What's going on down there?

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Abstract

What is it that underlies our reality? I discuss various options, and argue that mental, material and mathematical bases for our universe are all in some way unsatisfactory, and that a computational viewpoint is to be preferred, although there is likely to be something extra which at present we find hard to accept.

1 Introduction

In the 2nd century AD Ptolemy produced the Almagest, using epicycles to predict the movements of the planets. His Earth-centred model was accepted for over a millennium but eventually people began to worry about it. It was good as a calculational device, but was unsatisfying as a model of the way things were. ([1]p62). How far away were the planets? Presumably Saturn was further away than Venus, but in Ptolemy's model they could be in any order. Copernicus gave a Sun-centred alternative, but at the expense of having to accept some unintuitive ideas - surely things fell towards the centre of the earth. Copernicanism also had plenty of problems which were not resolved until much later - why don't we feel like we're whirling round and round, and what about parallax? There was also resistance from the Church who turned things round - Copernican theory could be used for calculation, but not put forward as an explanation of the way things really were. Once Copernicanism was accepted, however, it was possible for astronomy to move on. I can't help feeling that we are at a similar stage today in our understanding of physics, and in particular of quantum theory. Do we need to abandon some 'obvious' belief?

2 Mind over matter?

Philosophy of mind is a wide subject, but it boils down to two possibilities - dualism or monism. Dualism says that mind and matter are separate entities, while monism says that in the end they are the same. Each of these in turn has two possibilities. Dualism splits into property dualism - that mind is an epiphenomenon, existing separately from the physical world, but having no effect on it - and substance dualism: mind and matter are separate realms, each of which can influence the other. Monism splits into physicalism - that the physical world is all there is, with no separate entity called mind - and idealism, that mind is primary, and the physical world derives from it.

Substance dualism looks to match with the way we see things. I'm not sure why property dualism ever gained a significant following, but it did. In the end, though, any form of dualism is unsatisfactory, since an important part of science is a constant attempt to unify concepts. If we have separate mind and matter, then we will want to go further and find something which underlies them both. Hence we are left with monism. Physicalism is popular, but doesn't seem to have a place for mind. It suggests that mind is an illusion, but surely my mind is the one thing I can be sure about. What about idealism? The idea that everything is mind is appealing, but is too close to animism, which science has been trying to get away from for the last few millennia. With the coming of quantum theory, however, things seemed to change, with mind playing a more prominent role. This may be because quantum theory was much closer to a 'theory of everything' than the physics which had preceded it. If you're serious about a theory of everything, then your theory will have

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to have a place for mind, which may end up seeming to have more significance than is justified. But then again there's the *Free Will Theorem* [2]. This argues that if we have free will then so do electrons. It makes a reasonable case, but it does rather remind me of William Gilbert's argument in favour of Copernicanism: movement requires a soul, thus magnets (which cause things to move) have souls. Hence the Earth, which is magnetic, has a soul, and so can move. ([1]p92)

Maybe one day we will know enough about the interaction of mind and matter to be able to move forward, but currently it would seem best to exclude mind from physics. I would say that the important part of fitting mind into physics is precisely that - how it fits in, rather than any 'special' properties of mind. As I see it the way forward, or at least the first step, would be to model minds as software agents, within models of the rest of physics.

3 Living in a material world?

The idea that there is some fundamental stuff which underlies what we experience is an enticing one. Thales of Miletus saw everything as being made of water. Immanuel Kant talked of "things-in-themselves" (noumena) which could never be known directly. It used to be thought that the luminiferous ether was at the root of electromagnetic phenomena (including light). However, experiments failed to find the ether and it was realised that although it seemed to be a fundamental part of physics, it could never be detected. Then along came Einstein, and did away with the ether entirely - it couldn't be detected so there was no point in hanging on to it. Maybe we should do away with the idea of any fundamental stuff in the same way.

At the root of the idea that there is some fundamental stuff seems to be that this stuff behaves like the stuff we are familiar with, and in particular that the microworld works in the same way as the macroworld. But is this a satisfactory idea? To me the idea that the behaviour of billiard balls is described in terms of atoms, which are thought of as being like little billiard balls, looks very much like circular reasoning.

The move away from material stuff might be thought to begin with Isaac Newton expressing physics in terms of mathematics, and indeed his theory may be contrasted with the vortex theory of gravity. But Newton seems pretty clear about the issue:

that one body may act upon another at a distance through a vacuum without the mediation of any thing else ... is to me so great an absurdity that I beleive no man who has in philosophical matters any competent faculty of thinking can ever fall into it[3]

It's hard to be certain whether his thoughts were so definite - his letters to Bentley seems to be making sure that he didn't ruffle any religious feathers. If he was thought to be proposing 'occult' action at a distance then what next? Might he be accused of spending years working on secret alchemical experiments? [4] One big problem was that if gravity were acting via some medium then it would be expected to take time, but it seemed to act instantaneously. This nonlocality doesn't seem to have had the attention it deserved - one could say that [5] "Anybody who's not bothered by Newtonian gravity has to have rocks in his head." Eventually people got used to seeing physics in the light of mathematics, and non-material nature of gravity, seemed less of a problem. The non-local nature of Newtonian gravity was eliminated by Einstein's General Relativity, but mathematics kept a firm grip on our understanding of physics .

4 To infinity and beyond

So it looks like mathematics may be the best way to describe the universe. There are problems though. You may not be worried by Zeno's paradox - you accept that a line has an infinite number of points. Some of them, such as the length of the hypotenuse of a right triangle with unit sides, $\sqrt{2}$, may not be describable as a fraction, but there is a way of describing such a number. There's no problem with having a finite description for each point in an infinite set. But put the descriptions in alphabetical order, surround the n^{th} point in the list with an interval of length $\varepsilon 2^{-n}$ Then the total length of all of the intervals is less than ε - but this can be made as small as we wish. Hence the total length of all of the numbers in our list is negligible, and so cannot fill the line. A few simple assumptions lead to the conclusion that there are more points in a line than can possibly be described.

Mathematicians are over-keen on what I would call the dash to the infinite - always adding extra structure. This is all very well, but we can never be sure how much physics agrees with this extra structure.

Looking at it another way, what we are trying to do is to describe physics using the mathematics of real numbers. But the axioms for the real numbers involve second order logic - not just the properties of numbers themselves, but the properties of infinite sets of numbers. Now first order logic is syntactic in nature, which means that a first order proof can be mechanically checked for correctness. Second order logic is different - it involves semantics. That is to say we have to 'know' that certain things are true, separately from what is stated in the axioms. In particular, we have to have an intuition about how infinite sets behave, presumably based on what we know about finite sets. This can lead to trouble though, such as the Banach-Tarski paradox, which says that an object can be split into a finite number of pieces, which can then be reassembled to make two copies of the original object. I can't help thinking that it would be better to base physics on a form of logic where we could be more certain of what we were talking about.

In the end our models of physics are going to be implemented on a computer. They may be approximations, but to me it makes more sense to see them as approximating a more detailed computational model than to claim that our actual model involves the infinities of mathematics. I would see things the other way round - the continuous models from mathematics approximating the discreteness of our best model of reality.

5 The heat is on

When investigating the microscopic nature of the universe, it is important to see how the macroscopic world arises from the microworld. Statistical thermodynamics is central to this investigation. Early on in the development of statistical thermodynamics, Maxwell came up with the idea of his demon, a being which would separate fast from slow molecules. If such a demon could exist then it would upset the second law of thermodynamics by decreasing the entropy of a system. But what prevented it? The resolution was that in separating the molecules it would perform a process of measurement and data storage, and this process would create an increase in entropy which would be greater than the decrease obtained elsewhere. In particular, according to Landauer's principle, it is erasing of information which causes an inevitable increase in entropy. This implies that computational ideas are at the heart of thermodynamics.

5.1 Lions and Capercaillies

An interesting point is that in thermodynamics distinguishability of particles is important - particles don't come with a little label attached. But what if they did? Versteegh and Dieks argue that is wrong to treat particles as indistinguishable.[6] This argument says that if you have two different kinds of particles in a container, then in principle it is possible to separate them using a semipermeable membrane, and so there is an entropy of mixing, no matter how small the difference between the particles. Why should there be a discontinuity when the difference is reduced to zero?

Talk of semipermeable membranes made me think of the following:

Catching lions in the desert The thermodynamic method: We construct a semi-permeable membrane which is permeable to everything except lions and sweep it across the desert. [7]

It is possible to accept the argument of Versteegh and Dieks, thinking of the particles as being physically identical, but each having a unique identifier. The entropy would then be different to what it is normally taken to be, but you also need to think about how the distinguishability of the particles might be detected. There would need to be some sort of Maxwell's demon, reading the identifier for each. There would be an entropy cost to this - according to Landauer's principle it is when the demon needs to forget what it has read. This would presumably cancel out the difference in entropy in this model.

I once saw a pair of capercaillies in a wildlife park in an enclosure split into two parts. Between the two parts there was a hole which the female could get through, but the male, being considerably bigger could not. Hence the female got to choose whether she spent time with the male or not. So this is a semi-permeable membrane, differentiating one animal from another. Maybe the lion membrane isn't so far fetched... But then to distinguish lions from everything else would need more than a hole of a given size, it would need a system which recognised lions - some sort of artificial intelligence. Hence the claim that you can in principle find a semipermeable membrane to distinguish two different kinds of particles needs qualifying. It may be less a matter of what we think of as physics and more of a matter of computation. Whether you treat particles as distinguishable or not may affect the definition of entropy, but this turns out not to be so important - the numbers will work out OK in the end.

Quantum decoherence is another phenomenon where we have to be careful when thinking in terms of thermodynamics. It is easy to think of decoherence as always involving dissipation of energy, but this is not necessarily the case - it is information transfer which is more important.[8]

My conclusion is that, just as thinking in terms of material stuff as fundamental is likely to be counterproductive, so treating entropy and energy as fundamental can also lead to problems, and that again a computational viewpoint is preferable.

6 Quantum Weirdness

When it was being developed, quantum theory gained a reputation for weirdness, and it has kept it ever since. The equations can be understood, but what they mean, and in particular how you get from the microworld of the quantum to the macroscopic world we live in isn't so easy. Classical physics was conceptually straightforward, suffering from none of the problems of interpretation which plague quantum theory - supposedly. I disagree. The transition from the microscopic world of classical particles to the macroworld just doesn't exist. Earnshaw's theorem says that it is impossible to have a stable configuration of charges with inverse square forces, and attempting to have a dynamic equilibrium of moving charges is impossible because of the energy lost as EM waves. This means that there's no way of getting rigid bodies, and so no way of building devices such as pieces of measurement apparatus, from the classical microworld. So classical physics has similar problems to quantum physics. In the end, you have to postulate the existence of macro-scale phenomena such as rigid bodies. Now the Church-Turing thesis states that several different notions of computability are equivalent, and that these equate to what can be computed using physical devices, such as Babbage's analytical engine. I would turn this round and say that our notion of classical physics is essentially based on the physical devices (such as Babbage's engines) and so on computability.

So there were problems with classical physics - but surely they were much worse for quantum physics. Heisenberg's uncertainty principle said that it was impossible to base quantum theory on the deterministic behaviour of a classical physical model. The measurement problem, and problems of interpretation seemed to show that a whole new mindset was required, that it would be hopeless to try to base quantum physics on the old mindset. There is, however, a subset of quantum theory known as Gaussian quantum theory [9]. This looks very similar to normal quantum theory in that it exhibits the uncertainty principle and the measurement problem. However, Gaussian quantum theory can also be seen as being underpinned by a classical model. So maybe the quantum theory of the 1920's wasn't such a break from the past which so many people insisted it had to be. I can't help thinking that there is much to be said for the *Forman thesis [10],* which claims that the political uncertainty in Germany in the years following World War I was reflected in the development of quantum theory.

Gaussian quantum theory is isomorphic to a classical model in which observers cannot obtain full information about a system, and is thus related to thermodynamics. This link is hardly surprising, since quantum theory originated with Planck's treatment of the thermodynamic black body problem, but in the desire to present quantum theory as something completely new the relationship was minimized.

6.1 Quantum weirdness - the sequel

So the quantum world isn't weird after all? Not so fast. There's still one major problem - nonlocality. In the first decade of the 20th century, Einstein realised that nonlocality would pose a problem for quantum theory, and it has been suggested that his quantum thought experiments which followed were, in part, aimed at highlighting this problem.[11] Einstein had published four groundbreaking papers in 1905, but dealing with the apparent nonlocality of Newtonian gravity took over a decade. Presumably he thought that quantum nonlocality could also be dealt with, but it posed a greater problem than gravity, and people didn't seem to be queueing up to help to deal with it. In the end, though, things didn't turn out Einstein's way. In the 1960's J.S.Bell showed that it just wouldn't be possible to deal with the nonlocality of quantum theory in the same way as the nonlocality of Newtonian gravity. (The original 'rocks in his head' quote applied to Bell's theorem [12])

Bell said that you either have to give up locality or you have to give up realism. I think that this was an unfortunate choice of words. Many people seem to want to have locality, but insisting on realism - well that's just thinking in an old fashioned way, isn't it? The trouble is that I have never been able to work out what giving up realism is supposed to mean. Does it mean that, when not being measured, entities only exist as 'clouds of probability'? Well, that won't help, since a few years after Bell's result, it was extended to exclude local probabilistic models[13]. It would seem that the only candidate for giving up realism is the dominant interpretation in the 1960's, which was the Copenhagen interpretation. It is usually taken to mean the collapse of the wavefunction. But the collapse is nonlocal, so giving up realism seems to me to be saving locality by saying 'well the nonlocal parts aren't real' - simply playing with words.

There is an alternative form of the Copenhagen interpretation, Bohr's original version of the 1920's, which didn't mention collapse. [14] His answer to the problem of how to explain the results of quantum mechanics was simple: you don't. When you did certain experiments you got results according to certain rules, but apart from that the world went on in a classical way. This was really unsatisfactory. Imagine:

Interviewer: Mr Scientist, your experiment X gets result Y, what does that tell us about the world.

Scientist:It tells us that if you do experiment X then you get result Y.

I don't think that such a scientist would get much grant money.

The intrinsic randomness and the lack of mechanism of Bohr's Copenhagen interpretation may make us uncomfortable, but as I see it these are not its main problems. One thing is that it seems to give up on explaining correlations, and explaining correlations is an important part of science. For an analogous case, consider the Cosmic Microwave Background Radiation. The temperature varies very little, which is very surprising since the different places shouldn't have been in causal contact - the horizon problem. But cosmologists don't just give up and say 'well that's the way it is'. They require an explanation, such as inflation. And just as with the horizon problem, the correlations to be explained in quantum mechanics can be nonlocal, so that saying 'that's how it is' hardly counts as a local model. A further problem is that the Bohr relies on classical explanations as part of his interpretation, but this means that any attempt to derive the classical world from an underlying quantum world will be rendered invalid - Bohr assumed the classical world to be there to start with.

6.2 Does the weirdness matter?

It might be thought that our understanding of quantum theory is perfectly good enough for all practical purposes, it is just a few philosophical puzzles that some people worry about. But is this really the case? The laser is probably the prime example of a practical quantum device. It's operation seems reasonably straightforward. A molecule in an excited state emits a photon, which then stimulates the emission of a photon from another molecule in an excited state, and so on. Thus a large number of coherent photons are produced. When the principle of stimulated emission was first suggested, it was thought that it was forbidden by the laws of quantum mechanics. Lasers were invented anyway, to the great surprise of some. John von Neumann said 'That can't be right' and Niels Bohr 'But that is not possible' [15]. But lasers worked, so it seemed that amplification via stimulated emission was fine after all. However, in [16] Nick Herbert described how lasers could be used to build a device which exhibited superluminal communication. Something was clearly not right, and it was found that the device didn't obey the laws of quantum mechanics, in a result which became known as the no-cloning theorem[17]. The point of all this is that the straightforward description of the operation of a laser - one photon stimulating the emission of an identical photon - does indeed seem to be forbidden by quantum theory, and that a lack of understanding of what actually goes on in the microworld really has had an influence on knowing whether or not useful devices are possible.

6.3 A solution to the weirdness?

Bohr dominated the world of quantum theory, acting as gatekeeper to any new ideas - and he was very reluctant to let any through. For instance, Hugh Everett left academia after Bohr turned down his many-worlds idea. [1][18] Bohr's influence was still strong in the early 1960's, when Bell's theorem was devised, so it is understandable that Bell talked in terms of realism. As time went on, Bohr's influence waned, and

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[1] The moral is: don't have a goalkeeper as your gatekeeper (Bohr was goalkeeper for the Danish soccer team Akademisk Boldklub in 1905)

Bell moved away from talking about realism, and saw the alternative to locality as something different, known as superdeterminism. [19] Superdeterminism says that the world is so deterministic that the choices of experimenters are predetermined in such a way that quantum measurements can come out right without requiring nonlocality. As well as denying free-will, superdeterminism requires that quantum systems evolve in such a way as to give the right result when a measurement is made, which many see as too much of a conspiracy. Hence few accept superdeterminism as a viable alternative, and so it seems more and more likely that we will have to accept some form of nonlocality.

I find its hard to see why nonlocal hidden variables are so unpopular. We need an explanation of why we can't then send information faster than light, if there is superluminal informational transfer in our model of quantum theory. But that's what *hidden* means - we don't have access to the required information. This fits in very well with the computational viewpoint, since information hiding plays an important part in object oriented programming. I can't help thinking that applying this concept to quantum theory might provide some useful insights.

7 It from Bit

The word *Quantum* implies some sort of discreteness of the microworld. In the words of Anton Zeilinger [20]:

it may very well be said that information is the irreducible kernel from which everything else flows. Then the question why nature appears quantized is simply a consequence of the fact that information itself is quantized by necessity.

When combined with the understandable wish to be clear about what is going on in the microworld, this argues strongly for a computational viewpoint. But, in addition, there seems to be something counterintuitive which we will need to get used to, even if it is hard to tell what it is at the moment. Maybe the infinities of mathematics play a part. Taking the Schrödinger equation seriously leads to the idea that we are in one of infinitely many parallel worlds - the many worlds interpretation - which is growing more and more popular. But the many worlds interpretation may not solve all of the problems - we are likely to require something else before we finally have things straightened out. How seriously should we take *spooky* action at a distance? Does mind play a part - do we have to accept *the ghost in the machine*?[21] Whatever it is, it seems it will have an 'occult' quality, at least to our current mindset. It is important, however, not to see such a new concept as a limit to our investigations (which I what I see the denial of realism as doing), but rather as a new opportunity. To get the best from this opportunity we need to start from firm foundations, and my arguments above imply that the firmest foundations will be gained by taking a computational viewpoint.

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