

Beyond the frontiers of quantum physics

A new interdisciplinary research hub at Wolfson College

The chalkboard contains a dense collection of physics notes and diagrams. Key sections include:

- Wave Mechanics:** Equations for wave speed $v = \sqrt{\frac{T}{\mu}}$, wave number $k = \frac{2\pi}{\lambda}$, and angular frequency $\omega = 2\pi f$. It also discusses wave interference and diffraction.
- Optics:** Snell's law $n_1 \sin \theta_1 = n_2 \sin \theta_2$, Brewster's angle $\theta_B = \tan^{-1} n_2/n_1$, and thin film interference conditions $2L = (n+1/2)\lambda$ for minima and $2L = n\lambda$ for maxima.
- Thermodynamics:** Heat capacity $Q = mc\Delta T$, work $W = PdV$, and the first law of thermodynamics $\Delta U = Q - W$. It also includes the ideal gas law $PV = nRT$.
- Electromagnetism:** Electric field $E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$, magnetic field $B = \frac{\mu_0}{4\pi} \frac{q\mathbf{v} \times \mathbf{r}}{r^3}$, and the Lorentz force $\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$.
- Diagrams:** Several ray diagrams for lenses and mirrors, showing focal points, principal axes, and image formation. One diagram shows a converging lens forming a real, inverted image.

Vision

Science has never been more exciting than it is today. Boundaries between disciplines are disappearing, with several far-reaching unifications taking place across diverse fields of knowledge. One of the most fundamental unifications is now driven by physics: we are beginning to realise that the laws of physics at the microscopic scale – specifically quantum physics – permeate and affect the behaviour of objects at the macroscopic scale, ranging from DNA strands to solar cells, universal computers and black holes.

We intend to establish a world-class research hub that will take the lead in this ambitious unifying project. Its aim will be to investigate how quantum

physics can be extended beyond the microscopic domain into the domain of macroscopic systems, ultimately leading to a more fundamental description of physical reality. The hub will act as a beacon throughout the world, where the best minds will come together to work in a spirit of complete freedom to explore the deepest questions on the ultimate nature of reality.

It will be a world-leading project, where theoretical research in the foundations of quantum physics meets experimental science and connects to other fundamental fields of knowledge, in the spirit of independence and scientific diversity.



Big questions

- *What is quantum reality?*
- *Where do macroscopic quantum effects exist?*
- *What lies beyond quantum theory?*
- *Are living systems quantum?*

The mission of the research hub is to investigate, both theoretically and experimentally, the ultimate nature of reality. Since its beginnings in the work of such pioneers as Albert Einstein, Niels Bohr, Werner Heisenberg and Paul Dirac, quantum physics has become a uniquely powerful tool for exploring the deepest mysteries of existence. Drawing on the peerless intellectual resources of Wolfson College and the University of Oxford, the research hub will take on some of the biggest questions that still confront us.

What is quantum reality?

Quantum theory is extremely successful in its experimental predictions, yet the nature of quantum reality is profoundly elusive: we still don't understand what happens in these experiments beyond the abstract mathematics. We aim to probe the characteristic trait of quantum mechanics, quantum entanglement, and study what implications this effect has for quantum reality. This approach could reveal that deep problems arise merely out of our lack of understanding. Like proving Fermat's theorem in mathematics, solving the measurement problem would be a momentous leap.

Where do macroscopic quantum effects exist?

Quantum theory appears to fail on larger scales. Bridging the gap between micro and macro scales of reality is one of the most exciting outstanding problems in physics. We plan to use techniques from information theory, thermodynamics, quantum optics and many-body physics to bridge the gap between the micro

and macro worlds, both theoretically and experimentally. As a test bed of our theory, we aim to study and experimentally manipulate, in a quantum way, larger and larger organic molecules. This means creating larger entangled states and observing their behaviour under environmental influences.

What lies beyond quantum theory?

We intend to develop theories that go beyond quantum physics, encompassing the study of quantum theory in exotic physical regimes, having for instance even stronger entanglement. This is currently the most promising route to unifying quantum physics and gravity, which is the next frontier in our understanding of the physical world. These fundamental new insights could also lead to new technologies in quantum information processing, and to designing new experimental tests for quantum theory itself.

Are living systems quantum?

The founders of quantum mechanics, Heisenberg and Schrödinger, predicted a paradigm shift in biology when living systems would be studied using quantum physics tools. Many exciting questions can be raised in this domain which we are now able to investigate in detail both theoretically and experimentally. Is quantum coherence present in biological energy and information flow? Can living systems be simulated with non-living matter? Are there fundamental non-equilibrium laws of life? And, perhaps above all, is life inevitable or accidental?

Why Wolfson?

When quantum physicists around the world think of Oxford, they think of Wolfson College.

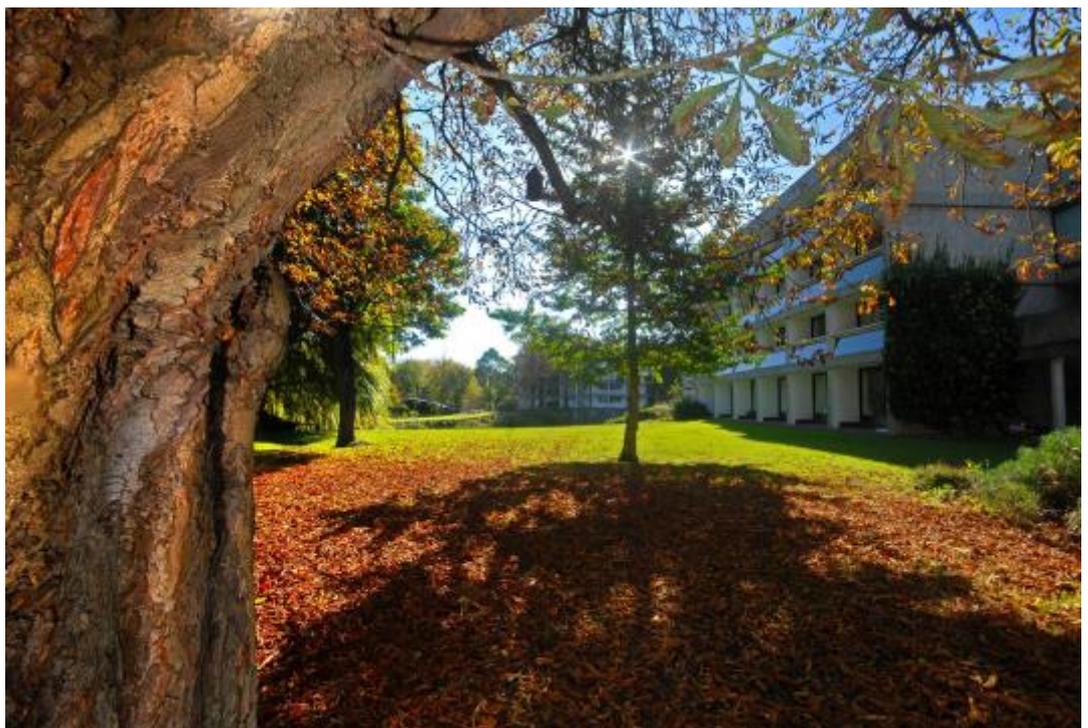
Wolfson is the pre-eminent Oxford hub bringing together the leading researchers in quantum physics, computer science, material science, biology and philosophy under one roof. This cohesive community embodies the original vision of the founder Isaiah Berlin, who intended Wolfson to stand out amongst Oxford colleges as ‘modern, open, democratic, multicultural, multidisciplinary, international, free of unnecessary hierarchy or fusty rituals’.

Wolfson is where quantum information pioneers laid down the foundations for the global field of quantum computing. Like the Princeton Institute for Advanced Studies, Wolfson acts as a second home to world-leading scientists from the best institutions around the world.

The spirit of free scientific exploration and adventure is as vibrant today as it was when Haldane performed his pioneering biological experiments on the site. This remains unique to Wolfson.

Its alumni and fellows, such as Professors David Deutsch and Artur Ekert, are pioneers in quantum computation and quantum cryptography. Currently, many fellows work in this exciting area, in the context of the existing Wolfson Quantum Cluster. This will be a powerful launch-pad for the research hub.

The research hub aims to establish an interdisciplinary unifying research programme that transcends the disciplinary boundaries imposed by the traditional university departments. Wolfson College, a beacon of scientific learning and multidisciplinary research, is therefore uniquely suited for such an innovative scientific enterprise.



The Research Hub

Activities

We will bring together a team of leading experts in their respective fields who offer complementary skills that will ensure the successful operation of the research hub. The joint theoretical and experimental approach we have adopted will entrench an interdisciplinary way of working in our team which spans the Oxford Physics, Philosophy, Computer Science and Materials departments.

On-going workshops between the members of the project team will take place every other month, and one-hour weekly review meetings will monitor progress against specific deliverables and bring speedy resolutions to problems when they arise.

Wider impact

The research hub will have a profound impact on different fields of knowledge. It will provide a radically new conceptual framework for a unifying understanding of reality and new tools to tackle fundamental questions in a wide range of disciplines.

We expect this unifying approach to research will help produce new understandings of physical reality – insights that can change the wider public’s view of the world. At the same time, this powerful research paradigm will demonstrate the efficacy of integrated scientific research. In order to foster these developments, we will engage in a variety of outreach activities – workshops, videos, festivals and open debates – to communicate our findings regularly to the public.

The advances in our understanding will underpin further progress in quantum technologies, which use superposition, entanglement and other quantum phenomena. The use of quantum processes in this intermediate micro-to-macro transition regime is a necessary step that will enable us to harness the

untapped power of quantum effects in order to make processing more efficient.

One example of how this would benefit us would be in optimising the use of energy and power that such quantum machines would use. Information technologies today account for a larger carbon footprint than the airline industry, so even a small percentage saving on information processing power would leverage a significant positive impact.

Other relevant technologies that would benefit from a better understanding of the intermediate quantum-classical regime are nano-electromechanical systems, molecular motors and ultra-high precision nano-mechanical sensors and quantum metrological devices. These devices currently exist only on drawing boards because of decoherence – the phenomenon that resets them back to the classical regime.

Only through a deeper understanding of the stages of decoherence, which represents the scientific focus of this project, can one optimise the design of these devices.

Opportunities for partnership

To create this ground-breaking research hub, we are seeking partnerships with visionary philanthropists who recognise the enormous importance of advancing the frontiers of physics and bettering the world with new knowledge, new technologies and a deeper, richer understanding of reality.

Below we outline the costs to bring this vision to fruition. This includes funding

for the academic firepower needed to drive the innovative and creative explorations of the research hub.

Also included are the costs for physical infrastructure, space and state-of-the-art equipment for experiments to verify and extend the research hub's theoretical work.

<i>Posts</i>			
	Annual cost per post	Endowment for single post	Total endowment
5 Senior Research Fellows	£100,000	£3 million	£15 million
8 Postdoctoral Fellowships	£60,000	£1.8 million	£14.4 million
8 DPhil Scholarships (£26,000 per year for 4 years)	£104,000	£780,000	£6.24 million

<i>Infrastructure costs</i>	
Equipment and space	est. £15 million



Recognition for our benefactors



Since its founding more than eight centuries ago, Oxford and its colleges have been shaped and sustained by the patronage of visionary individuals, groups and organisations, who share our commitment to advancing human knowledge. In turn, Oxford has been deeply committed to providing lasting and fitting recognition to its philanthropic partners. Major forms of acknowledgement include:

Clarendon Arch

A benefactor who has donated £5 million or above may have their generosity honoured by the engraving of their name in the Clarendon Arch, near the entrance of the world-famous Bodleian Library. Names inscribed on the Clarendon Arch include some of the most prominent benefactors in Oxford's history: King Henry VIII, Queen Elizabeth I and Sir Thomas Bodley. Benefactors added within the last generation include Mr George Soros, Her Majesty Queen Elizabeth II, and the Wolfson Foundation.

Chancellor's Court of Benefactors

Philanthropic contributions which cumulatively total more than £1.5 million by an individual benefactor or £3 million by an organisation, once received in full, may enable the Chancellor to invite the benefactor

to join the Chancellor's Court of Benefactors (CCB). The Court meets annually in Oxford for the formal ceremony of admission, business meeting and formal dinner. The Chancellor, The Rt Hon Lord Patten of Barnes CH, presides at CCB meetings.

Vice-Chancellor's Circle

The Vice-Chancellor's Circle recognises benefactors who have provided generous support of between £250,000 and £1.5 million to the collegiate University. The Circle engages members in the life and work of the Colleges and the University, and meets each year in Oxford.

Encaenia

Encaenia is the annual ceremony in which honorary degrees are awarded to distinguished men and women, and benefactors are celebrated. Major partners of the University's work are invited to attend this important occasion, held at the Sheldonian Theatre since 1670. Every year, the University's Public Orator delivers the Creweian Oration on the events of the past year and in celebration of the University's benefactors. In addition, the University records principal gifts to Oxford received during the past 12 months in the list of benefactions in the *Encaenia* Programme.



For more information, please contact:

William J Conner

Fellow and Development Director
Wolfson College
University of Oxford
Linton Road, Oxford OX2 6UD

T: +44 (0) 1865 284 333

E: william.conner@wolfson.ox.ac.uk

Professor Vlatko Vedral

Professor of Theoretical Quantum Optics
Co-Director of the Oxford Martin Programme on
Bio-Inspired Quantum Technologies
Oxford Martin School
34 Broad Street, Oxford OX2 6UD

E: vlatko.vedral@qubit.org

