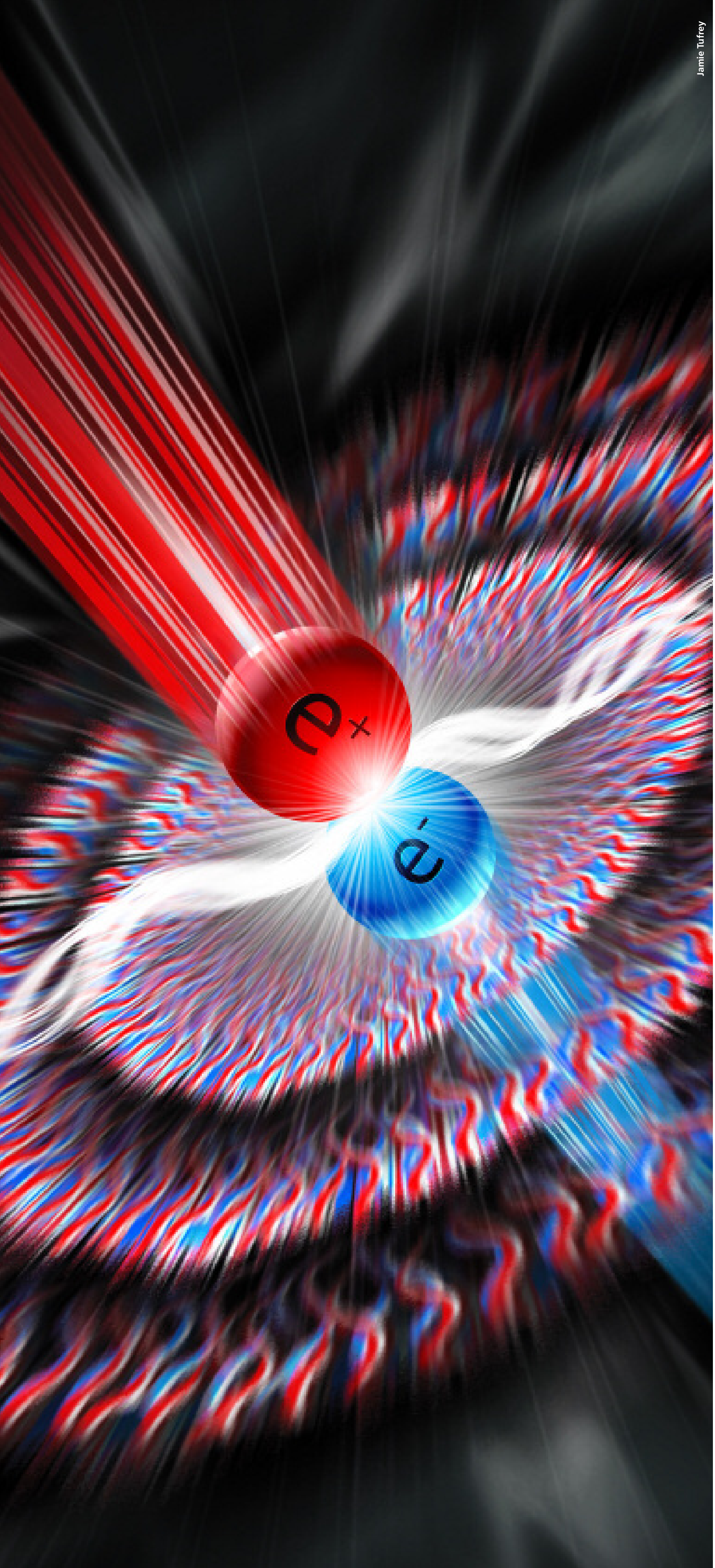


Australian Beamline to Expose Antimatter

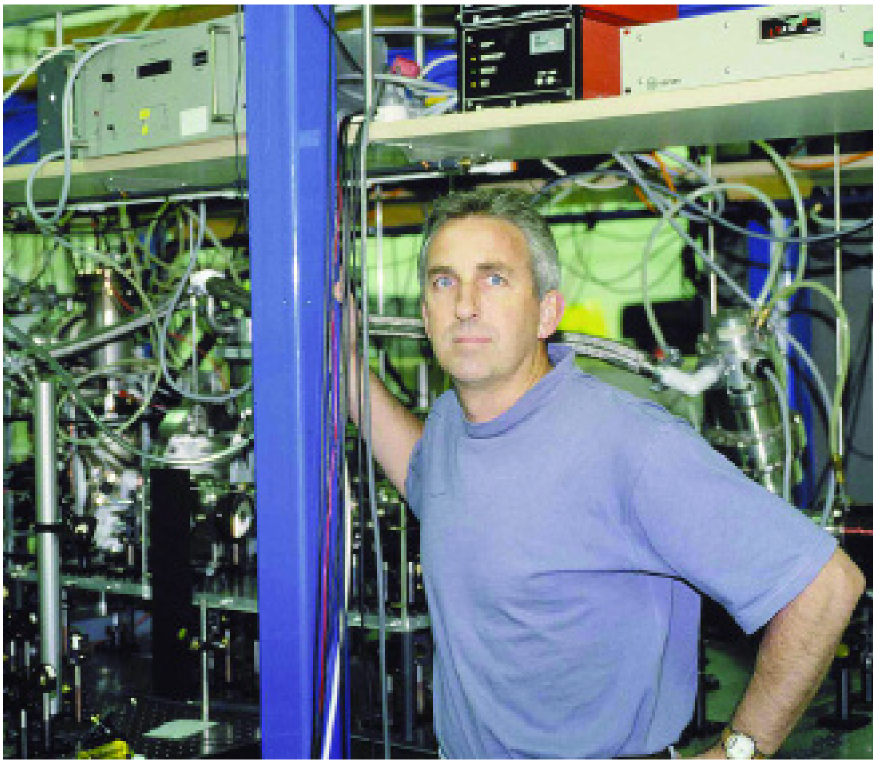
Antimatter research is coming to Australia with the construction of state-of the-art research facilities in Canberra. Simon Grose reports.

Positronium sounds like the kind of element you should keep in a lead-lined box. But it's not even an element. It has no atoms. "It's sort of like a light hydrogen atom, except it doesn't have a nucleus," is one way that Prof Stephen Buckman of the Australian National University (ANU) describes it.

An atom of hydrogen consists of an electron orbiting a proton. Pull the electron away from this or any other atom and it seeks a new home. Most electrons bash and bounce their way into orbit around another nucleus, but some bump into a positron and take an instantaneous terminal trip to oblivion.

Almost instantaneous, because for 140 nanoseconds the electron and the positron spin together in the transitory state dubbed positronium. But like a suicidal tango, it's an exotic union with a spectacular end. "Positrons and electrons are quite delightful in that if you bring them together they form positronium in which they orbit one another then annihilate and produce gamma rays," Buckman says.

Director of the Australian Research Council's newly funded Centre of Excellence for Antimatter–Matter Studies (www.positron.edu.au), Buckman is an expert on this fleeting



Prof Steve Buckman is leading Australian efforts to study how positrons interact with atoms and molecules, offering new insights into the relationship between matter and antimatter.

fatal attraction. "Positronium lies at the heart of a lot of our research," he says.

He began his research career as an electron physicist, but a sabbatical in the US turned him on to antimatter. Moving from electrons to positrons is considered a trip to "the dark side" in atomic physics circles, but in Australia it was also an empty paddock in a fertile field. "I saw an opportunity for us in Australia – where we are very strong in this field of electron atomic physics – to venture into a new area that was entirely complementary."

In January last year Buckman led a group that received just over $1 million from the Australian Research Council in a mix of equipment and salary funding. Partly matched by contributions from the ANU and other institutions, this is funding the construction and installation of a low energy beamline at the ANU's Research School of Physical Sciences.

The additional Centre of Excellence grant, worth $7 million over 5 years, will pay for a high energy beamline to run alongside it. The low energy beamline has a peak energy of 100 eV, making it suitable for investigating biological systems and other areas of fundamental research. Materials science research will be made possible by the high energy beamline's initial range of up to 100 times that energy, with plans for a further doubling.

> **"Researchers will bombard materials with positron beams and decipher what happens by observing the creation and demise of positronium."**

The Centre's funds will be bolstered by around $3 million in cash and $7 million in-kind contributions from more than a dozen member institutions from Australia and overseas. Buckman estimates that about 75% of expenditure will go to pay staff, mostly young academics and research students.

This mix of state-of-the-art machinery and the resources to fully utilise its capacity will create the basis for an Australian research facility at the global forefront of positron physics. "I think that is witnessed by the fact that we have a large number of international collaborators who have joined this centre," Buckman says. "Some of the experimental techniques that we are developing are unique to this beamline."

The University of California, San Diego, a partner in the centre, has been a pioneer of positron research, along with the CERN facility operated by the European Organization for Nuclear Research. Buckman says the Australian centre will build on their work. "Our lab, with its two beamlines and a lot of second generation improvements to the technology, will have a more intense beam, plans to have higher resolution, and a broader program of study."

Researchers will bombard materials with positron beams and decipher what happens by observing the creation and demise of positronium. Nuances in the behaviour of positronium will reveal much about the nature of the surfaces under study.

This has implications across the research spectrum in physics and other disciplines. At the fundamental level it will enable researchers to study how positrons interact with basic systems such as single atoms and molecules, offering the prospect of new insights into the relationship between matter and antimatter.

What Is Antimatter?

When particle physicists say things like "every particle has an anti-particle", it may leave others worrying about the chances of everything disappearing in a blast of gamma rays as these particles meet up. But although each species of particle has an antimatter counterpart, they outnumber them – at least in our universe.

Big Bang theorists believe that matter and antimatter were almost certainly created in equal amounts, so one of the big enduring questions in physics is: where is all the antimatter?

One theory is that there was slightly more matter than antimatter so it came to dominate the universe. Other speculation includes the idea that there are parallel universes of antimatter.

There are still some pockets of antimatter being mopped up in distant galaxies of our universe. "You can tell where there is a bunch of antimatter," says Stephen Buckman. "You just look for photons at the right energy which are a signature of positron–electron annihilation."

Practical materials scientists will achieve a new intimacy with the nano-landscapes by observing how positrons capture electrons from surfaces. The patterns and timing of the gamma rays emitted by these suicide bombers will reveal details down to a molecular level.

"It's now being realised that positrons are an ideal tool for analysing surfaces, in particular new materials that are built around polymers," Buckman says. "Positronium likes to find space in materials. It migrates to where there are holes in between atoms. The lifetime of the positronium in the material is a direct measure of the size of the hole where it lived."

A high energy positron beam will penetrate polymer surfaces to a depth of about 1 µm. This will enable researchers from CSIRO and the Australian Nuclear Science and Technology Organisation to measure attributes such as pore size, conductivity and homogeneity of materials designed for use in filtration systems, packaging and other applications.

An area of medical research on the agenda is the study of the fundamental processes underpinning Positron Emission Tomography. PET scans identify sites in the body where levels of metabolic activity are higher than normal, possibly indicating the presence of a tumour or other change causing increased blood flow or immune system activity.

The procedure typically involves injecting a patient with glucose containing a radioactive isotope, usually fluorine-18, which emits positrons. As the body directs glucose to areas of high metabolic activity, the scanner can identify these sites by recording concentrations of gamma rays emitted as the positrons partner with electrons for a quick positronium polka.

While this is a well-developed diagnostic tool, little is known about how positrons interact with biomolecules to form positronium, despite the sophistication and cost of the technology involved. There is the potential to refine the sensitivity of PET scans by differentiating the rates at which positronium is formed in different biological materials, tissue types and fluids. This could lead to new techniques to tailor radioactive isotopes to the object of study, vary dose rates, and other measures that could deliver more accurate images.

The high energy beamline is scheduled to be operating by the end of next year, giving Australia a genuine state-of-the-art research facility in this specialised area of research. "The real attraction of this centre is the interdisciplinary nature of it – atomic physics, materials science, biophysics, theoreticians and experimentalists," Buckman said. "It's a combination of Australia being very strong in low-energy atomic physics, materials science and bioscience.

"There is no other centre in the world with such an adventurous focus on such a breadth of activities."

Who Matters in Antimatter Research?

The new Centre of Excellence for Antimatter–Matter Studies, hosted by the Australian National University, has a total of 15 collaborating or contributing partners. Australian members are Flinders, Murdoch and Griffith universities, the University of WA, CSIRO and the Australian Nuclear Science and Technology Organisation. Overseas partners are The Open University, The Universities of California in San Diego and Davis, The Lawrence Berkeley National Laboratory, Drake University, The University of Nebraska, Tohoku University, and the University of Munster.