Cosmology, the Many Universes Interpretation of Quantum Mechanics and Immortality

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Abstract

Observational evidence suggests that the universe is infinite, geometrically flat, homogeneous and isotropic on large scales. Hence we should expect to find large numbers of identical copies of any object consistent with the laws of physics including conscious identities like people. Under suitable notions of continuity of identity, This would imply that immortality of these conscious identities is a consequence of functionalism. I argue that the same conclusion can be drawn using an Everett Deutsch interpretation of quantum mechanics. I also argue why this is the correct interpretation. Lewis's "terrifying corollary" is reviewed and I discuss how Bostrom's simulation argument, if correct, might mitigate our futures.

1 Introduction

It has been referred to as "quantum physics dirty little secret" [1, p6] – perhaps because to publicise it might lead those people, who little understand it, to develop suicidal tendencies in the hope that they might get into a better universe – This is definitely not a good idea!

We'll look at this little secret in more detail later. But in order to do this we will need to develop some background.

First it must be said that the word "worlds" is often used interchangeably for "universes" in the literature. It is not used to mean planets like our own parochial world. Also, the idea of an observation or experiment translates into ordinary language as "looking", "listening", "touching" etc. as well as for more technical approaches such as using Charge Coupled Devices to detect individual photons of light in astronomy or interferometry.

2 Infinity - or at least an unboundedly large number!

When I first started to write this paper, I wanted to give an explanation which was largely free of the hieroglyphics of mathematics but I fear I have failed to some extent. However, to those not familiar with any mathematical terms that appear, my advice is to just skip over them and keep reading until you pick up the track of the argument again in the text. In any case I have put most of the mathematics into appendices. Unfortunately the language of the universe **IS** mathematics and so inevitably, it is true that ALL the theories of the physical world that work i.e. actually enable us to use them practically, prove them true experimentally, understand them and use them in terms of their explanatory power are all able to be written down in the form of mathematical equations. This means that they form a coherent integrated body of ideas and equations which have explanatory power, enabling new discoveries to be either accumulated into the body of existing knowledge or used as an insight restructure, which unifies that whole body of knowledge. When I speak of theories here then, I mean theories described in terms of mathematics. I also think it is largely true that biology and chemistry are really just emergent effects which arise from the underlying particles and fields which are governed by quantum theory and relativity.

There is however one somewhat obscure aspect of mathematics which I will need to draw upon in this paper. This is the notion of infinity - given by the symbol ∞. Mathematicians, engineers and physicists use infinity (in a less obscure way) all the time, especially because it forms the basis of one of the most powerful branches of mathematics ever discovered (by Newton and Leibniz), called “calculus”. For our purposes, here though, just a few of the more obscure properties about infinity will be needed.

First of all, if you have a continuous line of any length which lies in a continuous space, then the line will have a (continuously) infinite number of points on it [see note 5]. If you then divide this line into two equal lines, then each of these lines will also have an infinite number of points on them – even if the two lines are of unequal but finite length! It also comes as a surprise to many non-mathematicians to learn that there are as many points (an infinity of them) on a line of a given length as there are within a square which has a side equal to this length. Moreover, it is also true that two circles of different radii both have an equally infinite amount of points within them even though they are different in “size” or “measure”. This idea will be important later. *Essentially “a measure” is a method by which a theory gives meaning to proportions and averages of infinite sets of things such as universes.* Another thing about infinity which follows from what I have just explained is that infinity can be divided by a finite number and the result will also be infinite e.g.

$$\infty \div n = \infty$$

where n = any finite, non-zero number.

There are some people (called “finitists”) who argue that only finite abstract entities exist. The Oxford Physicist David Deutsch, Visiting Professor of Physics at the Centre for

Quantum Computation at Oxford University, works on fundamental issues in physics, particularly the quantum theory of computation and information. A leading proponent of the parallel universes ontology, argues:

“That finitists would say that only finite abstract entities exist. So, for instance, there are infinitely many natural numbers, but finitists insist that that is just a manner of speaking. They say that the literal truth is only that there is a finite rule for generating each natural number from the previous one, and nothing literally infinite is involved. But this doctrine runs into the following problem: is there a largest number or not? If there is, then that contradicts the statement that there is a rule that defines a larger one. If there is not, then there are not finitely many natural numbers. Finitists are then obliged to deny a principle of logic: the ‘law of the excluded middle’, which is that, for every meaningful proposition, either it or its negation is true. So finitists say that, although there is no largest number, there is not an infinity of numbers either!” [7, p165].

Again, non-mathematicians also find it strange to discover that there are even different kinds of infinity, but we will not have need to go into these details here. It’s probably easier to just imagine infinity to be an unbounded amount that is just so unbelievably huge that it makes your brain hurt to think about how big it could be!

Now we can begin to explain how immortality can follow from some basic facts and assumptions about the universe. The first step is to adopt the philosophical position called “functionalism.” Functionalism is the reasonable idea that our consciousness depends only upon the arrangement or structure of our brains and bodies. If you believe that we have some form of ethereal soul, and that consciousness cannot be described by the laws of science then we will never be able to explain consciousness. Functionalism on the other hand, says that our consciousness (as far as it is known) is an emergent property of the brain and therefore based on biochemical, electrochemical and cellular structure only. Essentially the brain is a very complex form of computational system which is self-conscious. The next step is to see that immortality is a not only a consequence of functionalism in modern classical cosmology, but also a consequence of Quantum Theory.

3 Cosmology

Cosmology is the study of the large-scale structure of the universe, whilst quantum mechanics is usually associated with the very small scale structure of matter. Cosmologists study mathematical models of the different universes we might be living in to try to figure out which one of these models corresponds to reality. Cosmologists around the world study the data coming from telescopes on land and on satellites in space to help them to develop equations which pin down the model that best fits our particular universe and then make predictions about its behaviour, its age, size, how it began and how it will end etc. These telescopes and instruments analyse incoming electromagnetic radiation from a wide range of wavelengths (including the visible part of the spectrum). The results of the analysis of the most up to date astronomical data tells us that the most likely cosmological model that fits the observed data is one in which the universe is so unbelievably huge, that it is effectively infinite [6]. It is also “geometrically flat” on large scales, which means that, in principle if two observers were travelling side by side in parallel, at the same velocity, they would continue to follow nearly parallel trajectories [see note 12]. Now, particles are normally attracted to each other by gravity, but the further apart they are the more they experience another new kind of repulsive effect due to the presence of a little understood form of energy called “dark energy”. This has never been directly detected but it causes the universe to grow at an accelerating rate. Data from supernovae, initially prompted our belief in such an exotic form of energy and has subsequently confirmed this accelerated expansion.

Such a “flat”, infinite space has remarkable implications. One of which is that if an observer were to set off in any direction, and travelled for long enough, then they would eventually come across other solar systems, some of which would be very similar to ours. If they kept on going and going, they would eventually, sooner or later, find a solar system so incredibly similar to the one we live in, that they would find in it an earth exactly the same as ours, along with a twin of ourselves doing exactly the same thing, thinking the exact same thoughts as we are now. Indeed, this twin would have a body and brain identical in every structural respect to the original. The cosmologist Max Tegmark has even calculated an estimate of how far you need to travel before expecting to run into your identical twin [6] Moreover, quantum physics tells us that, if two subatomic particles are of the same type then they are identical. For example, if you exchange all the protons in your body with protons from the metal in your car, then there would be no observable difference in the way either you or your car behaved physically. This implies that the identical twin that we found in our travels would not only be like us, but it would literally BE us. If space is truly infinite and filled homogeneously with galaxies as our universe appears to be, then we would not find just one twin exactly identical to us. Indeed, if we kept on going, we would find yet another and another and another…. all existing in lock step.

For those who still find it difficult to believe in an infinite universe, then it’s worth trying to think of an alternative. The cosmologist Max Tegmark steps in here and suggests whimsically what the alternative might be. He suggests that, somewhere out in space far far away, there might be a sign that says “Space Ends Here – Mind The Gap!” [5] or [see note 6]

So here is our first indication of where the possibility of immortality comes from. If there are infinitely many copies of me all doing the same thing, then effectively all of them are me, all having the same histories – a “history” from the mathematical viewpoint is just a curve in three-dimensional space which also traces out your path in the fourth dimension of time (You have to suppress one or two space dimensions to draw it!). One can imagine all these histories of <u>identical</u> me’s being represented by a bundle of infinite histories like the lines in the tubes or branches shown in Figure 1 below. Even though these histories are bundled together to form a kind of tube, they will usually be extremely far away from each other. What gives them “closeness”, as depicted in the diagram, is the fact that the histories are all identical. The histories define “lines” drawn in “space” which extend in time. Any bundle of identical histories is such that there is no way of thinking about “which history is which”. They are all identical. David Deutsch, an expert in fundamental quantum physics has referred to these types of histories as “fungible”! [7, p265], in that they are identical in every respect, except that there are more than one of them. In fact, there are an infinite number of identical instances of each history.

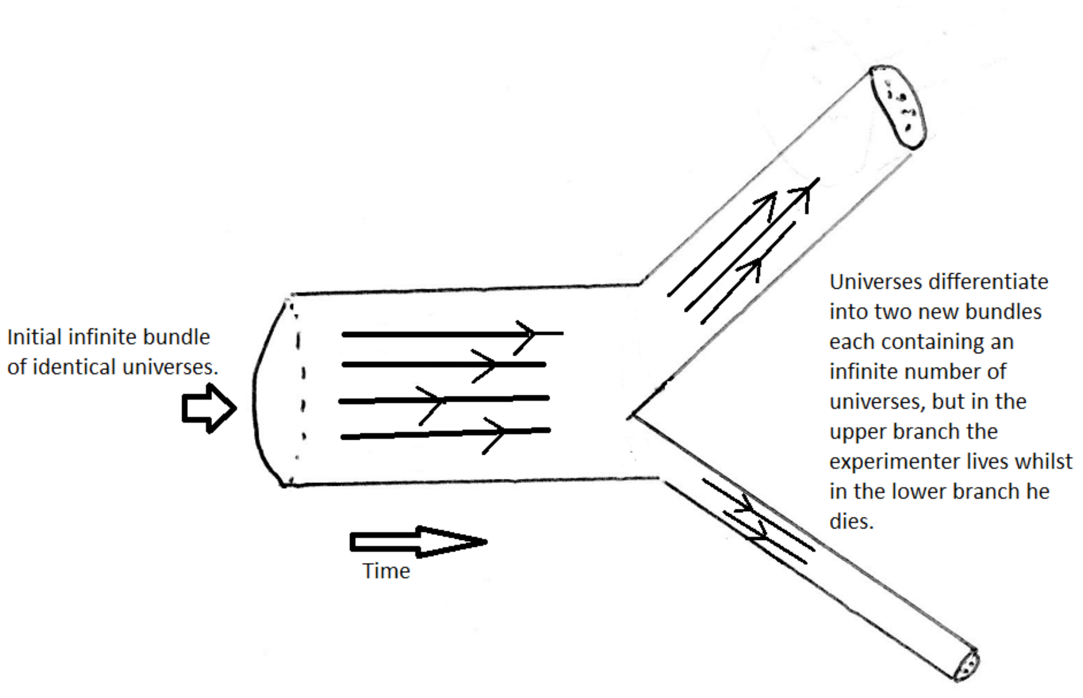
However, at times, these branches split – or rather, a proportion of the universes in them become different which means they too have now branched. This branching is due to a “measure” over the continuously infinite set of universes in a branch bundle). For example, in some proportion of the me’s in the initial bundle, perhaps one particle in my brain may move to a slightly different place than all the others in the bundle, making me do something differently than the rest and we can say then that these different versions of me diverge in all that they do, from then on. The parallel versions of me have now started to trace out different histories. At every instant that I make a decision - say whether to go out or to stay at home - an infinite number of me's end up staying at home whilst an infinite number me's end up going out - it's the "measure" or relative proportions of the whole that represent the difference in the different sets of universes. Note then that, although the original bundle divides into two or more bundles with different measure, each bundle still contains an infinite number of me's. Remember:

$\infty \div n = \infty$ where n = any finite non-zero number.

Which universe we end up in is indeterminate to some extent (because they are fungible), but if any of the branches diverge because the me's in them die, then there will always be some probability that there will be an infinite branch bundle with me's in them that live. Since I cannot experience death directly, the next most consistent extension of my experience will be in a branch bundle in which I find myself alive.

Working with infinite sets of histories like this is not as straightforward as I have made it here and involves dealing with this concept of the "measure" of a set in more detail. However, in practice, it means that if an infinite number of identical me's flip a fair coin and are immediately shot dead if it comes up heads then, in roughly half of the infinite number of worlds I was shot and my family mourns my passing. In the other half, they see me survive and are glad. From my point of view however, I can only experience a branch in which I am conscious so from my point of view, I would only ever see the coin land on a tails outcome and hence say "phew".

This means there are an infinite number of me's along with possibly an infinite number of observers. And every observer also experiences a similar branching effect – except they may see me die but find they are immortal. See Figure 1 below.



You might argue that your particular history was one which got tails, so you would just die! However, if at all instants, you cannot experience death then, since all of these branches are you, then you must only experience branches where you survive. In the diagram above, all the initial “thick” bundle of me’s start off experiencing the same thing. After any branching though, you will always find yourself in a universe (history) in which you are alive. My relatives in the lower branch however will see me die in their branch - but I’m not there to worry about it because my consciousness does not reside in a dead body! Because consciousness is implemented in all copies of you before the coin flips, if one or more copies is killed, the others live on, your conscious experience must follow the living versions. I repeat for clarity that, if your consciousness is simultaneously implemented in two perfect copies, then if one copy dies and the other lives, your conscious experience must “follow” the path of the one that lives. Since there are an infinite number of copies of me, then peeling any number off, or dividing them up won’t change the fact that there will always be a branch of histories in which I live. It’s just $\infty \div n = \infty$ again.

4 Quantum Theory

There is yet another way we can find ourselves to be immortal. Quantum theory (or quantum mechanics as it is often called) was discovered in the early 1900’s. There are lots of theories in physics like Ohm’s law - which explains how electrical circuits work, or the kinetic theory of gases which explains the behaviour of idealised gases i.e. gases made of small particles such as atoms, or atoms combined into compounds like carbon dioxide (CO_2). These theories are very important and their discovery has had an enormous impact on our lives. However, quantum theory is more mysterious and very deep. It was stumbled upon, and discovered bit by bit, by numerous scientists including Einstein, Bohr, Heisenberg, Dirac, Born, De Broglie, Pauli, Schrödinger, and many others. This is indicative of the fact that quantum theory is such a counterintuitive theory. It took quite some time (nearly a century!) to get to grips with what the structure of the theory was all about. It turns out that quantum theory is a theory like no others found before it. Quantum theory appears to underpin **all** the other theories of physics in a way which we could never have imagined. [see note 3].

Once the basic structure of the theory was discovered, it turned out to be one of the most powerful explanatory and predictive theories ever discovered. It helps to explain how the periodic table of elements has the structure that it displays and hence facilitates our understanding of chemistry. It enables us to design medical imaging devices like CT and MRI scanners. It underpins how hard drives, mobile phones and TV’s work and, in particular, how transistors function. This means we can build semiconductor devices which give us some of the most advanced computers the world has ever seen. Because we can apply quantum theory, we can devise ever more powerful computing machines. In fact, the progress in this respect is such that, the power of these machines has been expanding by doubling in speed every eighteen months or so. This is an amazing (exponential) pace. If your PC processor speed is limited to be 1Ghz today, then in eighteen months it could be designed to be 2 GHz. In eighteen months more, it could be 4GHz. According to this law of growth – called ‘Moores Law’, in just over fifteen years the processor speeds could, in principle, be designed to reach 1000GHz. Memory capacity and storage capability also grow in the same way.

I use the word "discover" regarding quantum theory because it should be remembered that all experimentally verifiable theories are not invented by people - they truly are discovered. You cannot discount quantum theory and say that it can't be true because it's… "just a theory!" On the contrary, the theories of physics that have been confirmed by experiments ARE the truth about nature's laws that are revealed in mathematical forms rather than created by people. Indeed, quantum theory and relativity are some of the most precisely tested theories in the history of science. What can be said though is that it is remarkable that people are able to uncover, understand and use nature's laws, but the reason why we can do that is because we know her language – and that language is mathematics.

Unfortunately, unlike relativity, which does have some intuitive structure, quantum theory is really very much like a mathematical recipe based on a set of postulates, discovered following a period of intense research in the early 1900's. Initially no one seemed to be able to understand or explain why the postulates are as they are - but no one could or can seriously have any doubts that they enable us to produce correct predictions to devised experiments. In fact, no one has ever been able to produce an appropriate experiment that quantum theory cannot predict the probabilistic outcome of. Even Einstein tried to devise an experiment designed to show that underneath the postulates were a set of "hidden variables" which would explain the theory in a more fundamental, intuitive and satisfactory way. This was the famous Einstein, Podolsky and Rosen (EPR) experiment. It was Einstein's guess that there was something missing in this strange set of postulates and he believed that the EPR experiment would show that somehow quantum mechanics was incomplete in some way. It was many years after Einstein's death before the technology enabled the EPR test to be carried out. Then in 1972 Clauser and Freedman [3] performed the experiment. The results came out in a way which Einstein would not have liked. They indicated that the predictions of quantum mechanics were correct and that no physical theory of local hidden variables could ever reproduce all of the predictions of Quantum Theory i.e. the hidden variables he thought would underpin quantum theory were not there – at least not in a form that Einstein would have expected [see note 1].

When quantum theory was being developed, an "interpretation" of the postulates and the corresponding mathematical formalism was given by Neils Bohr and Werner Heisenberg. This was known as the "Copenhagen Interpretation". Unfortunately, this interpretation suffered from having to add an extra ad hoc postulate involving a dynamical process called "the reduction of the wave function". The problem with this extra postulate was that the dynamic reduction process had no mathematical explanation and yet, for many years the majority of practising physicists subscribed to this interpretation by default. See [note 9]. Although it did not affect the correct application of the theory, wavefunction reduction was seen as a blemish on the theory because it introduced an element of randomness (indeterminism) and non-unitarity into the whole theory. For example, a radioactive atom could be in either a decayed or undecayed state, and in some sense, until it was observed, it was in a mixture of both at the same time (called a superposition). Observation seemed to make things firm up into one alternative or another. Unfortunately, this "collapse" or "reduction" onto one state (say the decayed state) rather than the other (undecayed state) seemed to require a part of the mathematical recipe -

called "coherencies" in what is called the "density matrix" to disappear magically (see appendix 4).

Then in 1957 Hugh Everett [10] published his theory of The Universal Wave Function. (otherwise known as The Relative State Formulation of Quantum Mechanics or The Many Worlds Interpretation of Quantum Mechanics [20],[18]).

This was a remarkable departure from the initial paradigm and took a while to gain any acceptance because its implications just seemed too weird.

In Everettian Quantum Mechanics (EQM), Everett dispensed with the ad hoc non-unitary collapse postulate associated with making a measurement or observation, reducing the number of postulates by one and restoring some measure of determinism into quantum mechanics. The quantum state vector was now described (as before in the Copenhagen Interpretation) by a vector $|\Psi\rangle$ in what is called an abstract Hilbert space, evolving under the influence of a self adjoint Hamiltonian operator $\hat{H}$ according to the famous Schrödinger's equation:

$$i\hbar \frac{d|\Psi\rangle}{dt} = \hat{H}|\Psi\rangle \qquad (1)$$

Don't worry about the formula here or about the strange brackets. What all this means is that, in The Many Worlds interpretation, quantum systems can now be seen to behave according to a predictable equation - both before, during and after a measurement. Remember that, according to the Copenhagen interpretation, the behaviour during a measurement was not able to be described in a mathematically consistent way.
In the Many worlds, Interpretation, however, there is no need for a separate ad hoc rule governing any kind of "wave function collapse". Rather, the observer as well as the system and environment are included as part of the quantum state and unitary evolution (i.e. according to equation (1)) causes the system, observer and environment (universe) to "split", or differentiate quickly into many branches or universes, each associated with a possible measurement outcome of an experiment. In short, instead of one universe with one outcome, we get many universes, each with one outcome occurring with a "measure" based on the weights predictable from one of the original postulates common to both interpretations, called the Born Rule. See Appendix 1 for an idealised measurement process.

Cosmology and Quantum Mechanics

Buosso and Susskind [12] and Aguire and Tegmark[13] independently have proposed that the many-worlds of quantum mechanics and the many universes of cosmology (the multiverse) are, in fact, the same thing.

5 Everett – Deutsch Quantum Mechanics

According to Deutsch, quantum mechanics underpins all of our experience of the world because it is the root theory from which all others come (possibly including General Relativity, although progress in this direction is slow and difficult).

Everettian Quantum Mechanics (EQM) [19, p279], [20], [see also note 2] implies that there are infinitely many universes (worlds). In some proportion of these, we are present and in an even smaller proportion of universes, we are doing exactly what we are doing now in this one. When these identical "instances" of me make an observation, the infinite number of universes which contain me, branch into different bundles each containing an infinite number of universes, and each bundle corresponds to one of the possible outcomes of the observation I can make. Any measurement e.g. like looking at something, hearing or touching something and even introspective observations of our own thoughts, count as measurements. The proportions of these universes that end up with me doing different things in them, including becoming dead, are governed by a "measure" over the worlds which roughly speaking, divides the bundles of universes according to how probable the outcome is. For example, if I toss a fair coin, then the infinite number of instances of me that toss the coin will differentiate into roughly <u>two</u> branches, one containing an infinite number of universes where I see "heads" and one containing an infinite number of universes where I see "tails".

If I throw a fair, six-sided dice, then in roughly 1/6th of the initial infinite bundle of universes in which I throw the dice, I will exist and see a six. Similarly, in roughly 5/6th of the infinite bundle of the initial universes in which I throw the dice, I will exist and see a number from the set {1,2,3,4,5}. I have used the word "roughly" here to account for the fact that, in a very tiny proportion of universes, I will perhaps see all sorts of improbable events like the dice will fall off the table and get swallowed by my dog! (This situation is dealt with in Appendix 2).

I will use the above Everett/Deutsch version of the interpretation in which, for any experiment, an initially infinite number of "fungible" universes, will differentiate into a number of separate fungible branch bundles corresponding to the different outcomes of the experiment. Each branch bundle will generally be a different "size" or measure (proportion of the original whole), but each branch bundle will still consist of an infinite number of universes. However, since the universes in the original bundle are fungible, the outcome of the differentiation for any particular observer in a particular universe is indeterminate. The thought experiment below gives an example of the recipe used in quantum mechanical experiments.

6 The quantum coin - a toy analogy

This is an imaginary example of an ideal experiment where we flip a "quantum" coin; we expect one of two outcomes. These are written as a linear "superposition" described by a state vector $|\Psi\rangle$ in a two-dimensional Hilbert space as

$$|\Psi\rangle = \alpha|Heads\rangle + \beta|Tails\rangle \quad (2)$$

Where α and β are two complex numbers [see note 7] satisfying $|\alpha|^2 + |\beta|^2 = 1$. As the state evolves unitarily (i.e. according to the Schrödinger equation), the values of α and

β can generally vary as $|\Psi\rangle$ rotates around the Hilbert space [25, p80] but in our analysis we can assume they are fixed. Also, the coin would be fair if $|\alpha|^2 = |\beta|^2 = 0.5$

If I flip the "quantum coin" then remember in EQM, there will be an infinite number of copies of me all doing the same thing at the same time until now. When we actually look at the outcome, we find, that in my universe, the coin lands on either "heads", with probability $|\alpha|^2$ or "tails" with probability $|\beta|^2$. Here we see how the quantum recipe provides a "measure" or proportion of the universes obtaining either of the two outcomes. Remember that of all the me's in the infinite number of universes that are performing this experiment, the proportion $|\alpha|^2$ of them will get heads as an outcome and the proportion $|\beta|^2$ will get tails. From my point of view, (often called the "inside "view"), prior to tossing the coin, I can only use $|\alpha|^2$ and $|\beta|^2$ to estimate the probability of getting an actual "heads" or "tails" result.

According to the Copenhagen interpretation of quantum mechanics, there are no parallel universes. The initial state $|\Psi\rangle$ in equation (2) has (mysteriously) "Collapsed" onto the measured state – either $|\Psi\rangle = |Heads\rangle$ or $|\Psi\rangle = |Tails\rangle$ with probabilities the same as in EQM but in a random way. No explanation of the dynamics of this collapse has been successfully given for this interpretation and it does not account for the effects of interference between worlds [19, ch2] which I discuss in appendices 3 and 4.

7 The Theory of Immortality

As I have discussed, the idea of immortality can be inferred directly by one or both of two ways. Either

> 1. Assuming that the premise of functionalism is correct (which most people probably do believe by default) and accepting that the universe is homogeneous, isotropic and infinite (or at least sufficiently large- which observational evidence indicates is the case). And/or;
>
> 2.Assuming that the Many Worlds/Universes Interpretation of Quantum Mechanics is the appropriate interpretation.

I have pointed out that there are those who would identify these two options as fundamentally the same, but I will not make this assumption in this work except to suggest in passing that the reason why I think there is an isomorphism of sorts relies on something more fundamental (The Simulation Hypothesis).

Many people find the quantum theory of immortality to be too unbelievable to be true, but it should not be rejected too easily, even though it is a strange idea. Some leading physicists and philosophers have studied it (and the cosmological idea of immortality discussed previously) in some detail and yet it has thus far, not been convincingly refuted. Also in spite of its appeal - it carries a sting in its tail!

A simple way to illustrate the idea of Immortality Theory is to imagine that you are chained to a bomb, triggered by some form of radioactive decay process that has a 50% chance of detonating the bomb within one hour. Thus, at the end of the hour you will be either dead or alive with equal probability! The question is, what will you experience? You are now taking the place of Schrödinger's cat! [34]. Remember that according to the Deutsch/Everett Many Worlds Interpretation of quantum mechanics, there will be an infinite number of copies of you all performing exactly the same experiment as you are, but they will be performing it in their universes – but they are all in the wave function of the universe too. This means that we can draw a diagram like Fig 1 again. Now remember, that, before the branching occurs, there is no such thing as which "you" is the real "you", because all of the instances of the universe you are in, are all identical. You are in all of them. David Deutsch: comments on all these identical instances of a person in his book. 'The Fabric of Reality' :
"…………If, aside from *variants* of me in other universes, there are also multiple identical copies of me, which one am I? I am, of course all of them. Each of them has just asked the question 'which one am I?' and any true way of answering that question must give each of them the same answer. [19, (p279)]. Hence, as I have argued previously, since we cannot experience death, then once again, from our own point of view, we will always survive.

Because consciousness is implemented in all copies of you before the experiment, if one or more copies are killed, then the others live on, your conscious experience must follow the living versions. Since there is an infinite number of copies of you, then peeling any number off or dividing them up into alive or dead, won't change the fact that there will always be a branch bundle of histories in which you live on.

Unfortunately, there is a down side to this: - I could be in one of a number of branches where the bomb went off and it wounded me seriously. So, I will have survived, but may have lost legs and arms etc. So, survival does not necessarily mean that your state of health is preserved. Every second that we live, we encounter life threatening possibilities and so we will find ourselves constantly cheating death, but not the effects of continued survival. As each moment of your life passes, you branch into a world where you get older and older. You see other people die, yet you keep cheating death. Never the less, you will grow very old and although sometimes you may find yourself in a universe where you gain more strength and agility because some new drug enables this, it will be more likely the case that in the long term your health will deteriorate (this is the second law of thermodynamics!). As you grow even older, the probability of death increases. However, subjectively, once you have achieved consciousness, you cannot then lose it - even if the body is damaged; there will always be some small probability of a branch which enables your consciousness to survive (see Appendix 2). Again, it is important to remember that you will see others die, and although subjectively they will also survive in their branch of the multiverse, it will be in a world which will one day be without you, This line of reasoning leads to each of us becoming older and more decrepit as well as very lonely. So here is the sting! The philosopher David Lewis saw this state of affairs as a "terrifying corollary" of the Everett interpretation and was personally shocked by its implications. In How Many Lives has Schrödinger's cat? [14][21], he remarked that,"….A terrifying corollary has gone unmentioned. As well as life-and-death branching, there may be life-and-life branching such that you suffer harm on some branches and not on others. In some of these branches, the harm branches get the lion's share of the total intensity/proportion. The intensity rule applies, so you should predominantly expect to find yourself harmed. As you survive deadly danger over and over again, you should also expect to suffer repeated harms. You should expect to lose your loved ones, your eyes and limbs, your mental powers, and your health."

Responding to Lewis's fears, the philosopher Istvan Aranyosi [22] has argued (somewhat convincingly), that, instead of a terrifying corollary we should see the Everettian ontology more positively since "……There are a few more statistical facts about dying that we need to make more explicit. Lewis talks about 'cumulative deterioration that stops just short of death' as what we should expect". But Aranyosi states that, "stopping short of death means suffering a life-threatening condition. Such conditions are most strongly statistically positively correlated with death, and second most strongly with very deep coma. Very deep coma (as measured by the Glasgow Coma Scale) strongly positively correlates with death, again. So, from a subjective point of view, what we should expect in terms of experiences is not stopping short of death in the sense of making it to the vicinity of death, but rather *not making it to that vicinity at all* (only to the vicinity of that vicinity), given that the vicinity of death is imbued with oblivion. We should expect not to make it as far towards death as to even lose consciousness. In other words, we should not expect to be in a life-threatening condition to begin with."

Up until this point, I can follow Aranyosi's argument. However, these last two sentences would seem to make his argument weaker, because we frequently do lose consciousness for all sorts of reasons other than life threatening conditions and yet we recover: e.g. sleep, concussion and anaesthesia for example. What I would suggest is that we should not expect to make it as far towards death as to lose the level of conscious functioning associated with continued living. Where that boundary lies is what I am guessing is the "vicinity of the vicinity of death" that Aranyosi is trying to convey. In other words, the unconsciousness "within the vicinity of death" is of a *different category* to that associated with sleeping, anaesthesia etc. Indeed, it cannot be classified as a form of consciousness at all as far as our experience is concerned because we cannot, from a first-person perspective, go into it. From the perspective of others however, it is a boundary that people do cross. This is a deep, important and mysterious area of interest, because it connects the nature of consciousness with the difference between subjective first person experience, compared to the experiences that observers see of us. It is interesting to note that Everett's thesis is sometimes called the Relative State Formulation of Quantum Mechanics. Our experiences are relative. We are all like "Schrödinger's cats". From the "inside" first person view, it appears that we ourselves only experience continued life, yet others will observe both our life and our death.

As we grow older and older the improbability of survival grows with it.
Some principles of physics like the law of least action and the second law of thermodynamics would imply that the universe we find ourselves in at one particular

instant will be the most probable consistent extension of the previous instant. This makes sense because in ordinary everyday life we recognise regularities. For example if we allow a drop of ink to fall into a glass of water, it is unlikely to enter the water, spread out into it (because of Brownian movement) and then suddenly coalesce back into a single ink drop somewhere in the glass. This could of course happen and will do in some universes, but the probability of this happening in the universe you are in is very low and so the "measure" (fraction of the infinite number) of universes where we happened to see this occur is going to be very very small. Thus, as we grow older and continue to survive, in spite of the improbability of survival, so it will be that we must in general find ourselves in universes that are ever more improbable. This being the case we can expect strange experiences. One possibility is that we find ourselves to be higher beings that have been dreaming our existence all along and eventually we wake up in some higher level of reality. Alternatively, we might find ourselves in a universe where we are in some form of simulation – although we may not realise it. Hopefully it will not be like the maligned one depicted in the film called "the Matrix" but one in which we were software constructs from the very start. Whatever is the case, we should expect to find ourselves in a universe that is conducive to our survival, by whatever means - it has been put forward that this might even include uploading of our minds into computers [38].

Why should we think this possible? I have argued earlier that our best theory (quantum mechanics) seems to be a recipe, or rather a number of postulates for making accurate predictions [15]. Efforts by many (including by Einstein) to find some form of intuitive underlying set of local variables which would explain why the postulates are as they are have been shown by Bells theorem to be unable to reproduce all of the predictions of quantum mechanics. Hence it may be that these variables just aren't there! If this were the case our world could well be an emergent effect of a program which is running with laws (i.e. a recipe called quantum mechanics) that was pre-programmed in from the very start. Thus, looking for any substructure would be futile. It would therefore be prudent to look for evidence as to whether we are in such a simulation.

Perhaps by sheer computer power, a computer simulation has managed by chance to generate enough copies or variants of all possible people so as to always have at least one copy of you which is always a consistent extension of you - hence you will continue to exist. Although this seems "whacky", it is not so improbable as it may seem. The cosmologist Frank J. Tipler discussed such possibilities in his book "The Physics of Immortality" [8]. Tipler's bold idea that everyone who ever existed (or could possibly exist) would be resurrected, relied on the universe being geometrically closed with mass energy density/cosmological constant, being sufficient to cause the universe to collapse asymmetrically, thereby producing sufficient gravitational shear energy to drive an appropriate simulation.

Criticisms of these ideas were harsh and to some extent, I think were unfair. Until we know whether "dark energy" decays into radiation or particles, the more conservative speculations of Tipler [26] should remain a plausible possibility. If dark energy does decay into ordinary matter, then the re collapse of the universe could be a possibility.

David Deutsch has argued that, although we may not yet have the technology to do this yet, it is theoretically possible to build a virtual-reality generator (simulation) whose repertoire includes every physically possible environment [19, p135]. I see this as including one where you find yourself very old and decrepit but a cure to regenerate you exists which rejuvenates you. Deutsch goes on to say that... "since building such a universal virtual-reality generator is physically possible, it must actually *be* built in some universes". Hence your next most consistent extension of experience may well be in a computer simulation, even if you are young, not just old and ill. I am here assuming that "identity" is inherently non-local. The nature of consciousness is truly a very deep issue which I have evaded in this work. However, what I am assuming here is something like that proposed by Soltau [2] i.e. Consciousness is somehow much more fundamental than we suppose [4]. Our reality may be more like some form of shared dream produced by a computer which may not even need to be physically implemented! [1, p78]. I assume for now that "consciousness" will find itself in whatever is the next most consistent extension of its previous form - wherever that may be in the myriad branching paths that make up the multiverse. Perhaps in some sense consciousness "surfs" or "supervenes" over the universes that make up the multiverse and as stated by Deutsch "other times are just special cases of other universes" [19, p278]. What I am proposing here is that, following Deutsch [19, p276], the multiverse is like an infinite set of universes which are (analogously) like the snapshots one finds in a reel of film. Consciousness is like the light from the beam that illuminates each snapshot [see note 4]. It should also be remembered that for every snapshot of the film, there will be an infinite number of snapshots which are identical to it!

Complementing the above speculations, the French logician and philosopher Bruno Marchal proposed a remarkable set of thought experiments [27] which demonstrated the non-locality of consciousness. Essentially, if a perfect copy of you can be made, then both of the resulting "conscious identities" would claim they were you - even if they were in very different places! - except that, as time passed by they would develop different identities/memories etc. If an identical copy could be made of you (by copying you via some form of scanner, which could record your structure down to a suitable level of substitution), then this data could be stored as re-creatable instructions on a disk drive. If the original person was immediately destroyed, then in principle, we could use the software on the disk drive, to reconstruct an identical copy of the conscious identity a year later. This copy of a conscious identity would also argue they were "you", but would not agree on the date! Such a model of conscious identity allows a "person" to "travel" through a pre-existing multiverse of many possible histories, Consistent extensions "snapshots/universes" will always be available at any time either, in the "real" multiverse, or in the nested reality of a universal reality generator which must necessarily exist somewhere in the multiverse. This means that, viewed from the "global outside" view, all possible universes can exist. Deutsch [19, p276] states that universes are limited to those that are effectively "glued together by the laws of physics", so for example although logically possible, he states that there are no universes where the charge on the electron is different from that in our universe. However others, Tegmark[6], Standish[1] have suggested that all logically possible universes do exist. [See note 4]. Hence it is always possible that your next experience is just as likely to be generated in a simulation as in the "real thing". In short, there would always (hopefully) be at least one consistent extension, in some universe that a conscious identity could supervene over so as to experience continuity of identity.

The assumption that there would **not be** such an extension is called the "No Cul De Sac" conjecture. One method of trying to prove the conjecture might be to use modal logic but as yet no one has proved it [1, p142]

What are the chances then that we are living in some form of simulation (Matrix)? Remarkably it might turn out to be more probable than you think. In 2002 The Oxford Philosopher Nick Bostrom put forward an argument (called The Simulation Argument [23]) which resulted in a startling mathematically probabilistic conclusion:

He says:

"A technologically mature 'posthuman' civilization (i.e. one that is capable of running high fidelity simulations) would have enormous computing power at their disposal. Based on this empirical fact, the Simulation Argument implies that at least one of the following propositions is true:

(1) The fraction of human level civilizations that reach a posthuman stage is very close to zero;

(2) The fraction of posthuman civilizations that are interested in running ancestor simulations is very close to zero; Possibly because of resource constraints

(3) The fraction of all people with our kind of experiences that are living in a simulation is very close to one."

If (1) is true then it must be that civilizations generally do not develop much after a certain level, perhaps they become complacent and eventually extinct after a fairly long period. It may be commonplace for civilisations to accidentally destroy themselves by nuclear war or by stumbling into some cataclysmic threat. One candidate is molecular nanotechnology, which in its mature stage might enable the construction of self replicating nanobots capable of feeding on dirt and organic matter, a kind of mechanical bacteria. Such nanobots, designed accidentally, - or, for malicious ends, could cause the extinction of all life on our planet. Asteroids also pose an existential threat, but this does seem a less likely candidate to be of concern for civilisations within galaxies generally. Also some form of virus could be accidentally unleashed causing an apocalyptic pandemic. There is also the serious problem of widespread infection at a time when critical development of antibiotics falls short of appropriate levels to manage bacterial infections.

(2) seems the most unlikely proposition, given that we ourselves, as an intelligent civilization utilise high resolution simulations for many applications like stock exchange prediction software, computer games and graphics. However, this makes the big assumption that the entities that create our experiences are in some way similar to us

(3) says that, if it turns out that the multiverse contains large numbers of posthuman type civilisations who also run large numbers of simulations that have "people/persons" like us in them as software constructs, then it becomes very probable that we are already in one of them! I have considered Bostrom's arguments in some considerable detail in the context of Physical Eschatology along with some form of Anthropic Hypothesis elsewhere [24].

So is there any real “physical” evidence that we live in a computer simulation? It’s hard to say, but a few researchers from the University of Washington [28] believe they’ve developed a way to test the theory. They take what is known about simulating very complex environments inside supercomputers, and then simulate a small region of space-time to see if they can detect anomalies known as “signatures” which would conflict with real data. This is currently being done using “Lattice Quantum Chromodynamics” to study the fundamental laws of physics, by representing space-time as a set of points arranged in a lattice. At the moment, the supercomputers can only simulate a tiny part of the universe – something of the order of the size of an atom. But in time, as computer resources get better, the size of the simulated volume will get bigger. Relativity tells us how particles in a non-constrained universe should behave along the edges of such a real-time lattice in space-time. Hence, we can compare real data with simulated data. For example, if the real data about high energy cosmic rays was consistent with a lattice, interacting unequally in all directions, then that would be a testable signature that we are all living in a much larger simulated environment. So, if the data regarding high energy cosmic rays does have the signature of being constrained, then this adds weight to the simulation argument. If it isn’t constrained and the high energy cosmic rays look like relativity says they should, then we probably aren’t simulated.

Whatever is the case, if we do live in a simulation then death may mean nothing more than moving from one level of the simulation to another. The whole history of a person’s experiences could be cut and copied by a software automated process, into a new interactive environment.

There is debate about what might be actually running the software which makes up our multiverse. One possibility is that a very simple abstract computer called a “Universal Dovetailer” [30] exists in the “platonic realm” along with other “ideals” like 1+2 = 3. Such an abstract computer simply generates all possible strings of bits (i.e. simulation programs and data) and executes them all, one step at a time by an algorithmic method known as dovetailing [29]. Such an abstract entity creates all possible experiences without any conscious intent and can therefore perhaps be accepted as blameless for the worlds it creates which inevitably cause suffering as well as joy. Standish [1] has also proposed the theory that all possible bit strings simply “exist” platonically and hence so do all possible universes, since they would be included as simulation programs in this infinite set. Such a set could, under a suitable definition, be classified as having zero information in it. Hence he called his theory “The Theory of Nothing” as opposed to a Theory of Everything.

These speculations are essentially idealistic. The alternative is that real beings have written the software which makes up our world. In which case, if they are benevolent, they could have designed a suitable cut and copy procedure of our whole histories into new environments where we could continue to grow and learn. The software may be carefully constructed so as to be resource dependent and might have the ability to fill in details when we look closely – obviating the need for an infinite multiverse. Whenever we use measuring instruments, for example, software interrupts may render the appropriate graphics such that when we look deeply into the universe over and above a certain level, for example as in experiments at the Large Hadron Collider, then appropriate detail is produced sufficiently to provide experimental outcomes that are consistent with the standard model of particle physics - because that is what is programmed to be there and that's it! In any case, any opportunity we have of testing whether our multiverse is a simulation deserves investigating.

Whatever is the case, we are here to behold our multiverse. What sustains it and causes it to "be" is one of the greatest of all mysteries.

9 APPENDICES

Appendix 1 Generalised measurement of a two state system

The following argument follows closely that given by Sudbury [25, p186] but is extended in Appendix 2 to include non-ideal measurements.

Let S be the state space of a quantum system and A that of the experimental apparatus (also considered as a quantum system) for measuring the system S

Consider the development of the combined system $S \otimes A$ and let $|\psi_1\rangle, |\psi_2\rangle \in S$ be two eigenstates of the object corresponding to two different results of the experiment. These results must leave the apparatus in different states $|a_1\rangle$ and $|a_2\rangle$ (describing say, different positions of a pointer.). Suppose the apparatus is initially in another eigenstate $|a_0\rangle$ - the "ready" state - and $|a_0\rangle, |a_1\rangle, |a_2\rangle \in A$. The experiment therefore consists of allowing the object and the apparatus to interact in such a way that if the object state is $|\psi_1\rangle$, then after the experiment, the object will still be in the state $|\psi_1\rangle$ and the apparatus will record the appropriate result, i.e. will be in the state $|a_1\rangle$. A similar argument holding for $|\psi_2\rangle$ and $|a_2\rangle$. This is what could be said to represent an ideal measurement in the sense that the measuring devices work properly. Thus, during the experiment the interaction Hamiltonian H_I must be such that:

$$e^{-i H_I \Delta t/\hbar}(|\psi_1\rangle |a_0\rangle) = |\psi_1\rangle |a_1\rangle$$
$$e^{-i H_I \Delta t/\hbar}(|\psi_2\rangle |a_0\rangle) = |\psi_2\rangle |a_2\rangle \quad (3)$$

Now, if before the experiment the system was in the state

$$|\psi_0\rangle = c_1 |\psi_1\rangle + c_2 |\psi_2\rangle \quad (4)$$

During the experiment, which lasts for a finite time Δt say, the systems evolves from

$$e^{-iH_I\Delta t/h}(|\psi_0\rangle|a_0\rangle) = e^{-iH_I\Delta t/h}(c_1|\psi_1\rangle|a_0\rangle + c_2|\psi_2\rangle|a_0\rangle) \quad (5)$$

to the final stage where the system and the apparatus together will be in the state

$$|\psi(\Delta t)\rangle = c_1|\psi_1\rangle|a_1\rangle + c_2|\psi_2\rangle|a_2\rangle \quad (6)$$

Where Δt is the time taken for the experiment to yield a definite result. How one is to interpret the result in equation (6) is what is known as "The measurement problem". The apparatus only reads either $|a_1\rangle$ or $|a_2\rangle$ so it feels natural to just ignore the result which was not obtained. However, I will argue in Appendix 3 and 4 that it is not correct to do this.

The above example is often used to describe the "Schrödinger's cat paradox [13] which is designed to illustrate the strangeness of placing a boundary between quantum and classical realms. This view, known as Cartesian dualism, assigns a special status to consciousness which is assumed to be able to "collapse" wave functions. The paradox arises when we observe states like (6) and argue that it is our observation of this state which "collapses" the wave function to give either

$$|\psi_1\rangle|a_1\rangle \text{ or } |\psi_2\rangle|a_2\rangle.$$

In the Everett interpretation, no such paradox arises since there are no "collapses" and no special status is assigned to consciousness. From the first person point of view however, such collapses "seem" to be the case since we only see what occurs in our branch. See [13] and the generalised case below.

Appendix 2 Non-ideal measurements

It is interesting to consider the experimental outcomes of real non-ideal measurements where say the apparatus was less reliable. Being a macroscopic device, with many degrees of freedom there will be many ways one could imagine from the classical point of view that false readings might occur – the pointer sticks for some reason etc. From the quantum, microscopic point of view, errors could occur simply because it may not be possible to make systems with Hamiltonians that are exactly appropriate. Anyway to account for non-ideal functioning of an apparatus we could guess that, during the experiment we might instead have a Hamiltonian which is such that equation (3) can be written as the more general possibility:

$$e^{-iH\Delta t/\hbar}(|\psi_1\rangle|a_0\rangle) = |\psi_1\rangle(a|a_0\rangle + b|a_1\rangle + c|a_2\rangle)$$

$$e^{-iH\Delta t/\hbar}(|\psi_2\rangle|a_0\rangle) = |\psi_2\rangle(a|a_0\rangle + c|a_1\rangle + b|a_2\rangle)$$

$$where\ |a|^2 + |b|^2 + |c|^2 = 1 \qquad (7)$$

$$and\ \ |a|^2, |c|^2 \rightarrow very\ small \approx 0, \quad and\ |b|^2 \approx 1.$$

Now, following the original argument, if before the experiment the system was in the state

$$|\psi_0\rangle = c_1|\psi_1\rangle + c_2|\psi_2\rangle$$

$$|c_1|^2 + |c_2|^2 = 1 \qquad (8)$$

Then after it, the system and the apparatus together will be in the state

$$e^{-iH\Delta t/\hbar}(|\psi_0\rangle|a_0\rangle) = e^{-iH\Delta t/\hbar}(c_1|\psi_1\rangle|a_0\rangle + c_2|\psi_2\rangle|a_0\rangle)$$
$$= c_1|\psi_1\rangle(a|a_0\rangle + b|a_1\rangle + c|a_2\rangle) + c_2|\psi_2\rangle(a|a_0\rangle + b|a_2\rangle + c|a_1\rangle)$$
$$= bc_1|\psi_1\rangle|a_1\rangle + bc_2|\psi_2\rangle|a_2\rangle + cc_1|\psi_1\rangle|a_2\rangle + ac_2|\psi_2\rangle|a_0\rangle + cc_2|\psi_2\rangle|a_1\rangle + ac_1|\psi_1\rangle|a_0\rangle$$

The first two terms (universes) are "almost those" of equation (3), but the probability amplitudes of the others are far less dominant because of the relative sizes of the $|a|^2, |b|^2, and\ |c|^2$ terms (see equation 7).

As pointed out earlier, we could assume that this can be interpreted as an experiment where the measuring apparatus usually works correctly but on rare occasions: -

(i) Does not detect anything when in fact it should have done - e.g. showing up in the presence of the $|\psi_1\rangle|a_0\rangle$ or $|\psi_2\rangle|a_0\rangle$ terms
(ii) Very occasionally it records the eigenvalue of one state $|\psi_1\rangle$ when it should have recorded the eigenvalue of the other state $|\psi_2\rangle$ eg. $|\psi_2\rangle|a_1\rangle$ and vice versa.

In the context of the immortality argument, the above shows that if we had a Schrödinger's cat situation where $|a_i\rangle$ represented the states of the cat and $|\psi_j\rangle$ the state of the atom and:
$|\psi_1\rangle$ represents the un-decayed state of the atom and no poison released,

$|\psi_2\rangle$ represents the decayed state of the atom and poison released,

$|a_0\rangle$ represents the state of the cat before the experiment (e.g. alive and well)

$|a_1\rangle$ represents the state of the cat as alive after 1 hour

$|a_2\rangle$ represents the state of the cat as dead after 1 hour.

Then terms like $|\psi_2\rangle|a_0\rangle$ could represent a decayed atom with poison released e.g. $|\psi_2\rangle$, yet cat unharmed e.g. $|a_0\rangle$. $|\psi_2\rangle|a_2\rangle$ might represent the case of a decayed atom with poison released and cat dead after 1 hour, whereas $|\psi_2\rangle|a_1\rangle$ could be interpreted as a decayed atom – poison released and cat very ill but still alive after 1 hour! Alternatively, $|\psi_1\rangle|a_0\rangle$ might represent the case of an un-decayed atom with no poison released and cat identical to its original state etc. Hence, whatever danger or difficulty we encounter, there will, in "real" situations, always be at least some (even if very small) probability that the cat will be able to have a next conscious experience, however strange it might turn out to be. This is because the result readily generalises to a spectrum of outcomes $|a_i\rangle\,|\psi_j\rangle$ for $i \in N$ and $j \in \{1,2\}$

In the real world, we all take the place of the cat as we live out our day.

Appendix 3 Ideal Measurement Example

The Quantum Coin experiment can be carried out using the method and appropriate device as below. This is a very simplified argument, based on the beautiful analysis given by Tipler [8, p483], but I have extended it to account for decoherence due to the environment.

In this experiment (see Fig 2 below), a beam of silver atoms coming in from the left with an odd number of electrons, aligned with their net spin in the x direction, enter an inhomogeneous magnetic field in the form of a measuring device (called a Stern Gerlach {SG} apparatus).
In the ground state, all but one of the electrons will pair to cancel their spins. The magnetic field exerts a force on the unpaired electron, causing the atom to move up or down in the z direction depending on the net electron spin. They then strike detectors. Since the spin of these fermions is either "up" or "down" – and in principle, no other value, the detector records atoms leaving the magnetic arrangement with either spin up $(+\frac{\hbar}{2})$ or spin down $(-\frac{\hbar}{2})$ respectively.

The wave function describing the initial atomic beam can be given by

$$|\Psi\rangle = |\uparrow_x\rangle |A_0\rangle |O_0\rangle |e_0\rangle \qquad (9)$$

Where: $\left|\uparrow_x\right\rangle$ represents an atom with spin up in the x direction, which is perpendicular to the z-(up/down) direction of the SG device which has a state in the "ready" form of $\left|A_0\right\rangle$. The term $\left|O_0\right\rangle$ represents an observer (a person) who is effectively just another type of measuring apparatus recording the behaviour of the SG device.

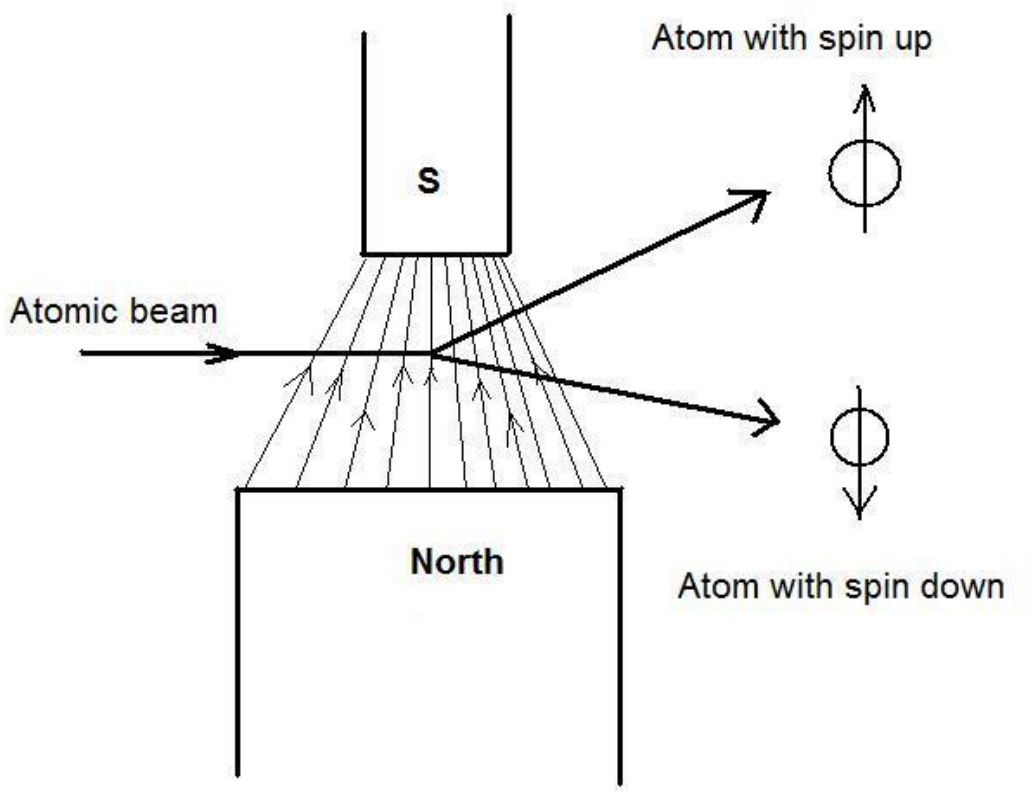


Figure 2

Finally $\left|e_0\right\rangle$ represents the environment state or the state of the rest of the universe. The central idea of the Many Worlds Interpretation (MWI) is that at all times evolution is via the Schrödinger equation

$$i\hbar\frac{d\left|\Psi\right\rangle}{dt}=\hat{H}\left|\Psi\right\rangle \tag{10}$$

where $\hat{H}$ is the Hamiltonian operator. Equation (10) can be integrated to give the propagation solution

$$\left|\Psi(x,t)\right\rangle=e^{-i\hat{H}t/\hbar}\left|\Psi(x,0)\right\rangle \tag{11}$$

$|\Psi(x,0)\rangle$ is the value of the wave function at the initial time $t=0$

It was Everett [10, 18] who maintained that the collapse postulate should be dispensed with and that the wave function of the universe would evolve unitarily according to (11) at all times eliminating the ad hoc collapse postulate which was associated with the physicists classified as the "shut up and calculate" brigade!

This experiment consists of allowing the atom and apparatus to interact in such a way that if the atom's state is initially "spin up" in the z-direction described by the basis vector $|\uparrow_z\rangle$ then after the experiment the atom's state is $|\uparrow_z\rangle$ and the apparatus will record the appropriate result i.e. will be in the state $|A_\uparrow\rangle$; and similarly if the state is initially "spin down" $|\downarrow_z\rangle$ then after the experiment the atom's state is $|\downarrow_z\rangle$ and the apparatus state changes to $|A_\downarrow\rangle$. Thus, during the experiment the interaction Hamiltonian $\hat{H}$ must be such that after time t,

$$e^{-i\hat{H}t/\hbar}|\uparrow_z\rangle|A_0\rangle|O_0\rangle|e_0\rangle = |\uparrow_z\rangle|A_\uparrow\rangle|O_\uparrow\rangle|e_\uparrow\rangle$$
$$e^{-i\hat{H}t/\hbar}|\downarrow_z\rangle|A_0\rangle|O_0\rangle|e_0\rangle = |\downarrow_z\rangle|A_\downarrow\rangle|O_\downarrow\rangle|e_\downarrow\rangle \qquad (12)$$

Now standard quantum mechanics gives $|\uparrow_x\rangle = \frac{1}{\sqrt{2}}\left(|\uparrow\rangle + |\downarrow\rangle\right)$ (13)

The up and down arrows here in the brackets should really be written as $|\uparrow_z\rangle$ and $|\downarrow_z\rangle$ but I'll not bother with these suffixes as long as you remember the up/down arrows represent spin in the z-direction.

Equation (13) tells us (even prior to the experiment) that there is a 50% chance that an electron going through the device will come out with spin up. Similarly, there will be a 50% chance that it will come out with spin down. This is because expressions like (13) are more generally written as

$$|\Phi\rangle = \alpha|\uparrow\rangle + \beta|\downarrow\rangle \qquad (14)$$

Where $|\Phi\rangle$ describes a general two state system and again α and β are complex numbers. According to the Born rule $|\alpha|^2$ and $|\beta|^2$ are the probabilities that on measurement, the system will be found in the state $|\uparrow\rangle$ or $|\downarrow\rangle$ respectively. This is

determined by the angle between the incoming particle spin axis relative to the orientation of the Stern Gerlach device, which in this case (perpendicular) simplifies to

$$|\alpha|^2 = |\beta|^2 = \frac{1}{2} \qquad (15)$$

.

The wave function of the universe is then described as previously in equation (9),

$$|\Psi\rangle = |\uparrow_x\rangle |A_0\rangle |O_0\rangle |e_0\rangle \qquad (16)$$

Note also that the apparatus $|A_0\rangle$ and environment or “rest of the world” $|e_0\rangle$ is also included in the chain to complete the effect of the interactions. The zero suffix stands for the “ready” state at the start of the experiment.

The ordering of (16) here helps to represents the time ordering of what goes on, but some authors can change the order to help with different explanations/proofs of how the Born postulate works[11].

So, the particle prepared in the $|\uparrow_x\rangle$ state (moving to the right), interacts first with the apparatus, then the particle plus apparatus interact with the observer and finally the interaction affects the environment. This could be the movement of a pointer or lighting of a lamp or even the possible release of poor Schrödinger’s cat etc. The “sphere of differentiation” [7, p278] will travel out into the environment at less than or equal to the speed of light.

The apparatus $|A_0\rangle$ is just the Stern Gerlach device towards which the $|\uparrow_x\rangle$ particle is heading for. Again $|\uparrow_x\rangle$ can be written instead in the decomposition form.

$$|\uparrow_x\rangle = \frac{1}{\sqrt{2}}\left(|\uparrow\rangle + |\downarrow\rangle\right)$$

To give a state vector for the universe:

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left(|\uparrow\rangle + |\downarrow\rangle\right)|A_0\rangle |O_0\rangle |e_0\rangle \qquad (17)$$

Once the particle enters the device, the unitary evolution according to the Schrödinger equation takes place which causes the particle to be potentially directed along one of two paths – either “up” or “down”, but the evidence shows that, when single atoms (with unpaired electrons) enter the device, they truly exist in the form of the superposition given in the bracketed term above, i.e. being in a state of being neither spin up nor spin down, nor both, nor neither! So the conclusion of many worlders (including me), is that the sending of the particle described by the state $|\Psi\rangle$ above into the SG device entails that, of the infinite number of me's in the branch of fungible universes carrying out this experiment on the particle, around 50% of them will end up in a branch where the measuring apparatus reads "up" and around 50% of the me's will find themselves in the branch where the measuring device reads "down". Note that we are assuming that the "particles" are still sufficiently isolated so as not to get infected with decoherence so the $|O_0\rangle|e_0\rangle$ terms don't evolve yet. This means that the split, or rather the differentiation, has not yet been propagated out too far and could even be rejoined with suitable recombination of the paths that the particles could take (i.e. by forming a Mach Zender type arrangement) [16, p56], [19, p204], [see note 10]

So now the system has evolved to

$$\rightarrow \frac{1}{\sqrt{2}}\Big(|\uparrow\rangle|A_\uparrow\rangle + |\downarrow\rangle|A_\downarrow\rangle\Big)|O_0\rangle|e_0\rangle \qquad (18)$$

where the Apparatus has become entangled into the electron's superposition. This means that the split has now propagated to the measuring device. The term "pre-measurement" is often used here which simply refers to the interaction between the electron plus apparatus before the end of the process which leads up to say a spot appearing on a screen.

Things can be a bit complicated here by the fact that the observer is part of the environment but can also choose not to look at the result straight away. To keep things simple, let's suppose that the observer looks at the result immediately it appears, then unitary evolution of the wave function will give

$$\rightarrow \frac{1}{\sqrt{2}}\Big(|\uparrow\rangle|A_\uparrow\rangle|O_\uparrow\rangle + |\downarrow\rangle|A_\downarrow\rangle|O_\downarrow\rangle\Big)|e_0\rangle \qquad (19)$$

This shows how the split propagates rapidly out into the environment. Once a spot appears on the backcloth detector showing that the electron was either up or down, then the news is out about which world we are in – the two worlds are now "decohering" from each other, which means their ability to interfere with each other in the future will be rapidly diminishing. Note though that the observer can now add to his record of observations which outcome occurred for him (knowing that his counterpart in another universe will see the opposite).

Now comes an interesting part. The next line shows the continued evolution of, and partitions of the multiverse that we could end up in.

$$\rightarrow \frac{1}{\sqrt{2}}\left(\left|\uparrow\right\rangle\left|A_{\uparrow}\right\rangle\left|O_{\uparrow}\right\rangle\left|e_{\uparrow}\right\rangle+\left|\downarrow\right\rangle\left|A_{\downarrow}\right\rangle\left|O_{\downarrow}\right\rangle\left|e_{\downarrow}\right\rangle\right) \qquad (20)$$

This means that we now have two environments (worlds/universes/partitions of the multiverse) in a superposition. One with spin up and everything consistent with this, and the other world with spin down and everything consistent with that. In fact for this to be true there should be no overlap of the environments i.e. they should be physically distinct and so their environment vectors should therefore be orthogonal - but, in fact the $\left|e_{\uparrow}\right\rangle$ and $\left|e_{\downarrow}\right\rangle$ have an inner product that usually is initially non zero but rapidly approaches zero asymptotically rather than ever reaching zero. This means there **is** always some overlap and hence some coherency remains. Thus, this never becomes a quantum mechanical mixture! This is what Everett said though. The wave function never collapses as it would if a quantum mechanical mixture was the end product. Moreover what Everett also said was that each branch, separated by the "+" sign in (20) above, exists in its own right - as opposed to the wave function collapsing on just one of them and assuming we can delete the rest as in the Copenhagen Interpretation. Deleting one branch just will not account for the fact that off diagonal terms in the density matrix occur (see the analysis in Appendix 4) and which will imply that "universes" will interfere with each other for the small time that it takes for decoherence to suppress the off diagonal terms sufficiently.

Thus although decoherence reduces the possibility of interference effects occurring between universes, the coherency of the superposition has leaked into the environment. The superposition above can sometimes be called an "improper mixture" of the two record states (up or down), since it would appear that neither state seems to have a determinate record. However, Everett and Deutsch would have it that in the above superposition each element contains a definite observer state, a corresponding system state and a well-defined outcome which can be stored in the record of observations of the observers in each branch. So, the last line is still a superposition. In fact, every line is a superposition. If any of them reduced into a mixture, then we would be out of Everett's interpretation and in some form of collapse option.

By choosing to observe the spin of this electron via this experimental interaction, the observer has made it have a determinate value for him. Hence his reality (made up of lots of particle/field interactions and their subsequent records) has been made determinate and defined by this collection of records. The observations need not be elaborate ones like in this SG example. Simply looking at the world around us means that countless photons will interact with the retina of our eyes making our reality determinate as observed and defined by the records of such observations. There is nothing special about human beings in this interpretation. They and other animate or inanimate objects are all just types of recording devices.

As mentioned previously, some authors [11] put the observer state $|O_0\rangle$ into a different order to that in equation (16), to indicate that the observer has kept his eyes closed with regard to the output of the measuring instrument. Hence the observer has not yet unitarily become cognitively aware of his determinate result and has not updated his records in this respect. This means that you don't know which world you're in yet and you are in exactly the same indeterminate state of knowledge as your opposite number in the other universe. This has some utility when deriving probability arguments to explain the Born rule [11].

So it is that we see spin up or down, Schrödinger's cat as alive or dead. Everett's insight was that, if a measurement was made, then it would leave the observer with the impression of a measurement outcome that was well defined and the linearity of quantum mechanics would also imply that a superposition of such states would lead to two definite outcomes- in effect two definite experiences belonging to two (now) different sets of observers in their own universes.

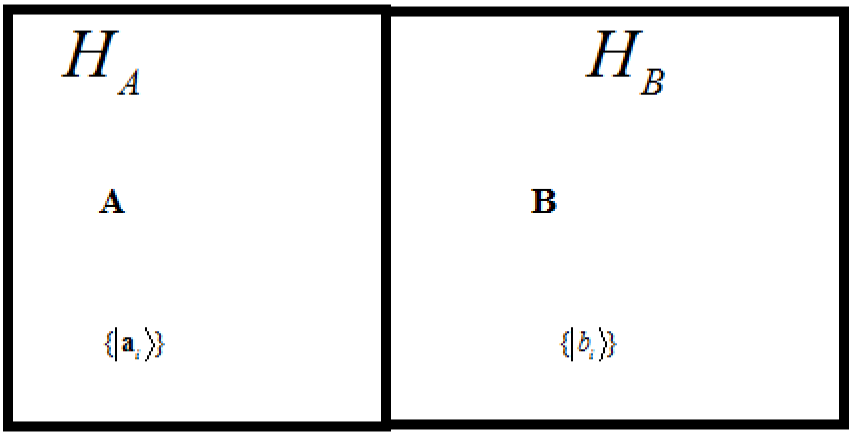
The Everett/Deutsch interpretation essentially means that quantum theory is a theory of infinitely many universes, in which a particle or indeed a macroscopic object in a superposed state is a member of an infinite number of interfering universes- even before it is subjected to a measurement. In this way, the measurement does not create any more universes (or particles) than there were initially present. However, the measurement causes two things to happen. Firstly, in each of the infinite set of universes, the state of the measurement devices become correlated with one of the (in this case) two eigenstates of the particle, in proportions according to the Born rule. Secondly, because the measurement device/environment is macroscopic, the process of decoherence then rapidly suppresses the interference between the (in this case) two branch bundles, each containing an infinity of universes registering the different results of the measurement. The Oxford physicist and philosopher David Wallace states that …… "this, in a nutshell is what the Everett interpretation claims about macroscopic quantum superpositions, …they do not describe indefiniteness, they describe multiplicity!" [17]

Something causes the outcomes of measurements to be detected in the proportions/ measures of universes according to the values $|\alpha|^2$ and $|\beta|^2$ (the Born Rule). Why this rule provides such a measure is the subject of intense research. In principle, if Everett was right, it should be possible to derive the Born Rule from the existing postulates and some progress has been made here [11] but this is beyond the scope of this paper.

Appendix 4 **Combined Systems - The Partial Trace**

Consider a system composed of two subsystems A and B with state space

$H_A \otimes H_B$ as shown below



The Density Matrix for the combined system will then be
ρ_{AB}, a positive hermitian operator on $H_A \otimes H_B$. If $\{|a_i\rangle\}$ is a complete orthonormal set of states for A and $\{|b_i\rangle\}$ is a similar set for B, then the trace of any operator

$\hat{\Omega}$ on $H_A \otimes H_B$ is

$$Trace_{H_A \otimes H_B} \hat{\Omega} = \sum_{i,j} \langle a_i | \otimes \langle b_j | \hat{\Omega} | a_i \rangle \otimes | b_j \rangle \qquad (21)$$

Where a Hilbert space vector

$$|\psi\rangle = \sum_{i,j} c_{ij} |a_i\rangle \otimes |b_j\rangle \quad (22)$$

Represents a state vector for the combined system $\in H_A \otimes H_B$

Let $\hat{A}$ be an observable on system A. Regarded as an observable of the combined system, it is represented by an operator

$\hat{A} \otimes \hat{I}$ on $H_A \otimes H_B$,

hence its expectation value is

$$\left\langle \hat{A} \right\rangle = Trace(\{\hat{A} \otimes \hat{I}\}\rho_{AB}) \qquad (23)$$

$$= \sum_{i,j} \langle a_i | \otimes \langle b_j | \left(\hat{A} \otimes \hat{I} \right) \rho_{AB} | a_i \rangle \otimes | b_j \rangle \qquad (24)$$

$$= \sum_{i,j} \langle a_i | \hat{A} \langle b_i | \rho_{AB} | b_j \rangle | a_i \rangle$$

$$= \sum_{i} \langle a_i | \hat{A}.Trace_{H_B} \rho_{AB} | a_i \rangle$$

$$Trace_{H_A} \left(\left(Trace_{H_B} \rho_{AB} \right) . \hat{A} \right) \qquad (25)$$

or

$$\left\langle \hat{A} \right\rangle = Trace_{H_A} (\rho_A . \hat{A}) \qquad (26)$$

where

$$\rho_A = Trace_{H_B} (\rho_{AB}) \qquad (27)$$

Eqns (26)and (27) are often written in a more sloppy form as

$$\left\langle \hat{A} \right\rangle = Tr_A \left(\rho_A . \hat{A} \right) \qquad (28)$$

where $\rho_A = Tr_B \left(\rho_{AB} \right)$ and

If A represents an observable of the system S embedded in another system E (e.g. the environment) then we can write these in the simple form.

$$\left\langle \hat{A} \right\rangle = Tr_S [\rho_S \hat{A}] \qquad (29)$$

where

$$\rho_S = Tr_E (\rho_{S+E}) \qquad (30)$$

Consider now an electron beam, initially prepared by a SG device in the state $\left| \uparrow_x \right\rangle$ which is sent through another SG device with its z-direction aligned such that the eigenvalues $\pm\left(\frac{\hbar}{2}\right)$ of the spin operator S_z, occur with equal frequency, then

$$\varphi(t=0) = \left|\uparrow_x\right\rangle \otimes \left|e\right\rangle = \frac{1}{\sqrt{2}}\left(\left|\uparrow_z\right\rangle + \left|\downarrow_z\right\rangle\right) \otimes \left|e\right\rangle \quad (31)$$

Where $\left|\uparrow_z\right\rangle$, $\left|\downarrow_z\right\rangle$ represent the standard basis $\begin{pmatrix}1\\0\end{pmatrix},\begin{pmatrix}0\\1\end{pmatrix}$.

Here also I have included the apparatus (SG device and/or human experimenter plus background environment/rest of the world etc.) to be lumped into one single vector called the environment $\left|e\right\rangle$ which has a very large number of degrees of freedom i.e.

$$\begin{aligned} &\left|e\right\rangle = \otimes_i \left|\varepsilon_i\right\rangle \\ &i \to \infty \end{aligned} \qquad (32)$$

Hence $\left|e\right\rangle$ is very delicate and can easily change state.

The system evolves according to the Schrödinger equation, each electron interacting with the SG analyzer to produce a state for each electron given by:

$$\varphi(t) = \frac{1}{\sqrt{2}}\left(\left|\uparrow\right\rangle \otimes \left|e_\uparrow\right\rangle + \left|\downarrow\right\rangle \otimes \left|e_\downarrow\right\rangle\right) \qquad (33)$$

where $\left|e_\uparrow\right\rangle, \left|e_\downarrow\right\rangle$ are normalised but not necessarily orthogonal so that

$$\left\langle e_\uparrow \mid e_\uparrow\right\rangle = \left\langle e_\downarrow \mid e_\downarrow\right\rangle = 1 \qquad (34)$$

The density operator for the system is given by definition

$$\rho_{S+E}(t) = \left|\varphi(t)\right\rangle\left\langle\varphi(t)\right| \qquad (35)$$

$$\rho_{S+E}(t) = \left(\frac{1}{2}\right)(\left|\uparrow\right\rangle \otimes \left|e_\uparrow\right\rangle + \left|\downarrow\right\rangle \otimes \left|e_\downarrow\right\rangle)(\left\langle\uparrow\right| \otimes \left\langle e_\uparrow\right| + \left\langle\downarrow\right| \otimes \left\langle e_\downarrow\right|) \quad (36)$$

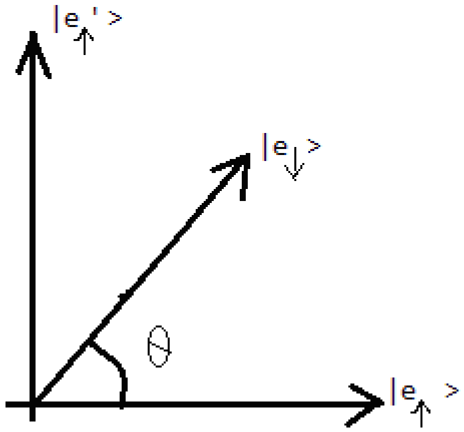
If we restrict our alignment of the SG analyzer to be in either the z or x direction, then

$$\rho_{S+E}(t) = \frac{1}{2}(|\uparrow\rangle\langle\uparrow| \otimes |e_\uparrow\rangle\langle e_\uparrow| + |\uparrow\rangle\langle\downarrow| \otimes |e_\uparrow\rangle\langle e_\downarrow| \tag{37}$$

$$+|\downarrow\rangle\langle\uparrow| \otimes |e_\downarrow\rangle\langle e_\uparrow| + |\downarrow\rangle\langle\downarrow| \otimes |e_\downarrow\rangle\langle e_\downarrow|) \tag{38}$$

Because we are interested only in what the two-state system is doing, and not the environment, one only needs to know the reduced density matrix of the two-state system, with the environment states traced out. For this purpose, so that we can form a trace, we need to choose environment basis vectors which are orthogonal. Any normalised orthogonal basis will do since the trace is basis independent.

The diagram below shows one such choice of the basis vectors:



Where

$$|e_\uparrow\rangle \text{ and } |e_\uparrow'\rangle \text{ are orthogonal unit vectors} \tag{39}$$

$$\langle e_\downarrow | e_\uparrow'\rangle = \cos(90^0 - \theta) \tag{40}$$

or $$\langle e_\downarrow | e_\uparrow'\rangle = \cos(\theta - 90^0) \tag{41}$$

$$= \sin\theta \tag{42}$$

And $$\langle e_\downarrow | e_\uparrow\rangle = \cos\theta \tag{43}$$

where $$0 \le \theta \le \frac{\pi}{2} \tag{44}$$

$$\langle e_\uparrow' | e_\uparrow\rangle = 0 \tag{45}$$

The reduced density operator matrix of the two state system is given by

$$\rho_S(t) = Tr_E[\rho_{S+E}(t)] = \langle e_\uparrow | \rho_{S+E}(t) | e_\uparrow \rangle + \langle e_\uparrow ' | \rho_{S+E}(t) | e_\uparrow ' \rangle \qquad (46)$$

$$\rho_S(t) = \frac{1}{2}(|\uparrow\rangle\langle\uparrow| \otimes \langle e_\uparrow | e_\uparrow \rangle \langle e_\uparrow | e_\uparrow \rangle + |\uparrow\rangle\langle\downarrow| \otimes \langle e_\uparrow | e_\uparrow \rangle \langle e_\downarrow | e_\uparrow \rangle$$

$$+ |\downarrow\rangle\langle\uparrow| \otimes \langle e_\uparrow | e_\downarrow \rangle \langle e_\uparrow | e_\uparrow \rangle + |\downarrow\rangle\langle\downarrow| \otimes \langle e_\uparrow | e_\downarrow \rangle \langle e_\downarrow | e_\uparrow \rangle$$

$$+ |\uparrow\rangle\langle\uparrow| \otimes \langle e_\uparrow ' | e_\uparrow \rangle \langle e_\uparrow | e_\uparrow ' \rangle + |\uparrow\rangle\langle\downarrow| \otimes \langle e_\uparrow ' | e_\uparrow \rangle \langle e_\downarrow | e_\uparrow ' \rangle$$

$$+ |\downarrow\rangle\langle\uparrow| \otimes \langle e_\uparrow ' | e_\downarrow \rangle \langle e_\uparrow | e_\uparrow ' \rangle + |\downarrow\rangle\langle\downarrow| \otimes \langle e_\uparrow ' | e_\downarrow \rangle \langle e_\downarrow | e_\uparrow ' \rangle) \qquad (47)$$

Now using the expressions (34), (43),(45) and the fact that outer product terms like $|\uparrow\rangle\langle\downarrow|$ define entries into a matrix like

$$|\uparrow\rangle\langle\downarrow| = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}$$

then we have that

$$\rho_s = \frac{1}{2}\begin{pmatrix} 1 & \cos\theta \\ \cos\theta & 1 \end{pmatrix}, \qquad 0 < \theta \le \frac{\pi}{2} \qquad (48)$$

Now if

$$\langle \hat{A} \rangle = Tr_s[\hat{A}\rho_s] \qquad (49)$$

Where

$$\rho_s = Tr_E[\rho_{S+E}] \qquad (50)$$

and if we set

$$\hat{A} = \hat{S}_z \qquad (51)$$

Where $\hat{S}_z$ is the operator for spin in the z- direction

Then

$$\left\langle \hat{S}_z \right\rangle = Tr_s[\hat{S}_z \rho_s]$$

$$= Tr\left[\frac{\hbar}{2}\begin{pmatrix}1 & 0\\ 0 & -1\end{pmatrix}\frac{1}{2}\begin{pmatrix}1 & \cos\theta\\ \cos\theta & 1\end{pmatrix}\right]$$

$$= Tr_s\left[\frac{\hbar}{4}\begin{pmatrix}1 & \cos\theta\\ -\cos\theta & -1\end{pmatrix}\right] = 0 \qquad (52)$$

This is the value “expected” since half of the time the electrons will come out as aligned in the positive z-direction and half of the time they will come out aligned in the negative z-direction.

But if we now rotate our SG device into the x-direction and recalculate our expectation value we find that with

$\hat{A} = \hat{S}_x$ where $\hat{S}_x$ is the spin operator in the z-direction. Then,

$$\left\langle \hat{S}_x \right\rangle = Tr_s[\hat{S}_x \rho_s]$$

$$= Tr\left[\frac{\hbar}{2}\begin{pmatrix}0 & 1\\ 1 & 0\end{pmatrix}\frac{1}{2}\begin{pmatrix}1 & \cos\theta\\ \cos\theta & 1\end{pmatrix}\right]$$

$$= Tr_s\left[\frac{\hbar}{4}\begin{pmatrix}\cos\theta & 1\\ 1 & \cos\theta\end{pmatrix}\right]$$

$$= \frac{\hbar}{2}\cos\theta \qquad (53)$$

This is not zero as “expected”.

Theoretical models [35] show that decoherence can act extremely rapidly and hence that in this model decoherence occurs when

$$\theta \to \frac{\pi}{2}$$
&
$$\cos\theta \to 0$$

Very rapidly.

For example consider a state with many degrees of freedom like the environment. Initially at t=0

$$\left|e_{\downarrow}\right\rangle = \left|\varepsilon_1\right\rangle \otimes \left|\varepsilon_2\right\rangle \otimes ..... \qquad (54)$$

Where each $\left|\varepsilon_i\right\rangle$ are the normalised

$$\left\langle \varepsilon_i \middle| \varepsilon_i \right\rangle = 1$$

and represent some small particle or minor subsystem of the background environment

And similarly

$$\left|e_{\uparrow}\right\rangle = \left|\varepsilon_1'\right\rangle \otimes \left|\varepsilon_2'\right\rangle \otimes .....$$

Then initially

$$\left\langle e_{\uparrow} \middle| e_{\downarrow} \right\rangle = \cos\theta = \left\langle \varepsilon_1' \middle| \varepsilon_1 \right\rangle \left\langle \varepsilon_2' \middle| \varepsilon_2 \right\rangle \left\langle \varepsilon_3' \middle| \varepsilon_3 \right\rangle ...$$

$$= 1 \qquad (55)$$

Now a state with many degrees of freedom and as I have said previously, is very delicate, meaning that it can change its state in a very small time.

If in a small amount of time each $\left|\varepsilon_i\right\rangle$ changed by only a tiny amount $\left|\delta(t)\right| << 1$ where $\delta \in \Re$ to

$$\left|\varepsilon_i'\right\rangle = \left|\varepsilon_i\right\rangle - \delta\left|\varepsilon_i\right\rangle \qquad (56)$$

or $$\left|\varepsilon_i'\right\rangle = \left|\varepsilon_i\right\rangle(1-\delta) \qquad (57)$$

then since initially the $\left|\varepsilon_i\right\rangle$ and $\left|\varepsilon_i'\right\rangle$ are normalised vectors and thus noting that the $\left\langle\varepsilon_i\middle|\varepsilon_i\right\rangle$ can only change to values that give inner products that are ≤ 1 then

$$\left\langle e_\uparrow\middle|e_\downarrow\right\rangle = \left\langle\varepsilon_1\middle|\varepsilon_1\right\rangle(1-\delta)\left\langle\varepsilon_1\middle|\varepsilon_1\right\rangle(1-\delta)\left\langle\varepsilon_1\middle|\varepsilon_1\right\rangle(1-\delta)...$$

And hence

$$\left\langle e_\uparrow\middle|e_\downarrow\right\rangle = \cos\theta = \left(1-\delta\right)^N \left\langle\varepsilon_1\middle|\varepsilon_1\right\rangle\left\langle\varepsilon_2\middle|\varepsilon_2\right\rangle\left\langle\varepsilon_3\middle|\varepsilon_3\right\rangle...\left\langle\varepsilon_1\middle|\varepsilon_1\right\rangle^N$$

Even using the conservative Avogadro’s number for N corresponding to a macroscopic surrounding environment:

$$\left\langle e_\uparrow\middle|e_\downarrow\right\rangle = \cos\theta = (1-\delta)^N \approx 0$$

Hence any effects that coherency (off diagonal) terms have, rapidly decay. However, the coherency terms do show that interference between the two branch bundles of differing universes in the superposition do occur and, in principle can be sustained for very short periods in some arrangements (i.e. Mach - Zehnder type interferometry experiments. [19, p205]).

Therefore, if one argues that the branch bundles of identical “universes” which did not get the result we measured (i.e spin down when we got spin up), can… “just be discarded as meaningless!”, just won’t do! Expectation values of measurements made on the original branch bundle of identical universes depend on the coherency terms as well as the diagonal terms of the density matrix. Both branch bundles with an infinite number of identical universes actually exist, each branch with their own particular outcome/observer/environment or partition of the multiverse, but for each (net) electron that passes through the SG device, the universes very quickly “decohere” such that the separate branches become isolated. Communication between universes is therefore not possible!

NOTES

[1] Stated more simply, the experiment provided strong evidence that a quantum event at one location can affect an event at another location without any obvious mechanism for communication between the two locations. This was called "spooky action at a distance" by Einstein (who doubted the physical reality of this effect). However, these experiments
do not allow faster-than-light *communication*, as the events themselves appear to be inherently random.

Einstein found quantum theory to be somehow incomplete. He objected to the fundamentally probabilistic nature of quantum mechanics and famously declared "God does not play dice". He was a firm proponent of hidden variables. Later Bell's theorem would show that local hidden variables were not possible. So, it appears Einstein was wrong to some extent.

[2] The Deutsch Everett version of quantum theory has a constant number of Branches which subsequently differentiate or branch according to a measure called the Born rule. Because they are "fungible", the outcome of the differentiation(branching) for anyone within each world is indeterminate.

[3] It probably ultimately explains everything both large and small. Whether there is anything underlying the recipe we call quantum mechanics is another story. Some experiments rule out certain classes of "hidden variables". A unification of gravity and quantum theory has been the subject of intense research for many years. Although they co-exist, thus far it has not been possible to find such a unification. See also the last paragraph of note [1] above.

[4] Consciousness is actually a very little known and poorly understood phenoma. Some people think it is fundamental (i.e. philosophical idealism – where we are living in a kind of shared dream – a modified position of which I am inclined to subscribe to. However, this can be ignored for moment. [5] Logically possible universes are those which for example do not have circles that are also squares or where 2+3 = 7.

[5] The number of points in a line segment is $2^{\aleph_0}$. The number of points in a square is $2^{\aleph_0}.2^{\aleph_0}$ which equals $2^{2\aleph_0}$ and that equals $2^{\aleph_0}$. Thus, there are the same number of points in a line segment as there are in a square. Likewise, for circles, however big their radii they still contain the same number of points viz. $2^{\aleph_0}$. $\aleph_0$ is the cardinality (number of elements) of the set of natural numbers {1,2,3,…} which is countably infinite.

If space and time are not continuous then I'll have to reconsider what I have written in this paper!

[6] To be fair, it actually IS possible that our universe is finite and indeed has no boundary. Such a space is geometrically curved. A two-dimensional analogy being the surface of a sphere, perhaps a little similar to an apple upon which ants may travel – they go round and round and just keep ending up at their starting point. However, this does still leave the question as to what space this universe is embedded in and we are back to arguments for infinite extensions again. In any case the astronomical evidence so far is against curved space and infinite cosmological models best fit the data (see reference 6).

[7] Complex Numbers are a generalization of Real Numbers. They have two parts, a real part and an imaginary part. Real numbers are like 0, 1, 2.546 – i.e they can be whole numbers or decimals. Imaginary numbers are just real numbers multiplied by the square root of -1. Complex numbers occur naturally as the solution of quadratic functions with a minimum value that is greater than zero.

[9] Most text books on quantum mechanics accept it as the default interpretation.

[10] Deutsch argues that "This remarkable nonrandom interference phenomenon is just as inescapable piece of evidence for the existence of the multiverse as is the phenomenon of shadows" – *i.e. in the double slit experiment when only a single photon or electron goes through the slit system.* (italics are mine).

[11] One example of a finite space, is a positively curved, three-dimensional space. The two-dimensional analogue being the surface of a ball. Another example would be if space had an unusual topology such as a toroidal shape. These spaces do have finite volume with no boundary, but if our universe were really like these shapes then we should be expecting some unusual effects in the observational data. A universe made finite because of its geometry would be like being surrounded by mirrors For example if the space is not too large, we should see multiple images of the same galaxy pattern or Cosmic Microwave Background patterns that repeat. The light rays constrained by such surfaces would inevitably return to their source repeatedly. Thus far these tell-tale signatures of finiteness have not been found. According to Tegmark [36], "…the cosmic microwave background radiation allows sensitive tests of such scenarios. So far however, the evidence is against them. Infinite models fit the data, and strong limits have been placed on the alternatives" [37].

[12] A positively curved space would cause the two observers to converge, whilst a negatively curved space would cause them to separate. Alternatively, very large triangles in a positively curved space have angles in them which add to greater than 180 degrees, whilst a very large triangle in a negatively curved space would have angles that add to less than 180 degrees. Finally, a flat space would have very large triangles whose angles would add to 180 degrees. See [39].

[13] Schrödinger's cat paradox was designed to show how Cartesian Dualism can lead to strange results i.e. Who collapses the wavefunction? Is it the cat? Or those who observe the experiment? The experiment consists of shutting up a cat in a box

containing a device which contains a single atom of a radioactive nucleus with a half-life of one hour. This atom is so placed that a Geiger counter will detect the decay of the atom - if it occurs. If the atom does decay a sealed glass tube of poison gas is smashed, releasing the poison gas which then kills the cat. The Copenhagen view is that the live cat and dead cat is in a superposition until the observer looks inside the box. When he does his consciousness collapses the state of the cat to either dead or alive. However, the paradox is compounded in an extension due to Wigner, who supposed that when another hour passed by after the box was opened you go into the room yourself to find out what happened to the cat. You can ask the original observer or see for yourself what the outcome was. The question is who collapsed the wave function that potentially killed the kitty?

Here $|\psi(\Delta t)\rangle = c_1|\psi_1\rangle|a_1\rangle + c_2|\psi_2\rangle|a_2\rangle$

can be thought of as

$$|\psi(\Delta t)\rangle = c_1|Cat-alive\rangle|observers-sees-cat-alive\rangle + c_2|Cat-dead\rangle|observer-sees-cat-dead\rangle$$

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[4] Consciousness is actually a very little known and poorly understood phenomenon. Some people think it is fundamental (i.e. philosophical idealism – where we are living in a kind of shared dream – a modified position of which I am inclined to subscribe to. However this can be ignored for the moment.

[5] To be fair, it actually IS possible that our universe is finite but has no boundary. See notes [6,11]

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[15] Essentially it requires the state of a system to be represented by a position like vector, rotating in a complex multi-dimensional abstract, vector space. Observables like energy, position and velocity are replaced by Hermitian self adjoint operators whose eigenvalues are values of the observable.

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