The Guy Foundation

SEEING THE LIGHT: ELECTROMAGNETISM IN THE BODY AND ITS PRACTICAL APPLICATION

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(Eds.)

Driving innovation in medicine through quantum biology

CONTENTS

SEEING THE LIGHT: ELECTROMAGNETISM IN THE BODY AND ITS PRACTICAL APPLICATION

– BETONY ADAMS AND ALISTAIR NUNN

'Quantum medicine' is a controversial phrase. This is perhaps because quantum theory often falls outside of our intuition. The familiar phrases associated with the science – a cat that is *both* dead and alive, spooky action at a distance – deny our recognised reality. As such, quantum theory is open to misinterpretation or, at the very least, loose interpretation. Photons, or particles of quantised light, are also central to the development of quantum theory, which arose out of the need to explain non-classical interactions of light with matter. Light plays a strong role in many spiritual practices. It is perhaps no surprise that 'quantum medicine' for the most part occupies a quasi-mystical rather than therapeutically verifiable place in the public imagination, as envisioned, for instance, by Deepak Chopra's approach to what quantum mechanics may mean for medicine. What practical, applicable insights, then, might quantum biology bring to our understanding of physiology and the practise of medicine?

It is instructive to be clear what is meant by medicine in this context. A great deal of progress has been made, over the course of modern medical practise, in understanding the anatomical mechanics of the body. Biochemistry too, has played its part and contributed to a pharmacological revolution. Further down the scale, on the level of quantum particles such as electrons and protons and photons, this revolution has so far been in the context of imaging the body. Less progress has been made in the therapeutic context. This is despite a long history of interest in electromagnetic effects in biological tissue. In 1895 the therapeutic application of light won a Nobel prize for Niels Ryberg Finsen. In 1923 Gurwitsch reported the weak emission of electromagnetic radiation by onion roots. Electric fish have been used therapeutically in a number of societies. The regenerative potential of electric and magnetic fields is also of growing interest. It is perhaps common knowledge that the intricate system of cells that constitute our brain and central nervous system depend on the rise and fall of electric potential. This potential is generated by the movement of charged ions across cell membranes. What is perhaps less well appreciated is that membrane potential is essential for all aspects of biology, ranging from nerve-based signalling to the movement of metabolites in and around cells, as well as how cells sense their environment. Arguably the most investigated membrane potential is the proton gradient generated by mitochondria as they capture energy from electrons – derived from food – flowing to oxygen, which, among other things, they use for the production of adenosine triphosphate – better known as ATP. The membrane potential of cells can also be manipulated to alter the morphology of organisms. The body is mechanical and chemical, certainly, but it is also inescapably electrical. What is more, electromagnetic radiation, in the form of photons, appears to play an integral role in biological systems. We are accustomed to seeing the light, our sense of sight, through the action of photon-activated retinal chromophores in our eyes. Perhaps more fascinating, however, is the fact that our bodies might 'see the light' in numerous other contexts as well. Photons appear to play a role

in the metabolic processes of electron transport chains. They are also key to essential systems of biological synchronisation, activating molecules such as cryptochromes. The cells of living organisms contain a variety of light-sensitive chromophores which may be implicated in a number of different biological functions, acting as ‘sunscreens’ to dissipate harmful energy or playing a role in the many redox reactions of biochemistry. Compounding this is the fact that biological systems produce their own light, endogenous biophotons, which may play a role in non-chemical communication and signalling.

Quantum biology is already preoccupied with electromagnetic processes. A great deal of effort, both theoretical and experimental, has been devoted to understanding the interaction of light with living matter during photosynthetic light harvesting and energy and charge transport processes between chromophores in electron transport chains. Quantum tunnelling, often cited as the first confirmed instance of non-trivial quantum effects in biological systems, involves the transfer of charged particles such as electrons or protons. Magnetism is also one of the staple topics of quantum biology. The spin of fundamental particles such as protons and electrons quantifies their response to a magnetic field in the same sense that charge quantifies their response to an electric field. The radical pair mechanism that has been proposed to underpin the avian compass depends on the spin states of correlated electrons, as well as how the body may deal with oxidative stress. What practical use, then, can be made from this in the context of medical therapeutics?

The Guy Foundation 2021 Autumn Series lectures take a closer look at how and where these electromagnetic effects, quantum or otherwise, might play out in the body. They also move this discussion from theory to therapeutic practise, outlining the very concrete advances that might be made in medical contexts as widely divergent as traumatic brain injury, COVID-19 and anaesthesia.

INTRODUCTION TO THE GUY FOUNDATION – GEOFFREY GUY

The Guy Foundation has been set up to support and promote the investigation of quantum effects in biology, with the aim of improving our understanding of disease and thus medicine. Our belief is that significant quantum effects may well have not only been essential for life to get going, but also enabled it to grow in complexity by amplifying these effects both in space and time. For example, all life is based on iron-sulphur compounds that can display interesting tunnelling properties, which could be enhanced by the addition of proteins and chromophoric molecules. These molecules were all created by well understood geochemical/interstellar chemical processes long before life got going, which coupled with established thermodynamic mathematical principles involving self-organisation of dissipative structures in energy gradients, do provide the basis of a starting point for life. In short, if significant quantum effects are part of life, the failure to maintain this state probably plays a role in disease and thus, the ageing process, and, of course, medicine

Of course this raises a question, why hasn't anybody thought of using quantum mechanics to explain biology? Well, actually, as indicated in the preface, they had, right from the beginning from the days of the pioneers of thermodynamics and quantum physics, and over the years, several leading scientists have discussed the possibilities that biology could be using significant quantum effects. Some, such as Roger Penrose, have even gone as far as suggesting it could explain consciousness itself, which, even today in the 21st century, is still far from being understood. In fact, with time, despite the 20th century optimism that by the 21st century mankind would have found cures for cancer and many other diseases, and possibly even for ageing itself, a deeper understanding of life seems to be still out of reach. It could be even further away as emerging global obesity appears to be *shortening* both a healthy and absolute life expectancy, which is resulting in spiralling health care costs across the planet. Despite mankind's emerging technical mastery of nature, we still have a very long way to go in terms of truly understanding it.

This therefore brings us neatly back to quantum mechanics and biology and the aims of the Foundation. Quantum mechanics is intuitively difficult to understand, and, as has been said, if you think you understand it, then you don't. Only now, after nearly 100 years, is technology reaching the point where one of the most difficult of concepts, quantum entanglement, can be tested. Einstein called it "spooky action at a distance", as he simply didn't believe it because it didn't fit with his general theory of relativity, and despite being one of the founders, he openly said that quantum mechanics had to be incomplete. He often argued with Niels Bohr over this. For many years the concept of "quantum realism" has stood quietly like a large elephant in the room, as many thought that only when a conscious observer observed something did its wave function collapse to give us the Newtonian universe we all understand. The latest experiments to test whether or not quantum entanglement exists continue to suggest that it clearly does, which indicate that two entangled particles, which share the same wave function, can still somehow communicate, instantaneously, even if they are on opposite sides of the galaxy. In fact, it is now finding uses, like other quantum effects, such as tunnelling, in everyday practical devices, such as eaves-dropper safe communication. Thus, it is likely that conventional

biology, and quantum mechanics, despite the odd attempt to communicate, have largely passed as ships in the night for nearly a century. The Foundation therefore aims to provide a platform and a forum for upstream push through and downstream pull through of the understanding of the role of quantum effects in biology in health and disease. We recognise these notions to be extremely avant-garde, oftentimes incomprehensible. However, we take a long view and see ourselves as pioneers in a new wave of medicinal science. With an emphasis on building a research community to further investigate these interests, The Guy Foundation operates in a spirit of collaboration rather than straightforward grant funding, to advance the course of useful knowledge towards the mainstream and bring it to the attention of more conventional funders. We aim to do this in various ways. By curating a programme of scientific meetings and publications that incorporates the diverse aspects of the field and facilitates engagement from scientists across relevant disciplines. By identifying what we see as research priorities and building a network of interested scientists through the funding of collaborative projects to accelerate relevant high-quality scientific research.

Professor Geoffrey Guy MB BS, LRCP MRCS, LMSSA, DipPharmMed, BSc, DSc

Founder and Chairman of the Board of Trustees, The Guy Foundation

ABSTRACT PROCEEDINGS

ABOUT THESE ABSTRACTS – ALISTAIR NUNN

Director of Science, The Guy Foundation

These are abstracts of a series of talks, hosted by the Foundation, that will be given online to an invited audience during the autumn of 2021.

They have been written by the presenters and have not been formally peer-reviewed. We hope you enjoy them; video recordings of the full lectures will be uploaded to the Foundation's website www.theguyfoundation.org.

ELECTROMAGNETIC COUPLING IN THE BIOLOGICAL CONTEXT – PROFESSOR DOUGLAS C. WALLACE

Director, Center for Mitochondrial and Epigenomic Medicine, The Children's Hospital of Philadelphia Research Institute and the Department of Pediatrics, Division of Human Genetics, University of Pennsylvania.

We have discovered that the mitochondrial inner membrane infoldings (cristae) are closed at the intermembrane interface by Opa1 and MICOS. This results in the mitochondrial inner membrane electron transport chain (ETC) pumping protons into the very small volumes of the cristae lumens, presumably resulting in high charge densities. The cristae across adjacent heart mitochondria are aligned which could be the result of electrostatic interactions. The ATP synthases are arrayed along the cristae such that the high intra-cristae charge density would maximize ATP synthesis. Uncontrolled proton pumping could increase the intra-lumen charge density sufficiently to disrupt the cristae membranes. This is obviated by the inner membrane adenine nucleotide translocators (ANTs) being bifunctional, exporting ATP in exchange of ADP across the inner membrane that separates the mitochondrial matrix from the intermembrane space, but within the cristae acting as voltage-sensitive proton channels with the channel opening at ~180 mv. Hence, the ANTs act as proton pressure release valves resulting in oscillating membrane potential. These oscillations could generate electromagnetic fields that are those that emanate from the brain and heart, fields that we have found perturbed in patients and mouse models associated with mitochondrial dysfunction. If coherent across adjacent mitochondria and cells, such fields could permit rapid inter-cellular signalling. Since mitochondria harbour high concentrations of protons and phosphate with nuclear spins of ½, mitochondrial magnetic fields might also process information.

MECHANISMS OF PHOTOBIOMODULATION AND APPLICATION TO THE BRAIN – PROFESSOR MICHAEL R. HAMBLIN

Distinguished Visiting Professor, Laser Research Centre, University of Johannesburg.

The history of the use of light to treat diseases spans >100 years. Electric light therapy, heliotherapy, and low-level laser therapy led to what we now call photobiomodulation therapy (PBM). PBM has traditionally been used for wound healing, pain and inflammation. However, in recent years there has been a growing interest in applying this method for treatment of brain disorders. PBM employs red or near-infrared (NIR) light (600-1100nm) from lasers or light emitting diodes to stimulate healing, protect tissue from dying, increase mitochondrial function, improve blood flow and tissue oxygenation, and stimulate stem cells. Progress has been made in identifying cellular chromophores and photoreceptors, including mitochondrial respiratory proteins and TRP ion channels. Results of small animal model studies as well as human studies show that PBM can also act to reduce swelling, increase antioxidants, decrease inflammation, protect against apoptosis, and modulate the microglial activation state. PBM delivered to the head is beneficial in cases of both acute and chronic traumatic brain injury. Moreover, PBM has now been shown to be effective against neurodegenerative diseases (Alzheimer's and Parkinson's) and psychiatric disorders (depression, anxiety and opioid addiction). Cognitive enhancement in normal individuals is another application.

UNCOVERING ELECTRODYNAMIC DESIGN PRINCIPLES OF LIVING CELLS AND A POTENTIAL ROLE OF QUANTUM INTERACTIONS IN CELLULAR SIGNAL PROCESSING

– PROFESSOR JACK TUSZYŃSKI

Allard Chair, Department of Physics and Department of Oncology University of Alberta, Edmonton, Alberta, Canada and DIMEAS, Politecnico di Torino, Torino, Italy.

The structure-function relationship is the basis of quantitative analysis of living organisms whose fundamental unit is a cell. Cellular structural and functional complexity is a challenge to our understanding of responses to various environmental changes affecting cells. Electrical and electromagnetic interactions with cells are particularly poorly understood. I will discuss recent experiments performed in parallel with computational modelling aimed to develop an integrated model of the cell as a bioelectric circuit. I will summarize key bio-electric properties of the cell as a whole and its major components, which will allow to reverse engineer the underlying bio-electrodynamic design principles. While much is known about the electric properties of cell membranes, explorations of the cytoskeleton, are still nebulous. Key cytoskeleton components, actin filaments and microtubules, play essential roles in cell motility, mitosis, cell differentiation, transport and signalling. Their elementary protein building blocks self-assemble into cell-spanning filaments, and are strongly affected by temperature, ionic concentrations, pH and other factors. These factors are involved in cellular structure formation and significantly affect cellular responses to electric and EM fields. My ultimate objective is to uncover an electrodynamic design blueprint for eukaryotic cells accounting for these factors, both generically and in comparison between normal and cancer cells. While cancer cells exhibit major changes in their electro-chemical properties compared to normal cells, this property is yet to be substantially exploited for therapeutic applications, although some promising advances have recently been made and I'll discuss them in this talk. This work is intended to unveil a new paradigm for health and disease and enable new therapeutic interventions. Finally, in relation to the potential role of the cytoskeleton in quantum mechanisms of consciousness, I'll report some recent experimental and computational results obtained within the Templeton Foundation supported project I am coordinating.

APPLICATION OF LIGHT AND ELECTROMAGNETIC FIELDS TO REDUCE HYPER-INFLAMMATION TRIGGERED BY COVID-19

– PROFESSOR MARGARET AHMAD

Director of Research, Institute of Biology Paris-Seine, Sorbonne University.

The primary cause of COVID-19-related morbidity is exaggerated inflammation and cytokine production in the lungs, leading to acute respiratory failure. The cellular mechanisms underlying these so-called 'cytokine storms' involve viral induction of the innate Toll-Like Receptor 4 (TLR-4) signalling pathway in alveolar cells, followed by uncontrolled cytokine secretion. The cellular factors regulating this response are well understood and include modulation by ROS (reactive oxygen species); this pathway has therefore been extensively researched to identify possible anti-inflammatory drugs. However, current treatments of late-stage COVID-19 using steroids or monoclonal antibody-based drugs are costly, have undesirable side-effects, and/or are of only limited effectiveness.

Intriguingly, exposure to either red/infrared light (photobiomodulation) or low intensity magnetic fields (pulsed electromagnetic fields – PEMF) are therapies currently on the market to treat underlying inflammation in a range of medical conditions (e.g. lupus, chronic pain, wound and bone healing, chronic arthritis etc.). These are non-invasive, safe, affordable interventions which require the affected body part to only be exposed to stimulation once or twice daily, and for short intervals. Both of these therapies are furthermore known to modulate intracellular ROS, suggesting a possible conserved underlying mechanism of action that could make both effective against late-stage COVID-19.

In this talk I will present results showing significantly decreased inflammatory cellular markers and a decline of up to 80% in cytokine secretion within two days of either photobiomodulation or pulsed magnetic field stimulation. The TLR-4 dependent inflammatory response, which leads to mortality of COVID-19 patients, was specifically triggered in these studies using either model cell cultures (HEKBluTLR-4), primary human alveolar cell cultures, or human macrophage cells. After establishment of inflammation, these cell cultures were then exposed to either photobiomodulation (infrared) or pulsed electromagnetic fields over a period of several days. Both treatments significantly reduced the inflammatory response in all cell types, as was determined through reporter gene assays for inflammation, cytokine gene expression analysis, and direct ELISA test of IL-6 cytokine secretion. Furthermore, the wavelength, intensity, and time-dependent parameters of the light signal used for photobiomodulation were assessed in detail, and as well as the critical aspects for the duration, frequency, and intensity of the pulsed magnetic field signal in the different cell types. These parameters were surprisingly strict, suggesting that any signal 'dose' must be rigorously defined for the pathology in hand in order to be of therapeutic benefit. Finally, both signals were shown to modulate cellular ROS (reactive oxygen species), consistent with a similar physiological mechanism. We therefore suggest that either or both photobiomodulation and PEMF therapy may be a safe, affordable, effective treatment for late-stage COVID-19 which could be implemented immediately.

RADICAL PAIRS IN XENON-INDUCED ANAESTHESIA AND OPTICAL COMMUNICATION CHANNELS IN THE BRAIN

– PROFESSOR CHRISTOPH SIMON

Institute for Quantum Science and Technology, University of Calgary

Could quantum physics help answer some of the big open questions in neuroscience, such as the binding problem of consciousness? Could nature have discovered quantum information processing before we did? Motivated by these questions, I investigate two potential ways in which quantum effects might be important in the brain, as well as their potential connection. The first direction concerns biophotons, which could serve as classical and quantum information carriers. We have suggested that axons could serve as natural waveguides for these photons [Kumar et al., Sci. Rep. 6, 36508 (2016)]. The second direction concerns radical pairs, i.e. pairs of entangled electron spins that, together with nearby nuclear spins, might serve as quantum memories and processors. We have suggested that such radical pairs play key roles in anaesthesia [Smith et al, Sci. Rep. 11, 6287 (2021)], bipolar disorder [Zadeh-Haghighi and Simon, Sci. Rep. 11, 12121 (2021)], and the circadian clock [Zadeh-Haghighi and Simon, arXiv:2107.10677]. Reactive oxygen species provide a potential bridge between photons and spins, thus opening up the possibility of natural quantum networks in the brain.

HINDSIGHT: LESSONS FROM THE SERIES

– BETONY ADAMS AND ALISTAIR NUNN

Since their inception in Spring 2020, The Guy Foundation lectures have seen scientists address a number of questions relevant to the future of medicine. The range of this engagement has covered quantum interactions on the microscopic scale as well as how this quantum nature might be applicable on the scale of the human body. While fresh insights have been added with each new presentation some common threads lend themselves to being teased out.

Perhaps foremost of these is that the mitochondrion may play a central role in building on the progress made in quantum biology thus far. Photosynthesis has, for the last decade or more, been the dominant theme of quantum biological research. Mitochondrial function, however, shares various features with photosynthesis, including the centrality of redox activity in electron transport chains and the creation of membrane potentials. Mitochondria have also been implicated in photonic activity, containing chromophore networks as well as being a primary source of ultraweak emissions known as biophotons. As such, many of the advances made in understanding quantum effects such as coherent energy transport and tunnelling in the context of photosynthesis might be equally applicable to mitochondria. The mitochondrion has come up repeatedly in presentations, both to anchor hypotheses about hormesis, health, disease and aging as well as being the reported site of new therapeutics. The role of mitochondria in the bioenergetics of disease is of growing interest, and as such they are well placed to widen the scope of quantum biology to include physiological concerns and medical innovation.

What has also become clear is that the conventional description of mitochondria as the power station of the cell is only partially accurate. Although they are very much implicated in energy production in the cell, mitochondria also play a central role in signalling and communication systems. Indeed, mitochondria link energy to information in various ways, through the production of a membrane potential as well as reactive oxygen species and biophotons. Perhaps a more general way of looking at this is to acknowledge that the conventional view of biology has been fundamentally chemical oriented, its focus on the molecular interactions that ensure the efficient function of living systems. What has been neglected, to some extent, is how living matter interacts with fields, in particular those fields relating to electromagnetism. This has emerged as a theme in many of the presentations. The modulation of electric fields has been shown to profoundly change biological structure, at the level of both organelle and organism. While long-range interactions have often been dismissed due to screening in biological systems, there is growing evidence that these effects are not limited to short-range interactions. Biological systems interact with electromagnetic radiation, absorbing and emitting photons of various frequencies. This is an accepted fact in research relating to photosynthesis but has had much less development in other contexts such as photobiomodulation. The

successful field of spin chemistry, which describes how magnetic fields and quantum spin change the outcome of chemical reactions, has also begun to be applied to the wider context of physiology. In particular, the spin states of reactive oxygen species lend themselves to manipulation by magnetic and electromagnetic fields. It has even been suggested that mitochondrial coupling and uncoupling generates oscillating electromagnetic fields that may interact with reactive oxygen species. In summary, a great deal of evidence, both theoretical and practical, points to the importance of non-chemical or field-enhanced mechanisms of homeostasis in biological systems. A better understanding of these field effects, from both quantum and classical standpoints, may offer insights into how living systems harness energy dissipation towards self-organisation; how they are, in effect, 'tuned'. Furthermore, these insights may have diagnostic and therapeutic relevance, underlining how living systems might be effectively 'retuned' through medical intervention.

How then, do these insights translate into mainstream medical practise. There is still a great deal of reluctance to accept therapeutics that are seen as alternative, despite evidence that, in the context of COVID-19 inflammation, these interventions can be life-saving. Some of this scepticism may be attributed to suspicion of the way in which 'quantum medicine' is associated with pseudoscience. However, there is also the fact that the mechanisms by which these treatments work remain unclear. There is also more work to be done in translating quantitative research into the familiar medical terminology of dosage. One way forward is then perhaps to focus on the standardisation of these new therapeutics, fixing the parameters that allow for efficacy, safety and repeatability in their application. The Guy Foundation 2022 Spring Series hopes to spark discussion in this direction by focusing on how theoretical research is developed towards commercial outcomes, with the tension between innovation and regulation that this entails.

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