Department of Physics and Astronomy at Curtin University

IGOR BRAY
DEPARTMENT OF PHYSICS AND ASTRONOMY, CURTIN UNIVERSITY

Fig. 1: Landsat image shows the exposed reef around Montgomery Island as well as the distribution of turbid water in the surrounding ocean.

HISTORY

The Physics and Astronomy Department at Curtin University started life in 1901 as the Department of Physics in the newly formed Perth Technical College. It transferred to its current Bentley site in 1966, as the Department of Applied Physics, with the founding of the Western Australian Institute of Technology. In 1987 the Institute became known as Curtin University of Technology, which was renamed to Curtin University in 2010.

Historically, the Department had a strong "applied" focus, and was named "Applied Physics" for much of its existence. However, in 2007 it also incorporated theoretical physics and radio astronomy, and was renamed to "Physics and Astronomy" after the current Head was appointed in 2010.

MISSION

The Department is organized along its research strengths of Environmental Physics, Materials Science, Radio Astronomy and Theoretical Physics. Its mission is to provide a broad world-class undergraduate education in physics, with advanced courses and postgraduate studies being aligned with the research strengths.

RESEARCH

Environmental Physics

Remote Sensing and Satellite Research Group

The Remote Sensing and Satellite Research Group (RSSRG) has its origins in the 1970s, when Earth satellite remote sensing was still in its infancy. RSSRG developed research and R&D activities in, to name a few, Lidar[1)] technology and its use for atmospheric sounding, radiative transfer in geophysical media (essentially the atmosphere and oceans), atmospheric correction of satellite observations in the visible, near infrared and thermal domains, and development of algorithms to determine

[1] "Light Detection And Ranging"

so-called "geophysical properties" from the remotely-sensed electromagnetic spectrum. The RSSRG activities are grounded in physics, which means that the remotely recorded signals (whether from a satellite, a plane or a drone) are quantitatively interpreted in order to deliver robust geophysical parameters for subsequent quantitative use in environment studies of, e.g., land vegetation, coastal seagrass communities, and phytoplankton in the open ocean. Typically, environmental problems require the addressing of processes that are inherently non-linear, leading to ill-conditioned and ill-posed inversion problems requiring of radiometrically accurate information.

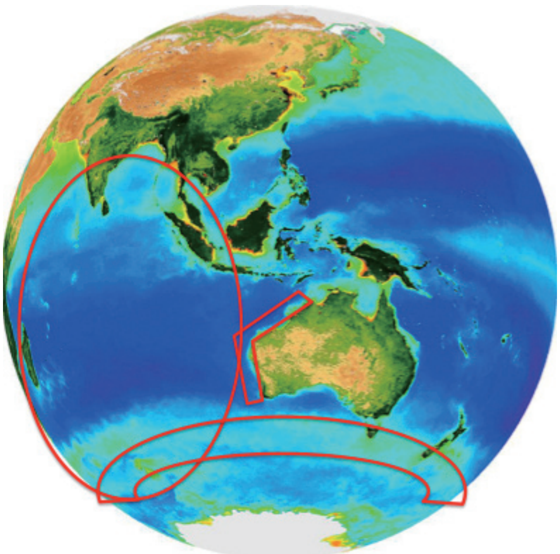

Fig. 2: The areas delineated in red, above a background showing satellite-derived phytoplankton biomass (warmer colours indicate increasing values).

Centre for Marine Science and Technology

The Centre for Marine Science and Technology (CMST) was established in 1985. It is Curtin's oldest research centre, and in fact, is one year older than Curtin University itself. The goal of CMST is to conduct marine research and development that is recognised nationally and internationally for the relevance of its outputs, the strengths of its alliances, the quality of its graduates and the responsible and ethical approach it takes to its staff and students, to society and the environment. Curtin University has significant capability and infrastructure in the field of marine research.

A long-term program of underwater noise monitoring was conducted from November 2014 to July 2015 during the offshore construction works off Onslow (WA), associated with the Wheatstone project by Chevron. Five

Fig. 3: Image of the deck of RV Whale Song with a sea noise logger ready for deployment in the Perth Canyon.

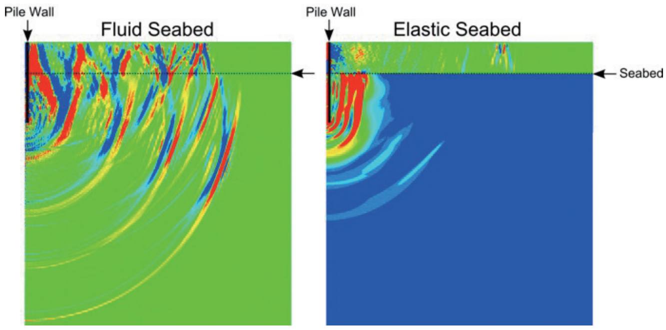

Fig. 4: Comparison between the modeled acoustic fields produced when the same pile is driven into a seabed with properties resembling a fluid (left) and as an elastic solid (right).

noise loggers were deployed in the operation area and nearby. The main objectives of the program were to: (1) compile a library of underwater sound emitted by piles of different size and type (vertical and slanting) driven at different hammer energy in water of different depth; (2) estimate furthest distances of potential physiological impacts, temporal threshold shift in hearing and potential behavioural disturbance from underwater piling noise; and (3) verify CMST's numerical model of underwater noise emission by marine piling. Also, underwater noise from seafloor dredging was recorded from three dredgers at different distances, which is used to construct an empirical model of underwater noise emission by dredging.

Materials Science

The study of materials science has a strong history within the Department. Currently, a number of key topics are focused upon with the main areas of Hydrogen Storage materials, Nano Carbon and semiconductors.

The Hydrogen Storage Research Group (HSRG) at Curtin University aims to produce technologically viable new hydrogen storage materials that will meet the ground transportation and static applications associated with a transition to a renewable hydrogen economy. The research focus is to contribute significantly to the development of the renewable hydrogen economy to meet the future sustainable energy needs of Australia, which will lead to a new class of hydrogen storage materials. Hydrogen storage is a hot topic at the present time due to the emerging market in clean vehicular transport as well as the market for static applications. If a suitable hydrogen storage medium was to be discovered it would revolutionise the energy sector by its implementation into many of the 1.1 billion cars on the planet. In addition, hydrogen storage materials have the potential to replace molten salts as the heat storage medium for electricity production at night (or non-sun periods) in concentrated solar power (CSP) systems.

The development of hydrogen storage materials is being carried out in a recently renovated laboratory allowing for world-class research to be conducted along with a world class safety system. The research focus of the HSRG is to conduct fundamental research on hydrogen storage materials for automobile applications and for heat storage applications (predominantly CSP applications). The HSRG is exploring a variety of materials as suitable candidates for hydrogen storage applications, these include: High temperature hydrides such as Na, Ca, Si, Mg, Al and their alloys, and low temperature hydrides for CSP applications. In addition, porous metal frameworks for the nanoconfinement of high wt.% complex hydrides are being developed that will lower the hydrogen desorption temperature of the hydride making it suitable for automobile applications.

Fig. 5: An image of the Hydrogen storage laboratory including the gas storage system.

Carbon is the most flexible of all the elements, underpinning the biological sciences and providing the richness of organic chemistry. In the physical sciences, carbon adopts myriad forms, including diamond, graphite, nanotubes, fullerenes, and the new wonder 2D material, graphene. The Physics department has integrated computational and laboratory programs covering many of these forms. One of the most fundamental questions being addressed is why some carbonanaceous materials graphitize upon heating, while others do not. This question is of both scientific and practical value, as carbons which don't graphitize are industrially valuable as source material for filters, water purifiers and gas storage mediums. Another research program is looking to create nanodiamond using a novel variant of an established coating technology. Motivated by the observation of nanodiamonds in ancient meteorites, the aim is to use high instantaneous pulses of electrical power to create concentric fullerenes which can subsequently be transformed into nanodiamond. From an environmental perspective, carbon is often associated with CO_2, but another combustion by-product, known as carbon black, is also a significant contributor to global climate models. Here, computer simulations are being used to characterize the nanocarbon structures that arise from combustion, and to relate their properties to experimental studies performed else-

Fig. 6: Custom built High-Power Impulse Magnetron Sputtering (HiPIMS) systems for the synthesis of concentric fullerenes (carbon onions) and nanodiamonds.

where at Curtin and around the world. Radiation effects in materials is a strong area of computational expertise, and here the carbon-focused research includes radiation damage of graphite and diamond via physical means, and chemical damage in DNA arising from radioactive transmutation of naturally occurring Carbon-14.

Zinc Oxide is very promising as a material for visible light emitting diodes (LEDs) which are the basis of a burgeoning solid-state lighting industry. Currently GaN is the material dominating visible LEDs but ZnO could be more efficient. What is holding back ZnO is precise control over its electrical properties. The generation of light in an LED depends on electrons combining with holes to produce photons in a so called depletion layer which is sandwiched between n-type material, with electrons as the charge carrier and p-type material with holes as the charge carrier. Making p-type ZnO on an industrial scale has proved to be difficult. We are exploring a new technique for making p-type ZnO borrowed from the silicon industry. It uses transmutation of the elements to produce p-type material. It relies on neutron transmutation doping to turn the Zn-64 isotope to copper, Cu-65. In collaboration with a group from Dublin City University who have supplied nanorods of ZnO enriched with Zn-64, we are using atom probe tomography to measure the distribution of isotopes in a ZnO nanorod.

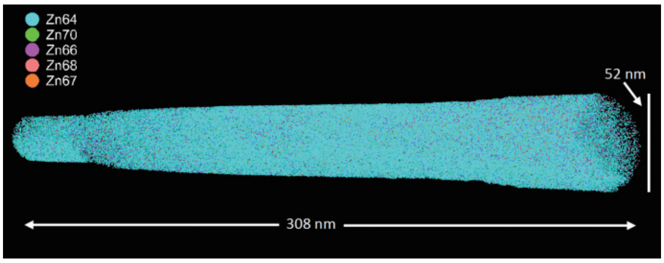

Fig. 7: 3D reconstruction of a Zn-64 enriched ZnO nanorod, colour coded with the legend in the top left corner. The Zn-64 has been enriched from a natural abundance of 48% to 71%.

Radio Astronomy

The Curtin Institute of Radio Astronomy (CIRA) was established in 2008 as a cross-disciplinary institute conducting high-impact science and engineering research in support of the Square Kilometre Array (SKA), and its precursor facility, the Murchison Widefield Array (MWA).

In 2009 the Western Australian State government provided funding for the International Centre for Radio Astronomy Research (ICRAR), a A$100 million joint venture established between Curtin University and the University of Western Australia in support of Australia's bid to host the SKA. In 2012, the SKA Organisation converged on a dual-site model for the telescope, with the low-frequency component (SKA_LOW) being located at the Murchison Radioastronomy Observatory (MRO) in Western Australia. This prompted continued support from the Western Australian state government, who in 2013 announced an additional A$26 million of funding over the seven years to 2019. The Curtin node of ICRAR currently hosts 58 staff and postgraduate students, working on SKA-related science and engineering programs, including pre-construction and antenna verification activities.

Key science research topics range from large-scale radio continuum surveys to the study of energetic transients and pulsars, and the detection of the observational signature of the epoch of reionisation. CIRA scientific staff have also assumed leading roles in the SKA science working groups, advising the SKA organization on both the key scientific goals of the instrument and the commensurate technical requirements.

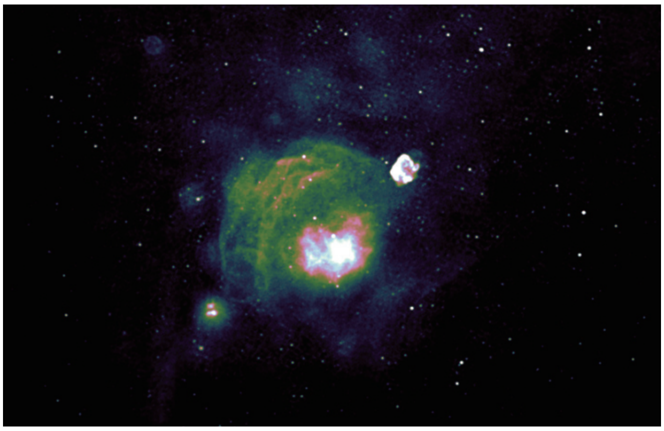

Fig. 8: MWA false-colour image of the Gum nebula region of the Galactic Plane, including the Vela and Puppis A supernova remnants. Image credit: R. Wayth and the MWA team.

As an SKA precursor facility located at the MRO, the MWA has played a key role in building the scientific and technical expertise required for the SKA. Developed by an international consortium with Curtin University as both lead and managing organisation, the MWA operates between 72 and 300 MHz, and focuses on four key science themes; the epoch of reionisation, Galactic and extragalactic surveys, time domain astrophysics, and solar and heliospheric science. Having been operating since 2013, the telescope is undergoing a significant upgrade in early 2016, doubling the number of antennas and increasing the maximum baseline to provide both enhanced sensitivity and improved resolution.

CIRA also has excellent national linkages, being one of seven nodes of the Centre for Excellence in All-sky Astrophysics (CAASTRO), a A$30 million Australian Research Council (ARC) centre for wide-field astronomy, comprising over 170 scientists based across Australia, and with additional partner institutions in seven different countries.

Fig. 9: An image of the Murchison Widefield Array (MWA). Image credit: the MWA team.

Theoretical Physics

The theoretical physics group came together during the 1990s at Flinders University in Adelaide. It moved together to Murdoch University in 2001 and then to Curtin University in 2007. Its expertise is in Few-Body Quantum Collision Theory, primarily within the context of atomic and molecular physics. It pioneered the convergent close-coupling (CCC) method for electron scattering on atomic hydrogen in 1992, which is continually being extended to more complicated projectiles and targets. The great strength of the CCC method is that it is applicable to all of the dominant excitation and ionization processes, and is valid for all projectile energies. The following are some examples of the group's achievements:

Electron-atom scattering

When electrons scatter on atoms several collision processes are possible: elastic scattering at all energies, excitation to a particular discrete state at energies above the excitation threshold for that state, and ionization at energies above the ionization threshold. The CCC method has to yield all of the corresponding cross sections accurately irrespective of the incident energy. One succinct way of seeing that the CCC method is able to do this is to compare with experiment the total ionization cross section. Being a unitary theory, obtaining correct ionization cross section implies that accurate elastic and excitation cross sections must also have been obtained. In the following figure we give an example of electron-impact ionization of helium, which shows excellent agreement with experiment.

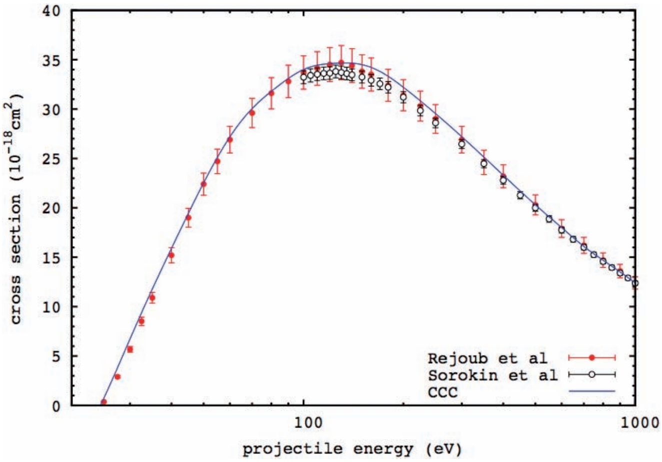

Fig. 10: Electron-impact total ionization cross section, see I.Bray and D.V.Fursa, J.Phys. B **44**, 061001 (2011).

Positron-atom scattering

It may seem a trivial step to change projectiles from electrons to positrons, but this is not the case due to the new reaction channel of positronium (Ps) formation. This bound state of an electron and a positron requires a reformulation of the scattering equations to incorporate Ps formation as the second centre in the problem. Below we demonstrate that the two-centre CCC theory is able

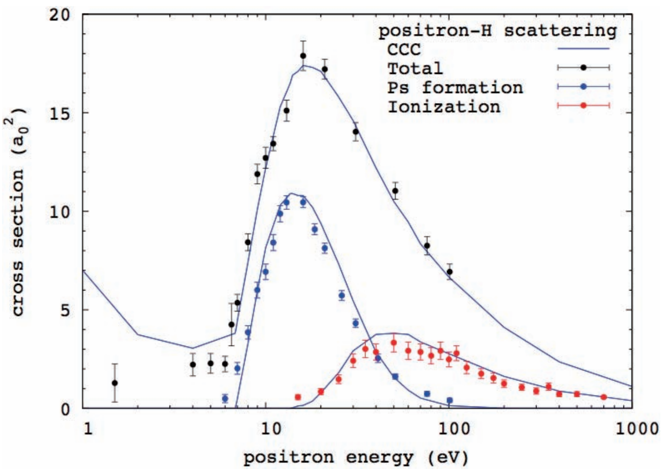

Fig. 11: Total, Ps-formation and ionization cross sections of positron-hydrogen scattering, see A.S. Kadyrov and I.Bray, Phys. Rev. A **66,** 012710 (2002).

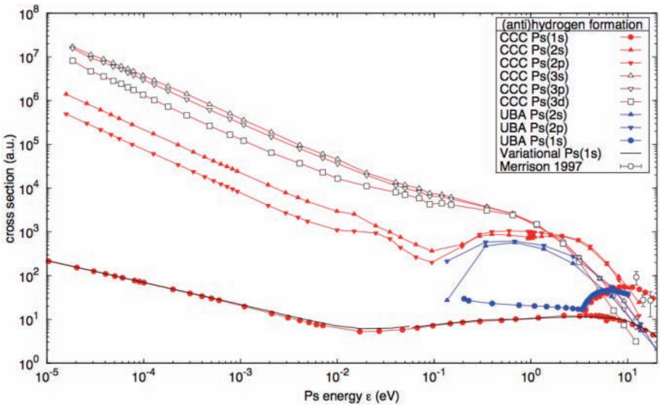

Fig. 12: Total (anti)hydrogen formation cross sections for Ps, in specified initial states, incident on (anti)protons, see A.S. Kadyrov et al., Phys. Rev. Lett. **114**, 183201 (2015).

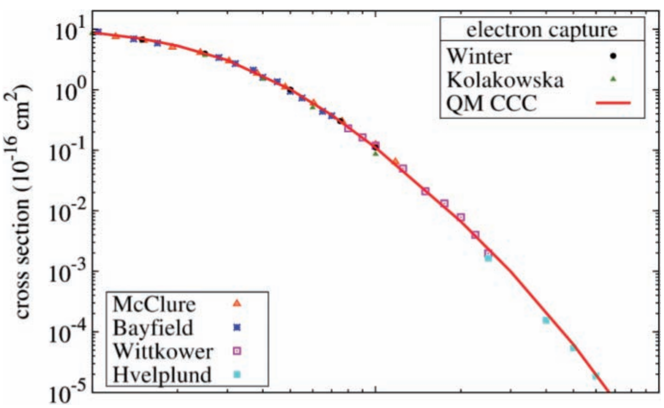

Fig. 14: Total cross section for electron capture for proton scattering on atomic hydrogen, see Abdurakhmanov et al., J. Phys. B **49**, 03LT01 (2016).

to obtain correct total, Ps-formation and ionization cross sections.

Antihydrogen formation

One consequence of being able to accurately calculate positron-hydrogen scattering is that the same computational method can be used for calculating antihydrogen formation from Ps scattering on antiprotons. This is because positron scattering on hydrogen is equivalent to Ps scattering on a proton to form hydrogen and a free positron. Replacing protons with antiprotons yields antihydrogen formation. Below we show the massive enhancement in the cross sections for excited initial states of Ps. This process for forming antihydrogen is currently being investigated at CERN for gravitational and spectroscopic experiments.

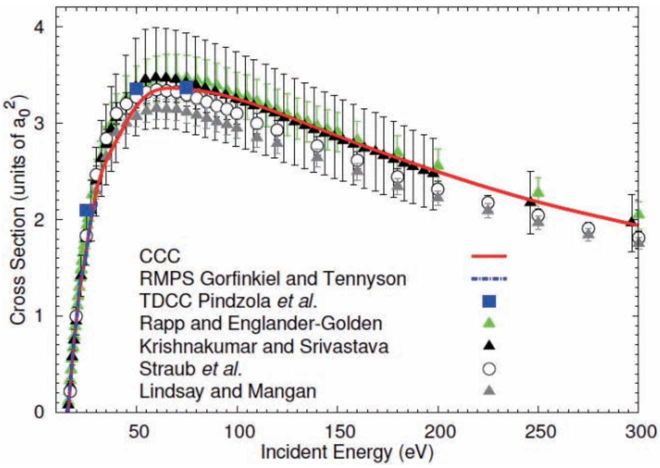

Fig. 13: Total ionization cross section of molecular hydrogen by electron impact, see Zammit et al. Phys. Rev. Lett. **116**, (2016).

Electron-molecule scattering

Very recently the CCC method has been extended to electron scattering on molecules. This was done within the fixed-nuclei approximation. Below is an example of application to electron-impact ionization of molecular hydrogen.

Proton scattering

Heavy projectiles like protons require a very different numerical approach, but the underlying physics is very similar to positron scattering in that there is an electron capture reaction channel.

Igor Bray is a John Curtin Distinguished Professor of Physics at Curtin University. He graduated with a PhD in Mathematical Physics from University of Adelaide. He changed fields to Quantum Collision Theory upon postdoctoral appointment at Flinders University, which was followed by Australian Research Council Research and Senior Fellowships. He moved to Murdoch University in 2001 where he obtained an Australian Research Council Professorial Fellowship. He moved to Curtin University in 2007 with yet another Professorial Fellowship and became the Deputy Director of the ARC Centre of Excellence for Antimatter-Matter Studies. He has published over 400 peer-reviewed articles, which have attracted almost 10,000 citations. He was also awarded the Walter Boas, David Syme, and Pawsey medals, and is a Fellow of the American Physical Society and The Institute of Physics. (UK and Australia)