# Suspended Reality

*A new interpretation of Quantum Theory*

## Abstract

An interpretation of Quantum Theory is proposed which uses the idea that, for short periods of time, reality can be 'undecided' or in state of suspension. This state is, however, temporary and there is a process called World Line Reduction (WLR) which eliminates some or all of the possible states, ultimately reducing the world line of the universe back to a single continuous line of reality which not only defines the present state of the universe but all of its history as well. All the main 'paradoxes' which have caused such a lot of trouble over the years are seen to have a simple explanation according to this interpretation. A tentative suggestion is put forward as to the situation which results in World Line Reduction.

## The standard interpretations of Quantum Theory

That the quantum world is strange, possibly even weird, is beyond dispute. Waves can apparently behave like particles and particles like waves. Electrons can apparently be in two places at once and photons can apparently communicate with each other over distances faster than the speed of light. These are facts which everybody accepts. What has been in contentious debate over the last fifty years or more is how we can make any sense of this bizarre world.

Very early on in the history of Quantum Theory (QT) one of its founders, Niels Bohr, put forward a radical idea that we should abandon the quest to understand the world as it really is, we should simply rely on the mathematical rules which have been derived to describe the quantum world (Quantum mechanics or QM) to predict the outcomes of experiments and to be content with that. This interpretation of QT, known as the Copenhagen interpretation has been the fall back position of all working scientists and it has been hugely successful.

At the heart of the mathematical formalism is the idea that quantum systems are best described by a mathematical entity called a wave function which evolves over time according certain mathematical rules and which, in effect, describe all the possible ways in which the system might develop. This process is completely deterministic. Given the initial state of the wave function, its future development is fixed. Roger Penrose has given this process the label **U**, standing for Unitary evolution (see Penrose 1989 p 250)[1].

The wave function does not by itself define the outcome of any particular experiment or measurement, however. It only defines the *probability* of any given outcome. To turn the wave function into a prediction about what might actually happen you have to apply the *Born* rule which says that when you actually make a measurement on the system, the wave function 'collapses' and the value which is recorded by the measuring device is chosen at random in accordance with the probability ascribed to it by the wave function. In complete contrast to the development of the wave function in time which is, in principle, a reversible process, wave function collapse is deemed to be irreversible. Penrose calls this process **R**.

Not surprisingly, many people have not been satisfied with this view of the world and have tried to eliminate wave function collapse. Proponents of the Many Worlds interpretation of QT simply deny that wave function collapse occurs at all. Others have followed de Broglie and Born and have proposed that the wave function is not just a mathematical convenience but a real physical entity which guides particles in real trajectories. This idea is known as the pilot wave model. There

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1   Roger Penrose (1989) *The Emperor's New Mind* OUP

are, of course, many other ideas as well but these are the principal two.

I have to confess that I do not like either idea. Wave function collapse is appealing to me because I believe, along with Penrose, that there are strong grounds for believing that, at the atomic level, there is genuine randomness at work and that the world is not totally deterministic. This belief rules out the pilot wave model because that is a deterministic theory. If we want to use the collapse of the wave function to be the reason why the world is not deterministic we must also reject the Many Worlds interpretation as well. The question then is – is there another interpretation of QT which gives a plausible role to wave function collapse and which makes offers a more reasonable ontology than the Copenhagen interpretation? I believe there is.

## Suspended Reality

Modern science has for ever made the assumption that at each point in time the whole universe could, in principle, be uniquely specified and that in the multi-dimensional phase space which determines the value of every possible parameter at every point in space, the universe occupies a single point and traces out a single line over time. This is precisely the kind of situation which differential equations describe and I suspect that it is the incredible success of the latter which has made our belief in the assumption so tenacious.

I want to make the bold assertion that there are circumstances in which the world line of the universe thickens so as to encompass multiple options and that, after a time, when the 'wave function collapses', the world line suddenly contracts down to a single line again. There are a number of different ways of using language to describe the state of the universe when its world line has thickened. You could say that the universe has split into multiple copies of itself, rather in the manner of the Many Worlds interpretation, but I do not like this terminology. It begs the question what happens to all these universes when the wave function collapses? Where do they go? You could say that the universe exists in a superposition of states – but this phrase begs the question, yes, but which state is the *real* state? I like to say that, during this phase, reality is *suspended* for a while. More pictorially you could say that Nature is *undecided* as to which of the states will eventually become reality. During this process the standard rules of Quantum Mechanics dictate how the wave function which describes the system evolves. But this state cannot last for ever. At some point, the wave function 'collapses' and reality is restored. Penrose's **U** could just as well stand for Undecided state and **R** for Restoration of reality.

Lets see how the use of the suggested language makes sense of some standard quantum situations.

## The half-silvered mirror
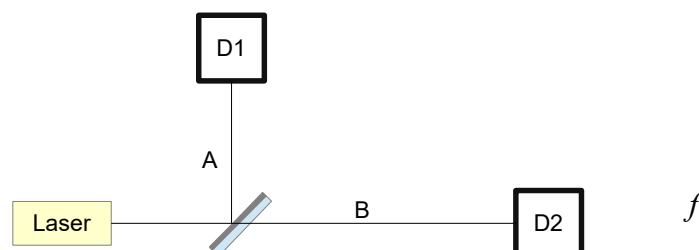


Suppose we have a light source which can emit a stream of individual photons. When a single photon impinges on a half silvered mirror, there is a 50% chance that it will be reflected and a 50% chance that it will be transmitted and the two detectors D1 and D2 will fire with equal frequency.

All interpretations of quantum theory (except the pilot wave model) agree that, in some sense, immediately after the photon has interacted with the mirror the system is in a superposition

of states. The Copenhagen interpretation of QT forbids us from saying anything about where the photon actually goes in the time between when it was emitted and the time it was detected. According to Niels Bohr, it is perfectly possible that the photon went to Timbuctoo and back. 'Who knows?' he would say. Indeed he would go further and say 'Who cares?'. Well I care. I cannot hold with a theory that abrogates its responsibility to explain what is going on that easily.

What can we say about the situation using the language of Suspended Reality (SR)?

When the photon interacts with the mirror, Nature is faced with two choices so She tries both. In one potential world, the potential photon is reflected and in the other world the potential photon is transmitted. After a certain time one of these potential photons will hit the closer detector (D1 in this case). At this point we assume that, for some reason, wave function collapse occurs; but there are two possible outcomes of this collapse. One possibility is that the reflected potential photon is the real photon – in which case the detector fires. Note that there is no need for the system to inform the potentially transmitted photon to cease to exist because in this world, there is no transmitted photon. The other possibility is that the potential photon which triggered the collapse is not the real photon and didn't exist anyway. This leaves the real photon, the transmitted one, to continue along its way and cause $D_2$ to fire some time later.

The beauty of this story is that it allows us to say with certainty after the event what actually happened during the event. If D1 fires, we know that the photon must have been reflected. If D2 fires, it must have been transmitted. The whole chain of cause and effect is completed all the way back to the time when the photon was emitted. Reality is restored – in retrospect at any rate.
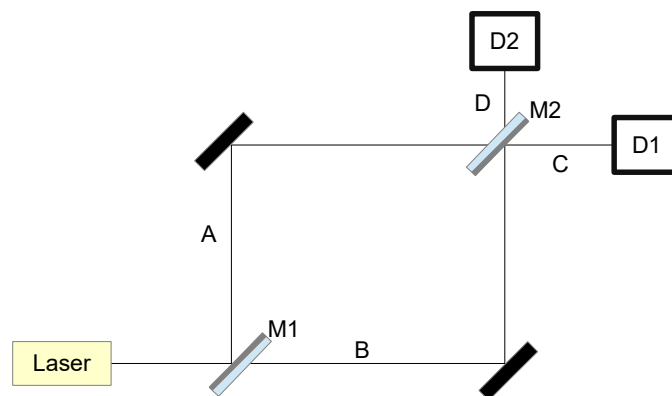
## Two half-silvered mirrors
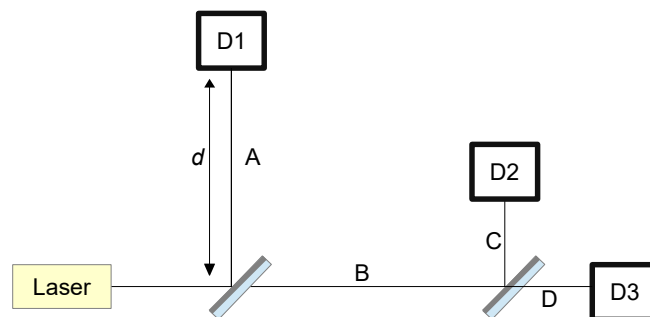


Suppose we have two half-silvered mirrors arranged as in the diagram above. It is easy to see what will happen. D1 will fire 50% of the time; D2 and D3 will fire 25% of the time. Now suppose that the distance $d$ is such that, just before the potential photon in arm A gets to D1, there are potential photons in arms C and D. When the first potential photon reaches D1 wave function collapse occurs but the important thing to note that, if Nature decides that photon A is not the real photon, the collapse does not extend to photons C and D. All that happens is that the possibility that A was the real photon is eliminated. The status of the photons C and D is still undecided. In this respect, the phrase 'wave function collapse' is misleading. It is all too easy to suppose that when the potential photon reaches D1 and wave function collapse is triggered, it has to collapse everywhere. This is not true. Only those possible world lines which are affected by the event which caused the collapse are decided; the other possible world line remain undecided. I shall use the phrase 'World Line Reduction' (sometimes abbreviated to WLR)  instead of 'wave function collapse' from now on to remind you of this very important fact.

## The Mach-Zehnder Interferometer

One of the most instructive instruments for probing the mysteries of the quantum world is the Mach-Zehnder Interferometer. It consists of two half silvered mirrors M1 and M2 (in blue with the silvering shown in grey), two front silvered mirrors (in black), two detectors D1 and D2 and a laser which, in principle can be arranged to produce individual photons. The interferometer is adjusted so that the arm lengths are exactly equal. When this is done correctly it is found that D2 is silent. Photons are only detected at D1. The classical reason for this is that a phase change of 180° occurs whenever light is reflected off the front surface of a mirror but no phase change occurs when it is reflected off a back surface or when it is transmitted. Photons which reach D1 via either arm A or arm B undergo two front reflections and therefore arrive at the detector in phase. Photons which reach D2 via arm A undergo one front reflection at M1 and one back reflection at M2 and therefore suffer a phase change of 180° while those that arrive via arm B do not suffer a phase change at all. These photons are out of phase. Destructive interference occurs resulting in D2 remaining silent. (We can ignore the phase changes at the front silvered mirrors because all photons are reflected once off these.)



Now lets use the idea of suspended reality to explain what happens when a single photon passes though the apparatus. As we have seen, when the photon reaches first half-silvered mirror M1 Nature tries out both options. But later, both of these potential photons arrive at the second half-silvered mirror M2 at the same time. As before, it is the well established mathematics of Quantum Mechanics which determines how the state will evolve. What it predicts is that the wave functions which describe the two photons interfere with each other resulting in a new distribution of probabilities which predicts that in the world in which the photon travels along arm A, there is no chance that it will travel along arm D; also, in the world in which the photon travels along arm B, there is no chance that it will travel along arm D either! Both potential photons travel along arm C and arrive at D1 simultaneously; world line reduction (WLR) occurs and, surprise, surprise, detector D1 fires – every time.

Now just before this happens, the world line of the universe has split into two potential trajectories. At the instant of WLR, one of these trajectories is eliminated and the other is declared real. This has no effect on the outcome of the experiment because both trajectories end with D1 being activated. It does, however, mean that is is legitimate to ask ' well, which arm did the photon actually go through?' The obvious thing to do is to repeat the experiment but put a detector D3 in one of the arms. The trouble is, if this detector blocks the passage of the photon completely, then we are back to the familiar two silvered mirrors scenario. D3 will fire 50% of the time and D1 and D2 will fire 25% of the time. We can tell which arm the photon took but the effects of interference are destroyed.

But what if we are a bit more devious? When a photon bounces off a 45° mirror its

momentum is changed and by Newton's Third Law (action and reaction are equal and opposite) an impulse must be given to the mirror. If we attach a very sensitive vibration detector to the mirror, perhaps we can detect the passing of the photon without impeding its passage. Let us call this 'mirror-detector M-D.
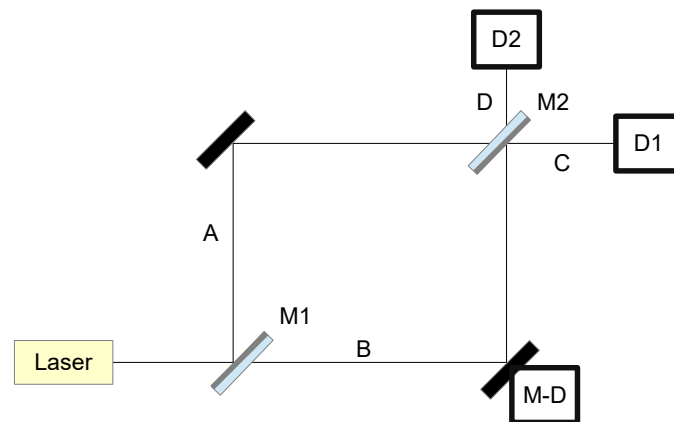


You can probably guess what is going to happen. If M-D is 100% effective at measuring the transit of a photon, then M-D fires 50% of the time but the interference effect disappears and D1 and D2 each fire 50% of the time. Classically, this is explained by saying that the recoil of the mirror results in a tiny change in the wavelength and frequency of the light wave which reflects off it. When the wave reaches M2 it is no longer has the same phase that it would have had if the mirror was fixed. We say that the wave loses its *coherence* and the interference pattern is destroyed.

The Suspended Reality interpretation offers a different way of looking at the situation which completely avoids any reference to phase changes or coherence. What I believe happens is this: When the potential photon travelling along arm B reaches M-D, the interaction with the wobbly mirror is sufficient to *cause World Line Reduction*. Now Nature has to decide between one of two possibilities. Either the potential photon B is real – in which case M-D registers a hit and the photon goes on to the second half-silvered mirror M2 where it is either reflected or transmitted in the usual way. Alternatively, the photon in arm B is not the real photon, in which case M-D does not fire and photon A goes on to split equally when it reaches M2. The result is exactly as predicted (i.e. the interference is destroyed) – but at least we now know which arm the real photon actually passed along!

## A polarising filter

Another way in which we might find out which way the potential photons in arms A and B actually go is not to detect them as they pass by but to *label* them in some way. This can be done by introducing a pair of polarizing filters. But before we have a look at this possibility, let us look at what happens when a vertically polarized photon (i.e. one whose electric vector is vertical) impinges upon a polarizing filter which is at an angle $\theta$ to the vertical.

From a classical point of view, the vertically polarised incident wave of amplitude $A$ can be resolved into two components: the component parallel to the plane of polarisation of the filter is $A \cos \theta$ while the transverse component has amplitude $A \sin \theta$. It is worth noting that since the energy of a wave is proportional to the square of its amplitude, the total energy in the two components is equal to $A^2 \cos^2 \theta + A^2 \sin^2 \theta = A^2$. It is only the parallel component which is transmitted and the plane of polarization of the transmitted wave is turned through an angle $\theta$ so that it is parallel to the plane of the polarizing filter. The other component is absorbed

From a quantum viewpoint, it is assumed that that out of a large number $N$ of photons incident on the filter, $N \cos^2 \theta$ will be transmitted and $N \sin^2 \theta$ will be absorbed.

Now what does SR have to say about this situation? It is not difficult to see. Nature has to choose between two options: to transmit or not to transmit with relative probabilities $\cos^2 \theta$ and $\sin^2 \theta$. But this choice is a no-brainer. In the world in which the photon is not transmitted, it is absorbed and this causes an immediate World Line Reduction. Either the photon is absorbed with a probability of $\sin^2 \theta$ or it will be transmitted with a probability of $\cos^2 \theta$. (In the case when $\theta = 0$ i.e. the polarizer is parallel, no absorption takes place so there is no WLR – but then, there is no need to eliminate an option whose probability is zero anyway. It is also worth noting that, if the photon is transmitted, its plane of polarization becomes that of the polarizer, not the original plane of polarization of the original photon.)

## A quantum Eraser

In our next thought experiment we shall try to discover which arm the photon took by labelling the two potential [hotons in some way. We shall use a laser which produces individual vertically polarized photons. In arm A we shall place a polarizing filter inclined to the left at 45° while in arm B we shall place a filter inclined at 45° to the right. The idea is that we might subsequently find out which arm the photon travelled along by examining its polarization after it has undergone interference at the second half-silvered mirror.

Here is the initial set up:
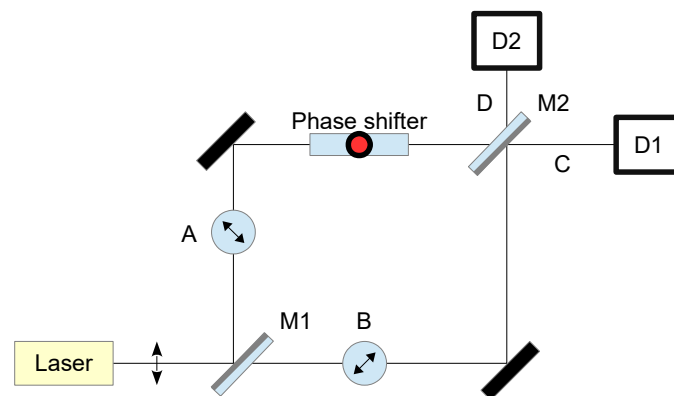


It is not particularly surprising to find that when we do this, the interference effect is destroyed and that D1 and D2 fire equally often. From a classical point of view it is simply that when the light waves arrive at the second half-silvered mirror M2 they cannot interfere because they are polarised at right angles. Just to make sure however, that the interference pattern has truly been destroyed we shall introduce a phase shifter into arm A. What this does is to introduce a phase shift of between zero and one whole wavelength by twiddling a knob of the front. When the knob is turned from one end to the other, there is no change in the frequency at which D1 and D2 fire. The interference pattern has truly been destroyed.

At this point you might conclude that there is no point in trying to determine which arm the individual photons from the laser travel along because the whole point of the experiment – the interference – has been destroyed; but we shall try it anyway. We place a third polarizing filter in arm C inclined at 45° to the left. This reduces the rate at which D1 fires but does not affect D2. Nor does it change what happens when we twiddle the knob on the phase shifter. Basically what is happening is that the detector D1 is only responding to photons which are polarized at 45° to the left and since all these photons have travelled through arm A, interference is impossible. The same thing happens (or rather, doesn't happen) when the polarizer is inclined at 45° to the right.

But there is a surprise in store for us. When we adjust the orientation of the third polarizer so that it is vertical (or, indeed, horizontal) and twiddle the knob on the phase shifter, D1 goes through a cycle of varying frequencies. In particular, at some values of the phase shifter, the detector D1

falls completely silent showing that destructive interference has occurred. (By the way, while we are twiddling the knob on the phase shifter, the detector D2 continues to be unaffected and continues to fire at a constant rate.)

It is not the job of SR to explain how this surprising result occurs – that is the job of Quantum Mechanics. What it does say, however, is that at the end of the day, when one or other of the potential photons finally arrives at either D1 or D2 or is absorbed by the third polarizer, world line reduction occurs and a reality will emerge which is consistent with whatever the rules of QM decree.

But this still leaves the question: how can the insertion of a polarizer do anything other than simply alter the polarization of the light which is already there? It is as if, just before the photon hits the polarizer it contains more information than just its amplitude and direction of polarization. Attempts to explain how the interference pattern can be restored have used bizarre ideas such as non-locality or even retro-causation. The truth is a lot simpler. The only bizarre idea you need is that the universe can be in a state in which some aspects of it have not yet been decided. Just before one of the two potential photons reaches a detector, the world line of the universe has split into three branches. In one branch a photon is detected by D1; in another it is detected by D2 and in the third it is absorbed by the third polarizer. The balance of probabilities shared between these branches is determined by the rules of quantum mechanics as applied to the whole system. When WLR eventually happens, one of these options becomes reality and the other options are simply eliminated. It really is as simple as that. There is absolutely no suggestion of any mysterious 'spooky action at a distance' nor is there any need to invoke backward causation or even Which-Way Information to explain what is going on. What happens is just a consequence of the mathematics which governs the evolution of a quantum state.

## Wave-particle duality.

Once you accept that some aspects of the world can be in a undecided state, all sorts of things become clear that were previously confusing. One such issue is the wave/particle duality.

When Thomas Young performed his famous double-slit experiment in 1801 it pretty well proved that light was a wave. But then in 1905 Albert Einstein showed that in order to explain the photoelectric effect, you had to assume that it was a stream of particles. On the other hand, while J. J. Thomson demonstrated in 1897 that cathode rays consisted of a stream of particles with a definite mass and charge, subsequent experiments showed that electron too could display interference patterns when passed through a thin crystal.

Under SR, the respective roles of the wave and particle aspects are clear. Particles exist except when that part of the universe is in a state of suspended reality. For a while the properties of the particle such as its precise position and momentum are undecided and are determined by the evolution of a mathematical entity called the wave function. When WLR occurs the existential status of the particle is reconstructed so that its past existence is continuous throughout time.[2]

## Entanglement

When Einstein, Podolsky and Rosen published their famous paper in 1934, they thought they had dealt a fatal blow to the fledgling theory of quantum mechanics. Apparently two widely separated particles could behave in a way which was inconsistent with common sense and logic. While we can see that the blow was not, in fact fatal, further theoretical ideas by Bell and others and new experiments have confirmed the authors unease and appear to show conclusively that entangled particles such as a pair of photons produced simultaneously by a device called a parametric

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2   The only thing that I would add is that quantum theory requires that all particles are actually in a continuous state of suspension so perhaps, nothing actually exists NOW – only the past exists!

downconverter really do have measurable properties which are incompatible with the ideas that a) they cannot communicate with each other (localism) and b) that they both have real properties before they are measured (realism).

The pilot wave model gets round the problem by being explicitly non-local. The Copenhagen interpretation gets round the problem by being explicitly non-real. What does the Suspended Reality interpretation have to say about the problem?

When the photons are generated, the two photons are in a single entangled quantum state in which the polarization of the photons is *undecided*. The world line of the universe thickens into a rope which includes the possibility that the photons could be oriented at any angle. When the polarization of one of the photons is measured, for example, by passing it through a vertical polarizer, WLR occurs and the rules of QM decree that all but two of these world lines are eliminated leaving one in which both photons are vertical and the one in which both photons are horizontal. This issue is also resolved immediately with the result that either the photon is absorbed, in which the other photon will be found to be polarized horizontally, or it is transmitted with the other photon being vertical.

Now that the decision has been made we can see that there is no need to appeal to 'spooky action at a distance' as Einstein called it because, at the end of the day, the two photons turned out to have the same polarization for the simple reason that, in the world which was chosen, they had the same polarization all along! There is absolutely no need for the two photons to communicate with each other so locality is preserved. On the other hand, I would have to agree that SR does ask us to make a slight change in our definition of what counts as real *at this instant*. But when WLR occurs, reality is restored all the way back to the point where reality was initially suspended so although we may not be able to say what is happening in the system *right now*, when the experiment is over, we can, in principle at any rate, say exactly what happened in the past.

 I think that is a very small price to pay.

## Quantum tunnelling

All the situations we have so far considered involve particles in motion whose behaviour is described by a wave function which evolves through time in accordance with Schrödinger's Time Dependent Equation (the STDE). However, the greatest successes of quantum theory have involved systems which are in what is known as a stationary state. The best example is, of course, the Hydrogen atom whose energy levels and hence optical spectra were predicted with exquisite accuracy. The simplest example of this kind of behaviour is to be found when we consider a particle confined inside a potential well. If the walls of the well are infinitely high and a large distance apart then the wave function will bounce back and forth between the two walls. But if the walls of the well are separated by a distance comparable to the wavelength of the particle, then for certain values of that wavelength (i.e. certain values of the particles energy and momentum), a stationary wave may be set up with a whole number of half wavelengths between the walls. The electron in a Hydrogen atom is confined to a spherical 'box' and, as I have said, QT predicts the precise energy values of the allowed levels very precisely. These energy values can be calculated from a version of Schrödinger's Equation which applies to stationary states called Schrödinger's Time *Independent* Equation (the STIE).

An atom of the common isotope of Uranium ($U_{238}$) has 92 protons and 146 neutrons. It decays by spitting out an alpha particle (consisting of 2 protons and 2 neutrons) at random with probability of $4.9 \times 10^{-18}\,s^{-1}$. (This gives it a half life of 4.5 billion years.) A popular explanation for this behaviour is that the alpha particle has some sort of independent existence inside the Uranium atom and that it is confined there by high walls of potential. It is supposed that the alpha particle has a certain kinetic energy $E$ inside the atom and that in order to escape from the atom, it would have to surmount a barrier of height $V$ where $V$ is a lot greater than $E$. From a classical point of view this is

impossible but the solution to Schrödinger's Time Independent Equation permits a small degree of probability to leak out of the well.
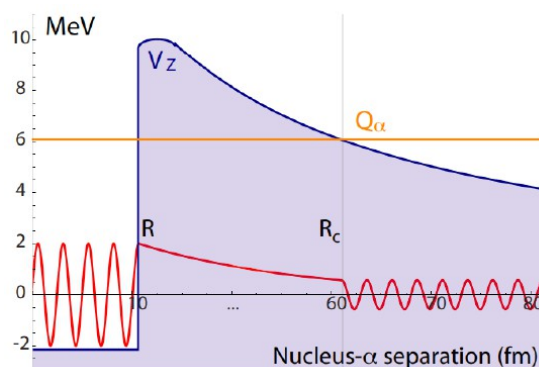


*Quantum tunnelling*

In the above illustration[3] a particle is shown tunnelling through a potential barrier. The red line is a solution to the STIE. At every point $x$ along the axis the function has a value which is a measure of the probability of finding the particle at that point. (Notice that, both inside the well and outside it there are places where the particle will never be found.) It can be seen that, providing the walls are neither infinitely high nor infinitely thick, QT allows there to be a finite probability of finding the particle outside the well.

Having said that, this analysis does not provide a convincing explanation of the *process* of radioactive decay because it leaves out the very factor we are interested in – namely, *time*. We want to know the probability of finding the particle outside the well during a specific interval, not just in general. In order to do that we must imagine that the particle is bouncing around inside the well and that it hits the walls of the well at a definite frequency. This will require us to make some assumptions as to how fast the particle is going and how big the well is. Surprisingly, perhaps, the results of this calculation predict values of half live which agree with the experimental values at least within an order of magnitude[4].

In a sense, all this mathematical detail is unnecessary to my purpose. What I want to convey is a picture in which, every time the contained alpha particle comes near the edge of the nucleus, a tiny branch splits off the world line of the universe representing the possibility that, on that occasion, the alpha particle escaped. This potential alpha particle then proceeds to interact with the environment (for example, by knocking an electron off a nitrogen molecule). At this point WLR occurs and a decision is made as to whether this is a real alpha particle or not. Only very rarely does the decision go the particles way but once in every 4.5 billion years, the alpha particle is declared real and the universe finds itself in possession of a new atom of Thorium$_{234}$, a real alpha particle and an ionized Nitrogen molecule.

## The Hydrogen atom

The Hydrogen atom is neutral and has no dipole moment. It consists of a positively charged proton and a negatively charged electron. QT tells us that the probability of finding the electron while it is in its ground state forms a spherically symmetric cloud round the proton. How, under these circumstances, can we be justified in calling an electron a particle?

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3    The illustration is taken from
     https://phys.libretexts.org/Bookshelves/Nuclear_and_Particle_Physics/Introduction_to_Applied_Nuclear_Physics_(Cappellaro)/03%3A_Radioactive_Decay_Part_I/3.03%3A_Alpha_Decay

4    In the case of an alpha particle inside a Uranium atom, the tunnelling probability is calculated to be p = 4 × $10^{-39}$, the speed is $v$ = 4 × $10^7$ ms$^{-1}$, and the diameter of the nucleus is approximately d = 5 × $10^{-13}$ m. The probability that the alpha particle will escape in any given second is therefore $\dfrac{v}{2d} \times p = \dfrac{4 \times 10^7}{2 \times 5 \times 10^{-15}} \times 4 \times 10^{-39} = 1.6 \times 10^{-17}$ which translates into a half life of about 1.3 billion years.

It was considerations like these that cause Niels Bohr to abandon any attempt to say what is going on inside an atom – or, indeed, in any system when you are not actually observing it. For Bohr, the electron inside a Hydrogen atom has no meaningful existence at all. Proponents of the other main interpretations of QT do not appear to think that there is a problem. But if you believe, as proponents of the pilot wave model believe, that electrons are real particles with real trajectories at all times, what do you imagine a electron in a Hydrogen atom is actually doing? What does the Many Worlds Interpretation have to say about the issue? Probably nothing at all.

But, as always, the idea that (parts of) reality can be undecided or in suspension comes to the rescue. It is simply that the status of the electron inside a Hydrogen atom is in a permanent state of suspension. Nature does not have to decide where the electron is at all times – it can be anywhere, governed only by the rules of QM. From the outside, its negative charge appears to reside at the centre (which explains why the atom normally has no dipole moment); but if an energetic photon passes through the atom, there will be a finite probability that the photon will interact with the electron and the latter will be ejected. Whether this process necessarily results in WLR is an issue which we can defer no longer.

## World Line Reduction

The apparently bizarre effects of QT such as entanglement or superposition may be difficult to reconcile with a naïve realist version of the way the world works but at the end of the day, we just have to accept them. The elephant in the room of any interpretation which relies on any form of 'wave function collapse' is what is known as the *measurement problem*: when exactly does a quantum system transition between quantum and classical behaviour and what causes this to happen? In the case of SR we must ask – is World Line Reduction a physical process? If so, what causes it? Is it just another phrase for Wave Function Collapse? If not, how does it differ?

The first thing to make clear is that WLR cannot be a *physical* process because it is a process in which certain non-physical entities (potential worlds) are eliminated. It is a mathematical or logical process and it does not have a physical cause. Having said that, since WLR always occurs at a specific *time*, it makes sense to assume that there are physical circumstances which 'cause' it to happen at that time. Consider the following analogy: a lottery ticket may be purchased for £1 and, indeed, it can sensibly be traded for goods to the value of £1. But at the instant the winning numbers are published, the ticket becomes worthless. The 'collapse' of the value of the ticket was 'caused' by the way the balls in the lottery machine fell but this does not mean that the loss in value had a physical cause. It certainly does not imply that there was any instantaneous communication between the machine and the ticket[5].

Penrose has noted that, while the unitary evolution of the wave function – the process he calls **U** – is time symmetric, the collapse of the wave function – **R** – is not. When looking for a physical event which could be the trigger for **R** it would seem reasonable therefore to examine events at the atomic scale which are not time symmetric.

As is well known, elastic collisions between two atoms or molecules obey Newton's laws which are time-symmetric. What this means is that, given the positions and  velocities of the particles after the event, the positions and velocities of the particles before the event can be calculated by simply reversing the signs of the velocities and running the equations backwards. There are two ways in which this scenario can be changed. In one scenario the two particles coalesce into one. Before the event, we need 12 parameters to specify the positions and velocities of the two particles in three dimensions, six each. After the event we only need six parameters because there is only one particle. It is impossible to calculate the positions and velocities of the two

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5   It may be objected that, although no signal is needed to pass between the lottery machine and the ticket, there may yet be an inconsistency in maintaining that the ticket 'loses its value at the instant the winning numbers are published' when the effects of Special Relativity are taken into account. It is, however, recognised that, in the case of entangled photons, there is no inconsistency with the requirements of Special Relativity.

particles before the event given only the position and velocity of the single particle after the event because *information about the past history of the particles has been irretrievably lost*. A process like this is called *irreversible*. Where does this information go? The answer is that an interaction like this always results in the loss of kinetic energy which must reappear in the form of internal energy within the coalesced particle. Perhaps the simplest real example of such an irreversible event is the absorption of a photon by an atom leaving the latter in an excited state. Although playing a film of the event backwards will show a plausible event – namely an excited atom emitting a photon – just reversing the velocity of the excited atom will not reproduce the original event in reverse because the photon could be emitted in any direction at almost any time.

The second scenario which is time asymmetric is the converse of this, namely a scenario in which two particles collide to produce three or more. In this case *information about the future history of the system has been created*. Consider the case where an alpha particle collides with a Nitrogen atom ejecting an electron. The 12 pieces of information about the positions and velocities of the alpha particle and the Nitrogen atom before the event are now insufficient to determine the 18 pieces of information required to specify the states of the three particles after the event. This is not an irreversible process because, given the latter data it is perfectly possible to calculate the former, so it deserves a different name. I shall call this sort of process *irrepeatable* because if you try the same experiment again, you may get a different result.

I shall now make the bold proposal that it is *irreversible* or *irrepeatable* events which trigger world line reduction. Conversely, reversible and repeatable events do not trigger WLR.

The reflection or transmission of a photon by or through a half silvered mirror is reversible and repeatable and does not cause WLR. However, the absorption of a photon (or a potential photon) by a polarizing filter is irreversible and triggers WLR. An elastic collision between molecules is reversible and repeatable but a collision which results in the expulsion of an electron is irrepeatable and causes immediate WLR.

We can now see why it is so difficult to maintain a physically large system in a quantum state. In May 2023 Scientific American ran an article with the headline 'Biggest ever Schrödinger's Cat' in which it is claimed that a sapphire crystal containing $10^{17}$ atoms has been placed in a superposition of states. Other theories of objective reduction which rely on the mass of the system or the number of particles to trigger wave function collapse will find it increasingly difficult to keep up with the experimental evidence that there really is no limit to the size of an object which can be placed in a superposition of states – providing that you can ensure that no irreversible or irrepeatable events occur within it. This generally means keeping the object at extremely low temperatures and shielding it from every possible outside influence that might cause such an event.

I mentioned earlier that there are strong grounds for believing that the laws of physics are not deterministic at the atomic level. The evidence for this assertion is the Second Law of Thermodynamics. We are now in a position to see exactly how this breakdown of determinism occurs.

## *Irreversibility and the Second Law of Thermodynamics*

The canonical example of the operation of the Second Law is the behaviour of a small phial of gas released in the corner of an evacuated box. The gas immediately fills the box and entropy (a measure of the disorder in the system) increases. Now the classical laws which govern the collisions between gas molecules are symmetric with respect to time. It follows that, if you were to reverse the velocities of all the molecules in the box in an instant, then the gas molecules would retrace their steps precisely and end up back inside the phial. This can only happen because there is a huge degree of correlation between the motions of all the reversed molecules. I think we can all agree that, although the experiment could not possibly be done, if you could do it, the entropy would decrease for a short while but then it would increase again. We can conclude from this that the laws

which govern gas molecules cannot be precisely reversible or repeatable.

Now even on a quantum scale, a collision between two gas molecules is quite a big event. If we are wanting to find a potentially irreversible or irrepeatable process we need to look towards a smaller scale – on the scale of individual electrons or photons. Even in the least energetic collision between atoms, there is always a small possibility that an electron could be lifted into a higher energy level (an irreversible process) or that a low energy photon could be emitted (an irrepeatable process). If this is correct, then whenever two gas molecules collide, Nature must consider the possibility that energy is emitted or absorbed. Usually the answer is no, but occasionally the answer is yes and an irreversible or irrepeatable event will occur which destroys the coherence which is necessary to ensure that there are ever circumstances which could result in significant decreases in entropy.

Robert O. Doyle has calculated that in the case of a litre of gas at STP, such an event might occur about once every second[6]. Of course, as soon as one molecule has lost all correlation, then the effect will spread exponentially through the whole gas and in a fraction of a microsecond, all correlation is lost completely and entropy will start increasing again. It is the irreversible nature of photon absorption and the irrepeatable nature of spontaneous photon emission that explains the Second Law of Thermodynamics and, I suggest, it is the same process which results in WLR and which introduces the essential element of randomness in all quantum processes.

It follows from this that if you could prevent such an event from happening, WLR could be postponed indefinitely. Consider the fate of a single neutron in completely empty space. The half life of an isolated neutron is 12 minutes and decays into a proton and an electron. According to SR, the neutron is continually ejecting potential electrons which travel out in all directions. Since these potential electrons never interact with anything the state of the system has to be described by an ever expanding wave function which encodes information about all the possible ways in which the neutron might have decayed. There is no logical inconsistency with this, and advocates of the Many Worlds interpretation will find the idea totally familiar. It would be completely wrong, however, to infer that the half life of the particle was extended indefinitely. Suppose that, after 100 years of travelling through empty space, this 'cloud' of potential electrons encounters some matter triggering WLR. Sooner or later one of these events will result in a decision which reveals that the neutron actually decayed a few minutes after its creation, just as we would expect.

Another alternative is that, by actively promoting WLR you might be able to hasten (or delay) a quantum process. This effect, if it exists, is known as the Quantum Zeno effect. Wikipedia details three teams who claim to have observed such effects in the last couple of decades. This is a pitifully small sample and the interpretation of their results is controversial but I would dearly love to see far more effort going into proving whether anything like WLR can be shown to occur and if so, whether the effects are consistent with my theory.

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6   Robert O. Doyle *The Origin of Irreversibility*
    https://informationphilosopher.com/problems/reversibility/Irreversibility.pdf