Glowing diamonds are a quantum scientist's best friend

Dr Lachlan Rogers, based at the **University of Newcastle** in Australia, is investigating diamond colour centres. His aim is to enable the development of new quantum technologies that will revolutionise many aspects of life.

Dr Lachlan Rogers

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PROFILE

Field of research
Quantum optics

Research project
Investigating the quantum properties of diamond colour centres

Talk like a ...
quantum optics physicist

Electromagnetic — a force created by the interaction of an electric field with a magnetic field

Electron — a subatomic particle with a negative electric charge

Magnetic resonance imaging (MRI) — a non-invasive biomedical imaging technology that uses magnetic and radio waves to produce three-dimensional images of certain structures in the body

Photon — packets of electromagnetic energy that make up light

Quantum metrology — the field of study using quantum mechanics for measurements

Quantum sensor — a sensor that makes use of quantum properties to make sensitive and precise measurements

Spin — a form of angular momentum carried by elementary particles, composite particles and atomic nuclei

Ultraviolet — light that has shorter wavelengths than visible light

Diamonds are precious stones that were formed on Earth more than one billion years ago. They are the hardest natural substance on our planet and are made of only one element – carbon. They are formed deep within the Earth's crust, when intense pressure and heat cause carbon atoms to crystallise. However, as technology advances and scientists perform tasks and experiments that would not have been possible just a few decades ago, researchers are now able to grow diamonds in a laboratory, by reproducing the geological conditions needed for them to form.

At the University of Newcastle, Dr Lachlan Rogers is using lab-grown diamonds to investigate diamond colour centres. When we think of diamonds, we usually imagine a silvery white, shining jewel, but diamonds come in many colours. For his research, Lachlan grows diamonds in his lab that are about four nanometres in size, approximately 100 times smaller than the wavelength of visible light.

Lachlan and his team are using diamonds grown in a lab rather than naturally occurring diamonds because naturally occurring diamonds have too many atomic defects. Lab-grown diamonds have an extremely high chemical purity, allowing control of the colour centres that form. It is these colour centres that open up an exciting world of quantum technology applications.

Colour centres are defects where a non-carbon atom interrupts the regular array of atoms within the diamond, and they

Quantum analysis and control of light fluorescing from lab-grown diamonds @EQUS

absorb visible and ultraviolet light. "They are what give some diamonds 'colour' and the 'centre' refers to the fact they are just an atom or two in size – about as small as it gets in a crystal," explains Lachlan.

Why are colour centres important to Lachlan's research?

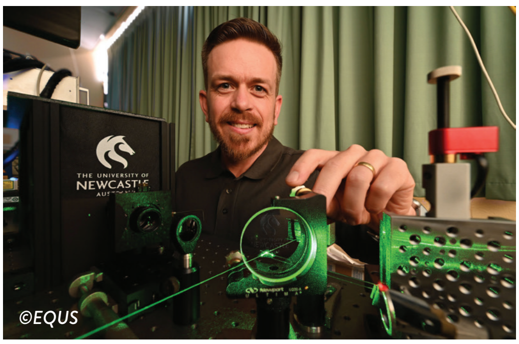
It is only the colour centres of diamonds that interact with, absorb and emit visible photons – bundles of electromagnetic energy that makes up all light. The pure diamond crystal surrounding these centres is transparent to visible light and is essentially useless when it comes to experiments in quantum physics. "A single colour centre can emit a clearly detectable amount of light, so we can 'talk' to just one at a time," says Lachlan. "However, there is a limit on how small you can focus light, so even with the best lenses, there are tens of thousands of atoms in the optical 'detection spot'. To be able to talk to just one colour centre, we need to know that the typical distance between colour centres in the diamond is much more than this focus size." Lachlan's aim is to have just a few colour centres per billion carbon atoms in the diamond crystal.

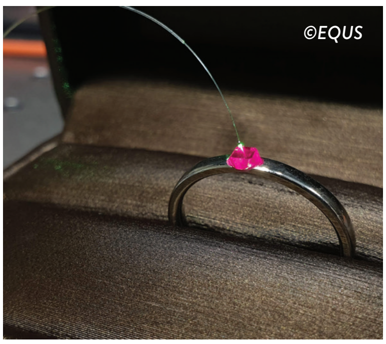
How does the team harness colour centres to build quantum computers?

Lachlan and the team are looking at the light that comes from a single colour centre, which essentially means they are 'talking' to a single electron. Diamonds are a vehicle, providing a convenient way to hold that single electron in place. "Electrons have physical properties such as mass and energy, but they also have a quantum property, known as 'spin'," explains Lachlan. "This spin can be used to store and process quantum information."

What is quantum metrology?

In addition to exploring the possibilities surrounding quantum computing and a quantum internet, the team's investigations consider how colour centres feed into quantum metrology – which makes use of quantum details to improve measurement precision and sensitivity. One notable example of this at work is the atomic clock, which is the most accurate means of determining the time, and which is based on the interaction of electromagnetic radiation with the excited states of atoms. Another example is magnetic resonance imaging (MRI), which is used in hospitals to look inside a patient's body.





Recently, it has become possible for researchers like Lachlan to control and interact with single quantum objects at a time. "A single diamond colour centre can do the same measurements as an MRI machine, but on a single molecule in a biological cell," explains Lachlan. "By giving us access to single quantum objects, diamond colour centres are enabling quantum measurement of magnetic fields, electric fields and temperature."

What is Lachlan's goal?

Quantum physics has capabilities that cannot be explained by classical physics. Lachlan's work is focused on harnessing capabilities that could give rise to a quantum internet which, in theory, would be able to perform tasks that are not possible using the internet of today. In addition, the field of quantum sensors has the potential to revolutionise molecular bioscience and improve treatments, therapies and the lives of people around the world. Experiments in these fields are extremely difficult, but diamond colour centres provide a means of helping such technologies work at room temperature, instead of inside massive super-fridges. Lachlan's aim is to discover and engineer diamond colour centres that have better quantum properties and that could help to revolutionise our world.

About *quantum optics*

Quantum optics is the study of how photons interact with atoms and molecules. Scientists like Lachlan are working on accurately controlling these interactions and creating quantum states of matter and light that can facilitate the development of a wide range of quantum technological applications. The research and experiments that Lachlan is conducting could help create a quantum computer and develop sensors made from individual atoms. It is difficult to overstate how much this would change the world as we know it.

One of the most exciting aspects of quantum physics is that it is weird and 'magical', and flies in the face of many things we consider intuitive. Quantum physics will always throw up fascinating surprises. "It is a fantastic time to consider a career in quantum science, because so many new options are opening up. Once upon a time, electromagnetism was a fundamental research field in university laboratories, but it is now normal to study electrical engineering because so many commercial and industrial tools rely on electronics," says Lachlan. "The same is happening right now for quantum technologies – we are on the cusp of the first-ever generation of quantum engineers."

Quantum optics is a large and active field in Australia, and researchers have developed a strong research focus on quantum science and its wide range of applications. "Not all quantum technologies are optical (others use electronic control and readout), but optical control has some advantages because it does not require physical contact," explains Lachlan.

We are all familiar with computers and digital communications, which are electronic devices that enable us to perform an enormous range of tasks. While these technologies are based on the principles of classical physics, quantum optical technologies will run much faster. If you have broadband in your home, you might have optical fibre internet, which has significantly sped up the speed at which users can connect to the internet. There is a similar potential for optical computers, even if they are not quantum computers.

Pathway from school to *quantum optics*

A sound understanding of mathematics and physics is a basic requirement for studying quantum optics, but other subjects are important for a working scientist. For example, you will need English skills for writing funding applications, scientific papers and presentations, and IT skills, which will help give you a greater understanding of computing.

You will need a degree in a relevant subject for postgraduate study. You can learn more from Prospects: **prospects.ac.uk/careersadvice/what-can-i-do-with-my-degree/physics**

Explore careers in *quantum optics*

The Optical Society (**optics.org.au**) is a brilliant resource for those interested in understanding more about optics and photonics.

The world of physics is changing and becoming more inclusive than it has historically been. Lachlan's position at the University of Newcastle is part of generational handover, where many professors have recently retired and been replaced by younger academics. The physics department there is 50% male and 50% female, which shows that the field is heading in the right direction.

Meet *Lachlan*

I don't remember specifically wanting to be a scientist, but I have always found science and mathematics very interesting. When I was young, my dad would play games with me when slicing apples: "Would you like one third or two eighths?" and I had to work out which one gave me more apple!

My dad and (maternal) grandfather both have science PhDs, so an interest in maths and physics certainly seemed 'normal' to me as a child. At various times, I visited universities for holiday programmes and public lectures, and I was enthralled by all the amazing instruments and lab devices. I think part of my interest in physics is also that I like playing with cool toys!

When I was an undergraduate student, I applied for a student travel scholarship to attend the Australian Institute of Physics Congress. The form had a field for areas of interest, and I wrote quantum computing because it sounded cool to me. A professor saw this form and offered me a tour of their research lab. I was so excited by the things I saw that I ended up doing my PhD under the supervision of that professor!

After my PhD, I moved to Germany to do postdoctoral research for a few years. I was successful in applying for an early-career research fellowship in Australia and came back to work with Dr Thomas Volz. I learnt loads of things – but the main scientific tasks I worked on were temperature sensing and optical cavities (light bouncing back and forward between two mirrors). We were trying to make a diamond-powered laser to measure tiny magnetic fields.

The research fellowship that I had working in Thomas's lab was on a fixed-term contract, not ongoing, which is very normal for early-career academic research. I applied for numerous positions over a few years and was delighted to be offered a job at the University of Newcastle. This has been geographically close enough to enable me to keep collaborating with Thomas and other colleagues in the Sydney area. Getting an ongoing position (a 'proper job' as I often joke with friends) is a huge step on the career path of a researcher. It means my research is interrupted more by having to teach (luckily, I enjoy teaching), but it also means that I can make longer-term research plans and work towards larger goals and projects.

Lachlan's *top tips*

1. If you want to get into quantum optics, you can never do too much maths! It is very much the language of physics, so improving your mathematical fluency will always serve you well throughout your studies and later career.

2. Being able to write software has turned out to be a bit of a 'superpower' in my research career. I am lucky that it was an amateur interest of mine throughout school. If you have the opportunity to study some coding or software design, you should take it.

3. The field of quantum optics (and quantum physics, in general) is developing at an increasingly fast rate. It is important to try and keep on top of the latest developments, so do your best to read science magazines and trawl through science websites. There are also lots of helpful, high-quality YouTube videos explaining scientific concepts.