# Science AMA Series: We are Johnjoe McFadden and Jim Al-Khalili, professors of biology and physics respectively at the University of Surrey in the UK and joint authors of 'Life on the Edge'. We are here

Quantum$_B$*iology*[1]*andr*/*ScienceAMAs*[1]

[1]Affiliation not available

April 17, 2023

**Abstract**

We got interested in the idea that quantum mechanics is involved in biology nearly two decades ago when Johnjoe was puzzling over weird kind of mutations that seemed to become more frequent when they provided an advantage to bacteria, and teamed up with Jim to see if quantum mechanics might provide an explanation. We wrote a paper describing a quantum model for the mutations back in 1999 (http://www.sciencedirect.com/science/article/pii/S0303264799000040) and have since maintained an interest in all aspects of quantum biology. The field exploded about a decade ago when microbes and plants were shown to use quantum coherence in photosynthesis and enzymes were found to use quantum tunnelling to accelerate biochemical reactions. Evidence for quantum effects has since turned up in avian navigation, the sense of smell, even how the mind works. We believe that biology's connection to the quantum realm provides life with the spark that makes us so different from the inanimate world. To describe this fascinating new field we recently teamed up again to write, 'Life on the Edge: The Coming of Age of Quantum Biology'. We are here today to talk about our own work and interests in the field of quantum biology but also the fascinating work of our colleagues who have discovered weird quantum effects in such a diverse range of biological activities. We'll do our best to answer any relevant fundamental quantum or biology questions, such as what is quantum entanglement or how do enzyme work. We are also happy to speculate on how revolutionary quantum biology technologies may be developed from these ground-breaking discoveries. We hope to stimulate interest in what, we believe, is the most exciting emerging science of the 21st century! We will be back at 1 pm ET to answer your questions, ask us anything!

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QUANTUM_BIOLOGY R/SCIENCE


## ABSTRACT

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**Hi there! Physicist here with no clue regarding anything that you're talking about.**

**Can you give us a super-brief introduction to the basics of your field. Do you assume that there are atomic quantum effects reflecting themselves on objects of large scale (i.e.: cells), are you hypothesizing that "quantum" equations/model might describe well some non-random phenomena that are de-facto random or are you hypothesizing that there are *new* "quantum-like" truly random effects not-dependent on the subatomic level at the cell level?**

**(hope the previous sentence is not too confused!)**

lucaxx85

we'll try the key insight is that life's dynamics, at a macroscopic level, depend on the motion of single or small numbers of fundamental particles. For example, the colour of your eyes is determined by a single molecule that you inherited from one of your parents. The genetic code of that molecule is instantiated in the position of hydrogen-bonding protons. So the position of individual protons IS the genetic code. Position of protons is correctly described quantum mechanically so quantum mechanical influences on

and joint authors of 'Life on the Edge'. We are here, *The Winnower* 2:e144067.76621 , 2015 , DOI: 10.15200/winn.144067.76621



genetics are inevitable. Similarly, the motion of individual electrons or protons are involved in how enzymes work. The motion of single excitons in photosynthetic complexes is reponsible for energy capture in photosynthesis. Since life manipulates the motion of individual particles then it can exploit quantum effects, such as entanglement, tunnelling or coherence, that are not available at the macroscopic level. Life thereby lives on the edge of the quantum and classical worlds.

**What role, if any, do you think Quantum Mechanics could have played in abiogenesis?**

**Novasry**

abiogenesis a really interesting question! The basic problem is a search problem - how to find a very rare self-replicating chemical by purely random processes taking place in the primordial soup. No one has ever made a self-replicating molecules so it is likley to be extremely rare so classical chemcial searchers - make a molecule -> it doesn't self-replicate -> unmake it and make another molecule -> it still doesn't self-replicate -> unmake it and ... so on a trillion trillion times and you may make a self-replicator. But quantum search routines are much more efficient as you can do parallel searches with a single molecule. So we speculated in our book that some kind of primordial chemical might have been able to quantum tunnel into multiple chemical configerations so that, potentially, a single molecule could have found the rare self-replictor by a quantum search algorithm. speculation, we know, but sometimes you need to

**Thanks for doing this AMA - this field is extremely new and being met with a lot of skepticism, and being latched onto by a number of psuedoscientists. What is your take on how 'quantum' is a buzz word that is frequently misused, and how people are discussing this emerging field? You both have proposed 'quantum mechanisms for consciousness' - can you talk about that a little? The brain is a very wet and warm space, with much of the underlying electrochemistry well described if poorly elaborated - why do you posit that quantum effects (cemis?) are underlying these interactions?**

**And secondly, do you feel that quantum effects are of interest to the field given how little we understand about even the crystal structures of the vast majority of proteins?**

**lzawwlgood**

well we haven't really proposed that qm is involved in consciouness. In fact we are profoundly sceptical of the most popular qm consciousness theory - the Penrose-Hameroff microtubule hypothesis (see comment above). the only quantum we consider feasible in the brain is maybe quantum coherence of individual ions (much easier to remain quantum coherent compared to big microtubule proteins) travelling through nerve ion channels. But that report was theoretical and currently lacks experimental evidence. Johnjoe's cemi field theory does not involve quantum mechanics, just conventional electromagnetic fields that are known to exist in the brain.

**Do you think tinnitus is caused by some phenomena at the quantum scale?**

**nickfromnt77**

no idea i am afraid

**Hello Professors, thanks for taking the time to answer our questions.**

**I have two(ish) questions, one for everyone and one for me. First, what sort of technological innovations do you expect from advances in quantum biology?**

**Next, I work at the level of cell signalling, both analyzing the molecular biology and constructing models. Your (Dr. Khalili) recent TED talk has me convinced of the effects of**

**tunneling with regards to enzymes. What of the larger protein to protein interactions and also of ion channels? And of the complete interaction of signaling molecules, since they are described by nonlinear changes of state is that a reflection of quantum processes? That was definitely twoish questions.**

**Thanks again for sharing your expertise.**

**CompMolNeuro**
quantum photosynthesis is already inspiring the design of new forms of solar energy capture. its also stimulating new ways ways to thinking about maintaining quantum coherence in quantum computers enzymes are targets for most drugs so understanding better how they work may lead to better drug design. Similarly, if olfaction is confirmed to be quantum mechanical then it is very similar to ligand-receptor interactions so new insight there might help in drugs that target receptors. We also speculate whether bringing quantum biology into synthetic biology - providing its missing spark - might lead to the creation of truly artifical life from inanimate chemicals

**For those that don't know, there are a few systems in biology where quantum effects are thought to be relevant. These include photosynthesis and the avian compass.**

**For an actual question...what do you think about quantum olfaction (smell)?**

**iorgfeflkd**
Turin's recent experiemnts where he demonstrated that fruit flies could sniff the difference between normal and deuterated olfactants has, so far, only one explanation and one that involves quantum mechanics. maybe there is some fundamental flaw in those experiments that hasn't yet discovered but, so far, quantum mechanics is needed to account for that observation. But those fruit fly experiments do need to be repeated in other labs to be sure that they are sound. Hopefully that will happen soon.

**For those more specialized in biology and have a basic theoretical understanding, without a background, of quantum physics, is there any literature, videos or lectures you'd recommend before reading your book? Or is your book friendly for the reader with a only a conceptual idea of quantum mechanics? Thank you for taking time for this AMA, the Reddit community grately appreciates it!**

**joshuaseckler**
our book requires NO knowledge of quantum mechanics! We give you what you need

**We believe that biology's connection to the quantum realm provides life with the spark that makes us so different from the inanimate world.**

**Doesn't the inanimate world have the same connection to the quantum realm?**

**deadname**
In inanimate objects made of trillions of particles, their quantum properties are all out of phase so the weird quantum stuff that depends on coherence gets averaged out to zero. What is left is the classical laws - order from disorder, as Schroedinger described it. The quantum behaviour of individual particles generates no observable effects at the macroscopic level. However, individual particles make a difference to macroscopic phenomena in living cells because of life's tendency to amplify molecular events to generate macroscopic consequences. So the quantum behaviour of few particles makes a difference in biology.

**What do you feel is quantum biology's contribution to the functioning of the brain? Particularly neurotransmission, given this is to some degree enzymatically regulated? Do you feel that an understanding of the quantum mechanics that underlie neurotransmission is imperative to gain a full understanding of the mechanics of the brain and how this translates to subjective thought and cognition?**

**JoeLivUni**
Hi Reddit Science! In our book we review the Penrose-Hameroff claim that quantum coherence in neuronal microtubules unpins consciousness. Basically, we don't believe it. Coherence of microtubules would be far too fleeting to be involved in brain function. There is however a recent theoretical study however indicating that ion transport through neuronal ion channels may be quantum coherent and, as these are responsible for nerve firing, if confirmed experiemntally, it would make quantum mechanics central to brain function. btw, one of us (johnjoe) favours an electromagnetic seat of consciousness in the brain that may interact with coherent ion transport.

**Do viruses experience any quantum effects that can be observed?**

**euphem1sm**
no evidence that we know of but its hard to detect quantum effects. most woudl go unnoticed. Certainly, viruses are small enough to have quantum behaviour The group in Vienna that showed than single molecules of fullerene were able to pass through both slits of the two slit experiment as a quantum coherent wave were planning to attempt the same experiment with viruses. But not news yet

**Is this still anchored in the science base or are there areas where it's feasible to start look at applications of this to e.g. therapeutics?**

**handmadeby**
most quantum biology is still very basic at present. quantum therapeutics are still soem way in the future

**Hello! This is very interesting and exciting. I was fortunate enough to be lectured by Professor McFadden during my undergraduate studies at Surrey Uni!**

**when Johnjoe was puzzling over weird kind of mutations that seemed to become more frequent when they provided an advantage to bacteria, and teamed up with Jim to see if quantum mechanics might provide an explanation.**

**When you were puzzling over the mutations, what made you think of quantum mechanics as a potential solution? Also, with quantum mechanics having an effect on such fundamental processes such as enzyme activity and the genetic code, should quantum mechanics become part of every biologist's repertoire?**

**angrytrousers**
I (johnjoe) became interested in quantum mechanics as a possible explanation for weird mutations, called adaptive mutations, that appeared to become more frequent when they were advantageous, contradicting the central tenet of standard evolutionary biology. I persuaded Jim to get involved and we wrote this paper: http://www.ncbi.nlm.nih.gov/pubmed/10400270 I went on to write Quantum Evolution: http://www.ncbi.nlm.nih.gov/pubmed/10400270 making a wider case for quantum mechanics in biology. Neither our paper nor my book persuaded many people but, in the last decade, lots of experimental support for quantum effects in other aspects of biology emerged, prompting us to write, Life on the Edge. And yes, I think that quantum mechanics will become an essential component of the biology curriculum

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**angrytrousers**
it struck me (johnjoe) that a possible mechanism for adaptive mutations would be that the DNA of cells could exist in a quantum superposition of both normal and mutated form. This would be irrelevant in the situation whether the mutation didn't provide an advantage but when the situation changed and the mutation could make a difference then, I speculated, that would act as a quantum measurement of the coherent state, kind of crystallising out the mutation out of the superposition

**Hello, thanks for answering our questions. Mine is perhaps more philosophical than scientific, and I want to first say that I would also put my money on some role of coherent ion channels on the phenomenon of the conscious experience. But even if some connections were scientifically proven, will that really provide any explanation for conscience? It seems to be yet another layer of complexity of understanding what happens in our brains without a fully encompassing understanding of how, or even better, why this occurs. It feels more and more likely that the only explanation for the conscious experience must be a metaphysical one. (I will never admit this because religious folk will surely rub it in the faces of anyone who is at least agnostic.)**

**papercut_eyelid**
well lots of philosophers, particularly those that subscribe to Identity Theory, would disagree. Many argue that consciousness is the experience of real physcial states in the brain. This does beg the question of what is 'experience'? In his cemi field theory, johnjoe proposed that consciousness is, essentially, joined-up information:
http://www.ingentaconnect.com/content/imp/jcs/2013/00000020/F0020003/art00007

**Hi guys, thanks for doing this AMA. Your research sounds facinating and I would love to read your book but im worried about how accessible it is to the layman. Will I have trouble getting into it or have you written the book in order to be accessible to those who have a limited understanding of quantum theory? One more question, if you dont mind, do you think that if we learn more about the way in which biology and quantum mechanics link, could it help with creating artificial leaves (artificial photosynthetic cells) for use in space (or at home)? Thanks again guys, super interesting field of study.**

**Wolfeeee**
The book is aimed at the layperson. This means a quantum physicist who knows no biology will learn from it, a biologist who knows no quantum mechanics will find it OK, AND, crucially, someone with no background in either should also be able to follow it to the end. As for whether QB might help us create artificial leaves, it's a lovely idea. Of course too early to say, but speculating, our understanding of the role quantum mechanics plays in photosynthesis could one day help us design more efficient solar cells.

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**Wolfeeee**
sure! see, for example: http://www.nature.com/nphys/journal/v10/n9/abs/nphys3017.html or http://pubs.acs.org/doi/abs/10.1021/nn406107q

**What is the one quantum advancement that you would like most to see accomplished in the next 100 years?**

**Mr_AwesomeGuy**
To be honest, for me (Jim), I think it has to be pinning down the correct interpretation of quantum mechanics (is there a multiverse? what is the measurement problem? what is the nature of quantum non locality?) Otherwise, I'd say building a working quantum computer.

**Hi Jim!**

**A bit off topic, but I just wanted to say I have your book "Quantum: A Guide for the perplexed". It was the first of many books I ended up reading on quantum mechanics and thoroughly enjoyed it. Everything was so well explained and easy to understand. I can't think of a better book to have started diving into the subject.**

**xzez**
Well, I'm very pleased to hear that. Thank you.

**Sorry this will be orientated more towards Jim,**

**I love watching your TV programs and think that they are an incredible watch. The pure passion that you bring to the Screen for millions is amazing and i think on some scale you and especially Prof. Brian Cox have had a massive impact on our future generation of scientists.**

**I guess my question to both of you is that what steps besides your TV shows are you or a general body taking to have a greater influence on the young generation who are not sure whether to go into science or maybe who are to scared of the huge task ahead. As well as this what would you say is the most interesting topic within quantum biology.**

**thanks for this AMA**

**kma181**
Well, our book, Life on the Edge is doing very well in UK and US and is being translated into 16 languages. It is so far the only book on quantum biology in the world aimed at a general audience. We also give public lectures, I (Jim) have a TED talk out recently on quantum biology, we do radio, we write newspaper and magazine articles. And we carry out our own academic research.

**How would Quantum Biology fit in with Darwin's theory of evolution?**

**harksin**
It doesn't conflict at all. If life has evolved tricks to give it an advantage, then there is no reason why

some of those shouldn't have a quantum origin.