QUANTUM UNCERTAINTY, WAVE-PARTICLE DUALITY AND FUNDAMENTAL SYMMETRIES

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ABSTRACT

The nature of quantum uncertainty and the origin of wave-particle duality can be linked to fundamental symmetries between the parameters space, time, mass and charge, which determine that conservation and nonconservation, and continuity and discontinuity, remain *exactly opposite* properties, with precisely defined meanings. The built-in physical oppositions produced by these properties ensure that indeterminacy is inherent within the fundamental structure that underlies the whole of physics. In particular, it can be shown that no fundamental choice can be made, on any physical grounds, between wave and particle theories, between quantum mechanics and stochastic electrodynamics, and between the Einstein and Lorentz-Poincaré versions of relativity. Duality is absolute because fundamental physical differences between space and time, which emerge from basic symmetries, ensure that their mathematical combination in Minkowski space-time has no unique physical interpretation. In addition, fundamental links may be established between quantum uncertainty and conservation laws, and between irreversibility and causality, and new theorems may be derived to link the conservation laws with established physical symmetries.

1. The fundamental parameters of physics

It is natural, when confronted with profound problems like quantum mechanical uncertainty and wave-particle duality, to look for sophisticated solutions, but this does not seem to be nature's way of operating. Sophistication in the face of fundamental or universal facts seems to be evidence that we have not penetrated to a deep enough level in our understanding. The deepest and most fundamental level has also always been the simplest. But how can we reach that level? The answer seems to be that we should strip away all unnecessary assumptions and investigate directly the fundamental parameters of measurement. This might seem, at first, an impossible task, for the fundamental parameters, being simple, necessarily resist analysis. However, it might be possible to reach an understanding indirectly, if we can discover patterns of symmetry between them. In other words, we might be able to transfer problems which seem to be complicated when looked at in terms of mathematics or philosophy into much simpler ones explicable by deep-lying symmetries.

So what is the simplest and deepest level at which we can understand physics? What are the fundamental parameters of measurement? Obviously, they must include space and time, which have always been considered ultimately simple. And it seems almost equally clear that the only information which can be regarded as equally fundamental is that regarding the ultimate sources of the four known physical interactions. Two of these are known exactly, namely mass and electric charge. At the same time, although we don't know them as precisely, there must be source terms for the weak and strong forces, which, according to the rules of quantum electrodynamics, should be more like electric charge than like mass. Since Grand Unified Theories of particle physics suggest that, under ideal conditions, the three nongravitational forces would be identical in effect, I have found it convenient to refer to these sources as weak and strong 'charges', and to describe the three nongravitational sources under the collective label 'charge', in exactly the way that this concept is used when we talk about the process of 'charge conjugation' in particle physics. Space, time, mass and charge, then, are the parameters we shall take as the most fundamental concepts in physics, and in which we will make our search for fundamental symmetries. Understanding the fundamental nature of these quantities is not a philosophical issue. It leads directly to new physics, and even to new mathematics.

2. Conserved and nonconserved: mass and charge versus space and time

The conservation laws of mass and electric charge are among the most fundamental in physics, and, to the best of our current knowledge they appear to be true without exception. In all probablity, also, some type of conservation law applies to the other two nongravitational sources, manifesting itself in such aspects of fundamental particles as lepton and baryon conservation. Very significantly, the conservation laws of mass and charge are not merely global, conserving the total amounts of these quantities in the universe, but also *local*, conserving the particular amount of each quantity at a given place in a given time. Element of mass and charge have, in effect, *identities*, which are specific and permanent, and which they retain through all physical interactions, subject only to the fact that elements of charge may be annihilated by elements of the opposite sign.

As is well-known, of course, space and time are nonconserved quantities; but it is not always realised that nonconservation is the *exact opposite* of conservation and that it is just as definite a property. Nonconservation is, in fact, one of the most vital and significant of all physical properties, and it has many manifestions. Thus, just as the elements of mass and charge have individual and unchangeable identities, so those of space and time have no identity whatsoever, and this nonidentity *must be incorporated directly into physics*. Space and time, for example, are both translation symmetric: every element of space and time is exactly like every other, and must be made indistinguishable in all physical equations. And translation symmetry is not just a philosophical issue; it leads to two of the most significant laws of nature, for Noether's theorem tells us that the translation symmetries of time and space are precisely equivalent to the conservation laws of energy and linear momentum. Space, also, as a three-dimensional parameter, has rotation symmetry, meaning that there is no identity, either, for spatial *directions*. Space not only lacks a unique set of elements, but also a unique set of dimensions; and this, according to Noether's theorem, is equivalent to the conservation of angular momentum.

We could, in fact illustrate the exact oppositeness of conservation and nonconservation by defining the identity or uniqueness properties of mass and charge in terms of 'translation' *a*symmetries, translation asymmetry implying that one element of mass or charge cannot be 'translated to' or exchanged for any other within a system, however similar. This is precisely what we mean by local conservation.

But there are other manifestations of nonconservation in space and time besides translation and rotation symmetry. The whole structure of physics is founded on the fact that systems are defined by differential equations in which conserved quantities remain fixed while nonconserved quantities vary absolutely. We define conserved quantities only with respect to changes in nonconserved quantities. Quantities like energy, momentum, force or action remain constant, or zero, or a maximum or a minimum, because of the more fundamental conservation requirements involving mass and charge, while the space and time coordinates, expressed in terms of differentials, alter arbitrarily.

The absoluteness of nonconservation is illustrated by the *gauge invariance* which occurs in both classical and quantum physics. Here, electric and magnetic fields terms remain invariant while arbitrary changes are made in the vector and scalar potentials, or phase changes in the quantum mechanical wavefunction, as a result of translations (or rotations) in the space and time coordinates. In principle, gauge invariance implies that a system will remain conservative under arbitrary changes in the coordinates which do not involve changes in the values of conserved quantities such as charge, energy, momentum and angular momentum. We cannot specify an absolute phase or value of potential because we cannot fix values of coordinates which are subject to absolute and arbitrary change. And, even more significantly, this nonconservation must be local in exactly the same way as conservation is local, for, in the Yang-Mills principle used in particle physics, the arbitrary phase changes are specifically local, rather than global.

3. Real and imaginary: space and mass versus time and charge

Space and time then, are alike in respect of nonconservation, but they are by no means indistinguishable, and the mathematical combination which produces four-dimensional space-time in special relativity does not make them identical. In fact, this very combination is a source of one of the differences, for, while Pythagorean addition produces positive values for the squares of the three spatial dimensions, the squared value of time becomes negative, suggesting that time should be represented here by an imaginary number. This is often described as a 'convenient trick', but it is important to understand *why* it is convenient.

In the parallel representation of mass and charge, we have the intriguing fact, long known but never really explained, that forces between like masses are attractive, with negative sign, whereas forces between like electric charges are repulsive, with positive signs. Now, these force laws effectively square mass and charge terms, just as space and time terms are squared in Pythagorean addition. We may, therefore, choose to represent charges by imaginary numbers and masses by real ones – a procedure that would have just as much validity as using imaginary numbers in Minkowski space-time.

We might also observe that the other two forces – the strong and weak interactions – are like the electromagnetic in being repulsive for like particles, and so their sources could also be defined by imaginary numbers, if these could be distinguished from each other in some way. By good fortune, the mathematics required for such a situation is well-known and widely-used. This is the *quaternion* system, based on unity and ***i***, ***j***, ***k***, the three square roots of –1. The real significance of quaternions is that they are unique. No other extension of ordinary complex algebra involving imaginary dimensions is possible: if we require a dimensional imaginary algebra (as this representation of source terms suggest we might) then we have only one possible choice: an algebra based on one real part and three imaginary. And the real part of the quaternion structure is also ready-made, for it allows us immediately to accommodate the parameter mass.

Using this mathematical structure, the three components of charge (say, ***i****e*, ***j****s*, ***k****w*) begin to appear like the 'dimensions' of a single charge parameter, with their squared values used in the calculation of forces added, in the same way as the three parts of space, by Pythagorean addition; and space and time become a three real- and one imaginary-part system by *symmetry*. The requirements of algebra and symmetry, then, specify both the number of fundamental forces possible and also the number of space-time dimensions. A combination of the 4-vectors used in space-time and the quaternions used in mass-charge, has been found by the author to be identical, in principle, to the algebra used in the Dirac equation.[1-2]

But, even though charge may be a three-dimensional parameter like space, we should still expect some fundamental differences, since one parameter is conserved and the other is not. In fact, we should expect conservation in dimension for charge as well as in quantity: charge should exhibit rotation *a*symmetry. That is, we should expect separate conservation laws for the sources of the electromagnetic, weak and strong interactions, and no mechanism for interconversion. Particle theorists attempting Grand Unified Theories have been puzzled as to why the proton does not decay, but basic reasoning suggests that there may be a simple answer: the proton, which has a strong charge measured by its baryon number, cannot decay to products like the positron and neutral pion, which have none. Again, separate conservation laws for charges would easily indicate the reasons for separate laws of baryon and lepton conservation, baryons being the only particles with strong, as well as weak, components, and leptons being the only particles with weak, but no strong, components. (We should note here that the Weinberg-Salam electroweak unification only says that the forces under identical conditions are identical in effect, not that they have identical sources.)

There is yet another great advantage to an imaginary representation of charge. This stems the fact that equal representation must be given to positive and negative values of imaginary quantities. Neither positive nor negative values of imaginary numbers may be privileged in algebraic equations. In principle, every equation which has a positive solution also has an algebraically indistinguishable negative solution. Consequently, all charges must exist in both positive and negative states. This is the precise requirement for the existence of antiparticles, even for those particles, such as the neutron and neutrino, which have no electric charge, for such particles still have strong and/or weak charges whose signs may be changed under the process of 'charge conjugation'.

4. Divisible and indivisible: space and charge versus time and mass

There are yet more differences between space and time. A striking characteristic of space, for example, is that it is the only parameter which can be used in direct measurement – it is impossible to measure anything but space. 'Time'- measuring devices, in particular, all use some concept of repetition of a spatial interval, and require special conditions to be set up, whereas any object whatsoever can be used to measure space. Space, again, is reversible but time is not; indeed, time 'measurement' requires the reversibilty of space.

The reason for these differences seems to be that space, as used in all measurement applications and physical observations, is discrete. Mathematicians, of course, often try to define space in terms of a Cantorian continuum of real numbers, but this is not how we use it in practice. Space, as used, is always constructible in terms of some algorithmic process, and is therefore always countable; this is why it is the parameter used in measurement. In measurement, space is assumed to be discontinuous in both quantity and direction, meaning that it can be reversed or changed in orientation – a truly continuous quantity could not – and, without both these properties, measurement would be impossible. The whole process of measurement depends crucially on the divisibility of space, or creation of discontinuities within it. Absolute continuity cannot be visualised and any process used to describe it would deny continuity. True, the units or divisions of space, unlike those of charge, remain unfixed and indefinitely elastic, but this is because space, unlike charge, *remains nonconserved*; it cannot be fixed in any way. The elasticity of its grain size or indefinite recountability has nothing to do with Cantorian continuity. Differentiability is a property of nonconservation and can be defined by a discrete (Leibnizian) process as readily as a continuous (or Newtonian) one.

It is time, rather than space, which exhibits Cantorian or absolute continuity. Time cannot be reversed, precisely because it is absolutely continuous; any reversal of time would require some kind of discontinuity. For the same reason, time cannot be multidimensional. It is interesting that the ancient problem posed by Zeno's paradoxes disappears as soon as we accept that we can have discontinuities or divisibility in space, but not in time. The continuous, and therefore unmeasurable, nature of time seems also to be responsible for the fact that it is the independent variable in dynamical equations, while space is the dependent variable. Of course, we often read about a 'reversibility paradox', where time, according to the laws of physics is reversible in mathematical sign, when it is clearly not reversible in physical consequences. Time, however, as we have already said, is characterised by imaginary numbers, and these are not privileged according to sign. Hence, it is quite possible for time to have equal positive and negative mathematical solutions because it is imaginary (leading to a CPT rather than a CP theorem), but only one physical direction because it is continuous.

Exactly the same distinction, as between time and space, applies also to mass and charge. Mass appears to be an absolute continuum present in all systems and (as energy) at every point in space; this is why there is no negative mass and no mass 'dimensions', for either concept would necessarily require a break in the continuum. Charge, on the other hand, is divisible and observed in units (fixed because charge is conserved); it is also multidimensional. Divisibility, on this basis, seems to be the ‘cause’ of dimensionality. Although we cannnot easily prove this, we can at least see why *absolutely* continuous quantities cannot have more than one dimension.

5. A group of order 4

From the preceding analysis, it would seem that the properties of the four basic parameters are distributed between three sets of opposing paired categories: real / imaginary, conserved / nonconserved, divisible / indivisible, with each parameter paired off with a different partner in each of the categories:

TABLE 1. Properties of the fundamental parameters

parameter	properties		
space	real	nonconserved	divisible
time	imaginary	nonconserved	indivisible
mass	real	conserved	indivisible
charge	imaginary	conserved	divisible

This seems to be an exact symmetry: properties which match appear to be exactly identical, and properties which oppose to be in exact opposition. In a mathematical representation, this would be a noncyclic group of order 4, with any parameter as the identity element and each its own inverse. Using this group as a working hypothesis, we can investigate constraints on possible laws of physics which result from group properties. The application of a numerical relationship between the units of space and time in 4-vector space-time and those between the units of mass and charge in quaternion mass-charge, for instance, when applied to the direct and inverse relationships required for the elements of the group as a whole, suggest the necessity for at least four fundamental constants of the kind already known (including G, c and h, and one representing some Grand Unified value of charge). We can even investigate how the quaternion representation and the requirement of separate conservation for charges might determine which fundamental particle structures are possible.

Some new mathematical results can be generated by even more direct uses of the symmetries. Noether’s theorem, as we have already stated, requires the translation symmetry of time to be linked to the conservation of energy, which is further linked by relativity to the conservation of mass. To put it another way, the nonconservation of time is responsible for the conservation of mass. This is a result we could have inferred from symmetry alone; and, by extending the analogy, we could link the conservation of the quantity of charge with the nonconservation, or translation symmetry, of space, which is already linked with the conservation of linear momentum. We could, therefore, propose a theorem in which the conservation of linear momentum is responsible for the conservation of the quantity of ‘charge’ (of any type), and, by the same kind of reasoning, we can make the conservation of *type* of charge linked to the rotation symmetry of space, and so to the conservation of angular momentum, as in the following scheme:

TABLE 2. Conserved quantities and linked symmetries

symmetry	conserved quantity	linked conservation
space translation	linear momentum	value of charge
time translation	energy	value of mass
space rotation	angular momentum	type of charge

Some special cases of these two general theorems are already known. The first incorporates the fact that the conservation of electric charge within a system is identical to invariance under transformations of the electrostatic potential by a constant representing phase changes – of the kind involved in the conservation of linear momentum. The second incorporates the link between spin and statistics, in which the spin angular momentum state of fermions and bosons depends on the respective presence or absence of a quantity of weak 'charge'.

6. Quantum mechnaical uncertainty

The application of real-imaginary 4-vectors and quaternions to a system of parameters based on group symmetry requires, as we have said, the existence of fundamental systems of units, and of algebraic laws by which they are related. This introduces the principle of *measurement*, in which fixed amounts of one quantity are set up against those of another. But it also brings us up against the first of the two major paradoxes of fundamental physics: that of quantum uncertainty. Quantum uncertainty is essentially an expression of the incompatibility of measurement and the definition of a 'conservative' *system*. The effects of the divisions between conserved and nonconserved parameters (defining the system), and real and imaginary ones (creating measurement), provide conflicting requirements for fundamental physics.

Conservative systems are defined so as to enable us to distinguish between conserved and nonconserved quantities. Effectively, we define a quantity, such as momentum, force, energy, action, or a function, such as the Hamiltonian and Lagrangian, by algebraic manipulation of the basic relations between units of measurement; and then we show that it behaves in such a way that the fundamental conserved quantities, mass and charge, remain unchanged while the nonconserved quantities, space and time, undergo continuous variation. A 'conservative' system so defined, however, would be incompatible with the principle of *measurement*. Systems and measurement cannot exist at the same time, though each is required by the fundamental symmetry. This is because measurement fixes the values of space and time, while nonconservation within a system requires them to remain unfixed.

The absolute measurement of nonconserved particle coordinates is an intrinsic impossibility, but quantum physics is required to overcome this difficulty without violating the principle of the conservative system; it effectively tells us, therefore, that physical measurement is incompatible with a system's exact definition. What Heisenberg uncertainty is telling us, then, is that a *physical* conservative system cannot be realised in practice because a 'measurement' fixes the values of space and time, quantities that, in a physical system, ought to be unfixed. In principle, a true system requires that $\Delta p = 0$, $\Delta E = 0$, $\Delta x = \infty$, $\Delta t = \infty$; changes of energy and momentum should never happen, changes of space and time should always happen. The immediate consequence of applying measurement, therefore, is that a fixed system cannot be conservative. In practice, we overcome this by deliberately making the system nonconservative, thus reducing the relationship between Δp and Δx or between ΔE and Δt to finite variations in each. Because the constant relating Δp and Δx, or ΔE and Δt, is very small in classical terms, we can make close approximations in classical physics to the ideal system, with the nonconservative aspects reduced to insignificance.

Quantum mechanics is not, thus, something of a different, probabilistic, nature imposed on an otherwise 'deterministic' system of classical physics; it is the logical result of applying measurement to a system in which the parameters space and time are *intrinsically* indeterminate. A deep understanding of the idea of nonconservation reveals that there is nothing fundamentally mysterious about the intrinsically random nature of quantum mechanics. "God playing dice" with the universe is merely a result of the absolutely symmetrical nature of the opposition of nonconservation and conservation in the fundamental parameters. As nonconserved quantities, space and time are necessarily translation and rotation symmetric, made up of units with no fixed identity, and described by values which are indeterminate within limits set only by the necessity of conserving mass and charge within a system. It is the application of the contradictory, but equally necessary, principle of measurement to such a system that forces on us the compromises of complementarity and Heisenberg uncertainty.

7. Wave-particle duality

The other great problem of contemporary physics is wave-particle duality. This is not explained by Heisenberg uncertainty, although the two may be linked by applying the de Broglie duality condition, $p = h/\lambda$, to the Heisenberg relation between momentum and position. Duality originates in an entirely separate symmetry: that between the continuous and the discontinuous parameters. Once again, the 4-vector combination of space and time – the 'Lorentz invariance' – and the related quaternion connection between mass and charge, both uniting real and imaginary quantities, is set up in opposition to a symmetry from another part of the parameter group.

Theories which incorporate Lorentz invariance as a fundamental component necessarily involve a mathematical combination of unlike physical quantities. Essentially, time and space are dissimilar in most respects – similar, in fact, only in their property of nonconservation. In particular, time is continuous, while space is discontinuous or discrete, and the same distinction occurs between charge and mass. These divisions, however, cannot be maintained when we combine them mathematically within the 4-vector or quaternion structures. Since unlike things cannot be combined by mathematical addition, we are obliged to make space timelike (and charge masslike) or time spacelike (and mass chargelike) to complete the process; and to combine all the quantities in this way requires making them either all continuous or all discrete. The choice between these alternative methods is responsible for duality.

However, as in the similar case of quantum uncertainty, we do not make all parameters discrete or all continuous by violating fundamental physical laws. The fundamental sharing of properties occurs in 'measurement' only, and not in ultimate 'reality'. When duality is combined with uncertainty, the system and measurement act together to restore the parameters to their true status.

The fundamental choice is available in many different forms: classical particles, Einstein-Minkowski relativity and quantum mechanics represent discrete options, classical waves, Lorentz-Poincaré relativity and stochastic electrodynamics continuous ones. The choice is completely arbitrary, because each option is fundamentally unphysical. Lorentz invariance is a mathematical procedure with no completely recoverable physical meaning, and the space-time combination is not, in fact, a true physical process. If we interpret it in wave terms, we obtain a classical wave theory incorporating the aether; if we choose a corpuscular explanation, we obtain special relativity combined with the Einstein process of signalling by lightquantum.[3]

Duality is absolute across the whole of physics, but it is shown most strikingly in the alternative theories of quantum and wave mechanics associated with Heisenberg and Schrödinger, which represent opposite extremes in both their definitions of the system and of measurement. Neither theory gives a complete description of reality in defining a mathematical system, and each requires completion with an ad hoc process of measurement. The Heisenberg formalism selects all the discrete options and is directly based on observables and real particles. The Schrödinger approach, on the other hand, chooses all the continuous ones, assuming a continuous, and therefore unmeasurable, interpretation of space and time in the concept of the wavefunction or state vector; particles such as electrons are delocalised and spread throughout space and time. Time, in this formalism, is no longer an observable quantity, information being derived from the wavefunction only by the application of momentum and position operators. In each case, a process of measurement, which is extrinsic to the system, restores the true attributes of the fundamental parameters which are lost in its definition.

The expressions in bold type in Table 3 represent the violations of fundamental conditions within each system, which must be corrected by the respective processes of measurement. The measurement processes introduce a virtual version of what each system excludes, thus providing a link between uncertainty and duality. In the Schrödinger measurement process, wavefunction collapse restores real localised particles in discrete space, both of which the system excludes, but only at the expense of knowledge of the wavelengths of the system. The Heisenberg measurement process, on the other hand, is made at the expense of causality, which the system retains; and, this time, measurement brings in nonlocality and the (real) vacuum.

Wavefunction collapse is, of course, not predicted within the Schrödinger *equation*. This is because the equation itself is not a true description of reality, allocating, as it does, a continuous nature to space. In the same way, the Heisenberg formalism is equally 'unreal' because it makes time discrete. The Schrödinger wavefunction is continuous, allowing no direct knowledge of time or position, and so denies causality of the discrete kind required by Einstein, until a virtual causality is introduced by the ad hoc process of measurement, when the observer introduces a particle-like discontinuity. Thus, the interpretation suggested by Born explains the squared wavefunction (squared because it links space with time in a process of measurement) as a probability amplitude when *we* (as observers) collapse the wavefunction. However, although position now becomes observable, the unobservable status of time remains. In the Heisenberg formulation, on the other hand, time is assumed to have a discrete structure, like space, and so can be brought into a meaningful uncertainty relation with energy.

TABLE 3. Comparison between Schrödinger and Heisenberg formulations of quantum mechanics

Schrödinger’s wave mechanics

The System			Measurement	
continuous	**space** **charge** **momentum** **ang. mom.**	**virtual particles**	restores discreteness of these	introduces localised particles
	time mass energy	real vacuum	not changed by measurement	

Heisenberg’s quantum mechanics

The System			Measurement	
discrete	space charge momentum ang. mom.	real particles	not changed by measurement	
	time **mass** **energy**	**virtual vacuum**	restores continuity of these	introduces nonlocalised vacuum

Much confusion has resulted from the fact that the two main formulations of quantum mechanics give the same basic results in application (FAPP, in John Bell’s terminology), for their basic physical assumptions are nonetheless incompatible, and the axioms of one cannot be used to comment on those of the other. Thus the discrete time involved in the Heisenberg uncertainty relation has no meaning in wave mechanics, and cannot be carried over into the alternative theory. Its absence from the Schrödinger theory should, therefore, be the cause of no philosophical difficulty whatsoever, for that theory is ‘correct’ in assuming that time is continuous within the system, and so correctly leaves time continuous in applying the process of measurement. At no time, in fact, are the correct physical assumptions of either theory altered in the process of measurement.

The Schrödinger and Heisenberg models also apply the same options involving space and time to mass and charge, deviating from ‘reality’ by assuming, either that continuous mass is discrete, or that discrete charge is continuous. Heisenberg’s quantum mechanics employs a discrete model of radiation, with discontinuous mass, and introduces the continuous vacuum and zero-point energy only as a result of measurement. This is why it is often assumed that the vacuum is a virtual concept that emerges only with the uncertainty principle. The alternative option, employed by Schrödinger, treats the zero-point energy as real from the beginning. And this is the basis, not only of the Schrödinger theory, but also of stochastic electrodynamics and the Lorentz-Poincaré version of relativity, or the classical theory of the aether. Again, neither the discrete nor the continuous option gives an entirely true picture of reality, as each is limited by the processes of measurement and incomplete without it. There is undoubtedly a truly continuous real distribution of energy or mass in the vacuum, but matter, on the other hand (representing 'charged' particles), is discrete.

8. Irreversibility and causality

The standard (Copenhagen) interpretation of quantum mechanics assumes that measurement takes place at the interface between the 'world' and the 'measuring apparatus'. In our terminology, there is *measurement*, which fixes space and time; and a *system* (equivalent to the Copenhagen 'world') in which space and time vary absolutely. The fixing of space and time required by measurement violates the space-time properties of nonconservation, and it also violates time's additional property of continuity. Stopping time at any point to make a measurement makes it no longer continuous, and so irreversibility immediately manifests itself. In effect, measurement requires us to determine the arrow of time. The measurement process 'breaks the rules': continuous or indivisible time becomes countable, so its direction becomes manifest.

According to all known laws of physics, whether quantum or classical, time has two indistinguishable directions of mathematical symmetry, and we have found this to be characteristic of quantities determined by imaginary numbers. Physical irreversibility allows only one time direction, but, because of the mathematical indistinguishability of imaginary numbers of opposite sign, this can never be known in absolute terms. The laws of physics, in being constructed always for quantities involving the second power of time, prevent a mathematical realisation of time's direction.

In classical theories, the direction of time is associated with the concept of causality, and direct causality is characteristic of those theories which assume discrete time, such as Heisenberg's quantum mechanics and its classical analogue, special relativity. (We can hardly imagine Einstein's concept of signalling via the exchange of lightquanta without it.) Causality is the specific direction of time which appears as soon as we interrupt its flow, making it discontinuous and irreversible. Causality also requires a discontinuous mass, again as in Einstein's theory. Wave theories, however, (with their built-in gauge invariance) are not based on identifiable sequences of causally related discrete events.

In quantum mechanics, we have no need of causality until we actually make a measurement, but, in the Heisenberg theory, classical causality, though defined as part of the system, is lost, and continuity of time restored, with the uncertainty introduced with measurement. (In the Schrödinger theory, of course, causality does not appear at all.) The actions of a quantum system cannot be defined by classical causality, for measurable events cannot be separated out in a system whose definition cannot be kept apart from the process of measurement. Causality, therefore, is only known relatively when we interrupt the flow of time and discover it to be irreversible. In particular, we cannot discover an absolute causality corresponding to the absolute irreversibility of time required by the system. Causality is, in principle, an effect of measurement, where irreversibility is an effect of the system.

Irreversibility, as we have said, can only be discovered when time is made as discontinuous as space, and the squares of the two quantities are linked by Pythagorean addition. In the parallel case of mass and charge, squaring is described as 'interaction'; and so, by symmetry, interaction is linked with irreversibility. It is certainly the process of interaction, which is unique for any set of elements of mass and charge, which leads to irreversibility in physical terms, producing, for example, the wavefunction collapse in quantum mechanics. In effect, it is 'charged' particles, or sources of 'interactions', which provide the so-called 'apparatus' required for quantum mechanical 'measurements', irrespective of whether there are any 'conscious' observers. A further implication is that all interactions at the quantum mechanical level are irreversible.

Now, the continuity of mass has exactly the same cause as the irreversibility of time, and one concept, by symmetry, presupposes the existence of the other. Our lack of knowledge of the absolute direction of time is, therefore, precisely identical to the fundamental indeterminacy which would result from the interaction of infinitely-many bodies in a classical system – providing a source for a direct link between quantum mechanics and its analogue in stochastic electrodynamics. Determinacy, which is related to causality, does not exist within physical systems of any kind, even classical ones; it occurs only in the process of measurement. Indeterminacy is a characteristic of all physical systems. It has a special significance, however, in the quantum case, because, there, it is intrinsically inseparable from measurement. Quantum mechanics is the ultimate expression of the process in which all three divisions of the attributes of space, time, mass and charge – real / imaginary, conserved / nonconserved and continuous / noncontinuous – are combined and manifested, respectively, as Lorentz-invariance, indeterminacy and wave-particle duality.

9. References

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