THE GUY FOUNDATION

The Guy Foundation research programme: presentation of initial findings

Betony Adams
& Alistair Nunn
(Eds.)

Abstract proceedings of the 7th Guy Foundation Symposium on Quantum Biology and Bioenergetics,
Spring 2023

Driving innovation in medicine through quantum biology

Published September 2023

Contents

Introduction to the 7th Guy Foundation Symposium

Betony Adams & Alistair Nunn

The Guy Foundation facilitates thinking and research into how a deeper understanding of electromagnetic effects in biology might improve our ability to practise medicine. As well as convening scientific meetings and symposia the Foundation has also curated and supported a programme of research into aspects of quantum biology and bioenergetics and these collaborating research teams presented their work in the 2023 Spring Series.

The research presented in this series reflects the genesis and evolution of The Guy Foundation's focus on how quantum effects might play a role in biological systems. The Foundation has long been interested in how light interacts with biological material, an interest that grew out of research into plant compounds, including cannabinoids. These molecules, often referred to as chromophores, play a central role in quantum biology. While this has been most obvious in the context of photosynthesis, where the chromophore chlorophyll facilitates light harvesting and energy transfer in plants, a number of other chromophores are generating increased interest. The role of light in biological systems has a long research history. In 1903 the Nobel Prize for Physiology was awarded to Niels Ryberg Finsen for the use of light therapy to treat lupus vulgaris. Quantum theory was also emerging at the beginning of the 1900s. Arising as it did out of observations of the interaction of light with matter, the new theory prompted a number of physicists to consider what insights it might offer the study of living systems and what role light may play in these systems. Not too long after this, the scientist Alexander Gurwitsch observed the non-chemical communication between onion roots which led to the identification of biophotons, the centenary of which we are celebrating this year. However, despite this long history, light-matter interactions in biology – particularly in animal studies – remain underdeveloped. This is in part due to biology diverging onto a path that prioritised the study of genetics. But it is also for a more practical reason: the lack of sufficiently sensitive experimental technology. The Guy Foundation, while it embraces unconventional research, also recognises that ideas that fall outside of the given paradigm require convincing experimental evidence. To this end, Gurwitsch's initial demonstration of non-chemical communication has been reinvestigated under carefully managed and sophisticated experimental conditions, from the mitochondrial to the organismal level. The Foundation's interest in fostering new ways to understand physiology and by extension disease also reflects this multi-scale approach. There is growing evidence that biological function is systemic rather than localised to single receptors. In this sense, the Foundation is interested in collective behaviours at every level of biological organisation: those properties that emerge from groups of chromophores or communities of cells. On the nanoscopic scale, networks of tryptophan chromophores offer robust quantum effects where single tryptophans cannot. On the macroscopic scale, the familiar shapes of anatomies emerge out of the combined membrane potentials of networks of cells.

Moving this field of research into the realm of medical practise will require persuasive experimental evidence. The Foundation is thus very pleased to see both novel ideas as well as rigorous experimental results emerging from its curated research programme, towards the ultimate aim of bringing quantum biology into mainstream medical parlance.

Introduction to The Guy Foundation

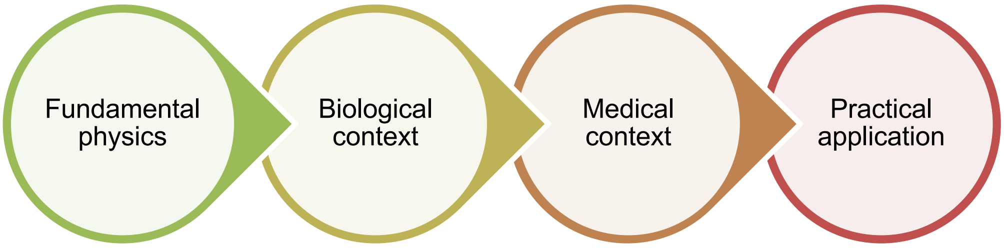
Professor Geoffrey Guy

Founder and Chairman, The Guy Foundation

The Guy Foundation aims 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 been essential for life to get going, but also enabled it to grow in complexity by amplifying these effects both in space and time. All living systems depend on iron-sulphur compounds that 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 began, 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.

The pioneers of thermodynamics and quantum physics, and – over the years – scientists, embracing many different disciplines, have discussed the possibility 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.

The Guy Foundation thus leads, supports and contributes to quantum biological and related research with the ultimate aim of advancing the development of new medical diagnostics and therapeutics. The Foundation believes this advancement can be achieved in a number of ways, which is reflected by the research we fund as well as the cross-section of scientists invited to give presentations. Our approach is summarised as encompassing research from bench to bedside.



Our priorities encompass the spectrum of theoretical, experimental, and practical advances. Understanding the fundamental physics (e.g., quantum mechanics, electrodynamics, thermodynamics) is important. More specifically we aim to understand this physics within the biological and physiological contexts, with the emphasis on furthering the study of medicine. Overall, we would like to see this knowledge translated and applied in new diagnostics and therapeutics.

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. 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. For instance, 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; as well as 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

These are abstracts of a series of talks, hosted by the Foundation, that were given online to an invited audience during the spring of 2023.

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 are available on the Foundation's website **www.theguyfoundation.org** and on the Foundation's YouTube channel **www.youtube.com/@theguyfoundation**.

The role of biophotonics and electromagnetic fields in cellular communications and bioenergetics

Dr Rhys Mould

Research Centre for Optimal Health, University of Westminster, UK

See video recording **here**

Cells emit light – UV-Visible photons produced at a very low intensity. These emissions are a result of interactions between Reactive Oxygen Species (ROS) and nearby biomolecules, including proteins or lipids. As ROS themselves are by-products of metabolism, the intensity of emission is too tied to the metabolic state of a cell – hence our term Metabolic Photon Emission (MPE). The roles of MPE, also known as biophotons and ultraweak photon emission, remain unclear. In 1923, pioneering scientist Alexander Gurwitsch, in the famous onion root experiments, presented evidence that chemically-isolated cells could communicate via electromagnetic signals, giving rise to the hypothesis that MPE facilitates non-chemical communication. Despite the potential to change our understanding of signalling, the field struggled to proliferate due to multiple reasons, including difficulty detecting and characterizing these photons. To study this further, we investigated potential non-chemical communication between isolated mitochondria – the chief source of ROS and therefore MPE in the cell. Separating mitochondria into individual quartz cuvettes, we found that inducing oxidative stress in one population significantly alters the bioenergetics in another. This was not observed when the populations were divided by an opaque barrier, indicating that the observed effect is mediated by light. We also show that the effect changes when the mitochondria are isolated from cancer cells, and when the experiments are carried out protected from ambient light. Altogether, we provide strong evidence that mitochondria are capable of MPE-based non-chemical communication over long distances. Our results highlight the importance of further study, and that we may yet unlock further understanding in how cells can communicate.

Using NADH one and two photon absorption imaging and anisotropy to study mitochondrial alignment and possible role of significant quantum effects in biology

Professor Stanley Botchway

Central Laser Facility (Octopus Group), UK Research & Innovation / Science and Technology Facilities Council, Harwell campus, Oxfordshire, UK

See video recording **here**

There is now evidence of inter- and intra-cellular mitochondria alignment, suggesting that biology maybe using non-chemically based mechanisms, such as electromagnetic fields. Furthermore, mitochondrial cristae alignment has also been observed using electron microscopy. Unfortunately, studying in vivo nano scale structure is technically very challenging. One option is to study a central electron carrier in metabolism, nicotinamide adenine dinucleotide (NADH), which is fluorescent and mostly located within mitochondria, and is regularly used for imaging them via their fluorescence [1]. Using one and two-photon absorption (340-360 nm and 740 nm, respectively), fluorescence lifetime imaging and anisotropy spectroscopy, of NADH in solution and in live cells, we show that mitochondria do indeed appear to be aligned and exhibit high anisotropy (asymmetric directionality). Aqueous solution of NADH showed an anisotropy of ~0.20 compared to fluorescein or coumarin of <0.1 and 0.04 in water respectively and as expected for small organic molecules. The anisotropy of NADH also increased further to 0.30 in the presence of proteins and 0.42 in glycerol (restricted environment) following two-photon excitation, suggesting more ordered structures. Two photon NADH fluorescence) of live mammalian cells (MCF7and CHO) also showed strong anisotropy of 0.3 to 0.4, respectively. NADH has a quantum yield of fluorescence of 2% compared to more than 40% for photo-ionisation (electron generation), when exposed to light at 340 nm. It is well known that mitochondria exhibit biphasic effects when exposed to light of this frequency, with the outcome depending on intensity and duration of exposure – ranging from stimulation of function to induction of apoptosis, which is commensurate with changes in mitochondrial shape, fusion and fission. The consequence of such highly ordered and directional NADH patterns with respect to electron ejection upon UV excitation could be very informative – especially in relation to ascertaining the extent of quantum effects in biology, including electron and photonic communication and modulation of effects such as spin and tunnelling. It is well known that many components of the electron transport chain are sensitive too, and can be manipulated by photons of the right frequency, suggesting a whole new order of unappreciated quantum homeostatic mechanisms operating in biology.

Reference

Rhys Richard Mould, Stanley W Botchway, James RC Parkinson, Elizabeth Louise Thomas, Geoffrey W Guy, Jimmy D Bell, Alistair VW Nunn. Cannabidiol modulates mitochondrial redox and dynamics in MCF7 cancer cells: A study using fluorescence lifetime imaging microscopy of NAD(P)H. 2021, Frontiers in molecular biosciences 8, 63010

Development, visualisation & modulation of bio-photons in living systems

Dr Alasdair Mackenzie

Central Laser Facility (Octopus Group), UK Research & Innovation / Science and Technology Facilities Council, Harwell campus, Oxfordshire, UK

See video recording **here**

Life has evolved to use and generate light, with the most well-known examples being photosynthesis, vision and bioluminescence. However, evidence suggests that during normal metabolism because of the movement of electrons, life can generate very low intensity light at around 10-100 photons/s/cm^2; the highest intensity seems to occur during oxidative stress and the decay of reactive oxygen species (ROS). As cells contain many small chromophoric molecules that act as essential cofactors in metabolism, the possibility exists that life could be using these ultra weak, or biophotons, in everyday intracellular homeostasis; this could extend to cell-to-cell communication. To study this further, and to confirm the existence of metabolically produced photons (MPE) and their possible role in homeostasis, we have custom built a highly sensitive light detection system to study photon emission in mung beans. To do this, we investigated growing mung beans in a light proof box, using dual top and bottom opposing photomultiplier tubes over 7 days at a constant temperature of 21 $\pm$ 0.5 ^{o}C. Over this time period we showed that in total, mung beans grown from seeds generated an average of 5 $\pm$ 1 photons per second above background. As the new bean stems grew, they showed a gradual increase in emission of up to 30 $\pm$ 1 photons/s. Actively growing seeds also showed episodic bursts of emission lasting around an hour before returning to their previous levels. The emission bursts did not correspond to day and night cycles.

The photon production was strongest underneath the growing beans, indicating that the emission was mainly coming from the roots. The bursts of photons also correlated with increased secondary root growth. Using H_2O_2 (0.167 µM), which promotes secondary root growth, we observed a significant increase in photon emission (1000x) compared to water alone. Altogether, we have demonstrated a clear and significant correlation between an increase in MPE with plant secondary root growth. Using our set up, we are able to separate MPE originating from the plant roots and that from the leaves where delayed luminescence involving chlorophyll may dominate. We speculate that the low level of

MPE detected may well support their role in biological homeostasis that is perhaps underappreciated, but was first observed a 100 years ago by Alexander Gurwitsch.

Cooperative and coherent quantum phenomena in the life sciences

Dr Philip Kurian

Quantum Biology Laboratory, Howard University, USA

See video recording **here**

Networks of tryptophan – an aromatic amino acid with strong fluorescent response – are ubiquitous in biological systems, forming diverse architectures in transmembrane proteins, cytoskeletal filaments, sub-neuronal elements, photoreceptor complexes, virion capsids, and other cellular structures. We analyzed the cooperative effects induced by ultraviolet (UV) excitation of several biologically relevant tryptophan mega-networks, thus giving insight into novel mechanisms for cellular photoprotection, signalling, and control. Our theoretical analysis in the single-excitation manifold predicts the formation of strongly superradiant states due to collective interactions among organized arrangements of up to more than 100,000 tryptophan UV-excited transition dipoles in microtubule architectures, which leads to an enhancement of the fluorescence quantum yield that is confirmed by our experiments. We demonstrated the observed consequences of this superradiant behavior in the fluorescence quantum yield for hierarchically organized tubulin structures, which increases in different geometric regimes at thermal equilibrium before saturation – highlighting the effect's persistence in the presence of significant physiological disorder. Our results motivate a revisiting of conventional assumptions about the computing limits of cytoskeletal and neuronal architectures, which are generally considered to signal via Hodgkin-Huxley action potentials (millisecond timescale). We show that these biosystems can harness superradiant effects (picosecond timescale) in tryptophan lattices to process orders of magnitude more information than exascale supercomputers, at significantly lower power consumptions, by operating extremely close to the Landauer bound for logically irreversible operations. We then conclude with a discussion of quantum information processing and the robustness of single-photon-excited superradiant states paired with subradiant states (second timescale) in biology, offering a novel paradigm for understanding large collectives of quantum emitters in warm, wet, and wiggly environments.

From molecular physiology to anatomical form

Professor Mike Levin and Professor Wayne Frasch

Allen Discovery Centre, Tufts University

See video recording **here**

The traditional view of evolution and developmental biology sees genotypes driving a specific, consistent phenotype. Beyond developmental plasticity and the role of environmental factors in choosing among a set of evolutionarily-canalized outcomes, lies a rich latent space of possibilities. Natural examples like elaborate galls formed by genetically-wildtype leaf cells (prompted by signals from a parasite embryo), and new advances in synthetic bioengineering are revealing a rich plethora of novel morphological, physiological, metabolic, and behavioral phenotypes. These phenotypes raise important questions about the origin of form and function in contexts (like Xenobots) without a history of selection for these novel configurations. We propose that synthetic morphology is a tool with which to explore the latent morphospace of possibilities around any biological system. More specifically, the bioelectric system of cellular controls offers a uniquely tractable interface through which to explore the reprogrammability of life. One especially versatile component of that interface is the V-ATPase, which links metabolism to bioelectric controls of growth and form in vivo. In this talk, we discuss the role of the V-ATPase in natural morphogenesis and its roles in novel constructs such as Xenobots. We also show a quantification of the planarian head morphospace as a way of beginning to merge continuous shape data with agent-based rules governing cell behavior.

Closing Note

Professor Geoffrey Guy

Founder and Chairman, The Guy Foundation

Five years ago, The Guy Foundation was set up and immediately began curating and supporting a programme of research around ideas related to quantum biology and bioenergetics. It is remarkable to see the progress that has been made in this relatively short time span, in spite of the SARS-CoV-2 pandemic. The 2023 Spring Series has demonstrated just how far we have come in the various objectives of the Foundation. While we believe in challenging rigid paradigms within which biology and medical practise are conventionally developed, we also know that new ideas demand persuasive experimental evidence. It is thus gratifying to see this evidence begin to accumulate within the various research projects that we have supported. In addition to this, the technical challenges involved in such rigorous experimental verification – the extremely low light conditions for example – have been identified and good progress made in addressing them. It is also exciting to see some common threads begin to emerge between the research programme and the lecture series. Rhys Mould's investigations of non-chemical communication, for instance, have been extended to incorporate the effects of photobiomodulation. This interplay between the experimental and theoretical aspects of the Foundation is already extending established horizons, with new evidence that photobiomodulation can differentially induce senescence in healthy and cancerous cells. The interactive nature of the research programme, culminating in the Spring Series and the final roundtable discussion, is also beginning to give some sense of how each research project contributes to the bigger picture of biological function. One of the problems to overcome in quantum biology research is the vast difference in scales, that range from the tiny distances of electron transfer between chromophores, to the more recognisable lengths of physiology and anatomy. It is thus encouraging to see how the research programme is working to bridge this difference in scale, relating light-matter interactions in microtubules, for example, to the role that they may play in morphology.

The Foundation is convinced that fostering these emerging relationships between the different scales of quantum and conventional biology is best achieved by a polymath approach, in which the boundaries between disciplines are challenged and surmounted. This is why, alongside working to generate convincing experimental data, the Foundations aims to encourage conversation and collaboration between scientists across disciplines. Testament to this are the various new projects facilitated in some part by the Foundation. This includes directly related research, such as the collaboration between Mike Levin and Wayne Frasch on the relationship between V-ATPase and morphology in Xenobots. We are also pleased to see that Philip Kurian has been awarded an Alfred P. Sloan Foundation grant for a collaborative research project with Mike Levin, a project that grew out of discussions between the various scientists involved in the Foundation's online lectures. It is promising to see that this collaborative spirit extends to the technological side of things as well, with instrumentation developed by Stan Botchway and Alasdair Mackenzie in a physics laboratory now ready to be moved into the biology laboratory at Westminster University, to further Rhys Mould's mitochondrial investigations.

In conclusion, we look forward to seeing how the Foundation will grow in the next five years. Whereas five years ago the debate might have centred around the possibility of quantum effects in biology, the various presentations in this Spring Series and the concluding roundtable discussion made it very clear that these effects are likely, if not given, and that the real focus is now on how to best realise that possibility. The fundamental ideas of quantum physics and mathematics are looking to be much closer to the reality of living organisms, in states of health as well as disease.

June 2023

www.theguyfoundation.org