What are the hot research areas that might spark the next big bang?

We examine citation data to get an idea of the most exciting and potentially ground-breaking research topics

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By THE reporters (/author/reporters)

Source: Getty

What are the hottest areas of research in contemporary science? Different people will give different answers, and a lot of those answers will stem from personal interest. For many researchers, the hottest area will, almost by definition, be the one they are working in.

But is there a more objective way to address the question? One approach might be to measure media interest. That would flag up the "big science" of the Large Hadron Collider (the discovery of the Higgs boson) and the European Space Agency (the recent *Rosetta* comet mission). But it would be blind to many areas of cutting-edge science that are too complex for easy popular interpretation, and also to fields that do not lend themselves to the agenda of a popular media obsessed with "major breakthroughs".

An alternative is to look at citations. After all, citations are typically seen, especially in science, as a vote for the importance of the paper cited. And citations have been shown to be a strong predictor of Nobel prizes. David Pendlebury, a senior citation analyst at Clarivate Analytics, has a strong record (https://www.timeshighereducation.com/news/nobel-prizes-us-dominates-predictions/2016167.article) on that score, having anticipated numerous winners in the science and economics categories in recent years.

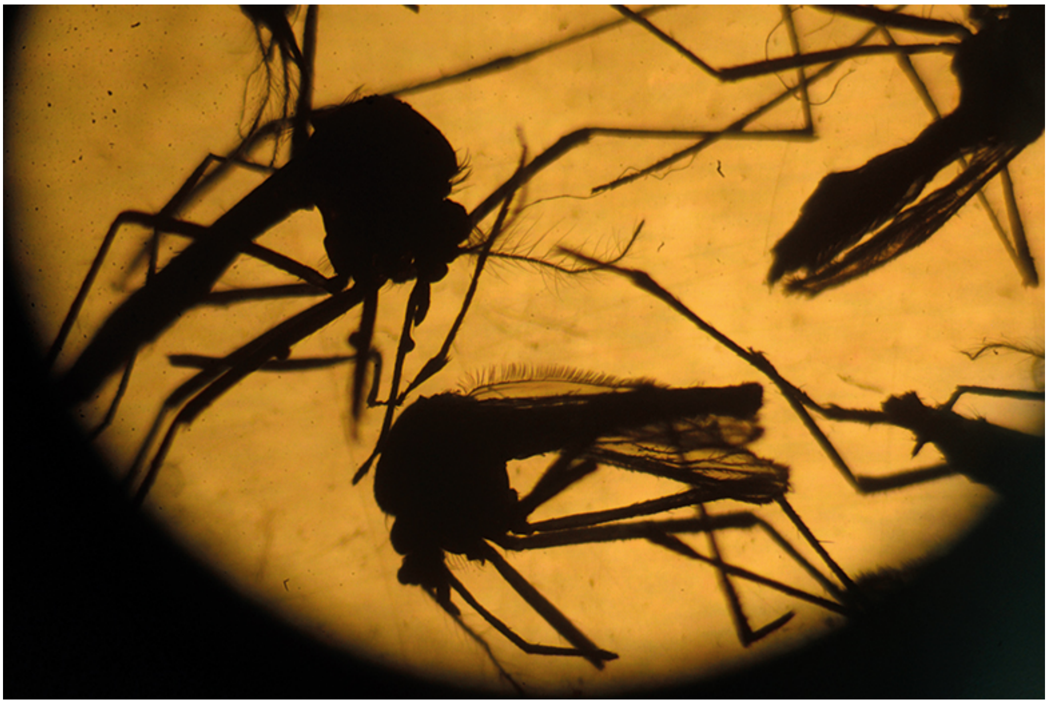
Of course, the Nobel Committee typically waits decades before awarding a prize, until the significance of the discovery in question is well established. Some papers and fields may burn brightly in the short term, only to be debunked or forgotten as science moves on. So identifying the papers currently garnering high numbers of citations might not necessarily provide any clue to their ultimate significance. But it nevertheless gives an interesting insight into where major new research fields *might* emerge.

For this analysis, Pendlebury draws on the concept of research fronts developed by Henry Small and the late Eugene Garfield at the Institute for Scientific Information (Clarivate's forerunner) in the 1970s. A research front is defined by a cluster of papers that form around a specific topic or problem, using data in Clarivate's Web of Science (previously the Science Citation Index).

The research fronts described in the following pages all appear in Clarivate's Essential Science Indicators database, part of the Web of Science platform. The papers making up each research front represent the foundation literature of the specialty. All are among the top 1 per cent for citation in their field in their year of publication. They are also of recent vintage: two years old or younger. According to Pendlebury: "A specialty whose foundation literature is young represents a fast-moving area that is dependent on new knowledge, and that, when coupled with high levels of citation, frequently reveals a hot or emerging topic." For the purposes of this article, we set a threshold of 200 citations for each research front, allowing us to narrow the field to about 60 research fronts, from which we are featuring 18.

We have grouped those fronts into four broader categories, reflecting their wider scientific environments and, in some cases, their potential applications. We also have a "behind the headlines" field, which reflects the fact that the Higgs bosons and *Rosettas* of this world do indeed lead to flurries of academic as well as newspaper articles.

The fronts featured take in everything from the fight against cancer, through studies into the spread of such viruses as Zika and Ebola, to innovations and discoveries in the fields of electronics and power and light generation that promise to have massive impacts on how we live in the near future. They do not represent every major research effort currently taking place, but they do highlight some of your best options if you do insist on putting £5 on the 2030 Nobel prizes.



Biology and medicine

Suitable cases for treatment

When some of the first reports emerged of the Zika epidemic in South America in early 2016, Dan Barouch's research group at the Center for Virology and Vaccine Research at the Beth Israel Deaconess Medical Center in Boston had a series of spirited laboratory meetings.

The team, whose members also research vaccines for HIV, felt that their expertise could help in the fight against the Zika virus, which was causing birth defects in babies born to infected women.

So the group, composed of researchers specialising in immunology, virology, animal modelling, vaccine design and clinical trials, set to work on developing Zika vaccines in animal models.

Within four months, they had published a paper in *Nature* demonstrating proof of concept of three different vaccines developed in mice. Two months later, they published a paper in *Science* demonstrating the same thing in rhesus monkeys.

"It was really dramatic. All the control animals got infected, and all the vaccinated animals were 100 per cent protected...People in the lab were rejoicing and crying [when they saw the results]," Barouch explains.

One of these vaccines has now progressed to Phase 1 clinical trials, and further animal model work is under way to see how long the vaccines afford protection.

The papers achieved "very substantial impact on the field" because they were the first to show vaccine protection against Zika in any animal model, says Barouch, who adds that many other groups worldwide are now working to confirm and extend their results.

The study of another headline-grabbing epidemic, Ebola in West Africa, has also generated a very active area of research for medical scientists.

When a doctor was evacuated from Sierra Leone to the Emory University (https://www.timeshighereducation.com/world-university-rankings/emory-university) Hospital in Atlanta, Georgia after becoming infected with Ebola, scientists discovered that the virus remained in his eyes even after the blindness that it causes had been treated and the virus had been cleared from his blood.

Steven Yeh, professor of ophthalmology at Emory Eye Center, was one of the specialists who took care of the doctor. "This persistent live virus in the eye was a new finding that really raised the alarm over the possibility that other West African survivors could also be developing eye inflammation that could lead to blindness," he says.

So Yeh travelled to Liberia and Sierra Leone to screen Ebola survivors to get a better sense of the extent of the problem. He and colleagues found that a quarter of the survivors they screened had developed eye inflammation, which was serious enough to result in some visual impairment in 60 per cent of cases and blindness in 40 per cent.

At the same time, other researchers discovered that Ebola could also persist in semen for longer than first thought. This has prompted a scramble to better understand the scientific and public health implications of the fact that the virus survives in these "immune-privileged" tissues.

Meanwhile, in a different medical field, close examination of tumour tissue from people with lung cancer has resulted in some ground-breaking findings that could one day lead to a new way of treating the disease.

By understanding the mechanisms that the immune system uses to fight cancer, researchers hope that they can develop treatment tools that intensify the body's own response against the disease.

The group of Evgeniy Eruslanov, assistant professor of surgery at the Perelman School of Medicine at the University of Pennsylvania (https://www.timeshighereducation.com/world-university-rankings/university-of-pennsylvania), has been looking at tissue samples taken directly from lung cancer patients during surgery. The research has found that some people's tumours harbour a unique subset of cells never before seen in cancer. The cells, known as hybrid neutrophils, possess the anti-tumour qualities of two distinct types of immune system cells.

"They have the potential to kill tumour [cells] by doing two things," Eruslanov says. The unique cells not only enhance an existing immune system response to tumour cells but can also kill tumour cells directly if antibody-based drugs are present. "We think that if we can expand [the numbers of hybrid neutrophils] it could be a really good beginning to fight the cancer."

He adds that although it is too soon to say for sure how effective this type of treatment could be against lung cancer, it is "likely" to be useful in other types of cancer, too.

Still in oncology, a much rarer cancer than lung cancer could benefit from recent developments in epigenetics – a field that looks at heritable changes in how genes are switched on or off. Researchers have uncovered a new class of targets within cells that drugs can act on, which has spurred a surge of activity in this field of research.

These targets – proteins – play a key role in the epigenetic mechanisms in a number of different diseases, including several cancers, such as the rare NUT midline carcinoma, and the process of inflammation. Scientists are designing compounds that inhibit these proteins in the hope of treating the diseases.

The work in this field by Stefan Knapp, professor of pharmaceutical chemistry at Goethe University Frankfurt (https://www.timeshighereducation.com/world-university-rankings/johann-wolfgang-goethe-universitat-frankfurt-am-main), has come out of a large open collaborative consortium of eight pharmaceutical companies, including GlaxoSmithKline, Pfizer and Eli Lilly, and six universities, including the universities of Oxford (https://www.timeshighereducation.com/world-university-rankings/university-of-oxford%23ranking-dataset/589595), Toronto (https://www.timeshighereducation.com/world-university-rankings/university-of-toronto%23ranking-dataset/589595) and Campinas (https://www.timeshighereducation.com/world-university-rankings/state-university-of-campinas%23ranking-dataset/589595) in Brazil.

Working in this way meant that the reagents that Knapp discovered could be quickly shared with other groups to test if they were relevant in other diseases. "[Pharmaceutical] companies got excited and started clinical programmes. Now we have close to 20 clinical studies in oncology, which is a surprisingly large number considering that we started the programme only in 2010," he explains.

He adds that these inhibitors help in the basic understanding of epigenetics and how epigenetic changes to a person's genome are inherited.

Holly Else

Biology and medicine: Topics for development

Research front	No of papers	No of citations	Key figure	
Structure, transmission, action and potential inhibitors of Zika virus	20	359	Dan H. Barouch	Ha
Identification of bromodomain inhibitors	12	289	Stefan Knapp	
Tumour-associated neutrophils and T-cell response	9	207	Napoleone Ferrara	University of Calif
Transmission and persistence of Ebola virus	6	246	Anna Thorson	Karolins

View all the research papers relating to these research fronts (https://www.timeshighereducation.com/next-big-bang-biology-medicine-papers)

Source: Getty

Energy and light

The better to see you with

Renewable energy has made huge strides in recent years, but there are still several big hurdles to overcome as the world transitions towards clean power sources. One of the most crucial is load balancing: ensuring that there is enough green energy available when it is needed. Recent cases of wastage in China (http://www.scmp.com/news/china/policies-politics/article/2088865/china-wasted-enough-renewable-energy-power-beijing) and shortage in Australia (http://www.theaustralian.com.au/opinion/columnists/australia-goes-from-being-power-rich-to-facing-an-energy-crisis/news-story/1693031fd970ba71df71e9e003af5315) demonstrate the need for systems that can store wind and solar energy when it is available and then distribute it when it is needed.

A promising technology in this field is redox flow batteries. Instead of a solid material encased inside a single container, flow batteries are made up of two tanks of liquid “electrolyte” separated by a central core containing a positive and a negative electrode (the cathode and the anode) separated by a membrane. When the battery is being charged, energy is transferred into metallic salts dissolved in the electrolytes, typically based on the transition metal vanadium, which are continuously pumped through to core and tanks. When energy is needed, the electrical current is reversed: the ion exchange between the liquids, across the membrane, generates the electricity.

Since 2007, Jens Noack has worked at the Fraunhofer Institute for Chemical Technology, near Karlsruhe in Germany, focusing on the development of such batteries. He says that they have a number of advantages over other rechargeable batteries, such as the lithium-ion ones found inside most smartphones and laptops. The first is that the use of liquid means that they can easily be scaled up to store large amounts of energy.

“In addition, the transitions in a vanadium flow battery have theoretically no limitations, and [so the battery] lifetime can be very long,” Noack says. And even when that lifetime is finally over, flow batteries – unlike lithium-ion batteries – can be reused or simply recycled.

Another advantage, Noack continues, is that redox flow batteries generally use non-toxic and non-flammable energy storage liquids, which makes them less prone than conventional batteries to fires and accidents. But there are disadvantages, too. One is flow batteries’ low energy density, which – unless it can be improved – limits their usefulness in mobile applications such as cars, where lighter and more energy-dense traditional batteries still reign supreme.

Hydrogen offers a more portable, powerful and flexible power system for zero-emission vehicles – but the challenge lies in producing “green” hydrogen. Research by James M. Tour, professor of chemistry, computer science, and materials science and nanoengineering at Rice University (https://www.timeshighereducation.com/world-university-rankings/rice-university) in Houston, Texas, into carbon-based “electrocatalysts” is relevant here, given the hopes that cars might one day run on hydrogen.

“Nanoparticle electrocatalysts provide us with a method to use a low voltage to split water and make hydrogen for use in fuel cells, for example,” explains Tour. “Right now, hydrogen is made from natural gas, creating carbon dioxide in the process. By splitting water, no greenhouse gases are formed. It’s much cleaner, plus fuel cells are very efficient. The hope is that one day we’ll see hydrogen made by this process on a commercial scale."

As well as creating and storing renewable energy, cutting energy use will also be vital in the battle against climate change. Because so much electricity is consumed in lighting, advances in low-power alternatives to standard bulbs could have huge implications. And since the invention of the blue LED in the early 1990s (a breakthrough that earned its Japanese inventors the Nobel Prize in Physics in 2014), researchers around the world have been working on ways to improve LED lighting.

Wolfgang Schnick, professor of inorganic solid-state chemistry at LMU Munich (https://www.timeshighereducation.com/world-university-rankings/ludwig-maximilians-universitat-munchen), has been working for more than a decade on the discovery and application of innovative luminescent materials, known as phosphors.

"Blue LEDs have enabled bright and energy-saving white light sources," he explains. "However, for the generation of white light from blue LEDs, highly efficient optical materials are necessary to convert the initial blue light into all the other colours of the visible spectrum. Our research group has invented and investigated efficient, high-performance materials like phosphors, which now find broad industrial applications in LED lighting and smartphones, for instance."

Creativity and the freedom to experiment have proved crucial to the group's work, with a key breakthrough coming when one of its members replaced strontium with europium – a rare earth metal that's used as an anti-forgery measure in European banknotes. The result of the switch was a bright orange compound that turns harsh, cold LED light into a warm, natural tone. Indeed, Schnick's group believe that they are approaching a point at which they can turn super-efficient LED lighting into a light source resembling pure sunshine.

Industrial collaboration has also been crucial, Schnick adds, noting that, since 2001, his group has "enjoyed a very fruitful cooperation" with the Lumileds lighting company's development centre (https://www.photonics.com/Search.aspx?Search=Lumileds%2bDevelopment%2bCenter%2bAachen) in Aachen, Germany.

"All major lighting and illumination companies worldwide are now using the same technological approach of inorganic high-performance materials to convert the blue LED light into all the other colours of the visible spectrum," Schnick says. "Application of these lights could save up to 20 per cent of worldwide electricity consumption."

Chris Hatherill

Energy and light: Power up

Research front	No of papers	No of citations	Key figure	
Nanoparticle electrocatalysts for water splitting	17	618	Yujie Sun	Utah State University (h
Red phosphors for next-generation white light-emitting diodes	19	746	Ru-Shi Liu	National Taiwan University (h
Redox flow batteries for storage of fluctuating renewable energy	10	417	Jens Noack	

View all the papers relating to these research fronts (https://www.timeshighereducation.com/next-big-bang-energy-and-light-papers)

Source: Getty/iStock

Behind the headlines

Big stories, big science, big steps

Big physics has been in the news a great deal over the past five years.

Space exploration always captures the public imagination, and the *Rosetta* probe's mission to study the comet 67P/Churyumov-Gerasimenko was no exception.

After a 12-year flight, during which it observed Earth, Mars and two asteroids, the craft attained an orbit around the comet in 2014 and deployed its lander module, known as *Philae*. Despite quickly losing contact with the solar-powered lander, which had settled in a position in the shadow of a cliff, Rosetta still managed to beam back a vast quantity of data before it was crashed into the comet last September.

The huge task of interpreting those data is ongoing, generating a handful of very highly cited papers. Measurements of the comet's density and the ice patches on its surface suggest that instead of being a snowball covered with dust, as previously thought, comets are actually more of a mixture of the two: an "icy dirtball" rather than a "dirty snowball", as John Noonan, an analyst for the *Rosetta* mission, put it in a blog.

High-resolution images have also enabled scientists to confirm that the comet – which is shaped like a rubber duck – formed from a low-speed collision of two previously separate comets.

Analysis has also found that comets are likely to be relics from when the early solar system was taking shape. The other possibility – that they are fragments from collisions between other icy bodies – seems unlikely now we know that the *Rosetta* comet is much less dense than previously thought: a violent collision would have crushed it into a denser body. If comets were around as our solar system formed, this will give astronomers a better idea of the nature of the nebula from which the Sun and planets emerged.

The mission captured information about more than 180 million points on the comet, explains Gianrico Filacchione, a researcher at the Institute for Space Astrophysics and Planetology in Rome, who has worked on the *Rosetta* results. As checking and calibrating all the data is a huge task, findings from the mission should keep coming for some time to come.

Further clues to the nature and origins of the universe were provided in 2015 when, a century after Albert Einstein theorised their existence, gravitational waves were observed for the first time. The waves, theorists believe, were created from the collision of two black holes about 1.3 billion years ago. Two extremely long lasers – one in Washington State, the other in Louisiana, separated to eliminate interference from events such as earthquakes – both detected the signal, opening up a new area of science.

"It's a field that has just been born," says John Veitch, a researcher at the School of Physics and Astronomy at the University of Birmingham (https://www.timeshighereducation.com/world-university-rankings/university-of-birmingham).

But what exactly are gravitational waves? Gravity is produced by the curvature of space and time around heavy objects, he explains, and what Einstein realised is that if space is curved, then it should have waves, rather like light. But to make a strong enough gravitation wave to detect, you need something that is very heavy, very dense and moving quickly. Two black holes speeding into each other fit the bill.

"Now that we've seen [the waves], it opens up a whole different way of looking at the universe," Veitch says. Physicists can use these signals to explore in detail how black holes spin, and what they might have formed from, for example. And on an even deeper level, probing black holes should lead to a better understanding of how gravity works. "The ultimate aim is to work out what [theory] comes after [Einstein's] general relativity," Veitch explains.

Another theoretical entity that has recently been detected experimentally is the Higgs boson. This subatomic particle was theorised by the physicists Peter Higgs and François Englert four decades ago, but it was only in 2012 that researchers at Cern's Large Hadron Collider at long last provided experimental evidence for it – resulting in Higgs and Englert's winning the Nobel Prize in Physics in the following year.

The quest is now on to find out more about the Higgs boson and to use this knowledge to shed more light on other areas of physics. A couple of hundred theorists worldwide are now working in this area, estimates Frank Petriello, a professor at the department of physics and astronomy at Northwestern University (https://www.timeshighereducation.com/world-university-rankings/northwestern-university) in Illinois. "While we know that [the Higgs boson] exists, we don't know a whole lot about it," he says.

The Higgs can decay into various other types of particles, such as photons, and it is this rate of decay that is now being measured, he says. Physicists also do not yet know whether the Higgs boson interacts with other particles, as predicted by the standard model of physics, Petriello continues.

The hope is that by discovering more about the Higgs, scientists can better understand other still poorly understood aspects of physics, such as dark matter. "The Higgs is something that we think is kind of a nexus to many of the mysteries we have around us," says Petriello.

In the wake of the discovery of the Higgs, new data from the Large Hadron Collider three years later, in 2015, sent physicists into an overdrive of speculation and theorising. Smashing protons together had produced more photon pairs than expected, raising the prospect that another new particle had been discovered.

Hundreds of papers were written on the "750 GeV diphoton excess" in an attempt to explain the results. In the wake of the Higgs discovery, "it was a well-known possibility that you could discover new particles", says Spencer Chang, an assistant professor in the University of Oregon (https://www.timeshighereducation.com/world-university-rankings/university-of-oregon)'s department of physics and one of those who produced articles about the data.

The sheer level of interest from theorists "was something I'd never seen before", he recalls. "It's not clear if people realistically thought they would win a Nobel prize," he says; one possible explanation for the activity is that they just wanted to "get in on this and get citations".

Some postulated a new particle, while others were more conservative and warned that the photon excess could just be a statistical anomaly – and so it turned out to be. Further tests failed to reproduce the headline-grabbing blip in the data.

Despite the false alarm, Chang does not consider the flurry of analysis to have been a waste of time. It resulted in a much more accurate understanding of the distribution of photons, he says. And new theories were explored that have applications far beyond that ultimately anomalous data.

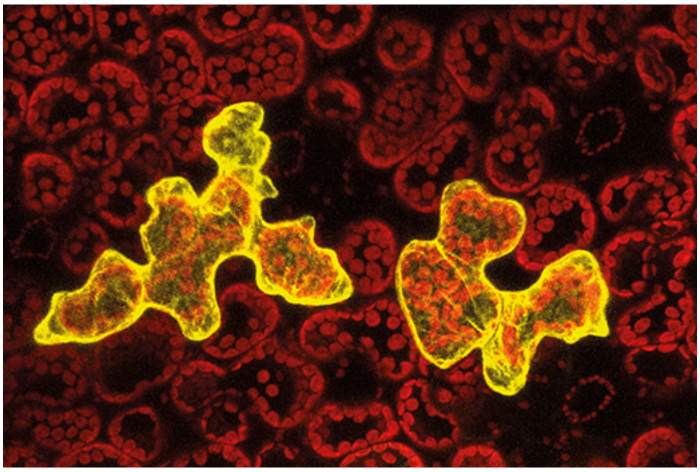
"There is a lot of noise, but there is a net positive to the experimental community from this work," he thinks.

David Matthews

Behind the headlines: popular and scholarly hits

Research front	Number of papers	Number of citations	Key figure
Theories concerning 750 GeV diphoton excess	13	486	Spencer Chang
Precision studies of the Higgs boson	8	266	Frank Petriello
Studies of comet 67P/Churyumov-Gerasimenko from the *Rosetta* mission	8	246	Gianrico Filacchione
Analysis of gravitational wave signals from inspiralling black hole binaries	14	621	Kip S. Thorne

View all the research papers relating to these research fronts (https://www.timeshighereducation.com/next-big-bang-behind-headlines-papers)



Source: Science Photo Library

Environment and ecology

The secret life of plants and more

When Jean-Benoit Morel's team at the French public agricultural research institution Cirad discovered "by chance" a group of genes that control the inner workings of the immune system in plants, it took them about a year to fully comprehend the significance of what they had uncovered.

The systems that plants use to fight infections are poorly understood. Although some components of their immune systems had been identified as long ago as the 1960s, little was understood until very recently about the functioning of the systems within cells that detect infection and help to fight it off.

"We broke the code," says Morel. "That was a major breakthrough."

Similar research, using molecular biology, genetic and bioinformatics techniques, about how the plant immune system functions was published by scientists at the Sainsbury Laboratory in Norwich at the same time as Morel, and now many labs are starting to work on the ideas and to apply the findings – which drew on data from the genomes of all 40 of the plants that have been fully sequenced around the world to date.

Armed with this information, biotechnology companies can manipulate the genes of plants to make them resistant to fungi, bacteria and viruses. In fact, Morel and his colleagues have already proved that the concept works in rice. This is important because, as Morel notes in one of his papers, one fungus alone causes the loss of enough rice to feed 60 million people each year.

The genetic engineering of insects is another area of ecological research that has taken off in recent years. In this research front, scientists have concentrated on manipulating the genome of entire populations of insects in the hope of stopping them from transmitting deadly diseases.

For the past 10 years, Nikolai Windbichler, research group leader in the department of life sciences at Imperial College London (https://www.timeshighereducation.com/world-university-rankings/imperial-college-london), and his colleagues have been developing a technology they call "gene drive". This piggybacks on a biological trick of genes that evolved so that they are passed on to almost all offspring even if they are harmful.

Using molecular techniques, the researchers have discovered how to engineer genes into the mosquito that carries malaria. The idea is that genes could be introduced that stop the mosquito being infected by the malaria parasite, and thus prevent the insect from infecting humans with it.

"This is all theory at the moment (no releases are planned until we know a lot more about gene drive), but the general idea is to find a sweet spot where you would produce and release just enough individuals in a few places so that the gene spreads quickly through the population but without the whole operation (of producing and releasing them) becoming prohibitively expensive to carry out," Windbichler says.

In 2011, Windbichler and his colleagues first demonstrated that the principle could work; in 2016, they showed that the revolutionary gene editing tool CRISPR could be used to create gene drive easily.

"Today, dozens of research groups all around the world are working on gene drive: the field has literally exploded," Windbichler says. Significant work is going on at Harvard University (https://www.timeshighereducation.com/world-university-rankings/harvard-university), the University of California, Riverside (https://www.timeshighereducation.com/world-university-rankings/university-of-california-riverside) and the Massachusetts Institute of Technology (https://www.timeshighereducation.com/world-university-rankings/massachusetts-institute-of-technology), he adds.

Using gene drive to stop the spread of malaria or other mosquito-borne diseases is still five to 10 years away. However, Windbichler says: "Given the enormous human cost of diseases such as malaria and given that the technology can at low cost affect entire insect populations over large areas while being specific and affecting only the target insect species, the potential to improve lives is huge."

Another environment-related research front involves improving the water quality in the waterways that flow through urban areas. Cities are designed so that when it rains, the water quickly runs off surfaces into drains and, eventually, into streams and rivers. But fast-flowing water erodes streams, washes out organisms that live in them and carries pollution into the ecosystem.

The group of Tim Fletcher, a professor of urban ecohydrology at the University of Melbourne (https://www.timeshighereducation.com/world-university-rankings/university-of-melbourne), studies how urban streams get degraded. In 2008, he and his research colleagues launched a project to retrofit an entire suburb of Melbourne with simple technologies that help rainwater to soak back into the ground slowly, as would happen in nature, to see if they could reverse damage to a creek.

The project led to big improvements in water quality. Fletcher says: "That creek, which was a typically polluted urban stream, now has water quality that more resembles the natural streams we see in that region of Australia."

The local water authority, which worked in close collaboration with the researchers, has begun implementing the same changes to a nearby suburb. It is also teaming up with the state government to look at installing these features in new suburbs as they are built. "That is a massive change to the way urban development happens," says Fletcher.

Meanwhile, in chemistry, there has been a flurry of activity around the use of natural light to help develop new products in a more cost-effective way. The new method, which allows reactions to occur under milder conditions than may have been possible previously, means that chemists use fewer toxic chemicals and create fewer dangerous by-products.

Frank Glorius, professor of organic chemistry at the University of Münster (https://www.timeshighereducation.com/world-university-rankings/westfalische-wilhelms-universitat-munster), was the first to use a gold as a catalyst to make molecules react using visible light. "The gold catalyst starts the transformation, and the photocatalyst completes the process. Neither of these two could do the job by itself: they need each other," he says.

Using this new method, chemists can make new molecules that had not been possible before and others that would have been too complicated or expensive to develop using existing processes.

Glorius adds that other research groups have been inspired by his work to explore how to use different metals in reactions that harness the energy of visible light. "This is a breakthrough in the field," he says.

"I can't claim that the products that we form have a specific application: this is more proof in principle," he says. It is hoped that the technique will be picked up by pharmaceutical and agrochemical companies to develop new useful products.

Holly Else

Environment and ecology: Greens, genes and gold

Research front	No of papers	No of citations	Key figure	Institution
Urban stream syndrome and management strategies	14	269	Tim D. Fletcher	University of Melb
Dual gold/photoredox catalysis	11	468	Frank Glorius	University of Mür
Plant immune receptors and signalling to defend against pathogens	11	306	Jean-Benoit Morel	Cirad, France
RNA-guided gene drives for the alteration of wild populations	5	238	George M. Church	Harvard Univer

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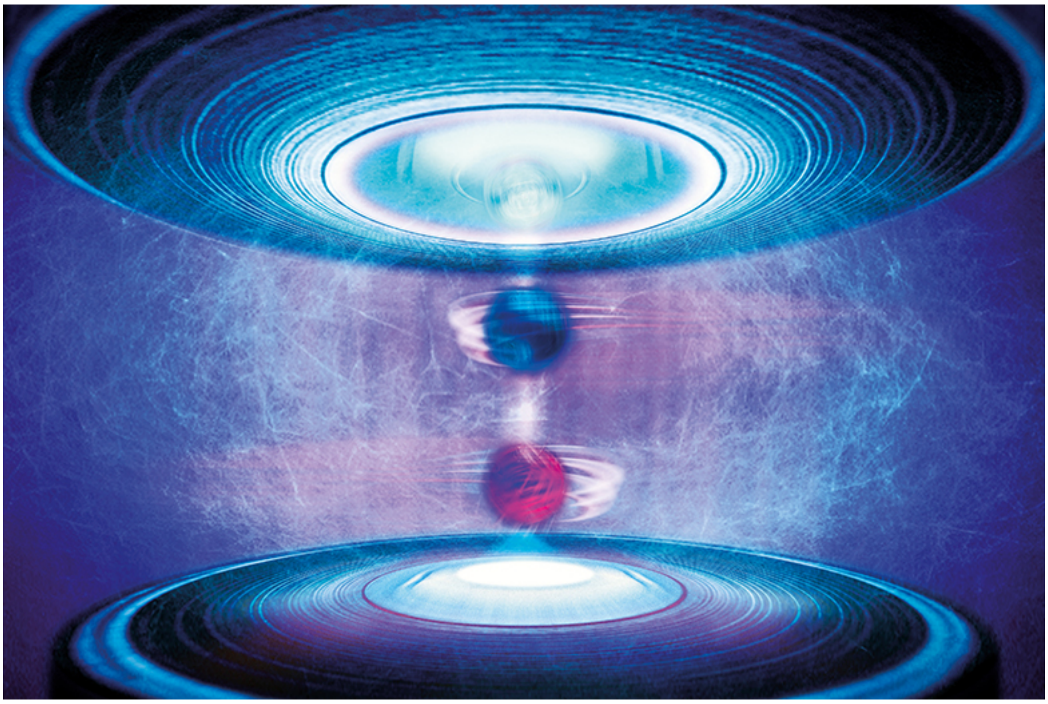

Source: Getty

Next generation electronics

Thin is in, with a spin

In labs around the world, researchers are working to create ever more powerful and efficient electronics by focusing on exotic behaviours of both existing and new materials. These experiments could lead to breakthroughs in everything from flexible screens and faster processors to truly radical emerging technologies such as quantum computing.

At ETH Zurich – Swiss Federal Institute of Technology Zurich (https://www.timeshighereducation.com/world-university-rankings/eth-zurich-swiss-federal-institute-of-technology-zurich), Atac Imamoglu's group is investigating materials that can emit photons in a controlled way, for use in electronics. Among these "solid state emitters" are "quantum dots": particles so small (measuring just a few nanometres across) that they behave like "artificial atoms" and emit light at a variety of useful wavelengths. Because they can be suspended in a solution and printed in layers, they could potentially be used in advanced and cheaper solar power cells, LED lights, lasers and medical imaging devices.

"Our research is aimed at realising solid-state emitters in two-dimensional materials," explains Imamoglu, a professor in the department of physics at the Swiss institution. "It can be described as the search for a way of controlling artificial atoms that can be used to generate single-photon pulses." He notes that there is "fast-growing community working on this topic" and that five other groups around the world have reported "the first observations of quantum emitters in two-dimensional materials".

Much of the most-cited research identified by Clarivate revolves around the implications of these "2D materials". Perhaps surprisingly, however, the original single-atom-thick material, graphene (whose discovery won the University of Manchester (https://www.timeshighereducation.com/world-university-rankings/university-of-manchester)'s Sir Andre Geim and Sir Konstantin Novoselov the 2010 Nobel Prize in Physics) does not feature in the current most highly cited list. This is because, as Clarivate's David Pendlebury explains, "key papers on graphene appeared in 2004 and 2005, so, in some ways, this is a mature field – which seems strange to say".

The early graphene research served to "focus attention on the remarkable electronic and optical properties of two-dimensional [materials more generally], and there has been a cascade of interesting materials studied in the wake of graphene, such as silicene and phosphorene: two-dimensional allotropes of silicon and phosphorus," he adds.

One of these new wonder materials is rhenium disulfide (ReS2). This substance has a number of unusual and useful electrical and optical properties that make it a promising candidate for use in solid-state electronics, solar power, fuel cells, LEDs and energy storage.

"Most of the 2D materials, such as graphene and boron nitride, are isotropic" explains Joshua Lui, an assistant professor in the department of physics and astronomy at the University of California, Riverside (https://www.timeshighereducation.com/world-university-rankings/university-of-california-riverside). "Their properties remain unchanged even if you [change their orientation]. But ReS2 is not isotropic. Its lattice structure is strongly distorted along a certain direction, so electrical conduction or light absorption is quite different if the electric field or light polarisation is along a different crystal axis."

As Lui points out, materials with such properties could lead to a post-silicon world and could help computers to keep pace with our ever-expanding thirst for more speed and data transfer and storage capacity.

“Two-dimensional materials hold out the promise of developing ultrathin, flexible and efficient electronic and optoelectronic devices,” he says. “There is now a wide variety of 2D materials with semiconducting, insulating and metallic properties – so we can potentially build the integrated circuit entirely with 2D materials.”

Another promising future alternative is known as “spintronics”. In essence, this involves using the magnetic properties of certain materials to transmit information in waves instead of in binary zeroes and ones. Because of the way magnetic materials can carry information, such research could lead to breakthroughs in quantum computing and in data transfer and manipulation.

Ludo Cornelissen is working on a PhD that is focused on “magnon spin transport” in the research group of Bart van Wees, professor of applied physics at the University of Groningen (https://www.timeshighereducation.com/world-university-rankings/university-of-groningen) in the Netherlands. “Spin waves – also called magnons – are a special kind of wave occurring only in magnetic materials,” he explains. Referring to the concept of “spin” – the angular momentum of elementary particles – he continues: “The nice thing about spins in a magnet is that they are strongly influenced by their neighbours; so this means that if one of them starts to rotate, its neighbours will follow and also start rotating. In this way, the spin rotation can propagate through the magnet, a bit like a wave moving through a stadium full of people.”

Most magnetic materials, such as iron, nickel and cobalt, are also good conductors of electricity. However, the magnets that Cornelissen uses are electrical insulators. The key feature of magnon spin transport is that while these magnets do not support electric currents, they can still transmit information via magnons.

“What we’ve demonstrated in Groningen is that you can ‘kick’ the spins on one side of the magnet using an electric current, causing them to rotate,” says Cornelissen. “This generates magnons in the magnet, which propagate through the material. These magnons can be detected elsewhere in the magnet by converting them back into an electric current. This means that we have transmitted a bit of information through the electrically insulating magnet, which is simply impossible if you have to rely on electric currents alone.”

This, he says, has brought “spintronics” – and the quantum leap in computing power it would bring – a stage closer.

Chris Hatherill

Next-generation electronics: Take a spin to get ahead

Topic	No of papers	No of citations	Key figure	
2D rhenium disulfide for future electronic and optoelectronic applications	10	302	James C. Hone	Columbia Un
Antiferromagnetic spin Seebeck effect and spin transport by magnons	13	327	Ludo Cornelissen	
Solid-state quantum emitters in atomically thin semiconductors	7	289	Atac Imamoglu	

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Find out more: the *Times Higher Education* Innovation and Impact Summit takes place in Hong Kong from 31 May - 2 June 2017 (http://www.theworldsummitseries.com/events/innovation-impact-summit-2017/event-summary-c7e1a3470135424e923467f3eee8cf7e.aspx)

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July 13, 2016

POSTSCRIPT:

Print headline: *The next big bang*

Reader's comments (3)

#1 (/comment/17709#comment-17709) Submitted by Jorg Huber on May 25, 2017 - 4:37pm

I enjoyed looking at this, but what about human, health and social sciences? I would include biopsychology, neuroscience and psychology more generally? Nothing exciting whatsoever?

I admit these areas are unlikely to generate 'big bangs', but perhaps they are as important or even more important than some of the 'hard science' bangs?

#2 (/comment/17781#comment-17781) Submitted by Dr. Victor Frankenstein on May 27, 2017 - 11:01am

"hot or emerging topic"

I still maintain that the best research is done without all this publicity and lime light. Articles, like this one, can do a lot of damage by propagating the view that resources need to be relocated into a few specialized areas that are currently trendy.

#3 (/comment/17799#comment-17799) Submitted by Jason T on May 29, 2017 - 10:32pm

An excellent read, very interesting. Thank you to all the reviewers.

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