




# QUANTUM BIOLOGY

## TRUTH OR DARE IN COGNITION

- 
- "I cannot define the real problem, therefore I suspect there's no real problem, but I'm not sure there's no real problem."




Richard Feynman

# Could a set of differential equations shed light on a complex system (a living being)?

- Biological enzymatic catalytic reactions
- Photosynthetic light harvesting
- Avian magnetoreception
- Sense of smell
- Turing patterns and morphogenesis
- Schrödinger predicted several of the functional features of DNA

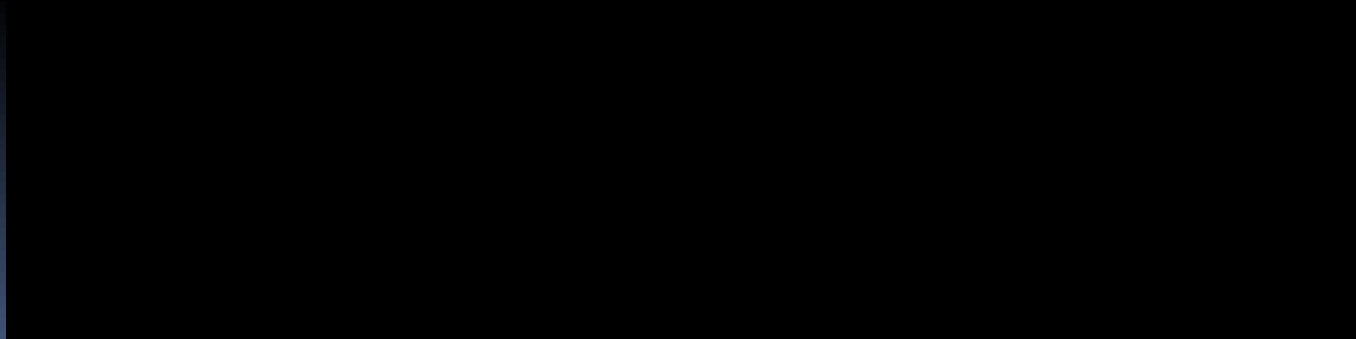


# Tunnelling in biological systems

- In quantum tunnelling, an electron can pass through a material to jump from point A to point B in a way that seems to bypass the intervening space. The crucial factor is resonance.
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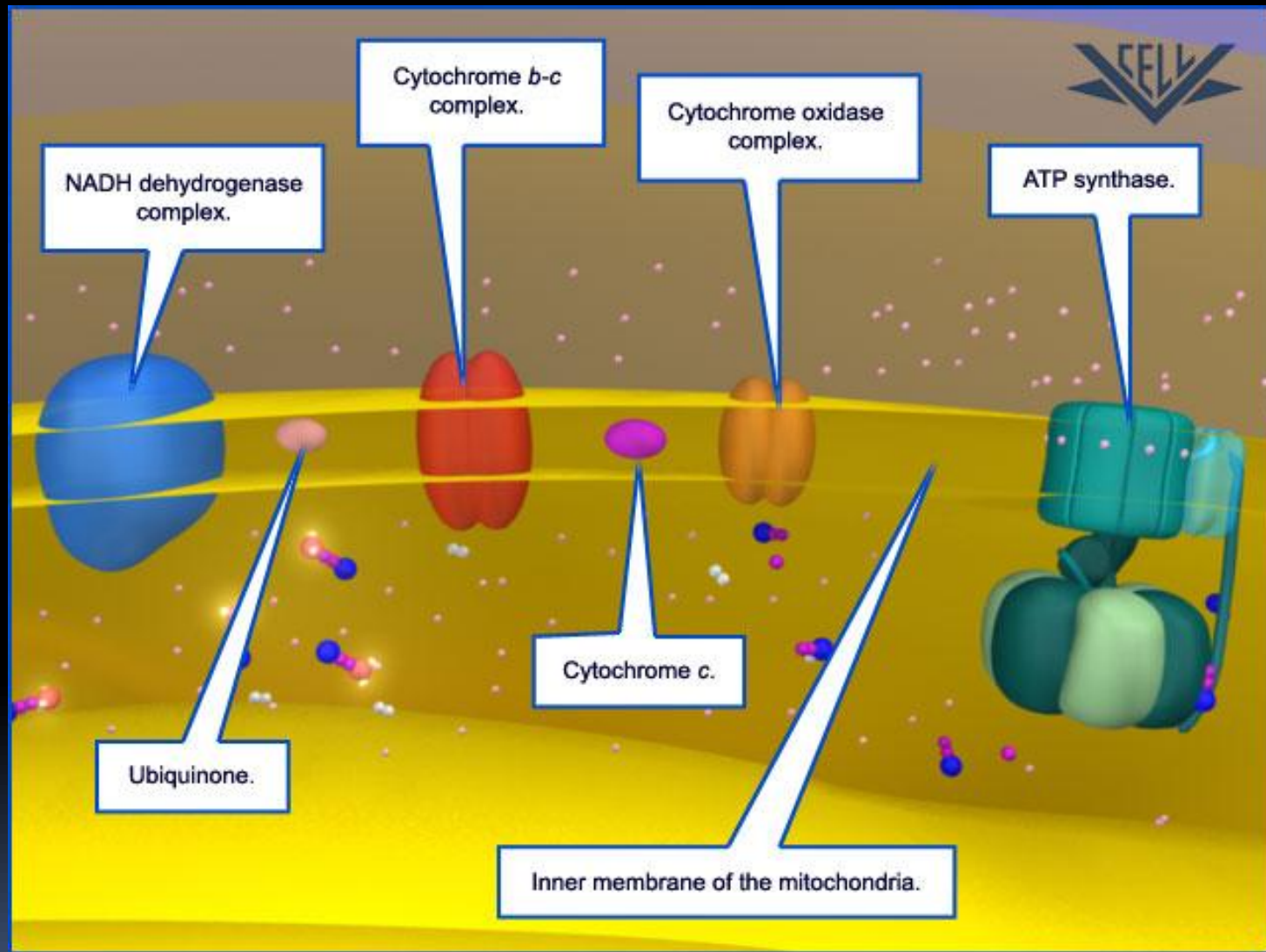


# Tunnelling in biological systems



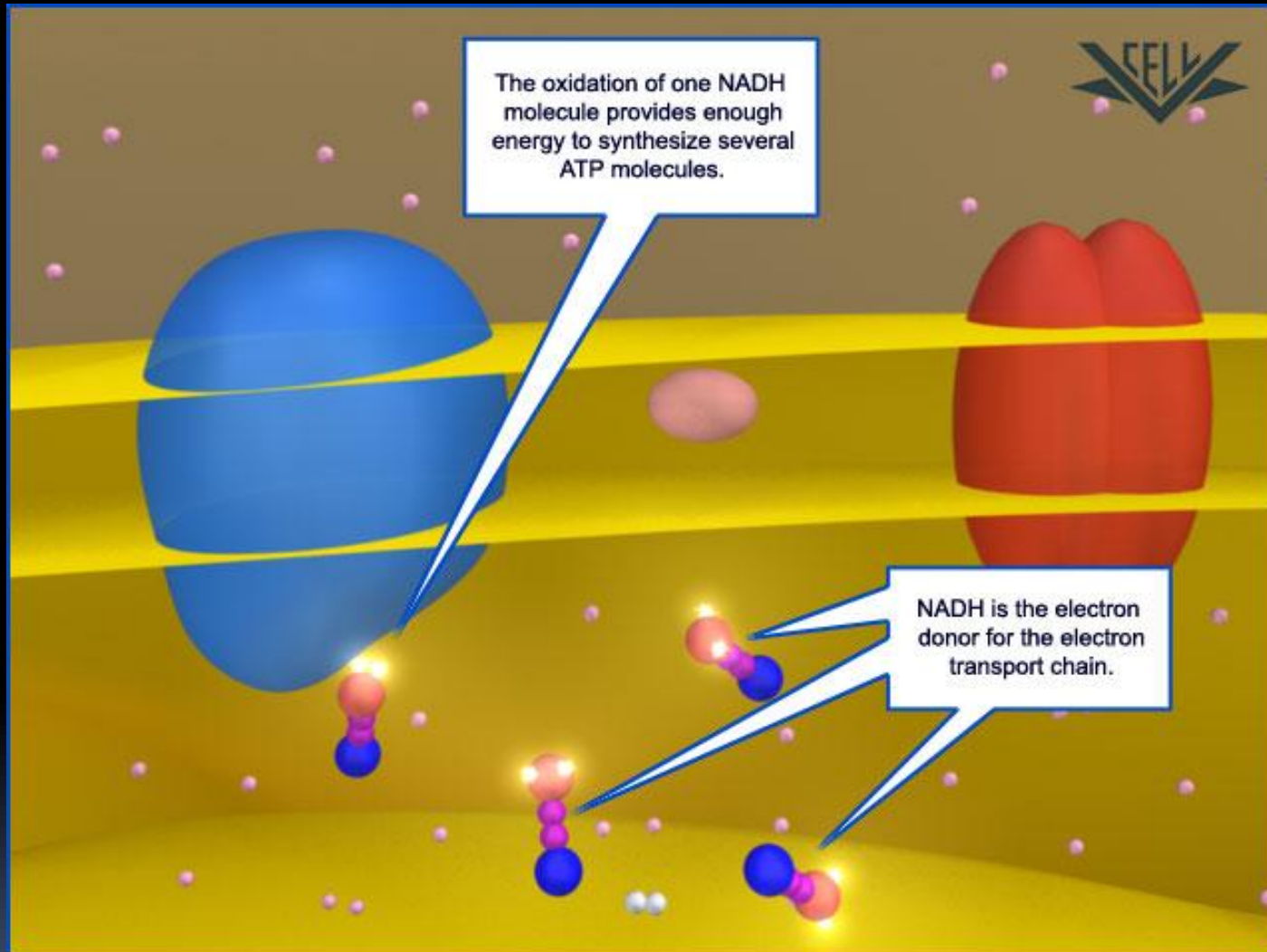
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# Electron transport chain



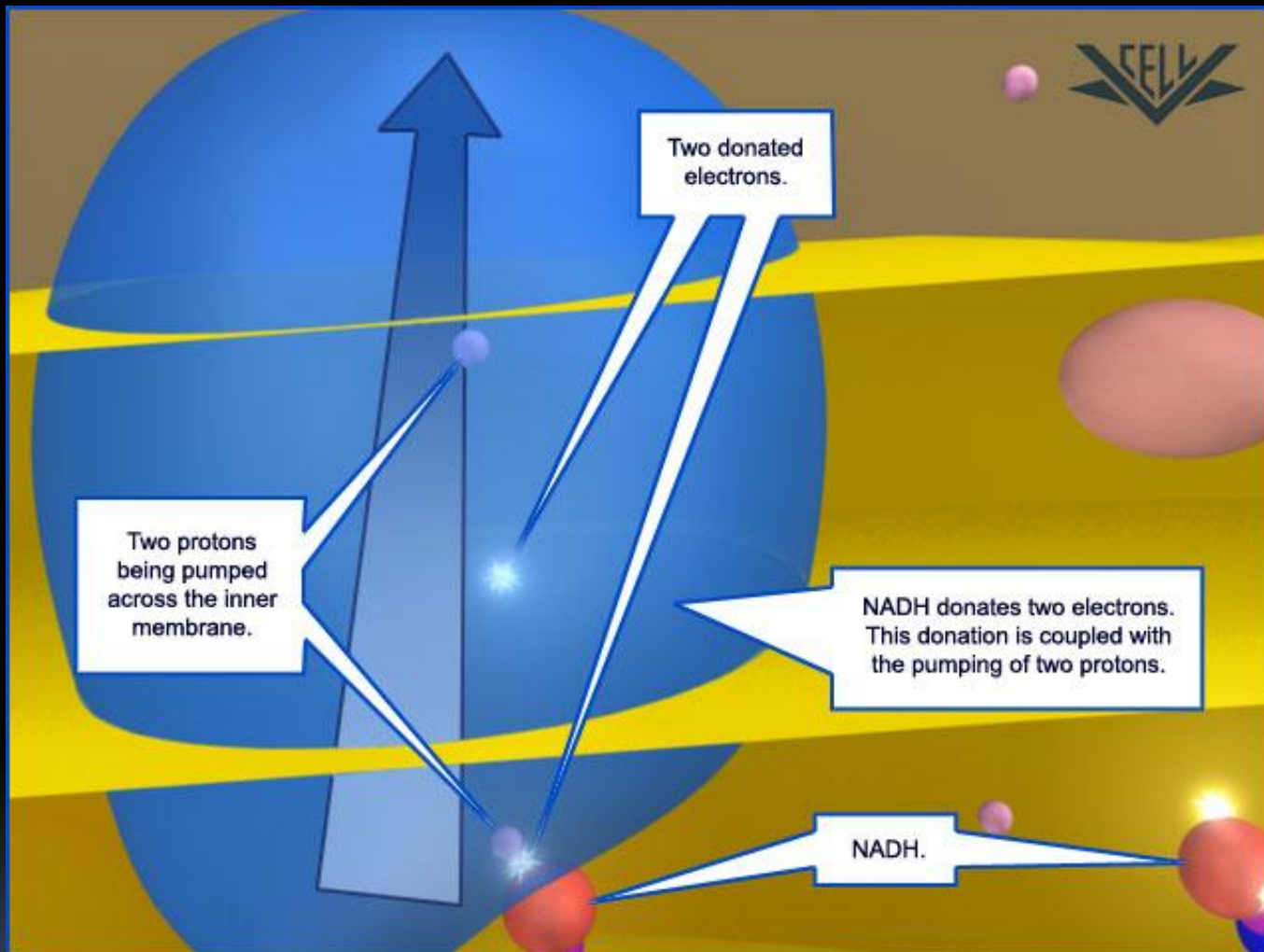
The electron transport chain is embedded in the inner membrane of the mitochondria. It consists of four large protein complexes, and two smaller mobile carrier proteins.

# Electron transport chain



NADH is the electron donor in this system. It initiates the electron transport chain by donating electrons to NADH dehydrogenase (blue).

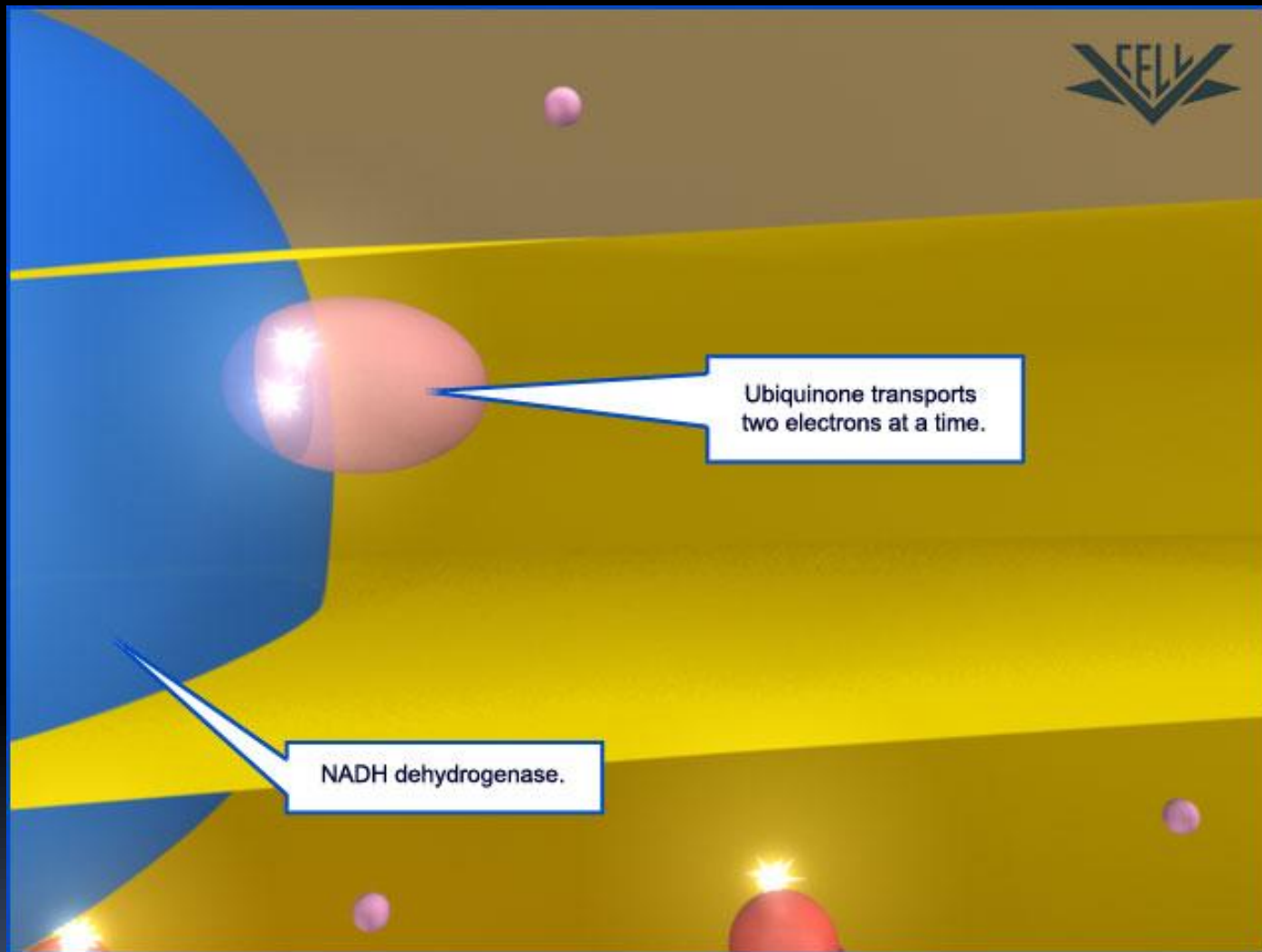
# Electron transport chain



NADH donates two electrons to NADH dehydrogenase. At the same time, the complex also pumps two protons from the matrix space of the mitochondria into the intermembrane space.

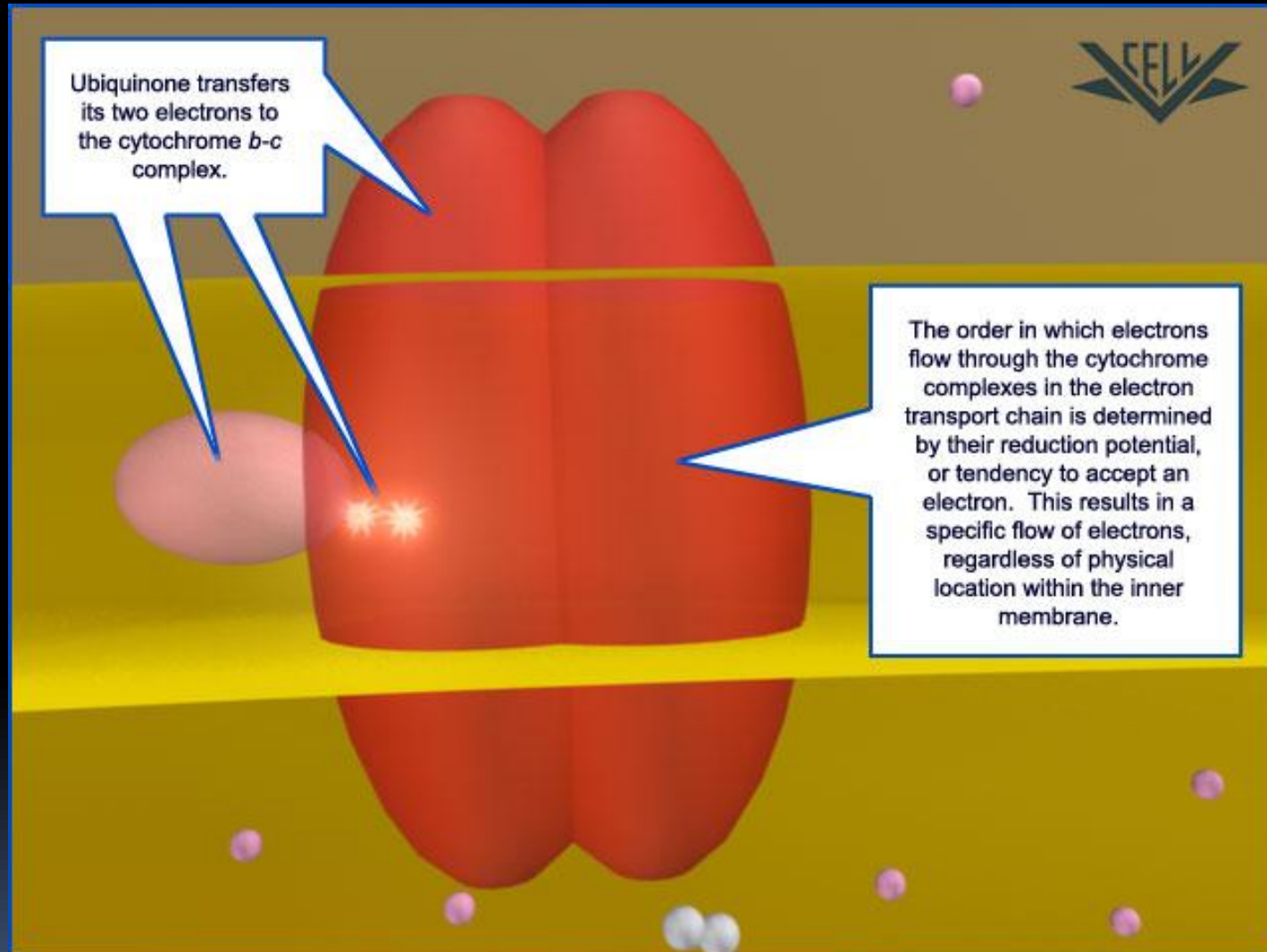


# Electron transport chain



The two electrons are now transferred to the mobile carrier protein known as ubiquinone. Ubiquinone transports the electrons, two at a time, to the next complex in the chain.

# Electron transport chain

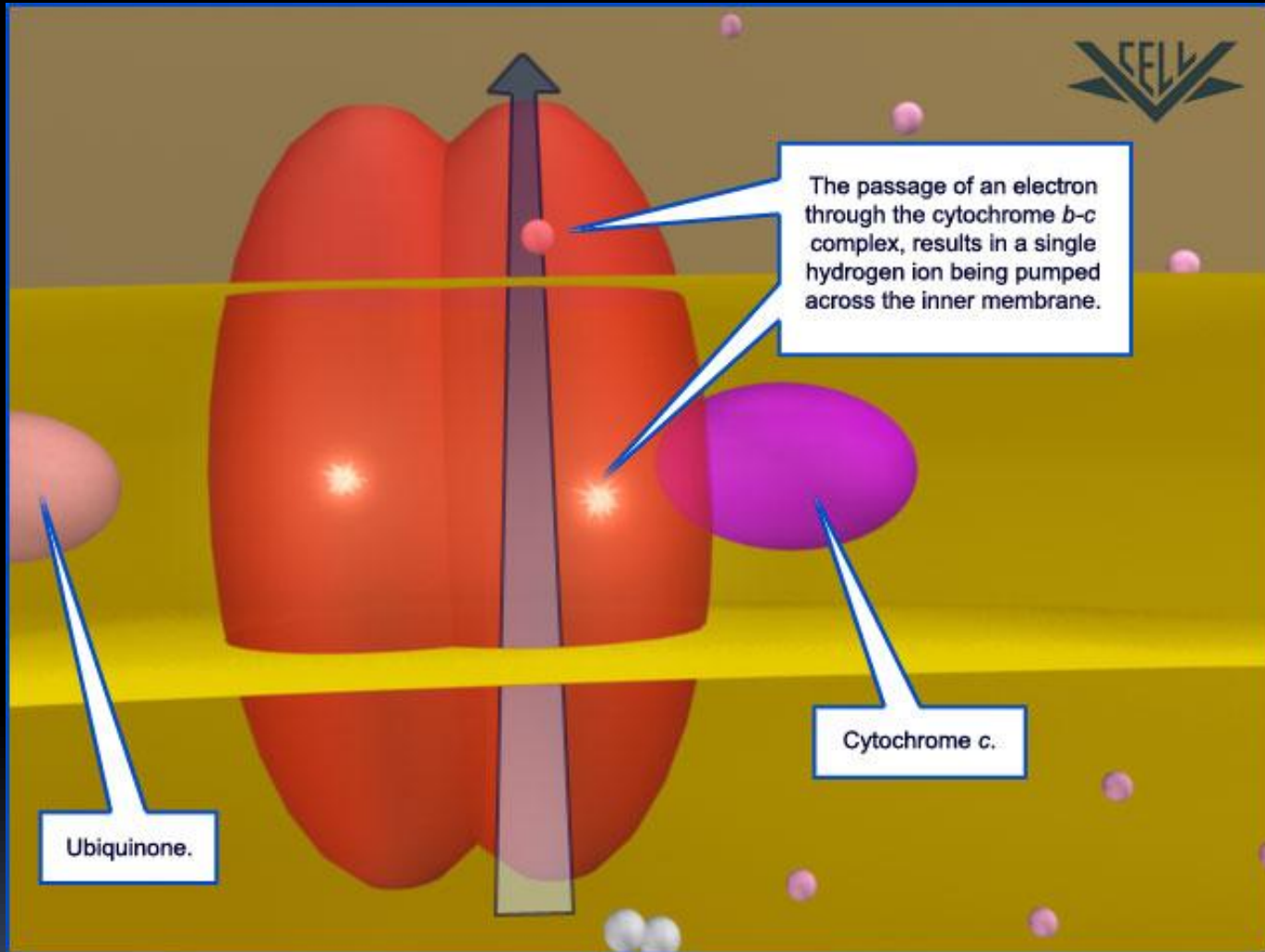


Ubiquinone transfers its two electrons to the cytochrome *b-c* complex.

The order in which electrons flow through the cytochrome complexes in the electron transport chain is determined by their reduction potential, or tendency to accept an electron. This results in a specific flow of electrons, regardless of physical location within the inner membrane.

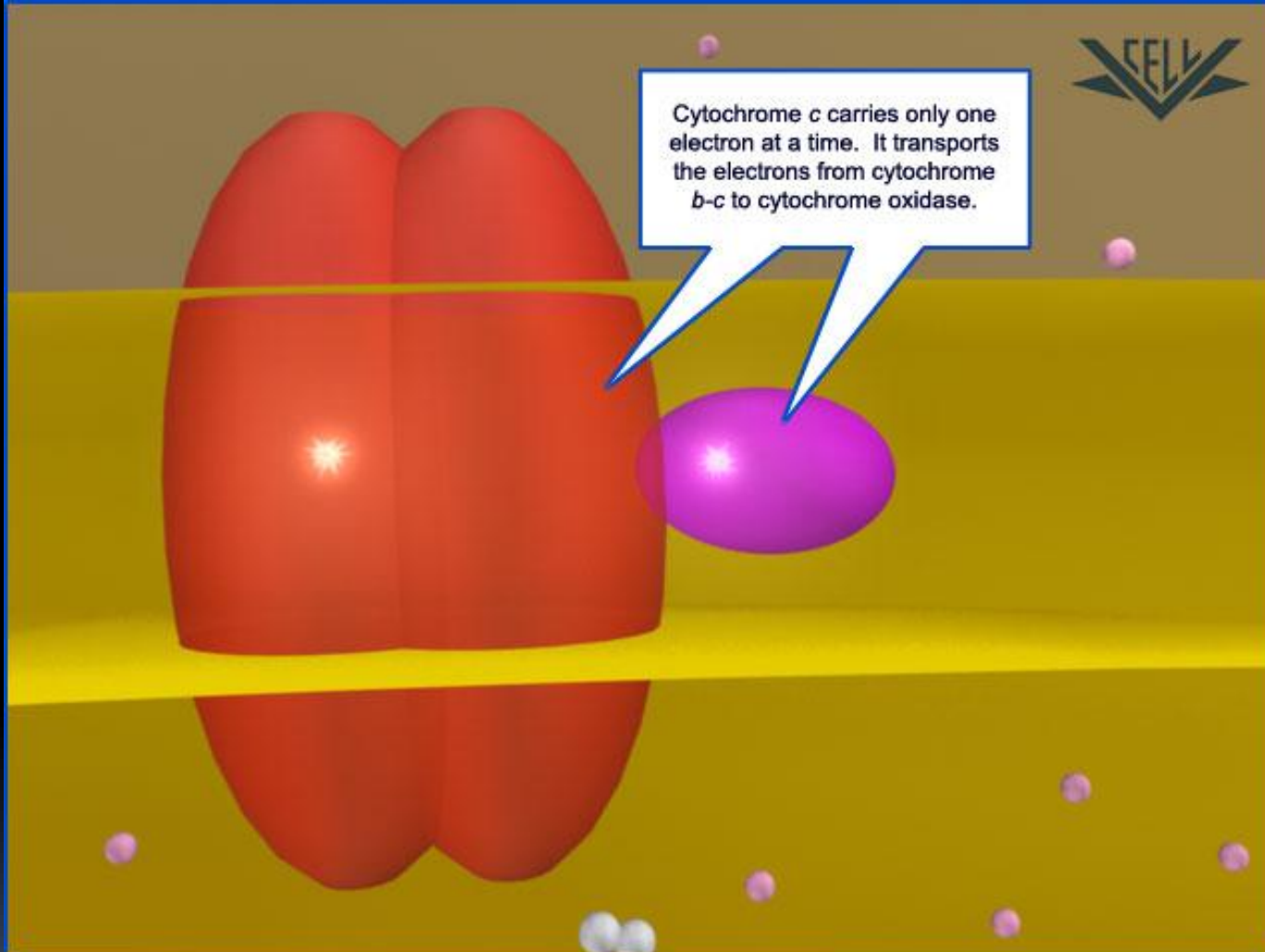
Ubiquinone (pink) delivers two electrons at a time to cytochrome *b-c1* (red).

# Electron transport chain



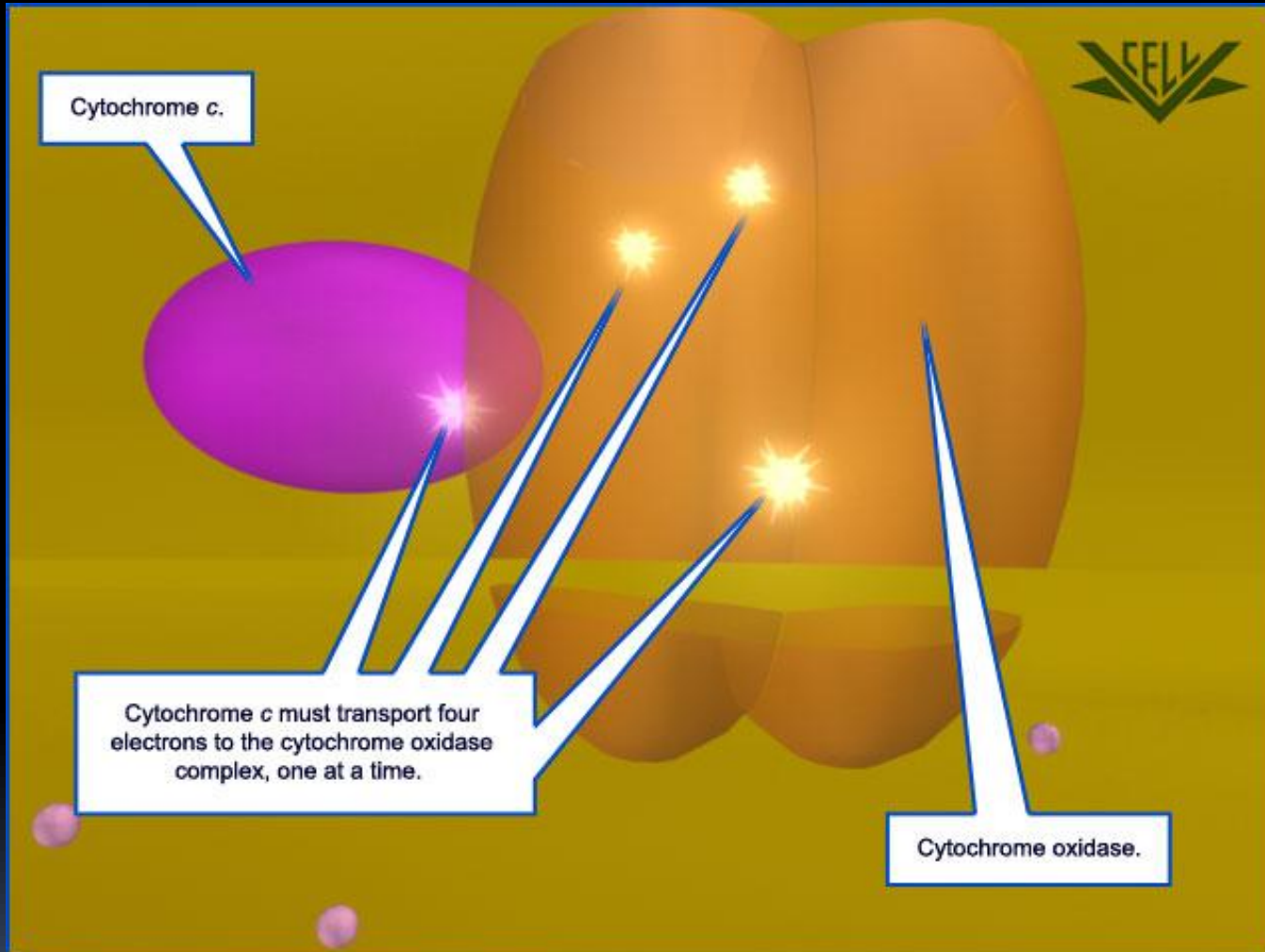
As each electron makes its way through the complex, a hydrogen ion (proton) is pumped from the matrix space of the mitochondria into the intermembrane space, helping to maintain the proton gradient.

# Electron transport chain



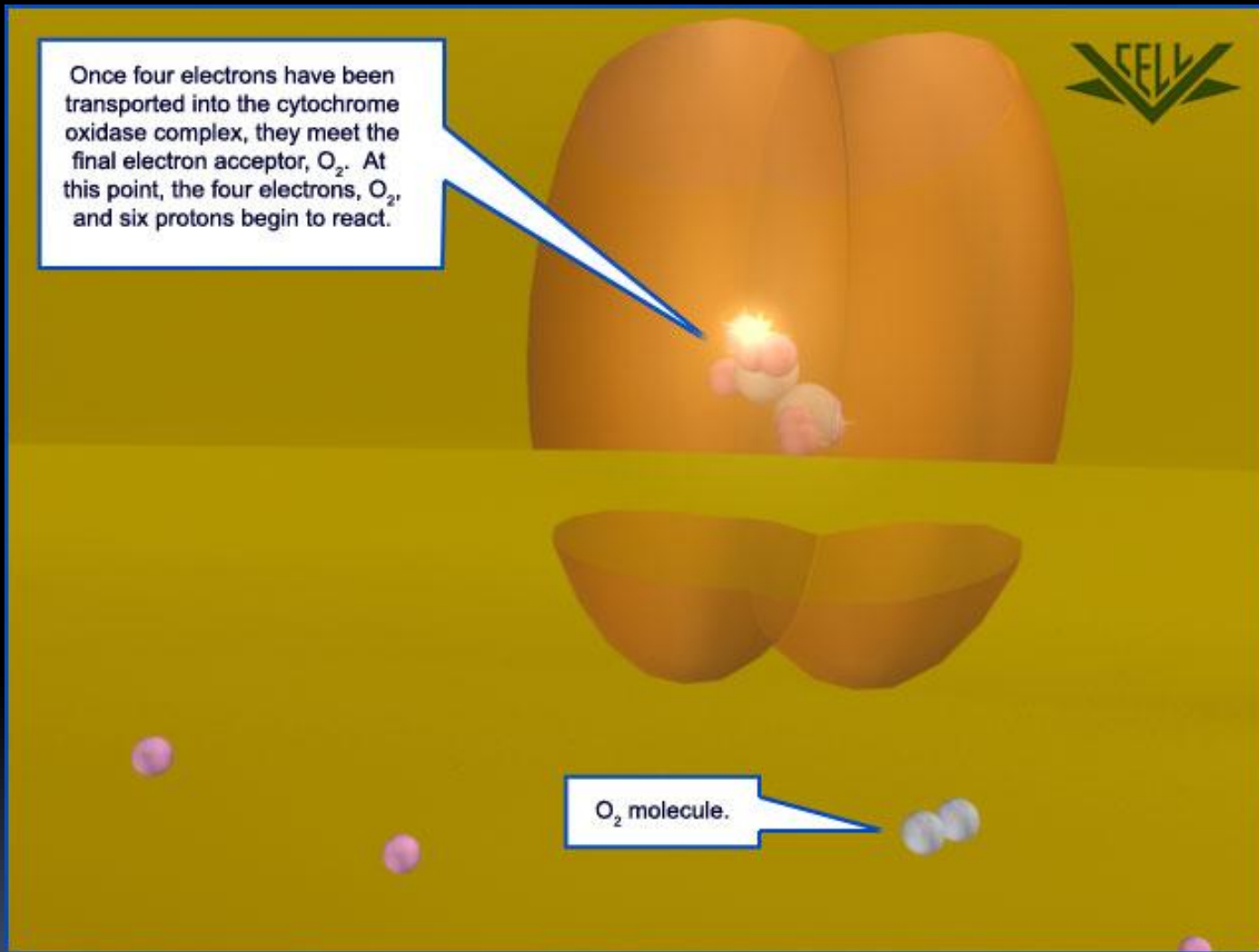
After affecting the pumping of a proton across the membrane, the electron leaves cytochrome *b-c1* and enters the mobile carrier protein, cytochrome *c* (purple).

# Electron transport chain



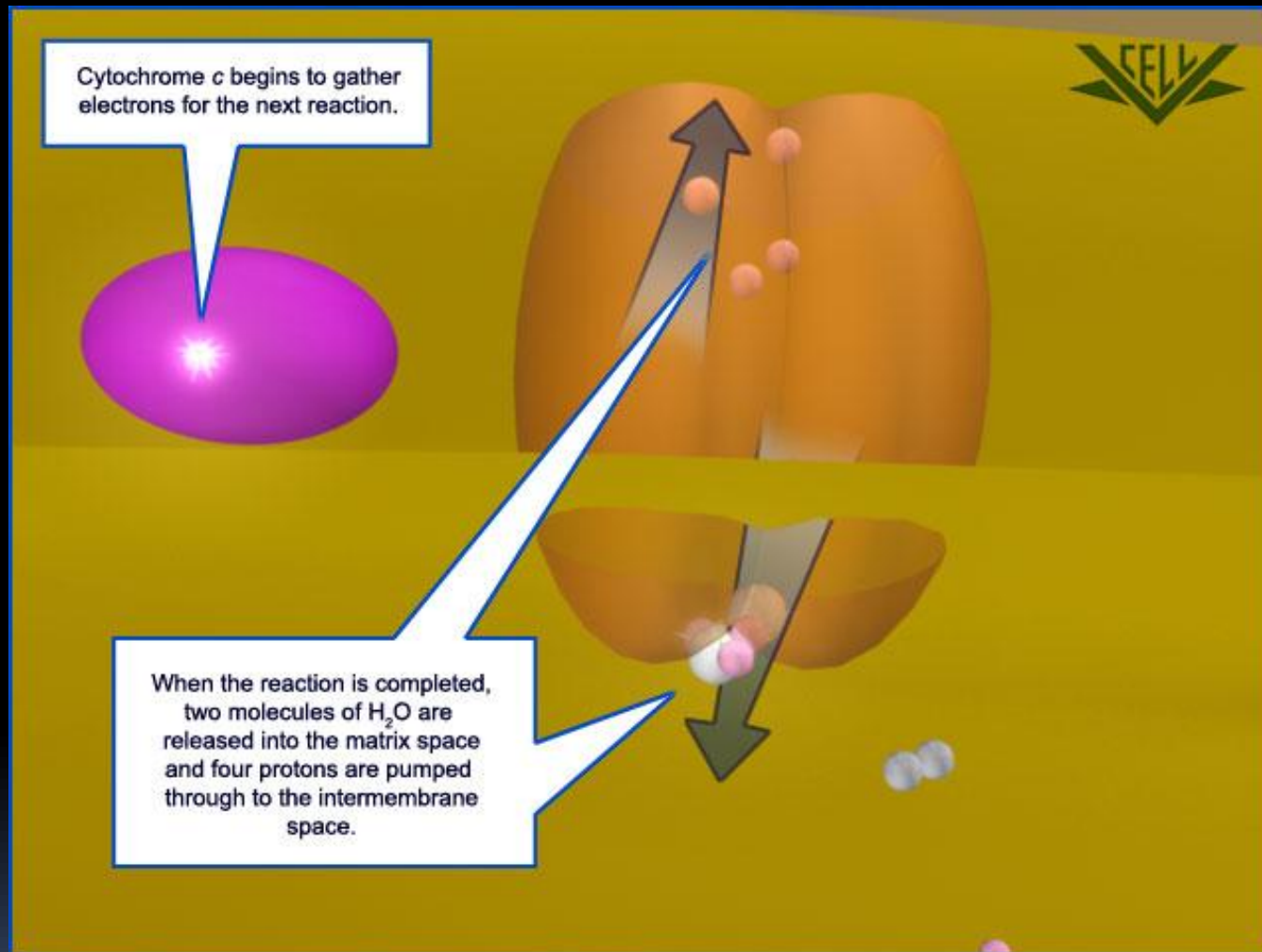
The mobile carrier protein cytochrome c (purple) transfers electrons, one at a time, to cytochrome oxidase (orange). Four electrons must be transferred to the oxidase complex in order for the next major reaction to occur.

# Electron transport chain



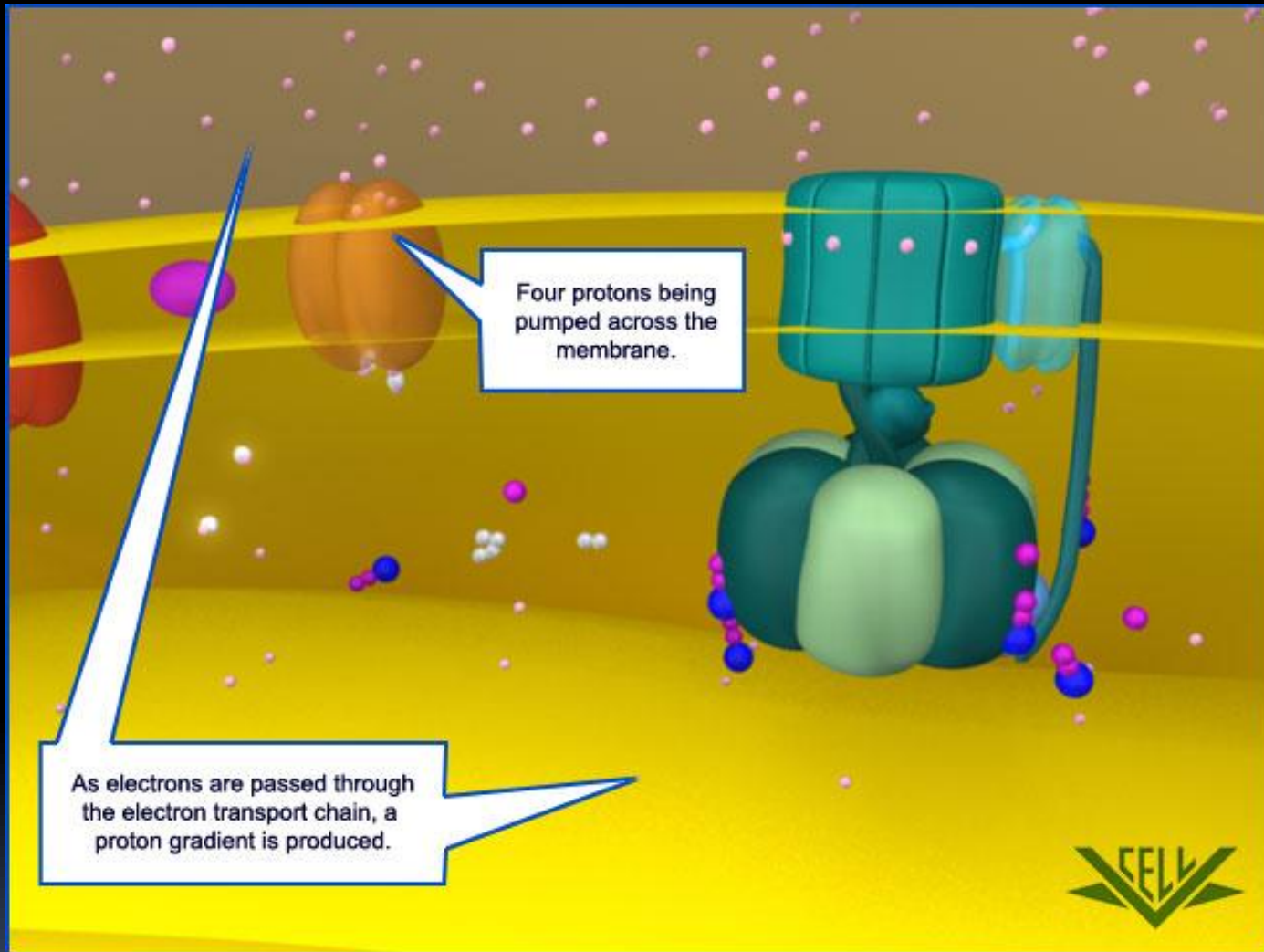
The next major event is the reaction of the four electrons, a molecule of  $O_2$  (oxygen), and eight protons.

# Electron transport chain



The reaction results in the pumping of four hydrogen ions across the inner membrane into the intermembrane space, and the release of two H<sub>2</sub>O (water) molecules into the matrix space.

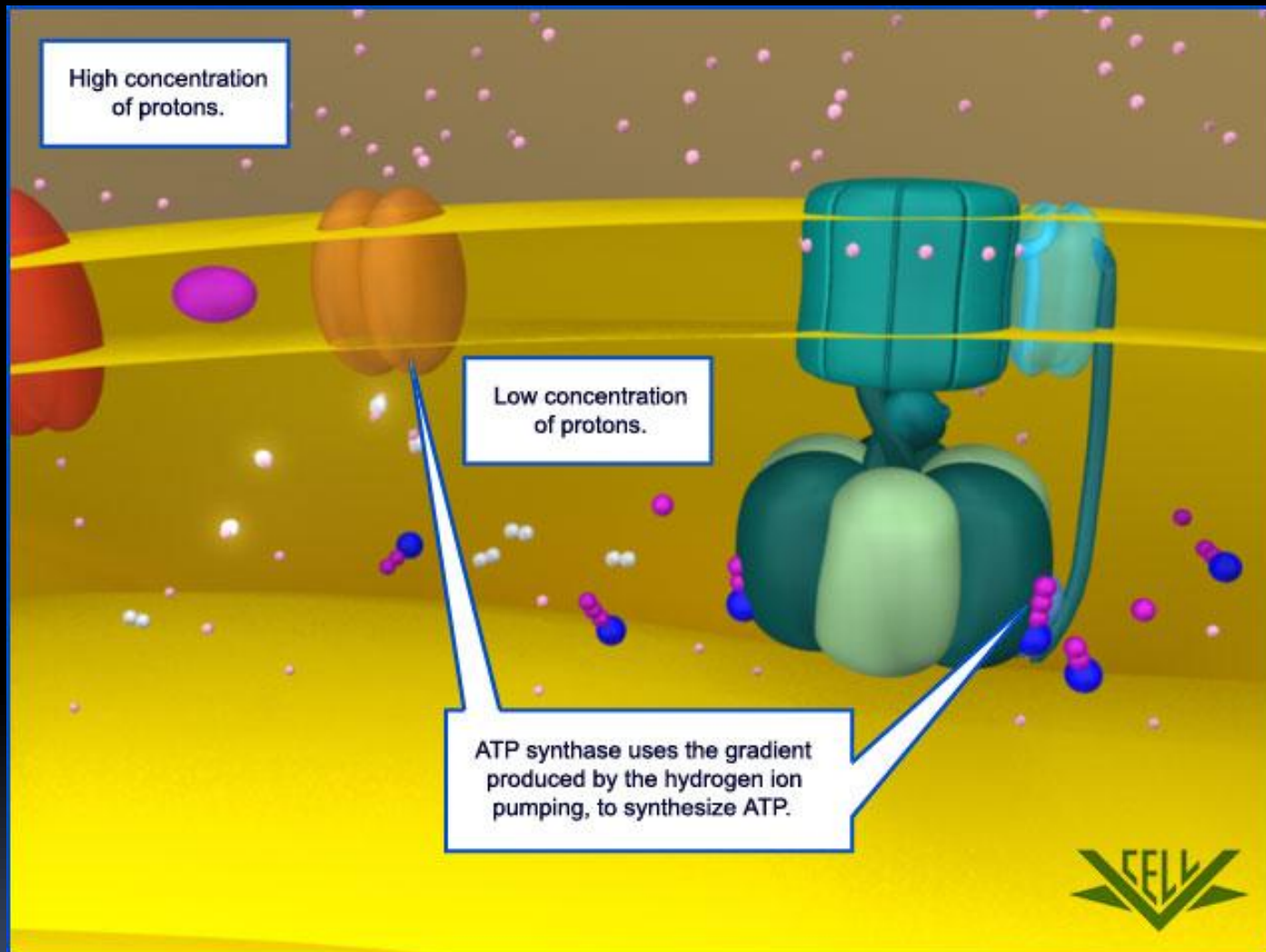
# Electron transport chain



ATP synthase accepts one proton from the intermembrane space and releases a different proton into the matrix space to create the energy it needs to synthesize ATP. It must do this 3 times to synthesize one ATP from ADP and Pi (inorganic phosphate).



# Electron transport chain



With the supply of NADH exhausted, the electron transport chain can no longer maintain the proton gradient that powers ATP synthase, and ATP synthesis comes to a stop.

# Electron transport chain

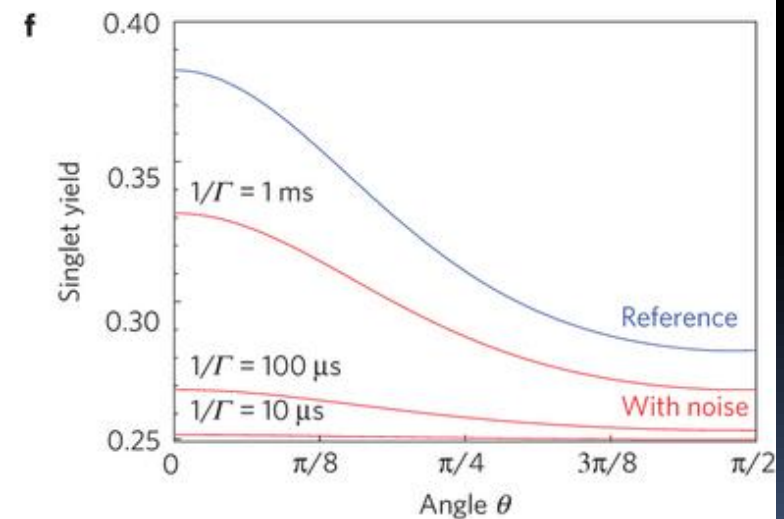
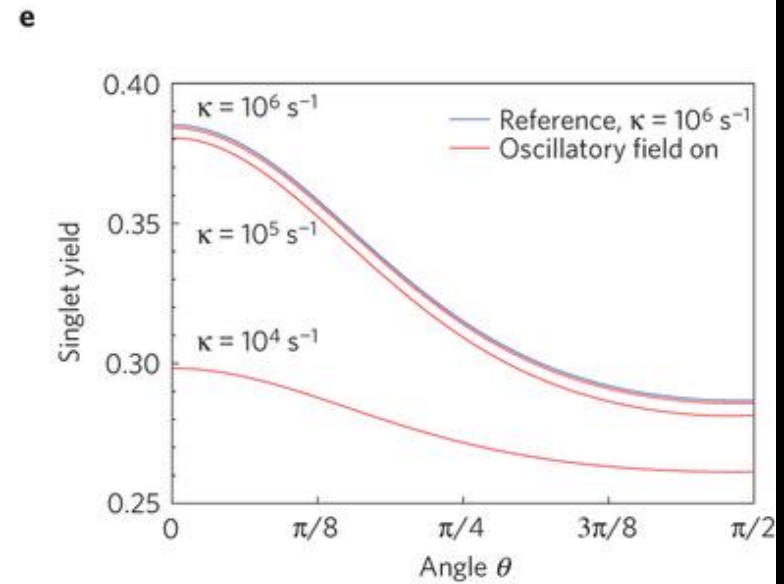
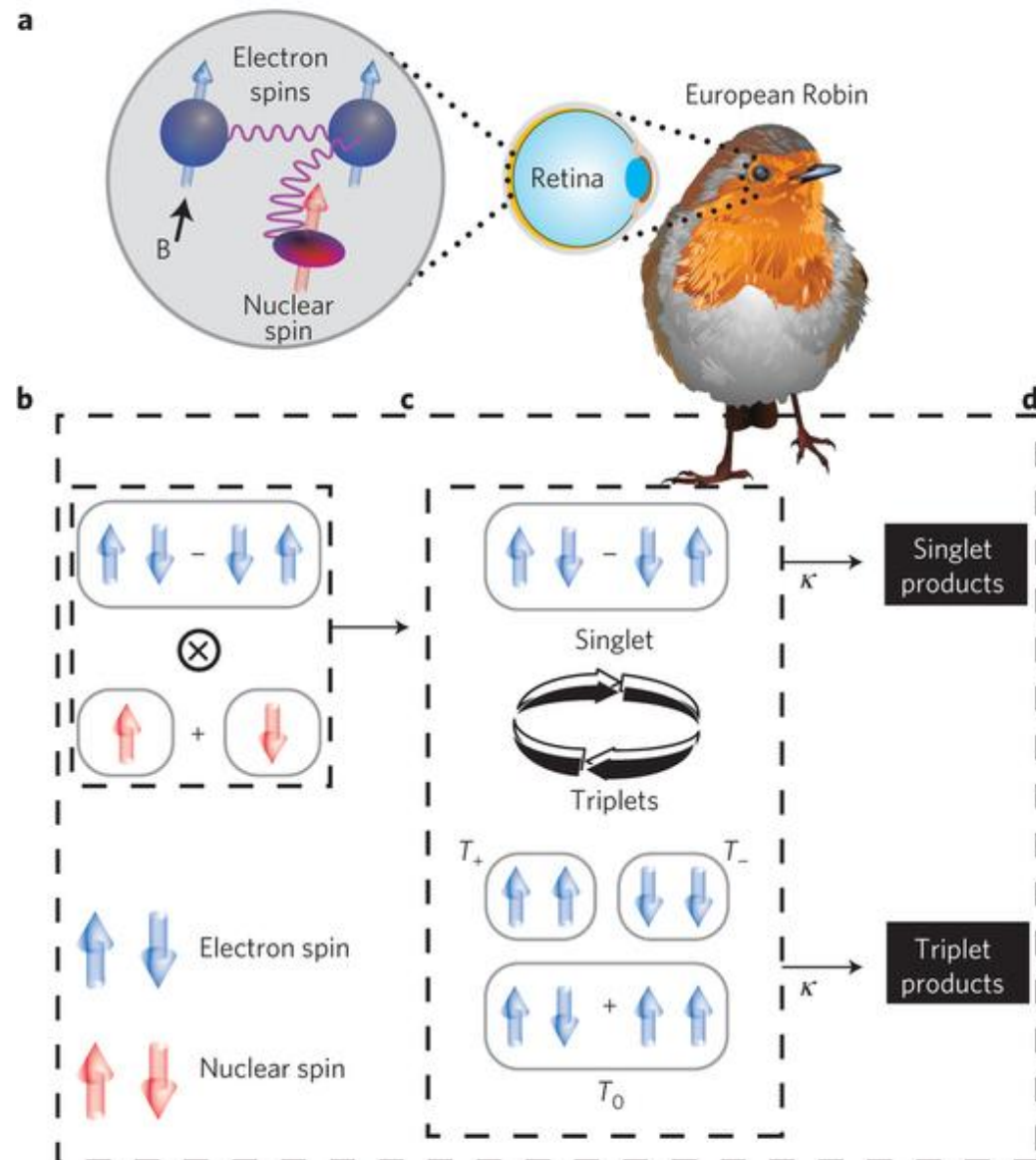
<http://vcell.ndsu.edu/animations/home.htm>

# Photosynthesis

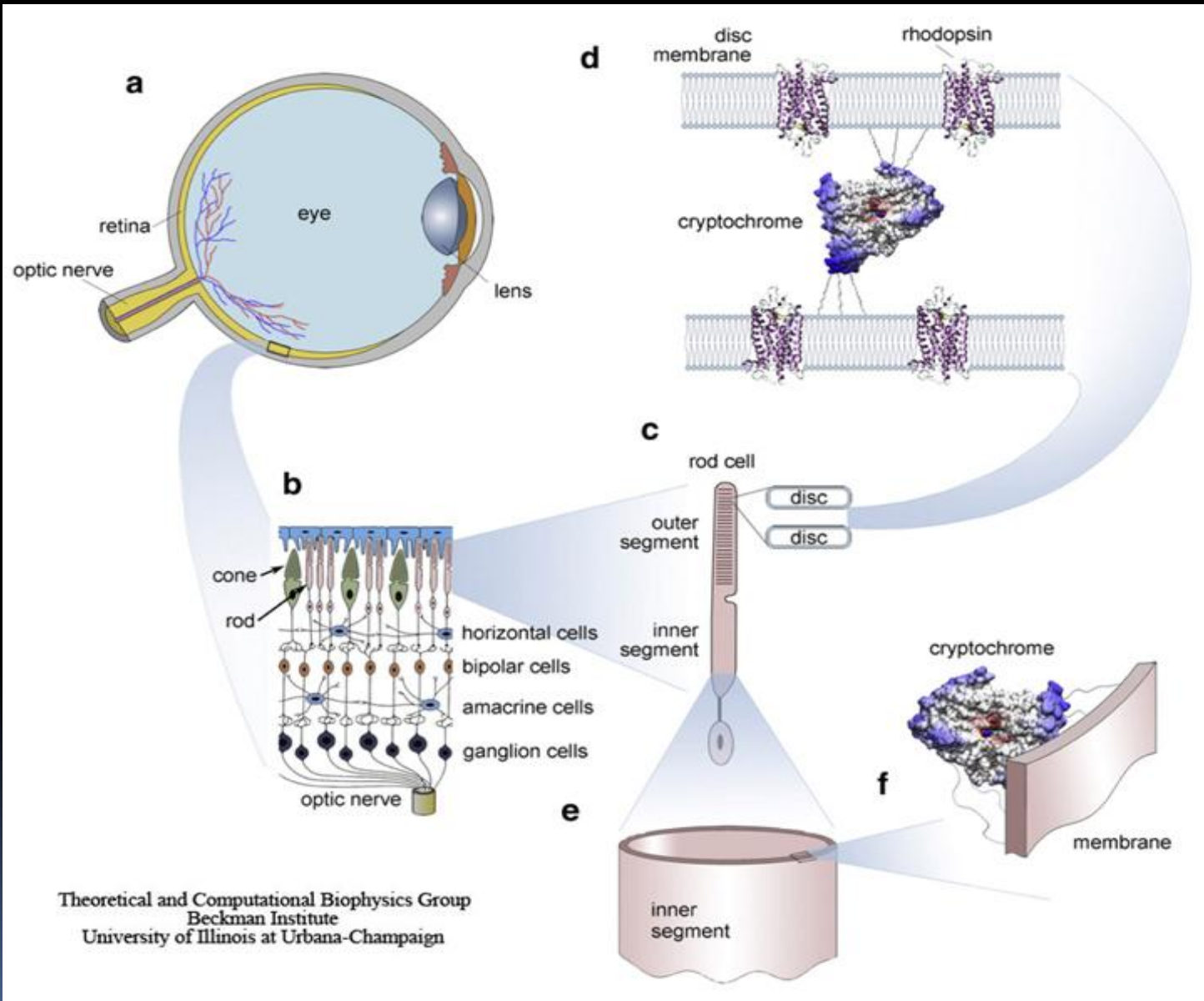
<http://vcell.ndsu.edu/animations/home.htm>

# Peter Hore – Magnetoreception

- (chemist at the University of Oxford, UK)
- the chemical compass in birds would work with the help of **radicals** (molecules with excitable lone electrons), and a quantum property known as **spin**.
- \* Electrons in molecules usually come in pairs, spinning in opposite directions and effectively cancelling out each other's spin. A "lone" electron spinning on its own, though, isn't cancelled out. This means it is free to interact with its environment – including magnetic fields.



# Photoreceptors

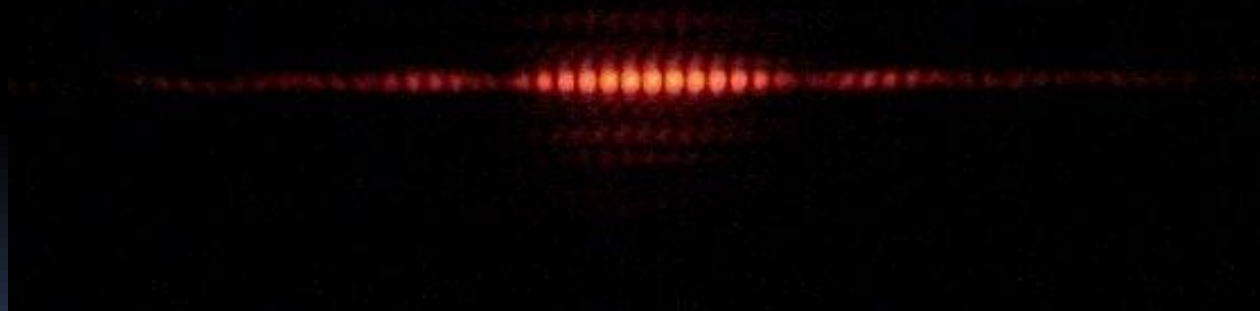


# QM and cognition

Single-slit pattern



Double-slit pattern



Same double-slit assembly (0.7 mm between slits); in top image, one slit is closed. In the single-slit image, a diffraction pattern (the faint spots on either side of the main band) forms due to the nonzero width of the slit. A diffraction pattern is also seen in the double-slit image, but at twice the intensity and with the addition of many smaller interference fringes.

# Pascual Jordan


- (physicist who worked with quantum guru Niels Bohr in Copenhagen in the 1920s)
- "observations not only disturb what has to be measured, they produce it... We compel [a quantum particle] to assume a definite position."
- "we ourselves produce the results of measurements."




# John Wheeler

- (American physicist)
- proposes in 1970 the "delayed choice" experiment (performed in the following decade). It measures the paths of quantum particles (generally, photons) after they should have chosen whether to take one path or a superposition of two.
- **it makes no difference whether we delay the measurement or not (as Bohr predicted).**


<https://journals.aps.org/pr/abstract/10.1103/PhysRevA.35.2532>

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- 1930 – the Hungarian physicist Eugene Wigner: "It follows that the quantum description of objects is influenced by impressions entering my consciousness (...)  
Solipsism may be logically consistent with present quantum mechanics."

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- Wheeler: the presence of living beings, which are capable of "noticing", has transformed what was previously a multitude of possible quantum pasts into one concrete history. We become participants in the evolution of the Universe since its very beginning – we live in a "participatory universe."

# Roger Penrose

- first proposed that quantum effects feature in human cognition in his 1989 book *The Emperor's New Mind*.
- Orch-OR (orchestrated objective reduction): the collapse of quantum interference and superposition is a real, physical process, like the bursting of a bubble.

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- Penrose developed this idea further with American physician **Stuart Hameroff**.
  - In his 1994 book *Shadows of the Mind*, he suggested that the structures involved in this quantum cognition might be protein strands called **microtubules**. These are found in most of our cells, including the neurons in our brains. Penrose and Hameroff argue that vibrations of microtubules can adopt a quantum superposition.
  - But... there is no evidence that such a thing is remotely feasible.

It has been suggested that the idea of quantum superpositions in microtubules is supported by **experiments described in 2013**, but in fact those studies made no mention of quantum effects.

The screenshot shows a web browser window with the URL [aip.scitation.org/doi/10.1063/1.4793995](http://aip.scitation.org/doi/10.1063/1.4793995). The page title is "Multi-level memory-switching properties of a single brain microtubule". The authors listed are Satyajit Sahu<sup>1</sup>, Subrata Ghosh<sup>1</sup>, Kazuto Hirata<sup>2</sup>, Daisuke Fujita<sup>1</sup>, and Anirban Bandyopadhyay<sup>1, a)</sup>. The publication information is "Appl. Phys. Lett. 102, 123701 (2013); doi: <http://dx.doi.org/10.1063/1.4793995>". The page includes navigation links for PDF, ABSTRACT, FULL TEXT, FIGURES, CITED BY, TOOLS, SHARE, and METRICS. The abstract text reads: "We demonstrate that a single brain-neuron-extracted microtubule is a memory-switching element, whose hysteresis loss is nearly zero. Our study shows how a memory-state forms in the nanowire and how its protein arrangement symmetry is related to the conducting-state written in the device, thus, enabling it to store and process ~500 distinct bits, with 2 pA resolution between 1 nA and 1 pA. Its random access memory is an analogue of flash memory switch used in a computer chip. Using scanning tunneling microscope imaging, we demonstrate how single proteins behave inside the nanowire when this 3.5 billion years old nanowire processes memory-bits." On the right side of the page, there is an advertisement for "HIDEN ANALYTICAL" featuring an image of a microscope and the text "ESPion". The browser's taskbar at the bottom shows various application icons and the system clock indicating 12:09 PM on 5/16/2017.

# Max Tegmark

- calculated that quantum superpositions of the molecules involved in neural signaling could not survive for even a fraction of the time needed for such a signal to get anywhere.
- Quantum effects such as superposition are easily destroyed, because of **decoherence**.
- Nerve signals are electrical pulses, generated by the passage of electrically-charged atoms across the walls of nerve cells. If one of these atoms was in a superposition and then collided with a neuron, the superposition should decay in less than one billion billionth of a second. It takes at least ten thousand trillion times as long for a neuron to discharge a signal.
- As a result, ideas about quantum effects in the brain are viewed with great skepticism.

<https://journals.aps.org/pre/abstract/10.1103/PhysRevE.61.4194>


# Luca Turin

- (chemist at the BSRC Alexander Fleming institute in Greece)
- the molecule's shape alone isn't enough to determine its smell; it's the quantum properties of the chemical bonds in the molecule that provides the crucial information.
- when a smelly molecule enters the nose and binds to a receptor, it allows a process called quantum tunnelling to happen in the receptor.




# Matthew Fisher

- (physicist of the University of California at Santa Barbara)
- the brain might contain molecules capable of sustaining more robust quantum superpositions. Specifically, the nuclei of phosphorus atoms may have this ability.
- study published in 2015 –  
<http://www.sciencedirect.com/science/article/pii/S0003491615003243>


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- At this point, Fisher's proposal is no more than an intriguing idea. But there are several ways in which its plausibility can be tested, starting with the idea that phosphorus spins in Posner molecules can keep their quantum coherence for long periods. That is what Fisher aims to do next.
  - All the same, he is wary of being associated with the earlier ideas about "quantum consciousness", which he sees as highly speculative at best.

# Adrian Kent

- one of the most respected "quantum philosophers" (University of Cambridge UK), speculated that consciousness might alter the behaviour of quantum systems in subtle but detectable ways (2016).
- <https://arxiv.org/abs/1608.04804>

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- "There is no compelling reason of principle to believe that quantum theory is the right theory in which to try to formulate a theory of consciousness, or that the problems of quantum theory must have anything to do with the problem of consciousness"

(Adrian Kent).

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- how our conscious minds can experience unique sensations, such as the colour red or the smell of frying bacon – "qualia" ? We all know what red is like, but we have no way to communicate the sensation and there is nothing in physics that tells us what it should be like. We perceive qualia as unified properties of the outside world, but in fact they are products of our consciousness – and that is hard to explain.

= David Chalmers – "**the hard problem**" of consciousness (1995) – <http://www.ingentaconnect.com/contentone/imp/jcs/1995/00000002/00000003/653>)

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