The Physical Sciences
Why they matter

#PhysicalSciencesImpact
Professor Kyriakos Porfyrakis, with a model of the world's most expensive material (pages 12-13).
The Physical Sciences
Why they matter

Physics, chemistry and materials science – the physical sciences – comprise our global DNA. By understanding the fundamental building blocks of our universe – heat, light, atoms, the elements, matter, gravity itself – EPSRC-supported physical scientists are unlocking its secrets and providing solutions to the key questions of our age.

Without the fundamental research carried out by physical scientists, the internet would run at a snail’s pace, not light-speed; doctors would still be using scalpels to see inside the human body, not X-rays; electric vehicles would barely make it to the shops and back; the water in our homes would not be safe to drink; and computer data would be stored in bungalows, not tiny memory chips. And electric light, fridges, television and mobile phones? There wouldn’t be any.

Physical sciences is, above all, discovery-led, through which physicists, chemists and materials scientists ask vital new questions as current ones are answered. Theirs is a continuous process of enquiry and exploration, opening-up new boundaries in space, matter and time itself (pages 16-17).

Because this research is fundamental and high-risk, its socio-economic impact can be many years away. For example, in 1917, Einstein proposed the process that makes lasers possible. But it would take nearly 40 years before scientists found a way to harness their potential.

EPSRC has invested in fundamental research into lasers for many decades. This research has gone on to shape the modern world (pages 6-7), leading to everything from the barcode readers in our shops and the automated welding machines in our car factories to the devices that drive the Internet superhighway (pages 4-5).

The fundamental, discovery-led physical sciences research supported by EPSRC spans all sectors, from healthcare (page 10) to agrifood (pages 8-9); providing the bedrock upon which our partners in UK Research and Innovation, industry (page 21), government and the third sector can build the innovative new technologies of tomorrow.

To develop the next generation of pioneers, EPSRC is also the UK’s largest investor in dedicated Physical Sciences doctoral training (pages 8-9), providing the platform upon which the scientists and innovators of tomorrow can use to build impactful careers (pages 18-19) as leaders in academia, industry, policymaking and the third sector.

It is essential that we continue to invest in a broad portfolio of high-risk physical sciences research and doctoral training – helping to turn innovative ideas into real-world future technologies (page 21), and ensuring that the UK remains a healthy, connected, resilient and productive nation.

Turning the stuff of science fiction into everyday reality.

#PhysicalSciencesImpact
Billion-year data bank

Scientists at the University of Southampton’s Optoelectronics Research Centre, which EPSRC has supported for over 40 years, have developed a means of storing data for billions of years in microscopic, almost indestructible format.

The technology has been developed by Professor Peter Kazansky and his team. They fired ultra-short laser pulses writing at speeds of one millionth of one billionth of a second onto nanostructured glass, to create ‘five-dimensional’ optical storage devices.

Given its potential durability, portability and longevity, the technology could have huge commercial implications, opening up a new era of ‘eternal’ data archiving for use in organisations such as museums and libraries.

To demonstrate the technique, which could conceivably be used to store all the books ever written, the team used it to store documents fundamental to humanity and to human history, including the Universal Declaration of Human Rights and the King James Bible. They also created a one-inch glass disc inscribed with Latin and English versions of the Magna Carta as a gift to Salisbury Cathedral.

The team’s breakthrough has attracted the interest of global organisations such as the International Court of Justice, Microsoft, Sony and Warner Brothers. The technology has also caught the attention of tech entrepreneur Elon Musk, who deployed it as a data bank of human history in a Tesla Roadster electric car, currently on its way to Mars aboard a SpaceX Falcon Heavy spacecraft and destined to journey forever around our solar system.

“Using this process, we can record 360 terabytes of data, the equivalent of 7,000 Blu-ray disks, on something the size of a CD. The device can be stored at room temperature for billions of years and will be capable of withstanding another ice age.”

Professor Peter Kazansky, Optoelectronics Centre, University of Southampton

About the Optoelectronics Research Centre

Technologies developed at the Optoelectronics Research Centre (ORC) at the University of Southampton are at the cutting edge of international manufacturing, healthcare and commerce.

The ORC’s patented optical amplifiers are fundamental to powering the global internet, while its fibre lasers are in worldwide use, performing delicate eye surgery, welding cars in state-of-the-art factories, and even marking the date on items we buy in the supermarket.

Supported for over four decades by EPSRC, ORC researchers have created 11 spin-out companies, generating £200 million in revenue and creating over 600 jobs. Over 800 ORC alumni are in key positions in academia and industry globally.
Using this process, we can record 360 terabytes of data, the equivalent of 7,000 Blu-ray disks, on something the size of a CD. The device can be stored at room temperature for billions of years and will be capable of withstanding another ice age.

Professor Peter Kazansky, Optoelectronics Centre, University of Southampton
Transforming the 21st century

With funding from EPSRC, Professor Alf Adams’ ground-breaking 1980s research into infrared lasers at the University of Surrey paved the way for low-cost, low-power commercial and industrial products that transformed the 21st century.

His research was fundamental to the development of technology that makes it possible for the Internet to send information around the planet at superfast speeds. It was also pivotal to the creation of the barcode technology so pivotal to everyday life – from grocery scanners at supermarket checkouts to computer mice.

At first, there were no takers for Professor Adams’ technology – his idea was considered too radical – until Dutch manufacturer, Philips, saw its potential, and used it to develop the first DVDs. The rest is history that’s still in the making.

Now, Professor Adams’ ‘strained quantum-well laser’ is considered to be one of the top 10 greatest UK scientific breakthroughs of all time.
Reducing global crop losses, saving lives

**FungiAlert**, a company set up by two young entrepreneurs, has developed a unique low-cost device for the early detection of plant disease, making soil-health analysis affordable and accessible to all growers.

The award-winning device is the brainchild of Dr Kerry O’Donnelly (pictured left) and Dr Angela de Manzanos Guinot (right), former students at the EPSRC Centre for Doctoral Training in Chemical Biology at Imperial College London.

By alerting farmers to the presence of plant disease in the soil before infection occurs, the company’s technology has the potential to increase crop yields by dramatically reducing crop loss, and helps to guide farmers’ spraying practices to reduce pesticide applications.

Based around a simple colour-change detector, the company’s disposable SponSenz device is the first in-situ early detection sensor for plant diseases in soil and water, and can detect pathogens such as the highly destructive *Phytophthora*, estimated to account for up to US$7 billion of worldwide crop failure annually, before infection occurs. It is the only in-field device capable of doing so.

The technology can also aid understanding of the health of a field before planting, helping farmers to make key decisions, such as the best time to harvest a crop.

Traditional testing involves sending soil samples to a laboratory for analysis. This can alter the microbial dynamic, meaning that the samples do not necessarily accurately reflect the natural dynamics of the soil conditions.

By contrast, FungiAlert’s technology detects micro-organisms while they are alive and active in the field and only those which are in high concentration. Because the testing is in-situ the time between sampling and reporting can be slashed from the standard three-to-five weeks to three-to-five days, and at a fraction of the cost.

FungiAlert has multiple applications for soft fruit crops, horticultural vegetables and ornamental plants and trees, amongst many others.

Drs Donnelly and de Manzanos Guinot founded FungiAlert in 2015 while completing their PhDs at Imperial College London, during which they won three entrepreneurial competitions, the prize money from which provided them with the funding they needed for the initial development of the technology and supported their first patent application.

Following successful field trials, and working with key stakeholders in the agricultural UK market, FungiAlert, launched its technology and services in October 2018.

The company is now based in the Rothamsted Research Centre in Hertfordshire, which is supported by UKRI’s Biotechnology and Biosciences Research Council (BBSRC). FungiAlert has received support from UKRI’s Innovate UK to develop and commercialise its business model.

Dr Donnelly says: “Our vision is to revolutionise disease management practices within agriculture. If global crop losses were reduced by just one per cent, 24 million people would get to eat.

“You can look at FungiAlert as a smoke alarm for farmers. It alerts you to the problem before it destroys everything – and does so weeks before symptoms are visible.”

In 2016, Kerry O’Donnelly was named by the Royal Society of Chemistry (RSC) as one of its 175 Faces of Chemistry, an initiative launched to mark the RSC’s 175th anniversary celebrations.
“Our vision is to revolutionise disease management practices within agriculture. If global crop losses were reduced by just one per cent, 24 million people would get to eat.”

Dr Kerry O’Donnelly
Chemistry-based spin-out company sold for £623 million

In August 2018, Ziylo, a spin-out company from the University of Bristol co-founded by Professor Anthony Davis, was acquired by global healthcare company Novo Nordisk in a deal worth £623 million.

Now, the company, which was formed to bring fundamental chemistry research to market, is helping to tackle one of the world’s most serious healthcare challenges through the application of its innovative technology platform which could lead to safer, more effective treatment of diabetes.

The new treatment could be available to the global healthcare sector within 10 years, and benefit millions of people around the world.

Novo Nordisk aims to incorporate a ground-breaking glucose-binding molecule developed by Ziylo into a radical new type of insulin that makes it easier for diabetics to manage their condition and minimises the risk of potentially fatal episodes of hypoglycemia.

Vital work to optimise the molecule for use in the new insulin is being undertaken by Carbometrics, a new company co-founded by Professor Davis, whose 11-strong team includes former PhD students and postdoctoral students from the Davis Group.

Ziylo’s breakthrough came out of 20 years of EPSRC-supported research at the University of Bristol, where Professor Davis is also a supervisor in the EPSRC Centre for Doctoral Training in Chemical Synthesis.
The quantum ‘compass’

A quantum ‘compass’ which could allow navigation without relying on satellites has been demonstrated by a team from Imperial College London and photonics and quantum technology company M Squared.

Most navigation today relies on a global navigation satellite system such as GPS, which sends and receives signals from satellites orbiting the Earth. The new device harnesses quantum technologies to create a self-contained system that does not rely on any external signals.

This is particularly important because satellite signals can become unavailable due to blockages such as tall buildings, or can be jammed, imitated or denied – preventing accurate navigation. One day of denial of the satellite service would cost the UK £1 billion.

The device was built by Imperial College London and M Squared with funding from Dstl, EPSRC and Innovate UK, and represents the UK’s first commercially viable quantum accelerometer which could be used in applications such as navigation.

The breakthrough was hailed in an editorial in The Times, which described the technology as ‘having immense potential application’.
World’s most expensive material

You are looking at a scaled-up model of the most expensive product in the world. No, not gold, diamonds or pixie dust, but nitrogen atom-based endohedral fullerenes – essentially a minuscule cage of carbon atoms, with a nitrogen atom inside. Price per gram? £110 million.

Known as fullerenes or buckyballs because of their resemblance to the geodesic dome designs by 1960s architect and futurist R. Buckminster Fuller, fullerenes are a type of carbon nanomaterial which, like graphene and carbon nanotubes, has unique physical properties, leading to applications in areas as diverse as energy and medicine.

Why so expensive? Well, given their size and complexity, endohedral fullerenes are very difficult to make. You also need specialist lab equipment. Fortunately, you don’t have to buy a whole gram for them to work their magic. If you have £22,000 spare, you might want to invest in a 200-microgram sample, available from Designer Carbon Materials, a University of Oxford technology start-up which has patented its technology.

Founded by Professor Kyriakos Porfyrakis FRSC (pictured on page 2), to bring his EPSRC-supported research to market, the company specialises in cost-effectively manufacturing commercially useful quantities of the spherical carbon cage structures.

Why would you want to buy some? Well, similar to their cousin graphene, endohedral fullerenes have highly attractive chemical, physical, magnetic and electronic properties.

Among potential applications, endohedral fullerenes could be used in a new generation of quantum technologies, such as molecular atomic clocks – but at a far smaller scale than typically used devices.

The ability to incorporate quantum technologies into these devices would be very useful in environments where GPS signals are weak or even lost, such as indoors or in tunnels. It would also make driverless car technology, for example, much safer. Other applications, which Designer Carbon Materials has scaled-up production to support, include energy harvesting, bio-sensing and quantum nanoelectronics.

“IT is possible to insert a variety of useful atoms or atomic clusters into the hollow interior of these ball-like molecules, giving them new and intriguing abilities.”

Professor Kyriakos Porfyrakis
Snowfakes

Artificial falling snow made in Bristol will soon be playing a starring role in Hollywood blockbusters and cult TV series thanks to an EPSRC-funded Masters student at the University of Bristol.

The cool creation has come about thanks to a partnership between the university and Snow Business, the world’s leading supplier of artificial snow and the creators of many famous movie snow scenes. Snow Business was keen to invent a new environmentally-friendly fluid which could be pumped out of its snow machines in the form of foam to create the effect of snowflakes.

The company got in touch with Bristol’s Research and Enterprise Development (RED) team, which put it in contact with Dr Wuge Briscoe, Senior Lecturer in Physical Chemistry.

RED also helped facilitate funding of the project through the university’s EPSRC Impact Acceleration Account (IAA), a scheme to aid innovation by helping businesses to access the academic knowledge available at universities.

Snow Business contributed to the partnership by supporting research by Masters student Lizzie Mould (pictured), who took the project on under Briscoe’s supervision. Lizzie subsequently landed a job at the Stroud-based company. Snow Business has created snow scenes for many major Hollywood blockbusters – including the Harry Potter films.

The remit was very specific. Snow Business required a realistic-looking end product that is robust in different climates, doesn’t cause adverse skin reactions, and doesn’t leave any residue. With expensive costumes and sets to consider, this is critical. Above all, the product had to be environmentally friendly – ideally as pure as the driven snow.

The project has its roots in fundamental chemistry research by the Colloid and Interface Science group at the University of Bristol, which is investigating how thin liquid films are stabilised by different molecules. This led to the formulation of the snow effect solutions.

Lizzie developed hundreds of formulations before finding the right combination. This resulted in two products, ProFlake and EcoFlake – which is thought to be the most environmentally-friendly snow effect fluid on the market. The two products have been launched to Snow Business’ global network of suppliers for use in everything from gentle snow flurries to raging blizzards. EcoFlake has also been used to create winter scenes at the Eden Project – which is testament to its green credentials.

Paul Denney, Head of Research and Development at Snow Business, says: “We had looked at developing the product ourselves but the chemistry involved was beyond our capabilities, which is why we approached the University of Bristol.

“We weren’t sure what Lizzie and Wuge would be able to do, especially as we had a long wish-list of characteristics, but they surpassed all our expectations with the fluids they created.”

“Having a full-time job with the company enabled me to see the process all the way through, from fundamental science to getting involved in the marketing and launch of the product. It was a fantastic opportunity. There aren’t many people who can say they create fake snow for a living.”

Lizzie Mould
Quantum ballet

Professional ballet dancer and quantum physicist, Dr Merritt Moore, describes her dual careers.

“My professional and academic journey has always been a balance – jumping from lab shoes to pointe shoes; from laboratory goggles to tutus.

I have juggled being a professional ballet dancer with the Zurich Ballet, Boston Ballet and English National Ballet while graduating in physics at Harvard, and studying as an EPSRC-supported PhD student of Quantum Optics at the University of Oxford.

It’s a double life that has sometimes caught me literally in awkward positions. I’ve been found doing the splits underneath my desk, or balancing with my leg above my head in full cleanroom gear, waiting for measurements.

During my PhD at Oxford, I focused on creating pairs of photons to be used for quantum information experiments. These photons exhibit fascinating properties of quantum mechanics, such as superposition – a phenomenon where, for example, very small particles can be in two places at the same time. A state I mirror in my dual careers.

I feel very strongly that the arts and sciences are not mutually exclusive. Creative thinking is required in science to explore unsolved questions and come up with innovative solutions, and yet often there is a stigma that science is a single-tracked pursuit that doesn’t require creativity. I’ve worked hard to pursue both, in the hope that other students can be encouraged to do the same.”

Merritt was awarded her PhD in 2018, and continues to pursue joint careers as a ballet dancer with the Norwegian Ballet and as a physicist.

In 2018 the influential business magazine Forbes named her as one of its 30 European-based artists under the age of 30 who are transforming society. She has also set her sights on becoming an astronaut, and was a contestant on BBC 2’s Astronauts: Do You Have What It Takes?.
Getting fresh

Alex Bond (pictured), a doctoral student at the EPSRC-funded Institute of Chemical Biology Centre for Doctoral Training at Imperial College London, has co-developed a simple but ingenious way to detect bacterial contamination of foods and food preparation surfaces.

With fellow students at Imperial, Rob Peach and John Simpson, and supported by Imperial Innovations and the Climate-KIC, Alex co-founded a company, Fresh Check, to bring their ideas to market. The company is revolutionising the way we understand infection by making bacterial contamination visible.

The team’s inspiration for the company came from their own experiences as hard-up students, when they would eat food past its sell-by date so as not to waste it – but not knowing if it was safe to eat.

They set about developing a biotech-style solution to the challenge of how to ensure food is fit for human consumption.

Fresh Check’s first product is a low-cost harmless colour-changing spray for use in restaurants, hospitals, food-producing plants and at home. If the colour of the spray changes from blue to orange after it has come into contact with food, such as on a chopping board or work surface, it will alert users that it harbours dangerous levels of bacteria.

The spray is safe for use on and around food production facilities, and has been independently verified for accuracy by independent food industry advisory service, Campden BRI.

Alex Bond says: “Bizarre as it seems, there is only one on-the-spot test for surface hygiene. By developing Fresh Check, we are the first company to offer an alternative to what’s out on the market. This will help save companies money and allow them to more thoroughly test the hygiene of their facilities.

Since developing its concept, Fresh Check’s business model has changed and grown, but the core colour-change technology remains the same.

Among a suite of products in the pipeline, the multi-award-winning company is incorporating its technology into infection-monitoring bandages for use in healthcare. It is also creating colour-change labels for food packaging, based on the three founders’ original idea about finding a way to determine whether packaged food is safe to eat. Once the technology becomes commercially available, it will help to prevent some of the 1.3 billion tonnes of global food waste we create from being sent to landfill.

In 2017, Alex Bond was named by Forbes magazine as one of its 30 under 30 young European leaders, inventors and entrepreneurs who are transforming society.

“Our business may not be the most glamorous or attention grabbing, but if we’re able to prevent even one outbreak of infection from bad cleaning practice we’ll be satisfied we’ve helped people out.”

Alex Bond
Saving our heritage

An EPSRC-supported research team have developed a safer, greener method for conserving waterlogged wooden artefacts, such as those recovered from Henry VIII’s warship, the Mary Rose.

The team, led by Professor Oren A Scherman, from the University of Cambridge, in collaboration with the Mary Rose Trust, developed a natural polymer-based system that appears to protect against all three primary causes of degradation in waterlogged wood, the first time this has been possible in a single treatment.

Initial tests of the material, carried out on wooden artefacts recovered from the ship, have shown that it effectively protects waterlogged wood against the main causes of collapse, and is a safer, greener alternative to current methods.

A number of factors can contribute to the degradation of wooden artefacts once they are removed from the sea. Warping or cracking as the wood dries out, damage from bacteria, and the build-up of acid formed by the corrosion of iron fastenings and bolts can all cause cellulose to break down.

The protective material created by the team uses two naturally-sourced polymers to build a molecular cage around the iron ions, preventing them from acting as a catalyst and generating acid in the timber. This not only traps iron ions, it helps to enhance structural stability. In addition, the material has antibacterial properties which protect against biological damage. Even if there is no iron in the wood, the treatment still works. The team are now conducting tests on larger wooden artefacts.

Dr Walsh performed the research while a postdoctoral researcher in the Department of Chemistry’s Melville Laboratory of Polymer Synthesis, which is led by Professor Scherman, an EPSRC RISE Rising Star.

The research was funded by EPSRC, the European Research Council, the Walters-Kundert Charitable Trust, the Mary Rose Trust, the National Science Foundation and the US Forest Service and Forest Products Laboratory.

“The polymer gets stronger relative to the amount of iron that’s there – in that way it’s quite responsive to its environment.”

Dr Zarah Walsh
Postdoctoral researcher
Cool fuel

Fundamental EPSRC-supported research in the 1990s at the University of Surrey, led by Dr Donald Highgate, underpinned the formation of ITM Power, a highly successful UK supplier of renewable energy.

Among a host of initiatives, ITM Power is rolling out hydrogen vehicle refuelling stations across the UK; it has also fuelled hydrogen-powered buses as part of its move into the international hydrogen bus market.

The research behind ITM Power began with a grant of £63,000 from the Science and Engineering Research Council, EPSRC’s predecessor, to develop a new material for use in hydrogen fuel cells. This project built on a unique material that Highgate had originally developed for soft contact lenses.

The company remains true to its original mission of working towards a more sustainable future based on clean fuel and energy storage.

Electric vehicles are usually charged from the National Grid, which uses a mixture of renewable and carbon-based energy sources. Conversely, ITM Power is able to produce its hydrogen on site using renewable energy from wind and solar sources, and so incurs zero use of carbon in generation and transport.

Today the company employs over 70 people and is a project partner on eight EPSRC-supported academic/industry research projects. It also works closely with two EPSRC Centres for Doctoral Training. Innovate UK, UKRI’s innovation agency, has awarded the company grants of over £1.6 million.

Dr Nicholas Van Dijk, Research Director at ITM Power, says: “There is a huge knowledge base in the UK. As a partner on EPSRC-supported projects we can help drive the direction of the research towards commercial success.”

After 50 years of innovation, Donald Highgate continues to push at the boundaries of materials science, and says the stakes have never been higher: “We are probably the first generation who, if we can dream of something, we can do it.”

“There is a valid reason for finding a hydrocarbon replacement fuel that won’t ruin the world for our children. The future will hold us responsible if we don’t do it.”

Dr Donald Highgate

Picture © ITM Power
Cool news

Scientists from the universities of Edinburgh and Dundee, led by Professor Cait MacPhee CBE, have unlocked the secret of slower-melting ice cream, thanks to a new food ingredient.

The team found that the ingredient – a naturally occurring protein – is not only more resistant to melting than traditional ice cream ingredients, it also binds together the air, fat and water in ice cream, creating a super-smooth consistency.

The protein works by adhering to fat droplets and air bubbles, making them more stable in a mixture. Using the ingredient could offer significant advantages for ice cream makers. It can be processed without loss of performance and can be produced from sustainable raw materials.

Manufacturers could also benefit from a reduced need to deep-freeze their product, as the ingredient would keep ice cream frozen for longer.

The protein, known as BslA, was developed with support from EPSRC and the Biotechnology and Biological Sciences Research Council (BBSRC). Its discovery could lead to lower-calorie foods and has potential for use in home and personal based products. The team have been in discussions with industry partners from a range of sectors interested in applying this technology commercially.
Smart packaging for a sustainable world

To tackle the UK’s 15 million tonne annual food-waste problem, Anacail, a spin-out company from the University of Glasgow, is harnessing the germ-killing power of ozone to make packaged food safer and longer-lasting. Other applications include medical device sterilisation.

The technology, developed by Dr Declan Diver and Dr Hugh Potts, uses electrodes to generate a cold plasma inside the packaging without having to open it. This ozone then circulates, destroying microorganisms on the food surface, preventing them from causing disease or spoiling food. It then returns to its original state, leaving no residues behind.

The product is not only safe and easy to use, it requires no change in current packaging of food products to be effective, and doesn’t require chemical additives.

Anacail is partnering with several leading food manufacturers and retailers to integrate its patented technology into their processes.

The company has also formed an exclusive licensing deal with Berry Gardens, which supplies British berries, cherries and plums to leading UK supermarkets.

EPSRC has supported Dr Diver’s plasma-related research for over 15 years, and Anacail has received follow-on funding from UKRI’s Science and Technology Facilities Council and from Innovate UK.

“This technology is game-changing in our industry, using Ozone, a proven sterilant, to reduce the presence of yeasts and moulds. This means extended shelf life, reduced waste and a better product for our consumer.”

Berry Gardens CEO, Jacqui Green