circumstances, under which we ask our questions is extremely important. For instance, physicists use experiments to answer their empirical questions. The apparatus that they use is part of that context: if the apparatus cannot be constructed, then the questions cannot even be asked. When we look carefully at what we are doing when we do physics, it soon becomes obvious that we have to take great care in how we ask our questions.

We should say at this point that we do have a specific view about how questions should be asked in physics, particularly quantum physics. This view is based on a concept that we call *contextual completeness*, discussed in Section 2.12. Contextual completeness is a measure, based on a simple algorithm, for deciding whether any given assertion or proposition is a reasonable scientific proposition or not. Specifically, we can establish whether it could be investigated according to proper scientific protocols, or whether it is a *vacuous* proposition, meaning that it cannot be empirically tested for a truth value. One of the surprising features of our analysis is that it shows that there are several degrees of contextual completeness, ranging from the completely vacuous (characteristic of metaphysics and philosophy) to the fully contextually complete proposition required in QM.

2.2 Physics and Time

In this book, we take the view that it is necessary and good physics to discuss the meaning of *time*, a central element in all branches of physics and certainly too important to leave to philosophers and metaphysicists.

There are two contrasting natural philosophies of time, called *Manifold Time* and *Process Time* (Encyclopaedia Britannica, 2000). Both of these philosophies are inextricably woven into the fabric of science. Neither is right nor wrong; each has value in the appropriate context. In this book, our focus will be mainly on Process Time, as this is the time most relevant to how humans operate when they do physics experiments.

Manifold Time

Manifold Time is the view that time is a "thing," an objectivized parameter modeled as a real geometrical dimension. An important development in Manifold Time occurred in 1908, when Minkowski proposed that time could be modeled geometrically, as one of the dimensions of *spacetime*, the four-dimensional Lorentz-signature manifold of special relativity (SR), in which all past, present, and future events are contained (Minkowski, 1908; Petkov, 2012). This model of the universe is often referred to as the *Block Universe* (Price, 1997).

There are several significant factors commonly used by physicists to support Manifold Time and the Block Universe concepts. Some of these are the following.

Relativity

Manifestly Block Universe theories such as SR and general relativity (GR) are based on spacetime manifolds with Lorentzian signature metrics. These are discussed in the Appendix, Section A.2.

Reversibility

The laws of Newtonian classical mechanics excluding friction are generally time-reversible. Lines in geometry do not carry any intrinsic direction. Therefore, if time is reversible, it may be possible to model it geometrically.

Unitary Evolution

In QM, states of SUOs evolving without observational intervention are described by Schrödinger unitary evolution, and this is regarded as reversible.

CPT Theorem

In high energy particle physics, the well-known charge, parity, time (CPT) reversal theorem involves symmetry operations in spacetime that are consistent with all experiments to date, particularly particle scattering amplitudes, which have empirically confirmed crossing symmetries (Eden et al., 1966).

Differential Equations

Many differential equations in mathematical physics, such as Maxwell's equations for electrodynamics and Einstein's field equations in GR, contain no dissipative terms, leading to both advanced and retarded solutions to the field equations with no natural (to the theory) reason to eliminate the classically unacceptable advanced solutions.

Process Time

In contrast to Manifold Time, Process Time (Encyclopaedia Britannica, 2000) is based on an acknowledgment that there are irreversible processes going on in the Universe and that humans experience a feeling that there is a "moment of

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the now." Time is no longer viewed as a *thing* but as a *process*. This implies the existence (in this context) of the systems or objects that are processing in time. According to QDN, the observers of those processes are fundamental to this discussion as well. Factors that we take here as supporting the Process Time paradigm are the following.

Irreversibility

Thermodynamics, one of the fundamental branches of physics, has irreversibility built into it.

The Born Rule

The Born rule in QM deals with probability, which is inherently asymmetric regarding time.

Observers

Observers have memory and intention, which are asymmetric regarding the direction of time. Observers operate contextually in an irreversible way, acquiring information as time progresses.

Hubble Expansion

The Universe appears to be expanding in an irreversible way from a definite point in the past. The Block Universe model has no empirical justification for postulating events earlier than that point. Indeed, the Steady State paradigm (Bondi and Gold, 1948; Hoyle, 1948) that postulated an indefinite past has been generally abandoned by cosmologists.

Contextual Incompleteness

The Block Universe paradigm is contextually incomplete with a generalized propositional classification of zero (contextual completeness and generalized propositional classification are discussed further on in this chapter). It is a vacuous, metaphysical concept.

2.3 Reduction versus Emergence

The Manifold Time and Process Time paradigms can be reconciled if context is taken into account. Manifold Time is based on a reductionist view of the laws of physics, whereas Process Time is associated with emergence (or complexity). Reductionism is the principle that all complex SUOs and indeed the universe can all be explained by a relatively few basic laws. It is a bottom-up view of science. Perhaps the purest form of reductionism is seen in elementary particle physics, which presupposes that there is a single Lagrangian that can be used to describe all phenomena by a Theory of Everything (ToE).

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Emergence, on the other hand, is an acceptance that there are situations that transcend reductionism. For example, life is a process, not a collection of atoms; there is no mention of life in the standard model of high energy physics.

Situations in physics that fall out of the scope of reductionism and require emergent thinking generally involve observers and large-scale processes typically involving numbers of particles on the scale of Avogadro's number and more, that is, of the order 10^{26}. Examples in the physical sciences that require emergent concepts are thermodynamics, gravitation, cosmology, and quantum physics. We take the view in this book that it is a fundamental category error to believe that reductionism alone can explain any of those concepts.

The question remains as to the status of reductionism in QDN. Does the relatively successful reductionist Standard Model of particle physics have a place in QDN?

Our answer is emphatically *yes*. Reductionism has a specific role in those aspects of observation that do not involve apparatus explicitly, and that is in the *information void*, the conceptual region between state preparation and outcome detection. We shall be greatly preoccupied with the information void, for it is in that region where the idealized Lagrangians of particle physics can be explored and used to work out the quantum signal transition amplitudes that QDN needs. Indeed, QDN has no way by itself of generating those amplitudes. In this respect, QDN is analogous to scattering matrix (S-Matrix) theory[1] in hadronic physics (Eden et al., 1966), which deals with the architecture of scattering processes but cannot account for the explicit details of amplitudes without introducing Lagrangians.

An important and useful point here is that, by definition, we cannot "know" what the information void is. We can only make models for the transmission of information from preparation device to outcome detector. This is useful because it means we are free in our choice of the models we use to calculate the transmission amplitudes from source to detector across information voids. These models need not be of the standard Lorentzian signature, spacetime manifold type that are used in relativistic quantum field theory. They could be more complicated, such as Snyder's quantized spacetime algebra (Snyder, 1947a,b), or even manifestations of superstrings. At the end of the day, such models simply provide "black box" recipes for the calculation of amplitudes that will have various degrees of empirical correctness but should never be regarded as reflecting absolute truth in any way. Of course, some models will be much better than others.

2.4 Peaceful Coexistence

Peaceful coexistence is a term often used to express the view that the two great scientific paradigms of the twentieth century, quantum theory and relativity, can

[1] S stands for *scattering*.

be reconciled without modification to either, and that neither is subordinate to the other. The problems encountered in failed attempts to reconcile these excellent theories arise because of a belief that they can each be explained in reductionist terms. Our view is that each is an aspect of emergent physics, distinguished by their contexts. To date, these contexts appear to be nonintersecting. General relativity (GR) holds as a classical description of processes involving spacetime and matter on large scales, while QM is an observer-centric description of processes where phase degrees of freedom are under the control of observers.

Denote the set of empirical contexts where GR appears necessary by $\mathcal{G}$, and the set of empirical contexts where QM appears necessary by $\mathcal{Q}$. Then the only place where a unified approach might be needed would be the intersection $\mathcal{G} \cap \mathcal{Q}$, assuming it is not empty. Currently, little is known empirically about such an intersection. Specifically, there seems to be no way at this time of empirically testing any of the proposed theories of quantum gravitation.

One area of great current interest is in the question of Beckenstein–Hawking radiation from black holes. If detected, such radiation would "merely" serve to confirm peaceful coexistence and not some incompatibility between GR and QM. Black hole thermodynamics, as generally formulated, involves QM on a classical curved background spacetime, is contextually incomplete (because observers are inadequately treated), and is therefore not the fully quantized theory of gravitation that many theorists would like to have.

We take the view in QDN that GR and QM are emergent descriptions in physics involving different empirical contexts, so there is no clash of principles.

2.5 Questions and Answer Sets

In physics, questions are asked by observers of states of SUOs. These states will typically be represented by elements of spaces such as Hilbert spaces. We shall use the *question and answer* notation introduced at the start of this chapter. We shall represent a given state of some classical or quantum SUO[2] S by a bold symbol such as $\boldsymbol{\Psi}$ and represent any question that we ask of that state by a barred bold symbol such as $\overline{\boldsymbol{Q}}$. Then our convention is that the answer to question $\overline{\boldsymbol{Q}}$ asked of state $\boldsymbol{\Psi}$ will be denoted by $\overline{\boldsymbol{Q}}\boldsymbol{\Psi}$ and referred to as a *contextual answer*.

Now the whole point of asking a question is to reduce an observer's uncertainty. Before a question $\overline{\boldsymbol{Q}}$ is asked of state $\boldsymbol{\Psi}$, the observer (the entity asking the question) will believe that the answer (still to be obtained) is one element of a set of possible answers. We shall call this set an *answer set* and denote it by $\mathcal{A}(Q|\Psi)$.

In principle, answer sets may be quite general. They could be sets of sentences, sets of numbers, or sets of symbols. An answer set may even be empty or consist

[2] By this we mean whether we have decided to use classical mechanics (CM) or QM in our discussion of the experiment.

of an infinite number of real or complex numbers. In this book, we shall focus primarily on answer sets based on real or complex numbers.

A critical, implicit factor in any question and answer process is the role of *contextuality*, that is, the circumstances under which a given proposition may be true or false. Observers do not receive fully formed answers directly from their equipment, such as "*the particle landed here on the screen*." Rather, an observer will look at a screen, either optically or via electronic equipment, and notice for example that all pixels except one are white. That exceptional pixel requires interpretation by the observer. A typical interpretation would be that it represented the impact site of a particle. That would be valid, however, only if the context of that particular experiment made that a reasonable inference. For instance, the observer might already have determined that the exceptional pixel in question was faulty and could not pick up any signals whatsoever, so did not represent a particle impact.

Context has a critical role, perhaps the most critical role, in quantum physics. In contrast, classical mechanics is based on the realist concept of *noncontextuality*, which asserts that SUOs "have" physical properties regardless of how they are observed or not observed.

2.6 Answer Set Collapse

Time plays a critical role in the concept of question and answer. *Before* we ask a question $\overline{\boldsymbol{Q}}$ of some state $\boldsymbol{\Psi}$, the range of possible answers is generally two or more. Having less than two possible answers in an answer set is of limited practical value in general.

On the other hand, *after* we have obtained the answer value $A \equiv \overline{\boldsymbol{Q}}\boldsymbol{\Psi}$, which is some element of the initial answer set $\mathcal{A}(Q|\Psi)$, our uncertainty has completely disappeared. That disappearance is accompanied by the disappearance, in our minds, of the original answer set. The transition $\mathcal{A}(Q|\Psi)$ to the singleton set $\{\overline{\boldsymbol{Q}}\boldsymbol{\Psi}\}$ is a completely natural result of the questioning and answering process. Unfortunately, it has been objectified by some quantum theorists as the sudden "collapse" of a quantum wave function or state and asserted as something to be concerned about.

The reason for this concern has to do with the interpretation of the wave function/quantum state vector and the role of time in QM. In general, questions cannot always be asked nondestructively. For example, to determine a person's blood type, some blood has to be taken. One of the fundamental differences between CM and QM is that in CM, it is generally asserted that questions can be asked of states of SUOs without affecting those states in any way. That is not always the case in QM.

The problem about *wave function collapse*, or *state reduction*, can be understood as follows. Suppose we ask a question $\overline{\boldsymbol{Q}_1}$ of a state $\boldsymbol{\Psi}$ of an SUO and get the answer $\overline{\boldsymbol{Q}_1}\boldsymbol{\Psi}$. There is no controversy about that, neither classically nor quantum mechanically. Now suppose that we wanted to ask another question, $\overline{\boldsymbol{Q}_2}$ of that state, *after* we have asked $\overline{\boldsymbol{Q}_1}$. There are three possibilities to consider.

Null Tests

The question $\overline{\boldsymbol{Q}_1}$ could be *completely nondestructive*, giving an answer yet leaving the original state unaltered. This scenario is assumed throughout CM, classical questions generally being assumed completely nondestructive. In standard QM this scenario is called a *null test* (Peres, 1995), being described by a state that is an eigenstate of the observable concerned. In his famous book on QM, Dirac discussed this scenario in terms of polarized light passing through two or more polarizing crystals (Dirac, 1958). If an unpolarized monochromatic beam of light is passed through a polarizing crystal, two polarized beams of light are observed to emerge. If either of these beams is then passed through an identical crystal with the same orientation as the first, that beam then goes through the second crystal without further splitting.

A spectacular example of a null test was discussed by Newton in his astonishing book *Opticks* published in 1704 (Newton, 1704). Newton showed that if a beam of sunlight were passed through a prism P^1, then it would be split into a set of sub-beams of different colors, defining a *spectrum*. If that spectrum was then carefully focussed onto a second prism P^2, then P^2 would undo the action of P^1, resulting in a reconstituted beam emerging from P^2 that had the same spectral properties as the initial incident beam. In essence, the combination P^1 followed by P^2 acts as a null test on the original incident beam. This experiment is discussed in detail in Section 11.4.

Partial Destruction

It could be the case that $\overline{\boldsymbol{Q}_1}$ is *partially destructive*, also known as a *measurement of the first kind* (Paris, 2012). After the answer $\overline{\boldsymbol{Q}_1}\boldsymbol{\Psi}$ has been obtained, the SUO is then in some altered state $\boldsymbol{\Psi}'$ different from the original state $\boldsymbol{\Psi}$. Any attempt now by the observer to ask question $\overline{\boldsymbol{Q}_2}$ would then be extracting not the answer $\overline{\boldsymbol{Q}_2}\boldsymbol{\Psi}$ but the answer $\overline{\boldsymbol{Q}_2}\boldsymbol{\Psi}'$.

Total Destruction

It could be the case that $\overline{\boldsymbol{Q}_1}$ is *totally destructive*, also known as a *measurement of the second kind*, or *demolitive measurement* (Paris, 2012). The process of asking $\overline{\boldsymbol{Q}_1}$ totally destroys the original state $\boldsymbol{\Psi}$, so that $\overline{\boldsymbol{Q}_2}$ could not even be asked.

In the real world, human observers get a lot of information about objects around them optically, which is by and large a weakly destructive process that gives the impression of being totally nondestructive. This has led to the classical conditioning that regards the ordering of questions as not significant. In contrast, QM is based on the empirical evidence that all observations that extract genuine information are never nondestructive, Planck's constant being a manifestation of that fact. The temporal ordering of questions is significant in QM and is generally discussed in terms of the commutation properties of the observables associated with the questions involved.

Answer set collapse has everything to do with the observer's state of information and nothing to do with any changes in the state $\boldsymbol{\Psi}$ per se. What happens to a state after a question has been asked is a separate issue and depends on the experiment and on the dynamics assumed.

Standard QM does not in general discuss the third of the above three scenarios; what happens to a quantum state when an experiment has finished and the apparatus has been destroyed or decommissioned is considered outside the remit of standard QM. In contrast, QDN has an agenda to consider such possibilities. Such matters are discussed in Chapter 25.

Whether the processes of observation are destructive or not, answer set collapse will still take place in general, illustrating the QDN view that QM is a theory of observation and not of objects per se.

2.7 Incompatible Questions and Category Errors

Not all questions can be asked sensibly of all states. For instance, suppose $\boldsymbol{\Phi}$ represents the state of an apple resting on my desk. Then if $\overline{\boldsymbol{Q}}$ is the question

$$\overline{\boldsymbol{Q}} \equiv \textbf{How far is the Moon from the Earth?} \tag{2.1}$$

it is obvious that $\overline{\boldsymbol{Q}}\boldsymbol{\Phi}$ is meaningless. This is an example of an *incompatible question*, a mismatch between the concepts used to define the state of the SUO (in this case, the apple on the desk) and the concepts required to formulate the question (in this case, the distance between the Moon and the Earth). Another term for such a conceptual clash is *category error*.

Experimentalists generally have to spend a great deal of time and resources to arrange for their questions and their states of SUOs to be compatible. Compatibility is always contextual: a question $\overline{\boldsymbol{Q}}$ that is compatible with states of one SUO will usually be incompatible with states of some other SUO. For example, a photon detector will click when placed in a laser beam, but will not click when placed in an electron beam.

An important source of incompatibility may be due to the mechanical structure and functionality of apparatus. This can come about in several ways. First, if a detector has not yet been built, or cannot be constructed for some reason, then any attempt to detect a signal is a trivial example of an incompatible question. We may call this *existential incompatibility*. It is the source of a basic error in the interpretation of quantum mechanics. Physics is an empirical subject. If an experiment cannot actually be done in principle or in practice, then theoretical conclusions should not be treated as empirical facts. For example, we have theoretical reasons to believe that no apparatus can be constructed that can detect simultaneously the exact position and exact momentum of an electron. Experimentalists such as Afshar have attempted to circumvent such a conclusion

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empirically in the case of two-path interferometry (Afshar, 2005), but the general consensus at this time is that they have not succeeded (Jacques et al., 2008).[3]

Suppose a detector does exist in a laboratory. It could be *faulty*, so that any attempt to detect a signal would be doomed to failure. Another possibility is that a detector exists and has registered a signal that the observer knows about (such as in a teleportation experiment), and then that detector has been deliberately *decommissioned* in some way by the observer so as to prevent further signals being generated. Any further attempts to detect a new signal automatically then involve a incompatible question.

Finally, even if a detector exists and is working properly, its compatibility will be contextual on the states being asked. For instance, a photon detector will not detect neutrinos.

There is a class of questions that appear to be nominally physically based, but which have an empty answer set under all known empirical circumstances. This means that there is currently no way known of answering such questions empirically. For example, the question **Is time travel possible?** is one such question. We just don't know the answer. We may refer to such questions as *speculative*. There is a place for them in science, in that they can stimulate reasonable discussion.

A more disturbing class of question is associated with *vacuous theories*, which are theories such that none of their critical propositions can be tested by any known practical means.[4] Such theories are often designated as *not even wrong* (Woit, 2006). Examples currently are the Multiverse paradigm, quantum gravity, and string theory. What is disturbing is not so much that they cannot be tested, but that some of their advocates claim that they represent real physics simply because their apparent mathematical beauty (a subjective opinion) is regarded by their authors as more important than a total lack of critical empirical evidence at this time (2017) (Woit, 2006). Vacuous theories may well be consistent with all currently known empirically established facts, but that is not enough to validate them. A common characteristic is that although they have a generalized proposition classification (GPC, discussed in Section 2.12) of zero or at best one, many of their supporters claim that they represent valid quantum physics (which requires a GPC of three). We disagree. They are speculations and we classify such theories as *mathematical metaphysics*.

2.8 Propositions

In this book, a *proposition* is defined as any string of symbols that may be of interest to an observer. For example, $\boldsymbol{P}_1 \equiv$ **Today is Tuesday**, $\boldsymbol{P}_2 \equiv \boldsymbol{XYZ}$,

[3] We are not at all critical of Afshar's attempts per se. Our view is that such attempts should always be encouraged. That is what science is all about. There *should* always be someone trying to upset the standard paradigms.

[4] A *critical proposition* would be a specific claim made by that theory alone and no other, that would, if confirmed, establish the scientific worth of that theory.

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and so on. It is important to note that, by themselves, with no further context, propositions such as P_1 and P_2 are neither true nor false.

Our view of physics will be based on the idea that observers formulate propositions about the Universe and then perform experiments to find out under which contexts those propositions can be deemed to be true or false. We cannot at this time explain *why* observers do such things, and simply take it as a given.[5]

2.9 Negation, Context, Validation

In two-valued classical logic, propositions are assumed to have truth values: given proposition $\boldsymbol{P}$, classical logic examines whether $\boldsymbol{P}$ is *true* or *false.*

To formalize this discussion, we introduce the *validation function*, denoted $\overline{\mathbb{V}}$. Validation is really a question, which is why we put a bar over the symbol $\mathbb{V}$. Validation questions a given proposition and maps it into the binary set $\{0, 1\}$, where the value 0 denotes *false* and the value 1 denotes *true.* If proposition $\boldsymbol{P}$ is false we write $\overline{\mathbb{V}}\boldsymbol{P} = 0$, whereas if $\boldsymbol{P}$ is true we write $\overline{\mathbb{V}}\boldsymbol{P} = 1$.

This leads to the concept of *negation.* Given a proposition $\boldsymbol{P}$, there is often an associated proposition, denoted $\neg\boldsymbol{P}$, called the *negation of* $\boldsymbol{P}$. For example, given $\boldsymbol{P_1}$ is the proposition **Today is Tuesday**, then $\neg\boldsymbol{P_1}$ is the proposition **Today is not Tuesday**.

In classical logic, the relationship between a proposition and its negation is the rule

$$\overline{\mathbb{V}}\boldsymbol{P} + \overline{\mathbb{V}}(\neg\boldsymbol{P}) = 1. \tag{2.2}$$

According to this rule, therefore, we need only establish the validity of a proposition to immediately know the validity of its negation.

There are the following issues to discuss here.

Mathematics Is Not Physics

Eq. (2.2) is a mathematical rule. It is not physics. In physics, we have to be more careful. A proposition such as $\boldsymbol{P_1} \equiv$ **Today is Tuesday** may have an obvious, physically meaningful negation, but a proposition such as $\boldsymbol{P}_2 \equiv \boldsymbol{XYZ}$ does not have any obvious, physically meaningful negation (but of course, we could always define it symbolically).

Classical Logic Is Insufficient

Classical binary logic deals with mutually exclusive answers, such as *yes* or else *no.* Unfortunately, we cannot be sure that such logic can be applied to every form of proposition in physics. For example, Jaynes put the case that classical probability is an enhanced form of classical binary logic, because in probability theory, answers are not *definitely yes* or else *definitely no*, but *a probability of*

[5] The explanation that *humans do physics in order to understand the universe* does not explain why they find themselves needing to do this. No other species seems to have this ambition.

yes and *a probability of no* (Jaynes, 2003). Another example is QM, where the answers are complex-valued amplitudes.

The Role of Context

Propositions in physics are often by themselves relatively meaningless. For instance, the proposition **Energy is always conserved** is too glib and potentially incorrect. What gives any proposition in physics a meaning and the possibility of a truth value is *context*, by which we mean the circumstances involved in establishing that truth value.

This last point is critical in QM. The rules of logic in QM have to be carefully respected because they are not quite the same as those of CM. The reason has to do with contextuality, which is not factored into classical logic in general. In particular, we should not make the following error of physics. Suppose that $\boldsymbol{P}$ is a physical proposition and we have constructed an apparatus $\mathcal{A}$ that allows us to conclude that $\boldsymbol{P}$ is true. Then we may write

$$\overline{\mathbb{V}}(\boldsymbol{P}, \mathcal{A}) = 1. \tag{2.3}$$

In other words, we have factored into our notation the context (apparatus $\mathcal{A}$) that is needed to empirically confirm the truth of $\boldsymbol{P}$. In words, we would express (2.3) as the statement that *proposition* $\boldsymbol{P}$ *is true relative to context* $\mathcal{A}$.

Example 2.1 In CM, suppose $\boldsymbol{P} \equiv$ **Energy is conserved**, $\mathcal{A}_1$ is a *closed* system, and $\mathcal{A}_2$ is an *isolated* system. Then by definition

$$\overline{\mathbb{V}}(\boldsymbol{P}, \mathcal{A}_1) = 0, \quad \overline{\mathbb{V}}(\boldsymbol{P}, \mathcal{A}_2) = 1. \tag{2.4}$$

2.10 Proof of Negation

Suppose that experiments showed that $\overline{\mathbb{V}}(\boldsymbol{P}, \mathcal{A}) = 0$. Does this imply that $\overline{\mathbb{V}}(\neg\boldsymbol{P}, \mathcal{A}) = 1$?

The answer is that in physics, we cannot assume that

$$\overline{\mathbb{V}}(\boldsymbol{P}, \mathcal{A}) + \overline{\mathbb{V}}(\neg\boldsymbol{P}, \mathcal{A}) = 1, \tag{2.5}$$

because the apparatus $\mathcal{A}$ that allows us to test for the truth of $\boldsymbol{P}$ might be completely useless to test for the truth of $\neg\boldsymbol{P}$. For instance, suppose $\boldsymbol{P}$ is the proposition **Supersymmetric particles exist**. To date (2017), experiments at the Large Hadron Collider have found no sign of such things. That does not imply the truth of the negation of $\boldsymbol{P}$, which is $\neg\boldsymbol{P} \equiv$ **Supersymmetric particles do not exist**. In order to prove empirically that such particles did not exist, we would have to find apparatus $\mathcal{A}'$ such that $\overline{\mathbb{V}}(\neg\boldsymbol{P}, \mathcal{A}') = 1$. It is most unlikely that such apparatus could ever be constructed, because proof of a negation is very often impossible (we cannot prove that fairies do not exist, for instance).

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We conclude that the rule (2.2) that holds in classical two-valued logical cannot always be replaced in physics by the rule

$$\overline{\mathbb{V}}(\boldsymbol{P}, \mathcal{A}) + \overline{\mathbb{V}}(\neg \boldsymbol{P}, \mathcal{A}') = 1, \tag{2.6}$$

simply because $\mathcal{A}'$ cannot always be constructed. The rule then in physics is *to say nothing about* $\neg \boldsymbol{P}$. Lack of evidence for a proposition is not evidence in favor of its negation.

2.11 A Heretical View of Reality

Apparatus defines context, and propositions in physics can only be tested by experiments based on apparatus. Therefore, we could logically take the view that scientific propositions have no meaning beyond the experiments that test them. What if the recent "discovery" of the Higgs particle was and will be the only time in the history of the Universe that evidence for the Higgs particle was ever found? We could then make the case for the assertion that the apparatus and its context had created/defined the object of interest, rather than helped in its "discovery."

Of course, such thinking goes against the grain of the physicists' human conditioning, that generally imagines that the Universe is "out there", waiting to be explored. That is the same line of thinking that led to Plato's *theory of forms*, which asserts that mathematics "exists" in its own realm of reality and that mathematicians stumble upon pieces of it (discover preexisting truths) every so often.

2.12 Generalized Propositions and Their Classification

The discussion in the preceding sections suggests that empirical physics involves a great deal of context that is frequently understated in discussions. In fact, the situation is generally worse, as we now suggest, because only the apparatus has been factored into the above discussion, with no mention of any observer. The solution we have developed is to introduce the concept of *generalized proposition* and a classification scheme for generalized propositions, as follows (Jaroszkiewicz, 2016).

Definition 2.2 A *generalized proposition* (GP) $\mathcal{P}$ is of the form

$$\mathcal{P} = (\boldsymbol{P}, C_{\text{int}} | O, C_{\text{ext}}), \tag{2.7}$$

where $\boldsymbol{P}$ is a proposition, C_{int} is the *relative internal context* that an observer O, defined by the *relative external context* C_{ext}, can use to test $\boldsymbol{P}$.

Relative *internal* context includes apparatus and the protocols (including axioms and theory) used to test propositions. Relative *external* context is generally classical information that establishes the relationship between the observer and the wider environment/universe in which they are performing their experiments.

A GP addresses the issues we raised in Section 2.1: ideally, any GP gives information about who is making the proposition, what that proposition is, and how the truth value of that proposition can be determined. This raises the following two points.

Identification

We should always ask the question:

For whom is this GP relevant?

The answer is: for the observer involved and not necessarily for anyone or anything else. It is, after all, an essential requirement of observation that an observer understands their own relationship to their environment. Even in CM, frames of reference have to be identified. No experiment makes sense if any aspect of the GP concerned is unknown to the observer concerned.

Missing Context

What happens if some or all of the contextual information in a GP is missing? We address this fundamental point now.

Definition 2.3 A GP is *contextually complete* if both relative internal context and relative external context have been supplied.

The problem is, there are various degrees of contextual completeness. We propose the following schema to classify any GP, allowing us a mechanism to decide whether a proposition is scientifically useful or not.

Definition 2.4 Given a GP $\mathcal{P} \equiv (P, C_{\text{int}}|O, C_{\text{ext}})$, its *generalized proposition classification* (GPC) $\#\mathcal{P}$ is given by

$$\#\mathcal{P} = \alpha + 2\beta, \tag{2.8}$$

where

$$\alpha = \begin{cases} 0, & C_{\text{int}} = \emptyset \\ 1, & C_{\text{int}} \neq \emptyset, \end{cases} \qquad \beta = \begin{cases} 0, & C_{\text{ext}} = \emptyset \\ 1, & C_{\text{ext}} \neq \emptyset, \end{cases} \tag{2.9}$$

where the empty set symbol $\emptyset$ denotes missing context.

With this schema, we classify several classes of generalized proposition as follows.

Metaphysical Propositions

These are completely contextually incomplete GPs of the form

$$(\boldsymbol{P}, \emptyset|\emptyset, \emptyset), \tag{2.10}$$

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where $\emptyset$ denotes a complete absence of any contextual information whatsoever. Metaphysical propositions cannot be validated, so the term *not even wrong* applies to them (Woit, 2006). A metaphysical proposition has a GPC of *zero*.

Mathematical Propositions
These are partially contextually complete GPs of the form

$$(\boldsymbol{P}, A|\emptyset, \emptyset), \tag{2.11}$$

where A is a set of axioms relative to which the truth status of proposition P can be established. A mathematical proposition has a GPC of 1.

Classical Propositions
These are partially contextually complete GPs of the form

$$(\boldsymbol{P}, \emptyset|O, C_{\text{ext}}), \tag{2.12}$$

where O is a primary observer described by relative external context C_{ext}, such as a statement of the rest frame of the observer. However, there is generally no mention of the apparatus used in the experiment, so a classical proposition has a GPC of 2. Such GPs are common throughout CM.

Complete Propositions
These are contextually complete GPs of the form

$$(\boldsymbol{P}, \mathcal{A}|O, C_{\text{ext}}), \tag{2.13}$$

where $\mathcal{A}$ is a specification of the *apparatus* that can be used to establish the relative truth status of the proposition $\mathcal{P}$. It is not enough to construct any apparatus; $\mathcal{A}$ has to be compatible with $\boldsymbol{P}$, allowing the truth value of $\boldsymbol{P}$ to be determined. It is not enough, either, to simply assert that such apparatus exists or could be built.

A complete proposition is a GP that has a GPC of 3.

QDN is designed to deal with complete propositions: relative internal context is explicitly modeled by quantum registers directly related to compatible apparatus, with an endophysical observer assumed to be operating in a well-defined laboratory running through a succession of temporal stages.