Hello, everyone. Welcome to another episode of Q&A about future of science and technology. I had a bit of a gap there, because I was away for a week or so.

Let's see, we have a few questions here. All right, somebody's been keeping track of where I've been, because they say that they heard I was recently at a quantum biology conference.

And they're asking, what is quantum biology? A good question.

the,

I wondered about that, too, when I was invited to this conference about quantum biology, and I was,

induced to go, partly because I was curious about what people might mean by that.

Let me try and explain, and it's a little bit confusing.

in…

Physics, for example, one thinks about classical physics, and one thinks about quantum physics.

That was a division that kind of started 100 years ago with the development of quantum mechanics, and in general.

Quantum physics tends to be about very small kinds of things, like atoms and below, so to speak.

And classical physics is kind of what governs the behavior of bigger systems.

So, what characterizes quantum behavior is, well, partly just… they're different kinds of things.

So, one can say… I mean, the word quantum

refers to, kind of, the idea that things are discrete. Like, the spins of particles are discrete, the energy levels of things are discrete, and so on. That's what the, sort of, term quantum in its rawest form means.

in…

In practice, kind of, the way that one thinks about, sort of, behavior of systems is a bit different between classical physics and quantum physics. In classical physics, for example, when one thinks about the motion of something, there's a definite law of motion.

And when you, you know, throw the ball, it follows a definite trajectory that is determined by its laws of motion, which depend on gravity, drag if it's in air, things like this.

In quantum mechanics.

sort of the key idea, as it's emerged over the last, I don't know, 50 years or so, is that things don't follow definite trajectories, they follow a whole cluster of possible trajectories, and what we measure is some probabilistic average of those trajectories.

So, in other words, in classical physics, definite things happen. In quantum physics, there is this sort of possibility of many things happening, and then there's this kind of tricky business of saying, well, what do we actually measure? What is it about those many things that can happen that we actually perceive?

And that's a… that's a complicated story that has confused things about quantum physics for the last, basically, hundred years.

I think in our models of physics from the last few years, we have a much better understanding of what

quantum mechanics really is, and that it really is associated with many branches of possible history for the universe, both the branching of those paths of history and the merging of those paths of history. That would take us a bit far afield to talk about that kind of thing, but I think we're getting a better conceptual understanding of this difference between classical physics and quantum physics. Classical physics

definite things happen. Quantum physics, there are these many paths of possibility, and there's only… and some aggregate or average or something of those paths is what we perceive.

Okay, so how does this relate to biology?

So, what one might have thought is that one could say, well, in biology.

Should we think of definite things as happening, or should we think of, sort of, the raw material of biology at a molecular scale as having cases where it matters that there are, sort of, many paths of possibility?

Well, let's talk for a moment about chemistry before we get to biology.

In… If we say, what's the structure of a water molecule, let's say? It's, you know.

It's, you know, an oxygen atom and two hydrogen atoms that are at a certain angle from the oxygen atom. And you kind of have this picture of a water molecule consisting of the oxygen with two bonds coming out of it, and those bonds are attached to hydrogen atoms.

And…

It's kind of a… a very… a picture where there's a definite water molecule and a definite orientation, and the water molecule, you know, if it's in a microwave oven, the water molecule is kind of spinning around because it's absorbing microwaves and getting lots of energy to spin around from that, or the water molecule might have… kind of might be vibrating with the hydrogens moving backwards and forwards.

And that's important in absorbing energy at different, different… from water vapor in the atmosphere and things like this. But the picture is really… there are these definite, you know, atoms in definite places with bonds that can be thought of as a bit like springs, and things sort of bounce back and forth that way.

That's a very classical picture of a water molecule.

Is that a correct picture of a water molecule? Well, for many purposes, it's a quite adequate picture of a water molecule, but if you really want to know what's a water molecule really like.

You have to use quantum mechanics, and you have to start thinking about, kind of, the, thinking about things in terms of these, sort of, many paths of history, and so on.

the thing that you can do when you think about these many paths of history is you can say, what's the quantum amplitude for things? Which means, instead of saying there's a definite position, let's take the example of a single… of an atom of hydrogen, for example.

There's a nucleus, in the simplest case, that's a single proton. There's an electron that's somehow somewhere near the nucleus. And the sort of very early pictures from more than 100 years ago now were that the electron was sort of orbiting around the nucleus, like a little tiny solar system.

But what became clear when quantum mechanics arrived was that that wasn't really the right picture. That the right picture is that that electron, instead of being… following sort of a definite trajectory around the nucleus, it's kind of following a whole collection of possible trajectories.

And you can represent that collection of possible trajectories by saying there's a certain quantum amplitude.

That will turn into a probability. It isn't quite a probability yet, but a certain quantum amplitude for the electron to be found at a particular position relative to the proton at the center.

And so, instead of saying, there's an electron, it's going around in this defined orbit, it's a definite position at every moment of time, you say there's a certain amplitude for it to be at different positions relative to the nucleus.

And so then, in the case of something like a hydrogen atom, there are a sequence of different energy levels that correspond to different patterns of where the electron will be found relative to the nucleus.

Those in chemistry are so-called orbitals, and again, some of the terminology is a bit confusing, but the kind of lowest energy orbital is one where the electron is found pretty close to the proton, but it has equal amplitudes to be in all different directions relative to the proton.

Then you get, that's the so-called S orbital, the names of the orbitals are… they're named after German words, so somewhat confusingly, it's the S orbital is the lowest one, then PDF. Those are the sequence of orbitals.

So the first one, the s orbital, lowest energy orbital, lowest energy possible state for the electron, the electron is, sort of, can be found, with equal amplitude any… anywhere, in… in any direction from the proton.

it has a certain distance from the proton, and its average distance is a thing called the Bohr radius, which is a sort of characteristic, length, about 10 to the minus 10 meters, of, relative to the, to the, to the proton at the center.

The proton at the center is 100,000 times smaller than that, sort of, the average distance at which the electron is found.

But so, then, so that's kind of the lowest energy
configuration. Then the next configuration is the p orbital, and the p orbital, there are… there are three different p orbitals, and they have, sort of, lobes that come out, going sort of up and down in two different directions, and those… with… with those in that
situation, the electron is more likely to be found, sort of, in the up direction, and sometimes further from the nucleus than that Bohr radius, and sometimes in the down direction. But there are several different
distinct p orbitals, three of them, that correspond to those, the, the electron being in, in different orientations relative to the nucleus.

Okay, so let's not dive down into explaining, sort of, all of quantum mechanics here, but the basic point is that when we think about a single atom, we're thinking about not the electron is in definite position, but rather the electron
can be, in this… has this amplitude to be in different possible positions, and the sort of… the quantum aspect of it
in some… the original quantum aspect of it is that there are a discrete set of possible, kind of levels, like the S orbital, the spherically symmetric one, the p orbital, the one which has sort of the dipole character, and so on, and that there are a discrete set of possible configurations that the electron can be… possible distributions that the electron could find itself in.

Okay, so that's for a single atom. The electron is not in definite positions, it's sort of smudged out.

Okay, what about for molecules?

Well…

If you have, for example, a hydrogen molecule, H_2, two hydrogen atoms that are… and you might describe that in chemistry as being bound together by a covalent bond.

And you might draw that, or you might make your sort of ball and stick model of it as having two balls for each of the hydrogen atoms, and then a stick that is the bond. That's kind of the classical picture of a hydrogen molecule.

Well, you can work out the quantum mechanical version of that.

There isn't really the, you know, there's no bond in the middle, that's just an overlap of possible electron positions.

And the sort of full picture of the hydrogen molecule says there's a certain amplitude for… there'll be, in this case, hydrogen. Each hydrogen atom has one electron, so together they have two electrons. The full quantum mechanical picture has a certain amplitude, a joint amplitude, for each of those electrons to be found in different places.

Well, the hydrogen molecule is a little bit tricky to do, but you can solve the hydrogen molecule in quantum mechanics. You can find the amplitude for each of those electrons to be in each different position, and they're correlated, so you have to get the amplitude for one electron to be in this position, another electron to be in that position.

It is an approximation to that to say that there's just this sort of bond that connects the two hydrogen atoms together.

But so the full, kind of, quantum chemistry version of this would say, well, actually, it's not like… it's not that these two atoms are a certain fixed distance apart according to the bond, that everything has quantum amplitudes, there's quantum amplitudes to find electrons in different places, to find protons in different places, and so on.

That's the full, kind of, quantum chemistry version of things. The, the way that one computes that is using the Schrodinger equation. That's a

a partial differential equation that tells one the… for the so-called wave function or quantum amplitude, it's that, as a function of the position of all of the different elements, the electrons, usually you only think about, in the simplest case.

of quantum chemistry, you only… you assume that the nuclei are kind of fixed, because they're a lot more massive than the electron. I mean, you know, to give a sense of that, a proton is 1836 times… 1800 times more massive than an electron.

So it's, so you can, when the electrons are sort of whizzing around and doing different things, the nuclei are much more sluggishly hanging out there.

It's a so-called Born-Oppenheimer approximation of quantum mechanics, assumes that the nuclei just kind of stay put, and it's the electrons that are kind of having all the action, so to speak.

In any case, in using the Schrodinger equation with considerable computational effort, you can solve the Schrodinger equation for something like the hydrogen molecule.

well, so can you do that? It gets more and more complicated, more and more, kind of variables in the partial differential equation and so on, more and more difficult to kind of do numerical computation. There's an additional complexity, which is that electrons obey the exclusion principle, they're so-called fermions, that means that

sort of two electrons can't be in the same state at the same time, and that is reflected in the case of the equation, in this operation of anti-symmetrization, which is kind of a constraint on how the solutions to the equation can look. And that creates even more difficulty in actually solving these equations, either

In analytical form or numerically on a computer.

So… Or analytically on a computer, for that matter.

But in any case, the main point is you can represent

And you can do, in principle, quantum chemistry, where instead of balls and sticks and so on, for atoms and bonds and things like this, you're actually taking account of all these different amplitudes for all these electrons and other things to be in different places.

Quantum chemistry is pretty hard.

And, in… if you just sort of say, well, I've got this whole collection of atoms, how will it fit together to make a molecule? In principle, you can work that out using the equations of quantum mechanics and so on.

In practice, that's not really possible for molecules with more than at most tens of atoms, and even at tens of atoms, it's really hard. So, sort of the full quantum picture of how, how all these things fit together, really difficult to do.

It's also very confusing, because for something like a water molecule, the… one of the things… I mean, this is… this is where… this is a… a sort of deep can of worms.

The, not, okay, so I mentioned that with a hydrogen atom, that the lowest energy configuration of a hydrogen atom has the electron with equal amplitude in all different directions. It's a spherically symmetric orbital.

Okay, well, it's a general rule about how quantum mechanics works, that the lowest energy configuration of systems tends to have that spherical symmetry property.

So if that's the case, how can we have a water molecule where we say there's a water molecule with definite positions for the hydrogen atoms, and it's a water molecule that has this orientation? Why isn't it the case that the sort of lowest energy…

version of a water molecule is a water molecule that's kind of where all directions are equal, and you can't really say that it's an oxygen with hydrogen sticking out in a definite orientation. This is a tricky point.

And it has to do with one of the pieces of… one of the many pieces of messiness in quantum mechanics. And, okay, so…

In…

In the case of an electron in a hydrogen atom, you say, well, there's a quantum amplitude to find the electron in different positions relative to the nucleus, and all different directions have equal amplitude.

But, if you actually, quotes, measure where the electron is.

Then you can come to the conclusion, yeah, the electron was in this definite place.

In other words, there's this whole bundle of possible histories of the universe, but as soon as you sort of actually observe something, you'd say, well, actually, I know it was… in fact, it was in this particular… I picked up this particular history of the universe.

the way I think one should think about it is that our… our… sort of the… the universe has all these different branches of history, and we happen to exist

In a particular branch of history, and that's the one which we sample.

So, even though the sort of the equations say the electron has equal amplitude to be in all these different directions, once we've observed where the electron is, then we know the electron was in that definite direction.

Okay

So… but the confusing thing is that we… we start off saying, well, it's in all possible directions. In the case of a water molecule, we might say, well, it could be in all possible orientations, but the fact is, we imagine it, using our sort of classical physics thinking, to be in this definite orientation that corresponds to our ball and stick model.

And the question is, why is that a reasonable thing to do, to think about it in terms of being in a definite orientation? And the rough answer to that is that, just as in the case of an electron with a hydrogen atom, we think of… we make a measurement on it. We do that by having it go through some magnetic spectrometer or some such other thing, and it has, you know, that… the…

the atom is led to go either to the left or the right, or something like this. We take an action that causes us to effectively make a measurement on it.

Well, a water molecule just hanging out

near other water molecules, the picture is that all those other water molecules are, in a sense, taking actions on the first water molecule. In effect, all those other water molecules are sort of continuously measuring the water molecule that we're interested in, and so that means that this thing where we say, well, it's in a definite orientation is sort of a reasonable thing to do, because the environment is somehow

continually making measurements on that water molecule. This is a complicated thing, and people, I have to say, you know, the pros often get extremely confused by this issue. But I think the right picture is that

It's… the sort of… the water molecule can be thought of in this sort of classical way, with balls and sticks and so on, in a good approximation, because it is kind of continually being jiggled by other water molecules, which is like

sort of the… the, an experiment being done, but it's continually happening, the experiment being… like the experiment being done that determines where the… where the electron in the hydrogen atom was.

Okay, so this was a long story about, sort of, quantum chemistry, and the… most of the time, when one does chemistry, you use, at best, semi-classical methods.

Which typically means, well, you know, you have a molecule, it's more or less balls and sticks, but there's a little… there's a certain amount of noise. The molecule's sort of being perturbed, and that kind of represents, sort of, quantum processes, quantum effects.

usually molecules are perturbed by the presence of heat. You know, the temperature determines… temperature is the… is… is…

is the kinetic energy, the energy of motion of things, and if you have little molecules, like water molecules, for example, they can just be whizzing around and maybe rotating or something like that. If you have a big molecule like a protein, it's a big floppy thing, and, you know, maybe a water molecule crashes into it, and then it will make the protein deform in a certain way, and so on.

Well…

Usually, kind of the analysis of what happens to the protein molecule is something which is kind of done at the level of more or less balls and springs and sticks and so on. It's, you know, it's a big… let's say you have a protein molecule with, you know, with a million atoms in it.

Well, it's completely infeasible to do quantum chemistry where you're solving the Schrodinger equation for all of those different atoms. Instead, you take a semi-classical approximation where you think of the molecule as being a bunch of masses corresponding to the atoms, and a bunch of spring-like things corresponding to the bonds between those atoms.

That's just an approximation to what's happening at the true quantum chemistry level.

But then you are… you're doing computations on those molecules, and that's already very difficult. Typically, the thing that is sort of the high-tech piece of this is so-called force fields that are the things that determine, for two atoms, what are the forces between those two atoms?

So roughly, for example, if the forces of the… if the… if you had atoms that were charged, ions, then roughly at least at long distances, the forces will be determined by electrostatic forces, and they would be an inverse square law of attraction, let's say, if the molecules were of opposite-signed charges.

But in fact, the forces between molecules are more complicated. There are very common cases, so-called van der Waals forces.

where… actually, the thing called the Leonard-Jones potential, where at long distances, the force between two neutral atoms, not ions, but atoms where there is a sort of a match between the electric charge of the nucleus and the electric charge on the electrons, neutral atoms roughly attract each other in a way where the force of attraction goes down.

1 over R to the 6th. It's actually sometimes 1 over R to the 6th, sometimes 1 over R to the 7th. Those are so-called van der Waals forces, and neutral atoms will attract each other by those forces. Then, at short distances, the atoms kind of start repelling, usually by the 1 over R to the 12th force law, so roughly, it's 1 over R to the 6th minus 1 over R to the 12th.

is kind of the… that's the so-called Leonard Jones potential between two atoms.

So, sort of the high-tech thing in working out how molecules behave is to have those force fields, those laws of attraction and repulsion between atoms. And the thing I told you is just a rough approximation to kind of your average, kind of, simple atom. In reality, the force fields are more complicated and depend on which type of atom you're dealing with.

And so on. But that's where a bunch of, sort of, fancy supercomputing gets done, and custom, custom computers get built to try to,

Do, the most accurate

sort of figuring out of the motion of molecules based on those kinds of force laws. And so, an untypical thing, I mean, the best efforts these days are looking at the motion of molecules on timescales of order femtoseconds, that's timescales of order 1,000 trillionth of a second. That's enough that you kind of see the wiggling of electrons

At the level of that… at speeds that correspond to… you see the kind of timescale of wiggling at frequencies that are not quite the frequencies of light, but at least the frequencies of microwaves and things.

And so you're getting sort of this series of configurations of molecules down to the level of what happens every femtosecond. And one of the things that's really tricky about quantum chemistry is that there's motion on many different scales.

So, little, little places where there are electrons, or little places where there are hydrogen atoms hanging off the backbone of a protein, for example, those hydrogen atoms will wiggle around on timescales of order femtoseconds, but the full, big protein might be, sort of moving around and sort of moving like a snake or something in… on timescales

Of order microseconds or, or more, which means that there's a… many… you have to be able to sort of deal with

When you do computations, you have to be able to have, you know, things where you're taking account of effects.

Where there are factors of a million difference between one effect and another effect.

So you have to be able to sort of get the things that are at a millionth scale, and the things that are at, sort of, one scale, and you have to be able to take account of all of those things. So it's very hard work.

But, as I say, most of what's done, you're not even dealing with full quantum mechanics there, you're just dealing with the semi-classical approximation of the motion of molecules and so on. Okay.

So, what does this all have to do with quantum biology?

Well, One thing that…

you might wonder is, are there, in fact, quantum effects that truly depend on, sort of, these many paths of history and all that kind of thing? Are there quantum effects that are somehow important in biology?

For individual molecules, There are certain effects.

Oh, like the,

delocalization of electrons that happens in rings of molecules where there is a ring of carbon atoms or something like that. There's some sort of trickiness that is a very quantum mechanical phenomenon that depends on all that quantum chemistry stuff, at least in some approximation. You know, are there things where, sort of, what happens in biology really depends on what's happening at the level of all of this, sort of, complicated quantum stuff?

Probably the answer to that is most of the time, it doesn't matter. Most of the time, molecules are flopping around, and you can use this sort of semi-classical approximation where there might be some sort of quantum noise that's kicking things around, some sort of thing that's sort of an injection of randomness that comes from quantum effects, but that most of the time, you can just think of the molecule as being like

Balls and springs and so on.

Maybe with these fancy force laws, if you… if you want to.

But, so there's sort of a question of, are there effects which really depend on, kind of, this many parts of history, quantum mechanics kinds of things, or this discrete energy level aspect of quantum mechanics, and so on? Are there features of biology that depend on those things? So that's sort of one question.

And the answer is it's… it's not clear. I mean, there are…

my own guess is that most of the time, it doesn't matter. But, you know, one feature of biology is that, in a sense, biology has an infinite chain of footnotes. When you say, it never matters in biology that, this, that, or the other, it never matters what the Earth's magnetic field is like, for example.

that will not actually be ultimately true. There'll always be some kind of creature that has some weird way of depending on how the Earth's magnetic field works, let's say.

So in biology, unlike in physics, where things tend to be rather clear-cut, it's either there is an effect or there isn't an effect. In biology, it's like, well, there usually isn't an effect, but just sometimes there is an effect.

So how does this relate to quantum mechanics? Well, there are a few particular phenomena where

there are sort of quantum phenomena which seem to be important to biology. So, in fact, one I mentioned related to the Earth's magnetic field is that,

the, there's a question of, do animals, organisms.

folks like us, are we sensitive to this Earth's magnetic field? I mean, you know, if we have a compass that has a magnet, a little tiny magnet suspended somewhere, that magnet will line itself up with the Earth's magnetic field, and you'll be able to tell which way north is, let's say.

But the question is, is there anything in us that does that? Well, we could have little tiny pieces of iron, for example, like little iron filings, that would actually move around in response to the Earth's magnetic field, and that… so that we could have little tiny compasses in some organ in us.

That's one possibility. The other possibility is that those tiny compasses could be really, really tiny, because it turns out that atoms and nuclei and electrons and so on

But they all act as tiny magnets.

And so there's a certain tendency for, for, well, atoms that have, high so-called spin, which is essentially some atoms, some nuclei.

And some atoms, will behave as if they're like little bar magnets

That have, that can be moved around by a magnetic field.

Because biomagnets try and align themselves with the magnetic field, and so it is with certain kinds of atoms and nuclei and electrons, for that matter.

That there'll be that kind of alignment that happens.

So…

So then the… one of the possibilities that seems very quantum is that that alignment could be happening at the level of individual

individual atoms. So, in particular, there's been a long-time claim that

in certain organisms, particularly pigeons, that there are atoms that are sort of embedded in cages inside proteins, and where those atoms will tend to move around in… those atoms have, essentially, magnetic… like, little tiny bar magnets, and they move in response to the Earth's magnetic field, and something about that cage

Is able to detect what the orientation of the atom is relative to that cage.

So that's a claim where sort of a thing that's very quantum mechanical, the spin of an atom, is, is something that has sort of an effect on biology, and that causes pigeons to know which way is north, type thing.

So that's one kind of effect. There are other kinds of effects that people have talked about, which I'm not a big believer in, that,

relate to, kind of, the features of cells. So, cells have lots of little fibers in them.

So-called microtubules, and as well as fibrils of various kinds, but microtubules are often on the surface of cells.

And they're little… think of them as little pieces of fiber, and they… they have, they, they, they're… they have… they can move, and they're just made of protein.

But there's a question of whether, sort of, the pattern of what microtubules do depends on quantum mechanics. It's kind of an attempt to say, well, quantum mechanics might affect how brains work, and the medium for that happening would be through these microtubules moving around different ways. I don't happen to believe that this is really an important effect, but in the general principle that

There's an infinite number of footnotes in biology. I'm sure there's some effect there, it's just a question of whether the effect is of any significance or not.

Okay, so those are some ideas about how, kind of, sort of, traditional quantum mechanics might have effects in biology.

But, in fact, what people sometimes mean by quantum biology today isn't really any of that.

It's really the interaction of things like light, with biology.

And why does that even make sense to call it quantum biology? Well, it makes sense because if we're thinking about the interaction of light… if we're thinking of light as consisting of a stream of photons, then photons are the quintessential quanta.

When we think about,

something like light. There's different views of light, we can think about it as kind of like a wave, but we can also think about it as a big cascade of photons. And…

For some purposes, it's much more useful to think of it as a cascade of photons, because, like, for example, in our eyes, when light falls on our retina, it's individual molecules, photoreceptor molecules that are proteins, that, where an individual photon interacts with that photoreceptor and generates a cascade of electrons inside the photoreceptor, and that's how we register

That we, you know, saw some light.

So it's sensible to think about the light that falls on our eyes as being a stream of photons, rather than just saying, well, it's a wave, and it's the aggregate of many photons, because the individual

photons can have an individual effect on generating electrons inside the photoreceptor cells in our eyes.
So…
In any case, one sort of meaning of quantum biology is it's really about the effect of things like photons on biology, and what's the relationship between sort of individual photons and what happens in biology. So, it's clear that
Photons have an effect on the photoreceptors in our eyes. They're specifically generating this, you know, cascade of electrical activity when the right frequency of photon falls on the right photoreceptor in our eyes.
So there's questions about, well, where else do photons show up in biology?
So, one thing people claim is that chemical reactions generate photons, and that you might be able to detect those from different things happening in biology.
Well, at some level, okay. Boy, we're getting into lots of different things.
Let's talk for a second about what heat is.
So, if you take
Block of metal, and you heat it up.
what… what is different between the hot block of metal and a cold block of metal? Well, the answer is, in the hot block of metal, the electrons and atoms in the block of metal are moving around much more than in the cold block of metal. The heat…
Is associated with the microscopic motion of molecules and atoms and electrons and so on in the material.
So that's… that's sort of heat in a material. But there's also radiant heat.
There's, and that's, that's… corresponds to streams of photons. So, when you heat something up, it eventually starts to glow. First, it glows red-hot, then it glows white-hot, then it glows blue hot.
And what's happening there? What's happening is that, from the motions of all those molecules, the, those, those molecules are emitting photons. As they move around, what's, what's really happening is that, in…
In atoms and molecules, there is this sort of… the molecule is in a kind of a… it gets into this Excited state where it has a higher energy.
And one way that it can lose that energy, one way it can lose the energy, is by crashing into another molecule and just exchanging its energy with… making its energy, turning its energy, its internal energy, into energy of motion of the other molecule, or the molecule itself.
But another thing that can happen is that that energy can be emitted as a photon.
And so, when it's in the… when it's, by the time something is red-hot, it's emitting visible light photons.
If it isn't quite red hot yet, it still will emit photons that are slightly lower energy than the ones that make… that are perceived by us as red. Those lower energy photons are infrared photons.
So, when things are at all hot, they're emitting infrared photons.
So, when… when, the… a thing that's hot
It both has motion molecules inside it, and is also radiating photons that
The frequency of the photons depends on how hot the thing is, but if the thing isn't very hot.
If it's, like, you know, only, I don't know, 100 degrees centigrade or something, it won't glow, it will just emit infrared photons of a certain frequency. And as you increase the temperature, the typical frequency of the photons will increase

Going from, for example, when it gets into visible range, red to… well, white is sort of a combination, because the distribution of frequencies of photons is quite broad. It's the so-called Planck distribution.

And, or black body distribution. And, things are never green-hot, because they… it's never the case that you're only generating photons that are in the kind of green

band of frequencies. Instead, by the time you're sort of… well, you would be green hot, you also have a certain amount of red hotness and blue hotness, and so the combination of those things makes it seem like the thing is white-hot. But in any case, so you're always emitting infrared photons whenever something is hot.

Okay, so what does this mean for biology? Well, in biology, there are lots of chemical reactions that happen, including ones that are… that produce heat.

And, you know, if we are… if we humans are regulating our temperature and keeping ourselves at, if you're in the, sort of, US, 98.6 degrees Fahrenheit or whatever, if we're maintaining that temperature, mostly our liver is… is… has chemical reactions going on that produce heat that can maintain that temperature.

But so, it is routine for us in biology to have chemical reactions happening that produce heat.

So we're producing infrared photons that way. But the question is, for example, one question is, are there other kinds of processes in biology that aren't, sort of, obviously just generating heat. but are somehow occasionally generating visible light photons, for example. In other words, is it the case that, sort of, we all glow in the dark just a bit because of chemical reactions that happen in us that produce a small number of visible light photons? So there are claims that that's the case.

probably, as I say, in my… there's always more footnotes in biology, there probably are some visible light photons that get produced. Just to give you a sense of why something like that might happen, one of the more bizarre phenomena is if you… if you break something, like, if you have a piece of, I don't know, a pencil or something, you snap it in two.

Okay, well, it makes a noise as you snap it in two, but as you snap it in two, it actually generates… it generates some… the… okay, what's happening when you snap it in two?

Well, you're breaking a bunch of bonds between different atoms and molecules and so on. And in fact, when you break something, some… some of what gets broken are actual bonds inside molecules and so on.

And there's a fair amount of energy associated with those bonds, and when you break them, that energy is released. And so, when you break something, there will be a tiny rate of production of visible light, even X-rays, as certain chemical bonds get broken.

because you took… I mean, even though the chemical bonds are quite strong, they're not strong relative to the amount of force that you're putting onto the pencil to break it. Each individual bond is absolutely a microscopic energy compared to what you're putting into the pencil to break the whole thing. And that breaking action that you make

somewhere down there, there'll be at least a few actual chemical bonds that get broken, and the result of breaking those bonds is to produce photons that have quite high energy. So you actually produce, in breaking things, actually produce visible light, tiny amount, even a tiny amount of X-rays.

So, it's probably unsurprising that in biological reactions, biological, chemical reactions, that there's a small rate of producing, for example, visible light and so on.

Is it measurable? Is it important? Is it diagnostically important? I don't think one knows yet. But that's an example of something that you could think of as being a quantum biological phenomenon

Because it sort of involves quanta, like photons. It's a little bit of a stretch, because you might think that when you're saying quantum biology, you mean kind of the quantum chemistry thing, but that isn't an example of that.

And so you can ask a bunch of questions about whether, what effect, for example, things related to photons have on, on biological organisms. You know, how much does, light

you know, how much effect does light have on things? How much, effect does magnetic fields, do magnetic fields have on things?

I think one of the things that has become sort of interesting in recent times is that, well, one thing is how far does light get when you shine it into you?

So, you know, you take a flashlight, you, you put it on one side of your hand, well, you see some light coming through the other side of your hand. It typically looks very red.

That isn't… it isn't red because there's blood in your hand or something like this. It's red for the same reason that sunsets look red. It's red because if you look at white light, which consists of all different possible colors of light.

It turns out the blue light

is more easily absorbed by things than red light. And so, for example, when you see a sunset, you're seeing what's left over, that the sun looks red because the blue light from the sun, the sun has… is producing both red light and blue light, and other colors of light.

But the blue light is kind of scattered away. It's absorbed in the, it's, it's, it's, it's, it's, it's basically… well, it's basically absorbed by the air.

It's not quite absorbed, it's actually scattered in a different direction, which is why the sky looks blue, because you're getting light that came from the sun, but it's being… the blue light, more than the red light, is being scattered in directions away from the sun.

But when you're looking straight at the sun, what you see is… well, in the case when the sun is high in the sky, you're just seeing kind of the, you know, lots of frequencies of light. When the sun is kind of close to the horizon, you're seeing it through a bigger column of air.

And so there's… what happens is more of the blue light is removed, and so the red light is left over.

It's basically the same phenomenon when you have a flashlight shining through your hand, that what gets left over is the red light.

So there's a question of how, if you have intense light, how deep does it get?

When you shine it into you.

And so one of the things that's pretty clear is that, yes, you can sort of shine light into… through the, you know, if you shine… a little bit of light will get through your skull and get into your… into your brain and so on. And does that have an effect? Well, I don't think one really knows.

The,

There is, you know, even things like the pituitary gland that sits in the middle of the brain, it's known that there has a lot to do with how your circadian rhythm is set.

It secretes chemicals depending on whether you're, you know, in sunlight or not.

Is there a direct effect of actual light that, you know, falls on your head, so to speak? A little bit of it getting into the pituitary gland and having an effect on how it

produces chemicals, I don't think one knows at this point. But another example of sort of a quantum biological phenomenon, at least you could call it that, is the effect of light on… direct effect of light on biological tissue.
There's also the question of whether magnetic fields have an effect on biological tissue. You know, if you go get an MRI,
There's a strong magnetic field that's used, to, actually, it makes use of the fact that, there is… that… that, hydrogen atoms can get sort of lined up in the direction of the magnetic field, and, or if you have
contrast agents like gadolinium. Gadolinium happens to be something where the nuclear… where the nucleus of gadolinium
is something which has a high spin, and so it has a sort of high magnetic moment. It tends to line up with magnetic fields.
But, in any case, the way that,
MRI works, it relies on having a high magnetic field, and so if you get an MRI done.
it's kind of, so for all we know, what appears to be the case is that we just don't notice that magnetic field. Nothing, it has no effect on us. It has an effect on the hydrogen atoms in us.
And that effect can be sensed by looking at the emission of microwave radiation from those hydrogen atoms and so on. But as far as us as biology, it doesn't seem to have any effect.
Is it really true that magnetic fields have no effect on us?
Well, there's some evidence that it does have some effect. As I mentioned, you know, for pigeons, it's believed that there are particular kind of structures where the Earth's magnetic field, which is quite weak, very weak, it's 100,000 times weaker than the magnetic field in a typical MRI,
That the Earth's magnetic field can be sensed by a pigeon.
An interesting question I don't know the answer to is what happens if you put a pigeon in an MRI machine? I wonder what the answer to that is, I don't know. It may be, as is often the case with these sensory organs, that sufficiently over… if it's sufficiently overloaded, the brain just doesn't sort of register anything as happening.
But, there are definitely questions about that. In any case, there are sort of these… kinds of…
Phenomena that are sort of the direct effect of
Things about photons, electromagnetic fields, and so on, on biology.
I mean, there are… there are claims that there are all kinds of different things related to electrical and magnetic phenomena affecting biology. I mean, you can ask, you know, if you use a small electric current.
does that small electric current have a… have a substantial effect? You can certainly, if you have a larger
electric current, you can have effect on muscles, you can, you know, that electric current will be, will make muscles contract, things like this, but will a small electric current have an effect? Will it sort of reset certain things that happen in,
in the reactions that are going on, or something, or some feature of how the cells in you are set up. You know, there's… there's… like I say, everything in biology has footnotes, and so there's surely some effect.
How big the effect is? Is it an effect that's important for medical purposes? I don't think one knows.
I mean, there are a lot of… there are a lot of funky things. I mean, the, you know, one feature of biological organisms is

you know, you think of them as having separated pieces. You've got the brain that's separate from the gut, that's separate from muscles, and so on, but in the end, there are, sort of effects that go between all these things. So one of the things that's emerged in recent years is the kind of the gut-brain axis, it's usually called.

Where features of the microbiome, the population of microorganisms in your gut that sort of are involved in the digestion of food and so on, those that

the sort of… the state of your microbiome has… can have an effect on… that your brain can have an effect on it, it can have an effect on your brain. And that's sort of surprising, until you realize that there are nerves that go both from the brain to the gut, and from the gut to the brain. And, you know, exactly how those things work is… is quite…

is still quite unclear, but that there is a connection is… seems to be the case. And another one of those connections is between the immune system and the brain. You might have thought your immune system making antibodies, having T cells going and attacking things and so on, perhaps having autoimmunity, where you have, where you have… where you're attacking your own cells and so on, that all those things were just features of the cells in the immune system.

and that there was no brain control to all those things. But it's becoming clear that there are ways in which at least nerves are connected to things in the immune system. There are connections between, sort of.

the brain and the immune system. Now, can there be connections to what you kind of consciously think and the immune system? Quite possibly. I mean, once there's a connection between the brain and the immune system, it's, you know, what… there's a kind of very fuzzy line between what you consciously think and all the things that are going on in your mind, in your brain.

So…

But it's a… it's all very subtle, because they're often very small effects, where in principle, you can measure some effect, but does it matter, or does it not matter? I mean, at some level, everything matters. I mean, the… you know, if you eat one piece of chocolate versus one piece of…

fruit or something, that… that…

that will matter to some microorganisms in your gut. You know, probably 10,000 microorganisms are affected by that one piece of chocolate versus that one piece of fruit.

But do the fact that those 10,000 microorganisms end up doing this versus that? Does it have an actual consequence to you that's of any perceptible importance in sort of your medical history or whatever? One doesn't know.

I think the thing that even confounds things even more is when you're thinking about, you know, what has a medical effect?

Well, as I mentioned, the brain has effects, things in the body.

from the immune system, to the things about… probably about the microbiome, to all kinds of other things. Things that we think of as not being under conscious control actually are, to some extent, under conscious control. I mean, I don't know, you know, the… you can end up… if you have enough of a sort of a shock

of, you know, if something sufficiently surprising happens, you can miss a beat with your heart, so to speak. And that's… although the operation of the heart

is governed by pieces of the brain that are not directly connected to your thinking. You know, there are claims that some people can mediate their heart rate just by thinking, but most of us can't do that. Most of us, you know, if we run upstairs or something, our heart rate will go up, but that's for reasons that have nothing to do with us thinking about running upstairs, or at least we don't imagine so. It has to do with a sort of lower level

Action of our brains.

So…

In any case, the idea that the brain can have an effect on things which we usually think of as just humming along without, sort of, conscious brain control is something that undoubtedly is the case. I mean, take breathing, for example. Most of the time, we don't think about our breathing. But if we put effort into it, we can think about it, and we can hold our breath, or do whatever else. But most of the time, it's kind of on autopilot.

And things like our heart really are much more on autopilot, and it takes much more, and I don't think… most people don't know how to, by sort of consciously concentrating, change what happens with their hearts, even though they can change what happens with their breathing.

So, you know, the question is then, so there's an effect of what you think on other things in your body.

And then that leads to all kinds of difficult, sort of confounding features when you try and do medical experiments. So, one feature is the placebo effect.

Where, if people are convinced enough that something is going to make them better, it's… it's,

That, through mechanisms that aren't really very well understood, that

can mean that their brain is sort of sending the signal, hey, this should make me better. And so it's… maybe it's affecting the gut, maybe it's affecting something about some muscles, or something like this. And by golly, it makes you better, even though the actual… if you were doing a clinical trial of a drug, and you get the placebo, that means you get something which is supposedly inert.

rather than getting the active drug. And so… but even the placebo, from the idea that you're getting this thing, you don't know whether it's a drug or the placebo, that that idea can make you better, so to speak, without any actual sort of medical molecular thing kind of happening.

So I have to say, it's a funny thing, you know, I was at this conference, I listened to a few presentations, and some of them were very, you know, there's this tiny effect, and we only see it sometimes, and you have to be in exactly the right place, and it matters whether it's this practitioner or that practitioner that's doing the thing, and so on.

And, you know, I'm thinking to myself.

If this was, kind of shamanistic medicine, kind of the witch doctoring and so on.

Would the… would the presentation really sound much different?

But then you realize that there's this complicated mixture of, kind of, the what you think is going on versus what is molecularly going on, and so on. And so, it's very hard to disentangle those effects.

And particularly in lots of kinds of medical things, sort of the ultimate effect is quite small, though it may have a big effect on you, you know, you have a little bit of a… I don't know, you have, you know, your toe is hurting, and so the result of that is that you limp slightly, and then the result of you limping slightly is that you kind of cause, you know, your back to get thrown out in some ways.

So, the small effect can turn into a big effect.

And, so, you know, just a little bit of a sort of tweaking of whether you are believing in something, not believing in something, whether there's a molecular effect or not, can end up sort of spiraling out to something that is a notable effect.

Right, that was a super long answer to that question about, About quantum biology.

Let's see…

Well, the questions here…

Ugh.

the question says, a question here about,

limit, but are mass spectrometers smaller when built on the Moon?

I don't think so. What is a mass spectrometer?

the…

Chemical elements are distinguished by having different numbers of protons in the nuclei of atoms. So, hydrogen has one, helium has two protons, lithium has three, etc, etc, etc.

The nucleus also contains neutrons as well as protons, and so you end up with nuclei with different numbers of neutrons plus protons. So, for example, standard hydrogen has just one proton, deuterium has a proton and a neutron, tritium has a proton and two neutrons.

And for heavier elements, they'll often be 5 or 10 stable isotopes with different numbers of neutrons.

Okay, what does a mass spectrometer do? A mass spectrometer takes whatever material you have, and you smash it into atoms.

And then you're trying to find out how many atoms of different, atomic weights do you have? So, for example, you would have some number of hydrogen atoms with one proton and no neutrons, some number of hydrogen atoms with a proton and one neutron, etc, etc, etc, some number

of, I don't know, carbon atoms with 6 protons and 6 neutrons. That's carbon-12.

Some number with 6 neutrons and 7

6 protons and 7 neutrons, and so on. So a mass spectrometer lets you measure how many of each type of isotope you have.

And the way they typically work.

Is you've got all these particles.

you sort of shatter your material, your sample, into its individual atoms. You just… you turn it, you break apart all the chemical bonds, you just get the atoms, and then a typical thing that you do is you accelerate the atoms by using an electric field, accelerate the nuclei by using an electric field, and,

They… they, depending on the mass.

They will be differently deflected by a magnetic field.

Because they're going with a certain momentum, let's say, and then they're depending… well, depending on their mass, a given magnetic field will deflect them, more or less. So that's how a mass spectrometer works. I don't think there's any effect of gravity on a mass spectrometer.

There are very subtle effects to do with atomic beams kind of falling under gravity, but that's a very, a very subtle effect beyond the level of what you're dealing with in a mass spectrometer.

Let's see…

Well, there's a question here about saying something about quantum algorithms versus traditional algorithms from Arif.

Well, okay, so… I talked about how in quantum mechanics.

There are sort of these many threads of history.

And, you know, the… kind of…

That's what sort of happens inside a quantum process.

when we…

are perceiving something quantum mechanical, we have to kind of knit together all those threads of history to come up with a definite conclusion.

That…

So, the idea of quantum algorithms is to make use of these many sort of parallel threads to do different computations in each thread. So the classic example of this is factoring integers, where if you want to know what are the factors of

3,722 or something. You could say, well, I'll try dividing that by 2, great, it divides by 2, so 2 is a factor. I can try dividing it by 3. I don't know whether 3 is a factor. No, it isn't in that particular case. But in any case, you can try dividing it by each different number, and

That if it divides, exactly, then that number is a factor, and so on.

Well, in a classical computer, roughly, to know how to factor that integer, you'd have to try dividing it by each successive integer.

And… But now in a quantum

if you said, well, I'm going to use all those threads of quantum mechanics separately, you could have one thread is divided by 2, one thread is dividing by 3, another threads divided by 5, 7, all the primes, and so on, and you could run all those threads in parallel.

So it was an algorithm invented in the early 90s by a chap called Peter Shaw, that,

kind of…

Tries to do that, tries to say, we're going to use all those parallel threads in quantum mechanics to do all those divisions all in parallel.

And then at the end, if a division worked, we'll be able to sort of detect that when we bring all these things together. It's not completely obvious how easy it is to do that detection. My own feeling is this is really one of these things that ultimately won't work.

And you kind of see that in the practical quantum computers people are making, there are all kinds of issues, but the idea is you use those parallel threads. The problem is.

You've… if we could perceive those parallel threads on their own.

then all well and good, but we can't. We can only perceive sort of the aggregate effect of those parallel threads, and in extracting that aggregate effect, we have to kind of put a bunch of computational effort in to kind of knit those threads together to get to a definite result.

in a sense, if our brains were… if our thinking was truly quantum mechanical, we would sort of see those threads separately, and we would be able to kind of sense what's happening inside the quantum computer. But as it is, we have to kind of classicalize what happens, and that, I think.

is something that's actually very difficult, and probably gives you no ultimate advantage by the fact that there are sort of all these threads in the middle. But there are a very limited number of algorithms that are known to be sort of doable, even in principle, with the standard sort of mathematical models of quantum mechanics. One of them is factoring integers, another is doing various kinds of searches over databases.

And that's kind of… that's kind of the main… that's pretty much it.

I mean, there are… there are, and so… people…

The factoring one, factoring integers one, is potentially important, even though I don't think it's ever gonna work.

But if it did work, it would be important, because a lot of cryptography is based on factoring integers.

So, in fact, public key cryptography that's used when, used for lots of kinds of… in… you know, all of us, every day, have used public key cryptography a zillion times.

Certainly probably hundreds to thousands of times.

In the way that websites secure themselves relative to your browser, in the way that, things happen with passwords, all that kind of thing.

I mean, the basic idea of public key cryptography is that

it is sort of a… you can have a key that allows you to encrypt something that's different from the key that allows you to decrypt something. So I can publish my public key and say, hey, here's a way that you can encrypt a message to be sent to me

And everybody knows how to do the encryption, but only I have the private key that allows me to decrypt the message.

And a bunch of public key cryptography, in fact, essentially all of it, is ultimately based on the apparent difficulty of doing factoring.

And roughly the way it works is that sort of one way round, you're multiplying numbers together to get a number, and the other way around, you're taking a number and breaking it into its factors. And

Taking a number of breaking into saturates is hard, but multiplying numbers together to get a number is easy.

And that's where the sort of security of public key cryptography comes from. So if a quantum computer could just immediately take all of those factoring problems and make them easy, then there'd be a problem with public key cryptography. And sort of in a day, if, you know, if the quantum computer worked.

in a day, all of that public key cryptography would, would disappear. Would not be secure anymore, because the thing where you assume that it's really hard to break it

To figure out a key without being told the key wouldn't be hard anymore, and so it wouldn't be a secure system.

So, I don't think this will happen. I think that that's not… it's not something… I think, as I say, that the… that the effort of measurement

is… is sort of not accounted for in the usual formalism, and is actually too large. But if you imagine that it could happen, then in a day, sort of all standard public key cryptography would… would sort of, be made insecure.

So people sometimes talk about, you know, post-quantum cryptography.

This is kind of a… it's kind of a little bit of a fake, because what it means is there are some algorithms, particularly so-called lattice algorithms for cryptography, which don't immediately depend on the difficulty of factoring.

And so here's the… it's a tricky story.

nobody's shown that there is no quantum algorithm that can break

Even in principle, these other forms of cryptography, it's just no such algorithm is known yet.

Okay, there's another tricky thing, which is that

there's cryptography, public key cryptography, actually cryptography in general, but public key in particular, depends on this idea of so-called NP problems.

computational problems. So an NP problem is that it stands for non-deterministic polynomial time problem. An NP problem is one where, sort of.

Knowing that you have the right… if you could guess the answer to the problem, you can check that the answer is right very quickly, but systematically finding the answer without knowing it can be very hard, and you may have to try sort of exponentially many possibilities in principle.

So, cryptography in general, and public key in particular, is based on these NP problems, which are sort of easy in one direction and hard in the other direction.

Okay, so it turns out that there's a notion of NP completeness which is certain kinds of problems, which are NP-type problems, have the feature that they are complete for NP.

Which means if you can solve that problem, you can solve any problem in NP. So, in other words, if it becomes easy to solve one of those NP-complete problems, then immediately all NP problems become easy to solve.

So, for example, there are NP-complete problems to do with whether a particular logic expression can ever be true for any assignment of truth values to the variables. There are NP-complete problems that have to do with whether you can find paths of certain kinds through graphs.

what, in practice, NP-completeness means is that given any one of these problems, like the thing with logic expressions or the thing with graphs, there's a way to encode one problem in the other problem.

So instead of a graph, you could take your graph and you can just say, well, which edge is connected to which other edge? And that would turn into a term in the logic expression, and so you can show an equivalence between the graph problem and the logic problem. So NP-complete problems, all of them are ultimately equivalent to other ones. They can all be encoded in each other.

So, if you could break one NP-complete problem, you've broken them all.

And if you can break one NP-complete problem, then all cryptography basically fails. You just can't do… you can't solve the problem of having something which is kind of easy to encrypt, but hard to decrypt.

Because, essentially, as soon as you… if you can solve all NP problems, then the thing… it's only hard to decrypt because you don't know the key.

But if you knew the key, it would be easier to decrypt. But it's an NP problem to go and say, well, that means it's an NP problem, because it's easy to check you got the right answer. It's easy to do the decryption if you know the key.

But if you could solve all NP problems, then you could just find those keys, easily. Just like in the factoring case I was mentioning, you just do all those pieces in parallel. You try all these numbers in parallel to see whether you've got it.

Well, in any case, so NP-complete problems, if a quantum computer could… I don't believe it will, but if it could solve an NP-complete problem, then all cryptography just crumbles.

Well, so the fact that there's a quantum algorithm, at least even in principle, for factoring, what does that mean? Well, it turns out factoring has never been shown to be MP-complete.

Maybe it is?

But that hasn't been proven. So what we know is there's a quantum algorithm for factoring, but factoring isn't NP-complete.

And that leaves the possibility that the quantum algorithm… so, so far as we know right now, there is no quantum algorithm which crushes general NP-complete problems. We have a quantum algorithm which, in principle, crushes factoring, but factoring isn't NP-complete.

So, that means that cryptography is still okay, because we don't have a quantum algorithm that crushes all NP-complete problems, only the class of NP problems that correspond to factoring.

So that's why people talk about post-quantum cryptography. They say, NP-completeness is going to be okay, there isn't going to be a quantum algorithm for doing NP-completeness, even though… but there might be a quantum algorithm, they say, for doing factoring, and so you've got to avoid all cryptography that involves factoring. I have to say, the cynical tech industry person that I am sort of says, well, it's kind of like there's an immense amount of infrastructure

that's based on factoring-type cryptography, and it's like, somebody's going to make a good living just replacing all that infrastructure with a different type of cryptography. I don't think that we have evidence
that if quantum computers could be made, which is a very big if, which I don't think is real, then, you know, then… and then we say, if quantum computers could be made, and quantum computers can crack factoring, but not general NP-complete problems, and not these other kinds of lattice problems and so on, then…
It will be worth, you know, reinstalling, you know, making your,
your system, work with these other forms of factoring. I have to say, I saw something just maybe yesterday. I was SSH-ing into a machine doing secure
secure connection to a machine, and it has a message that says, these keys are being stored. And, you know, be careful, because these keys might be stored way into the future when quantum cryptography… quantum algorithms become possible, and then somebody can go back
and take the key that you have here, and go back to what you were doing now, and use that to break into your computer. And I was like… I was kind of rolling my eyes, because the chain of dependencies where that message actually makes any sense is very bizarre.
So, I'm not, I'm not holding my breath for this all being relevant.
Let's see…
Gosh. Well, that's a very different question about,
From EMVO. Are we likely to see advances in targeted chemotherapy soon? Actually, it's not completely unrelated to the quantum biology questions.
So, well, what is chemotherapy?
when you get a tumor, and presumably we get… all of us get tumors all the time, but they're mostly… don't get very big, and our immune system kind of eats them up. But when we get a tumor that's big enough to cause a problem, then what's happening is that
Cells of some type are just replicating, replicating, replicating.
And, you know, in life as we know it today, we all grow to a certain size, and then we stop growing.
But tumors didn't get that message. Tumors are sort of a more primitive form of life that just keep growing and keep growing and keep growing, and that's a problem, because we have, you know, tens of trillions of cells in us. But if we suddenly have a tumor with 10 trillion cells.
It can disrupt lots of other things that are going on, and that's bad news. So the question is, how do you… how do you get rid of these things? Well, you can just cut them out if they're a solid tumor somewhere.
Maybe, if they don't leave over little pieces, but the other thing you can do is you can say, well, what's special about the cells that are in the tumor that's different from cells in the rest of your body? And can you essentially poison the cells in your tumor without poisoning the cells in the rest of your body? So chemotherapy, the idea is that you use some attribute of the cells in the tumor to
You give a drug that, or a chemical that,
will have an effect on the cells in the tumor, but not other effects on other cells in your body. So sometimes you just use the fact that tumor cells replicate more often than most other cells in your body, and you just zap all cells that replicate.
But if you're lucky, the tumor cells will have some particular characteristic. They will be cells of a certain type that have certain receptors on their cell surface, and you can just say, I'm going to send in some chemical that will just go and attack

cells that have that particular receptor on their surface. The thing that gets really tricky with tumors is that

They… the cells in them evolve, because they're all replicating all the time, and natural selection operates, and cells that sort of are evading the chemotherapy, for example, there'll be more of those cells, and so you'll have to change the… the tumor will kind of change its character.

And that's… that's a big trickiness, and certain kinds of…

kinds of cancers have more of that kind of trickiness than others, and it's a difficult business. And sort of some of the modern methodologies involve saying, these are the different kind of mutation pathways that tumors typically follow. Let's stop them before they get to that particular mutation, because while the thing is still small, and there's only a few cells of that type.

you have a much better chance to stop it than if it gets to be lots of cells of that type. So one of the things that is… one of the sort of technologies is… oh, and another thing to say is that one of the surprising things about chemotherapy is that using many drugs at the same time has often been found to be much more effective than just using one at a time, and that's probably because there's a certain… there are different types of cells in the tumor, and you have to zap all of them, so to speak.

And in some cases, it's like, there'll be mutations that lead to other ones, and if you're already ready to prevent that mutation path, then you can prevent that happening.

But, you know, there are many things that… it's a very complicated subject. I mean, there are many things, you know, tumors have a habit of pulling more blood vessels into them, and so you can do things based on that.

You can… another thing you can do

is you can start saying, let's try and do things to make it easier to deliver, a target to the tumor.

There are some things with, little magnetic

Things where you, you, you put…

little nanoparticles that are magnetic in, and you use a magnetic field to lead those nanoparticles to the tumor, and then when they get to the tumor, they kind of, you know, they blow up and try and poison the tumor. You can do

There's just all kinds of different approaches. Another approach, immunotherapy, has to do with getting the immune system to do what it probably normally does, and just go attack the tumor.

It doesn't tend to attack the tumor because the markers of whether the cells are cells from you or cells from… or some antigen, some external cells, the tumor has kind of faked itself as being your own cells, but it still has

differences from your cells, and the immune system and your antibodies and T cells and so on can

can detect… potentially detect those differences, and if you try and give sort of a more intense collection

of,

if you try and sort of stimulate the immune system to produce more cells that are targeted to the differences that exist in the tumor cells, then the immune system can be more effective. In the same way that if you're infected with some kind of virus, the immune system cells, the immune system amplifies the types of cells that will be the right ones to bind to the…

the markers of the virus and, and get rid of that virus. So the same thing can be done for tumor cells, and that's one of the big, sort of, things that was what mRNA vaccines were originally developed for before they got used for things like COVID, was the idea was to, still is, to have, kind of a, To be able to make a custom, basically custom antibodies that will go and attack your particular tumor.

There's a… Oh boy, there's a long list of these things. There's a so-called CAR-T therapy that's, what else does that stand for? Chimeric.

antigen or chimeric. The T stands for T cell.

So this is, using sort of custom-made T cells. T cells are part of the immune system. T cells actually go and, directly attack other cells. Antibodies just label cells to be attacked by T cells. But T cells just directly go and attack cells, and the idea is to put in T cells that will directly attack tumor cells, and that's something that's actually worked in some trials spectacularly well. For leukemias and things like that, where there are… where the… where the cells that are replicating without limit are just individual cells, like… like blood cells and so on, rather than a piece of solid tissue, so to speak.

But anyway, there's a lot of,

There's a… there's a… I would say there's a lot of motion in… in terms of…

new approaches to chemotherapy, whether that's understanding better, sort of, the mutation paths of tumor cells, whether that's, these sort of targeted, sort of immune system approaches, or even these physical things, like

Leading, leading, sort of, drugs to the tumor with… by magnetic means and things like this.

Which is all quite encouraging.

I think I need to go to my… Day job, here.

I'm just gonna… I'll address one more

question here from X7. It says, when you put a stem cell into the heart, it becomes a heart cell, so maybe it's based on neighbors, what type of cell something becomes. Is that something that we've explored with cellular automata, et cetera, et cetera, et cetera?

You know, the premise here, when you put a stem cell into the heart, it will become a heart cell. That was a claim made about 10 years ago. It doesn't seem to have panned out very well, unfortunately.

It would be very nice if you could say, I'm just going to inject stem cells, and they'll migrate to the places where they're needed, and differentiate into the types of cells that are needed. It doesn't seem to work that way.

In practice, when people make stem cells, they can… you can reprogram, sort of, any

kind of cell using this sort of cocktail of chemicals, Yamanaka factors. You can reprogram any cell to go back to sort of its stem cell state, where it is a pluripotent stem cell, where it has the potential to turn into anything. But then, there are particular protocols known to turn a stem cell into different kinds of cells. So, for example.

There are protocols known to do this for a day, that for a day, another thing, this nutrient, that, that condition, and so on, and in 10 days, you'll have a heart cell. Or in 70 days, you'll have a brain cell.

And they're very… they're things which sort of cry out for being automated in terms of automated labs and so on.

But, you're kind of attending your stem cells to get them to turn into a certain kind of differentiated cell. It doesn't seem to be the case that there's a kind of one-shot thing where you just stick it in, inject it, and it'll just go to the right place, and by virtue of its environment, become the right kind of cell. Instead, it seems like it needs this very elaborate sequence of steps

That maybe reproduce the sequence of steps and the, you know, they're sort of rough approximations, the sequence of steps in the embryo that lead to that differentiation of cells. And it's sort of an interesting question whether you can find, you know, with some fancy machine learning method or some such other thing, where you can find sort of the minimal sequence of pokes that you need to make to a cell, to a stem cell, to get it to turn into a cell of a particular kind. You know, there are maybe a couple of thousand types of cells that we know of in humans to get it to turn into each one

of those cells. It would be very useful to know what's the minimal set of sort of chemical treatments that you need to give

To… to make a given… make a stem cell turn into each of those different kinds of cells. It's been a challenging thing. I mean, a famous kind is pancreatic beta cells that produce insulin, which I think need 12… in the embryo, I think they have 12 steps of,

of kind of differentiation from one kind of cell to another to another, and so on. And there's a procedure that's known, I don't know how long it takes, 30 days maybe, something like that, to produce beta cells from stem cells.

It's, I think the,

this whole question about can you just inject cells and have them do the right thing? The only case that's very popular right now is mitochondria.

Mitochondria are sort of individual organelles inside cells. Probably 3 billion years ago, they were probably independent bacteria that got ingested into a cell and became the energy source for all of our cells. They actually have a lot of symbiotic

behavior relative to cells, because the proteins that are used in mitochondria, some of them are generated by… from nuclear DNA, from the DNA of the actual host cell. They aren't… but the mitochondria divide separately when cells divide, and any given cell has lots of mitochondria in it.

A fairly recent discovery is that mitochondria can migrate from one cell to another. So constantly in your bloodstream, there are lots of mitochondria that are flowing from places where you need less energy to places where you need more energy.

And so, it's… it's something… this is a surprising thing, but on timescales of, I think, minutes, mitochondria can be moving from, sort of, one type of cell in your body to another type of cell in your body. Again, how important is the effect? It seems to be an important effect, but it's like one of these things where there's an infinite chain of footnotes, and there'll be some version of that effect.

How important it is, is hard to tell.

But that means that it becomes interesting to, try and say, well, let's just give you better, stronger, healthier mitochondria. And, that's a,

That's something where, the, there are efforts underway,

To basically take mitochondria, like your mitochondria, and if you're an old person, many of your mitochondria don't work so well anymore,

The, but…

you can select some which do work well, take those and start replicating them in a bioreactor, and just something that just grows more and more cells. You get more and more and more mitochondria that are nice, healthy, strong mitochondria, then you inject them into yourself, and then you potentially have sort of a younger, healthier set of mitochondria that can add more energy to different cells in the body.

This may be a big deal.

this may be a kind of, you know, an elixir of, of youth or something. That's… it's looking somewhat promising that this will be that way. Now, of course, in biology, there are always footnotes, and it could very well be the case that, you know, if it's an old you, and you inject all these fresh, young mitochondria, they're making you, you know, try and do things that are, like, very high energy. It's like.

like, okay, now we've got all these mitochondria, you feel like you can, you know, jump, you know, jump high up, but actually there are other aspects of you, like your connective tissue or something, that isn't really up to the jump high, and so you land and you scrunch your ankle, or something like this. So it's, you know, it's not obvious that just adding, sort of, more energy from your mitochondria is going to be of systemic value.

But in any case, it's one of the, sort of, coming attractions of, kind of, medical, possibility.

I will say that I think, I haven't really seen a plot, but it would be an interesting one to see, coming back to the chemotherapy question, of sort of… there'd been a progression of types of tumors where more is known about, kind of, what

kind of chemotherapy can be used. It helps a lot when you can sequence a tumor, find its genetic sequence, because ultimately, what happens in tumors is that, presumably.

is, and I say presumably because there's still some uncertainty about this, certainly an effect in tumors is that their genetics is different from the… from your genetics, and it's often quite messed up.

But whether that's the cause or the effect is not completely clear. Probably it's the cause, and that means that if you want to know, sort of, what's the evolution of this tumor, what is it like

what will it respond to? What will it be attacked by? Getting these genetic sequences for the tumor and seeing how they differ from the genetic sequences for you is an important thing, and that's something where there's more and more technology available for that, and more and more different possibilities for, you know, how to attack

Different kinds of tumors based on that information.

So I'm, you know, whether, sort of, the cure for cancer will be, you know, at this point, many kinds of tumors are quite manageable, and, you know, the problem is always that the tumor, sort of, metastasizes, moves to other places in the body, and changes the types of cells that are in it. So that whatever it is that you were using in chemotherapy or something to sort of push down that tumor, there's now a new type of cell that isn't affected by that chemotherapy, and that can cause trouble.

But I haven't seen a plot, I'm sure somebody's made one, of kind of… if you look at all the different types of tumors that are known, all the different cell types that can lead to tumors and so on, over the course of years, how many of them do we now know pretty good

chemotherapy agents for, and I know it's, you know, it's an increasing number, but I don't know what the, you know, what the chart looks like, and how close we are to done, so to speak.

But that's, something to,

to look forward to, I guess.

All right, well, I should, you've asked a bunch more questions here, which I'm very inclined to try to answer, but I can't do it right now, so we'll have to wait for another time. But thanks for asking lots of interesting questions, and

Bye for now.