SCIENCE FOR SOUTH AFRICA

Quest

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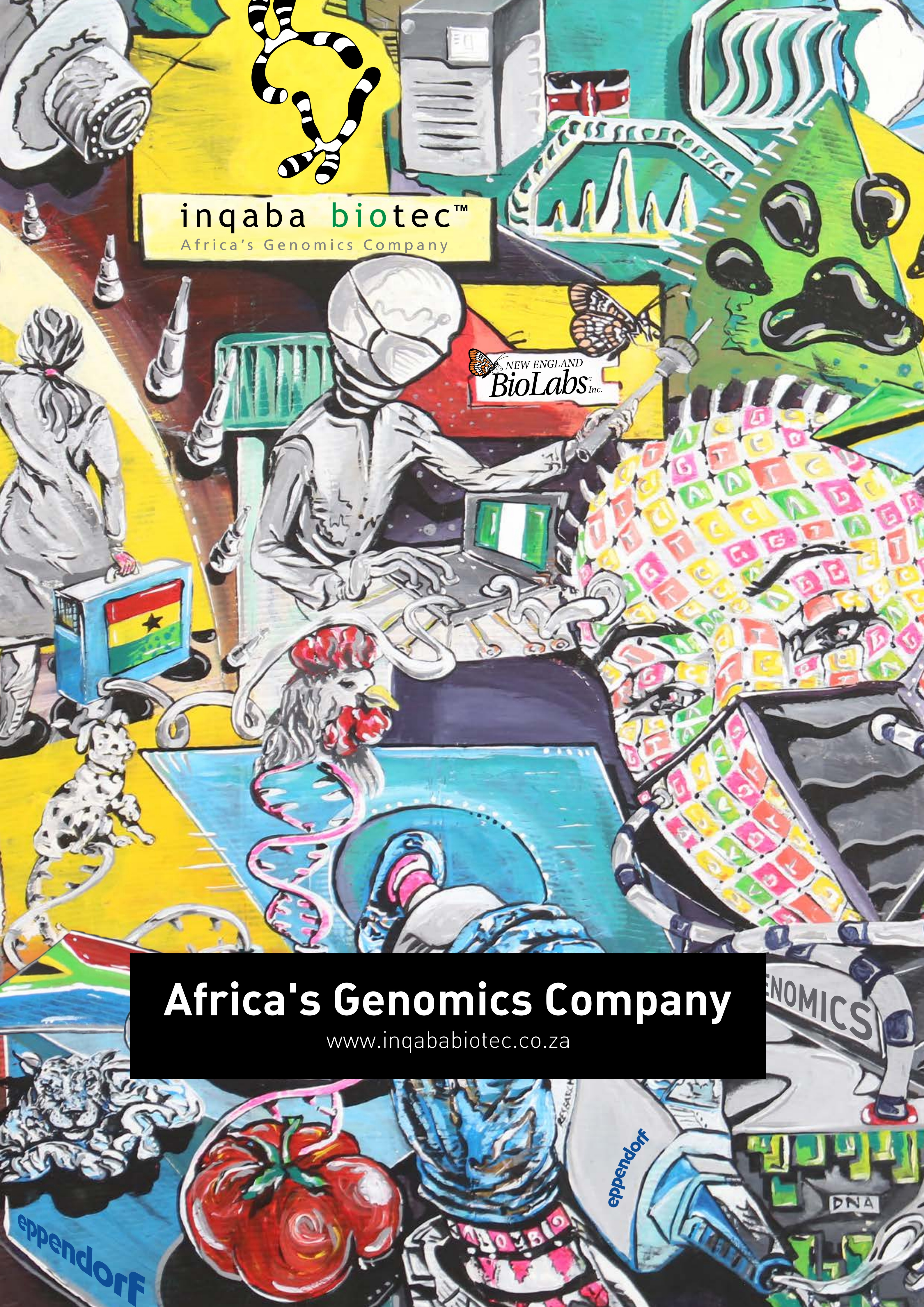
MAGNETISM

Observing the Earth's magnetic field

Boosting computer performance

Tracking continents in deep time

ACADEMY OF SCIENCE OF SOUTH AFRICA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Magnetism: the forces around us

Magnetism is part of our everyday lives, but the variety of ways in which it is used is commonly overlooked. While fridge magnets holding mementos and reminders in place are obvious examples, less apparent are the magnets or electromagnets in earphones, loudspeakers, doorbells, security systems and induction cookers. Our household appliances contain electric motors that rely on electromagnetism, which is also used by electric generators to produce electricity. Magnetism is even used to store data on hard disks in our computers and on the magnetic stripe on our bank cards.

Cranes fitted with powerful electromagnets are used to lift heavy metal objects, and magnetic separation is widely used in the recycling and mining industries. For example, sand-mining operations on South Africa's east and west coasts extract beach sands that are rich in heavy minerals. Magnetic separation is used to recover the magnetic ilmenite ($FETiO_3$), which is then smelted to produce titanium dioxide slag (TiO_2) and pig iron, from non-magnetic concentrate that undergoes further processing to produce rutile (TiO_2) and zircon ($ZrSiO_4$). The TiO_2 is a white pigment that is used in paints, paper and plastics, and South Africa is one of the main producers worldwide, since its production of ilmenite is second only to China, and its production of rutile is only exceeded by Australia. Zircon is mainly used in ceramics, such as tiles, sanitaryware and crockery.

Magnetic separation is now being taken to an extreme scale. The Pacific Northwest National Laboratory in the United States' Department of Energy has developed magnetic nanoparticles to recover valuable materials in effluent brines from, for example, mineral mining, geothermal plants and seawater desalination. The nanoparticles have an absorbent shell that selectively binds the compounds of interest, while the core consists of a form of iron oxide better known as magnetite. This means that exposure to a magnet attracts the nanoparticles, allowing them to be easily filtered from the brine. Two pilot projects have been initiated to test the technology's effectiveness in removing lithium from brines associated with oil and gas extraction and with lithium mining. Lithium is a rare earth element in high demand for use in batteries as well as in the manufacture of semiconductors and wind turbines.

Magnetic nanoparticles also have a range of applications in biology and medicine. For example, they are being used in the preparation of 'lab on a chip' sensors, and their potential as drug-delivery vehicles to cancer tumours is being tested.

At the other end of the scale, the world's largest magnet system is currently being constructed for ITER – a multinational collaborative project to build a magnetic fusion device designed to prove the feasibility of fusion as an energy source here on Earth. Fusion is the process that takes place in the intense heat of the core of the Sun and stars, when hydrogen atoms collide and their nuclei fuse to form helium atoms, with the release of vast amounts of energy.

The core of the ITER fusion reactor will be a thousand-tonne central solenoid made up of six modules, each consisting of a coil pack wound from niobium-tin superconducting cable. These modules are being built by General Atomics in California, and the first of the six was delivered to the project site in France on 9 September 2021. Fully assembled, the central solenoid's magnetic force could lift an aircraft carrier out of the water!

In this issue of *Quest*, we explore some uses of magnetism in science and technology, as well as its effects in the natural world.

Sue Matthews
Quest Editor

Lesisiqephu se *Quest* sikhuluma ngesayensi yomazibuthe, esetshenziswa ngezindlela eziningi empilweni futhi ibalulekile kwi sayensi nobuchwepheshe.

Translated by Zamantimande Kunene

Tshwane University of Technology
We empower people

Faculty of Engineering and the Built Environment

2022 New Qualifications

THE FOLLOWING HEQSF ALIGNED QUALIFICATIONS ARE PRESENTED

Bachelor of Architecture APS≥(25)
Bachelor of Architecture (Extended) APS≥(25)
Diploma in Industrial Design APS≥(21)
Advanced Diploma: Industrial Design (consult Prospectus for Admission Requirements)

Diploma in Building APS≥(26)

Bachelor of Engineering Technology in Chemical Engineering APS≥(28)
Bachelor of Engineering Technology in Metallurgical Engineering APS≥(28)
Bachelor of Engineering Technology in Materials Engineering in Polymer Technology APS≥(28)

Higher Certificate in Construction Engineering APS≥(20)
- Option 1: Construction Material Testing (HCCM18)
- Option 2: Water and Wastewater Engineering Infrastructural Operations and Maintenance (HCCW18)

Bachelor of Engineering Technology in Civil Engineering APS≥(28)

Bachelor of Geomatics APS≥(25)
Higher Certificate in Electrical Engineering APS≥(20)
Diploma in Electrical Engineering APS≥(28)
Bachelor of Engineering Technology in Electrical Engineering APS≥(30)

Higher Certificate in Industrial Engineering APS≥(20)
Bachelor of Engineering Technology in Industrial Engineering APS≥(28)

Higher Certificate in Mechanical Engineering APS≥(20)
Bachelor of Engineering Technology in Mechanical Engineering APS≥(28)
Bachelor of Engineering Technology in Mechatronics APS≥(28)

THE FOLLOWING NEW HEQSF-ALIGNED QUALIFICATIONS ARE PLANNED IN FUTURE

- Bachelor of Engineering Technology Honours in Chemical Engineering
- Bachelor of Engineering Technology Honours in Civil Engineering
- Bachelor of Engineering Technology Honours in Electrical Engineering
- Bachelor of Engineering Technology Honours in Industrial Engineering
- Bachelor of Engineering Technology Honours in Mechanical Engineering
- Bachelor of Engineering Technology Honours in Mechatronic Engineering
- Bachelor of Engineering Technology Honours in Metallurgical Engineering
- Bachelor of Engineering Technology Honours in Polymer Technology
- Diploma in Geomatics
- Advanced Diploma in Geomatics
- Postgraduate Diploma in Geomatics

ADMISSION REQUIREMENTS

A National Senior Certificate, or an equivalent qualification, with at least 4 for English, 4 for Mathematics/Technical Mathematics and 3 for Physical Science/Technical Science. A total APS of 20 will be considered for the Higher Certificate.

Diploma in Building
A National Senior Certificate with a bachelor's degree or a diploma endorsement or an equivalent qualification, with an achievement level of at least 4 for English (home language or first additional language), 3 for Mathematics or Technical Mathematics and 3 for Physical Science or Technical Science. Total APS of 26.

Diploma in Industrial Design
A National Senior Certificate or an equivalent qualification with at least an adequate achievement of 4 for English. Total APS of 21. To be considered for admission to this qualification, you must first meet the minimum academic requirements. All the applications should be supplemented with a portfolio.

Diploma in Electrical Engineering
A National Senior Certificate or an equivalent qualification, with a bachelor's degree or a diploma endorsement, or an equivalent qualification, with an achievement level of at least 4 for English (home language or first additional language), 4 for Mathematics or Technical Mathematics, and 4 for Physical Sciences or Technical Sciences. Total APS of 28.

Bachelor of Geomatics
A National Senior Certificate with an endorsement of a bachelor's degree or a diploma, or an equivalent qualification, with an achievement level of at least 4 for English, 5 for Mathematics/Technical Mathematics and 4 for Physical Sciences/Technical Physical Sciences. A total APS of 25 may be considered.

Bachelor of Architecture
A minimum score of 4 for English is required with a minimum of 25 APS score. Admission is subject to the completion of a Potential Assessment Test and available space. The purpose and intention of the assessment are to select only students who are likely to be successful in their studies in Architecture. The University reserves the right to select the best candidates for this programme. This is a six-hour written test.

Bachelor of Engineering Technology
A National Senior Certificate (NSC - completed Grade 12 in and after 2008), with an endorsement of a bachelor's degree or an equivalent qualification, with at least a *substantial achievement* of 4 for English, 5 for Mathematics/Technical Mathematics and 5 for Physical Science/Technical Science. Total APS score 28. For the Baccalaureus Technologiae: Engineering: Electrical, a total APS of 30 is applicable. This is a three-year qualification (integrated theory and practical).

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ADMISSION REQUIREMENTS FOR THE BACHELOR OF ENGINEERING TECHNOLOGY HONOURS DEGREE

The following HEQSF-aligned qualifications are planned in future. The Bachelor of Engineering Technology Honours Degree is a postgraduate qualification that prepares students for industry and research. This qualification typically follows a bachelor's degree, advanced diploma or relevant NQF level 7 qualification and serves to consolidate and deepen the student's expertise in a particular discipline and to develop research capacity in the methodology and techniques of that discipline.

The admission requirements for the Bachelor of Engineering Technology Honours in Electrical Engineering are as follows:
A Bachelor of Engineering Technology in Electrical Engineering, or a Bachelor of Technology in Electrical Engineering or an Advanced Diploma in Electrical Engineering or an equivalent with an aggregate of 60% for the final year of study or an NQF level 7 (old NQF and the new HEQSF) qualification in a closely related field obtained from an accredited South African University.

Admission requirements for the Master of Engineering

A Baccalaureus Technologiae in Engineering, Bachelor of Engineering Technology Honours, Bachelor of Engineering, or a Bachelor of Science in Engineering (in any related field), or an NQF level 8 qualification in Engineering (or any related field), with an aggregate of 60% for the final year of study obtained from an accredited South African university.
These programmes involve a research project with a dissertation and specified subjects. The candidates should prove that they understand a particular problem in the industry to which their research applies and can analyse it, arrive at logical conclusions or a diagnosis and make proposals for improvement or elimination of the problems.

Master of Building Sciences

Candidates with a baccalaureus technologiae (BTech), will be required to complete bridging modules at NQF Level 8 before registration (through an online mode):
- Engineering Data Analysis (EDY50BN)
- Life Cycle Management (LCY50BN) and
- Supply Chain Management (SPP50BN) (or their equivalents).

Master of Engineering in Chemical, -Civil, -Electrical, -Industrial -Mechanical, -Metallurgical and Polymer Technology.

A Baccalaureus Technologiae in Engineering, Bachelor of Engineering Technology Honours, Bachelor of Engineering or a Bachelor of Science in Engineering (in any related field), or an NQF level 8 qualification in Engineering (or any related field), with an aggregate of 60% for the final year of study obtained from an accredited South African university.

Candidates with a baccalaureus technologiae (BTech), will be required to complete bridging modules at NQF Level 8 before registration (through an online mode: BPENO7).

The modules are:
- Engineering Data Analysis (EDY50BN),
- Research Methodology (RMD50BN), and
- Systems Modelling (SYM51BN) (or their equivalents).

Master of Engineering in Engineering Management

Candidates with a baccalaureus technologiae (BTech), will be required to complete bridging modules at NQF Level 8 before registration (through an online mode: BPEMO8).
The modules are:
- Engineering Project Management (EPJ51BN),
- Quality Engineering (QUE51BN), and
- Systems Modelling (SYM51BN) (or their equivalents).

Master of Architecture

Admission requirement(s):
A Baccalaureus Technologiae in Architectural Technology (Professional), or a Baccalaureus Technologiae in Architectural Design (Professional), or a Bachelor's degree in Architectural Design (Professional), or a Bachelor's Honours degree in Architectural Design (Professional) obtained from an accredited South African university. The applicant should have a minimum grade of 60% for each major subject in the final year of study.
Holders of any other equivalent South African or international qualification may also be considered; see Chapter 1 of Students' Rules and Regulations.
Selection criteria:
Candidates who do not meet the 60% minimum academic requirements may be invited to appear before a Departmental Selection Committee for consideration. Further information regarding the process is available at the Department. Selection is based on academic performance, the student enrollment plan, available capacity, and broadening access. Applicants will be informed of their status per an official letter from the Office of the Registrar. Alternatively, they can check their application status on the Departmental website, www.tutarchitecture.co.za.

Master of Architecture in Architectural Technology

Admission requirement(s):
A Baccalaureus Technologiae in Architectural Design (Professional), or Baccalaureus Technologiae in Architectural Technology, or bachelor's degree in Architectural Design (Professional), or bachelor's degree in Architectural Technology, or bachelor's Honours degree in Architectural Design (Professional), or Bachelor's Honours degree in Architectural Technology obtained from an accredited South African university. The applicant should have a minimum grade of 60% for each major subject in the final year of study.
Holders of any other equivalent South African or international qualification may also be considered; see Chapter 1 of Students' Rules and Regulations.
Selection criteria:
Candidates who do not meet the 60% minimum academic requirements may be invited to appear before a Departmental Selection Committee for consideration. Further information regarding the process is available at the Department. Selection is based on academic performance, the student enrolment plan, available capacity, and broadening access. Applicants will be informed of their status per an official letter from the Office of the Registrar. Alternatively, they can check their application status on the Departmental website, www.tutarchitecture.co.za

Doctor of Architecture

Admission requirement(s):
A relevant Magister Technologiae: Architecture or master's degree in Architecture, or closely related field, obtained from an accredited South African university. Depending on the nature of the master's qualification, completing certain additional sub-

Entrance requirements: NSC, NCV, etc. Consult the latest Prospectus of the Faculty of Engineering and the Built Environment for detailed entrance requirements.

The introduction of the Higher Education and Qualification sub framework (HEQSF) in the Higher Education sector required all public and private higher education institutions (HEIS), including Tshwane University of Technology (TUT), to revise all its qualifications to ensure alignment with the HEQSF. www.tut.ac.za

TUT also offers qualifications for **Geomatics Technicians and Technologists**. A route exists for Geomatics Technicians and Technologists to register with the South African Geomatics Council (SAGC) in the Engineering Surveying (not to be confused with professional land surveyors).

In **Architecture**, TUT offers qualifications for professional architects and architectural technologists and is accredited by the South African Council for the Architectural Profession (SACAP) and the Commonwealth Association of Architects.

In **Industrial Design**, talented individuals who complete this programme will be able to provide junior-level industrial design-related services. This may include being a member of a design and development team or a junior design entrepreneur.

PROFESSIONAL RECOGNITION

Higher Certificate (HC)

With a *Higher Certificate* qualification, the undergraduate will be able to work in *engineering support occupations* such as draftspersons, installers and maintainers of engineering equipment and systems, engineering sales and marketing, site, and production supervisor.

Diploma

The *Diploma* enables students to register as *professional engineering technicians* with the Engineering Council of South Africa (ECSA), after having gained a minimum of three years' practical experience once they have qualified. Since these diplomas are internationally recognised through the Dublin Accord, qualified graduates can work as *engineering technicians* in co-signatory countries. An engineering technician is a competent engineering practitioner with sound technical knowledge who can convert ideas into workable plans, contribute to practical knowledge and solve well-defined engineering problems.

Bachelor of Engineering Technology (BEngTech)

The BEngTech degrees in **Chemical Engineering, Civil Engineering, Electrical Engineering, Industrial Engineering, Mechanical Engineering, Mechatronics, Metallurgical Engineering and Materials Engineering in Polymer Technology** enable students to register as *professional engineering technologists* with the Engineering Council of South Africa (ECSA), after having gained a minimum of three years practical experience after they have qualified. Since these degrees are internationally recognised through the Sydney Accord, qualified graduates can work as engineering technologists in co-signatory countries. In the UK, for example, an engineering technologist can work as an incorporated engineer (IEng) after registration with the Engineering Council of the United Kingdom (ECUK). The Bachelor of Engineering Technology (BEngTech) degrees have a strong application and practical focus and engineering technologists are competent engineering practitioners who can innovatively apply and modify engineering practices, solve broadly-defined engineering problems, give managerial inputs and work independently. The BEngTech degrees differ from BEng degrees, which allow registration as professional engineers, in the sense that the focus is more on the application of technological knowledge than on the derivation of knowledge from first principles.

Built Environment qualifications

In **Building Sciences**, TUT offers qualifications in quantity surveying and construction management for technicians and technologists who can register with the South African Council for Quantity Surveying Profession (SACQSP). After having gained enough practical experience and having passed professional examinations, candidates may register with the SACQSP as professional quantity surveyors. There is also a route for construction management students to register with the Chartered Institute of Building (CIOB) as chartered members.

jects may be required. Holders of any other equivalent South African or international qualification may also be considered; see Chapter 1 of Students' Rules and Regulations.

Selection criteria:

Each application is considered holistically, considering the applicant's background, experiences, perspectives, aspirations, values, accomplishments and possible fit within the graduate programme of the Department of Architecture. Assessments are based on the totality of information available, and no single factor is seen as decisive. The application process evaluates the candidates' previous academic performance; the submitted admissions' essay, reference letters, previous experiences in architectural design research or architectural technology research and career objectives. The interview panel will be looking to identify specific character traits including honesty, integrity, leadership, teamwork, maturity, creativity, and self-direction. The ability to make a positive contribution to society, the profession and the discipline are other important factors. Acceptance is subject to available capacity according to the Student Enrolment Plan (SEP) as well as supervisory capacity. Applicants will be informed of their status per an official letter from the Office of the Registrar, alternatively, they can check their application status on the TUT website, www.tut.ac.za. For detailed information on the application process, please contact the Head of the Department.

Admission requirements for Doctor of Engineering

A Magister Technologiae: Engineering, Master of Engineering, or a master's degree at NQF Level 9 in a related field obtained from a South African university.

Visit the website at www.tut.ac.za for detailed information on the various courses and access the Faculty of Engineering and the Built Environment page.

For more information:

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MRI

Quest takes a closer look at magnetic resonance imaging

Magnetic resonance imaging (MRI) machines play an important part in the diagnosis and monitoring of diseases, abnormalities and injuries affecting the soft tissues of the body. As the name implies, they use magnetism to make images, but how do they do this?

An adult human body is typically 50–70% water, with soft tissues having a much higher water content than bone. The hydrogen atoms in water molecules (H_2O) have a positively charged proton making up the nucleus, and each proton spins on its own axis, generating a tiny magnetic field with a north and south pole. Usually, the axes of the protons are oriented in different directions, but when a person is placed inside an MRI machine and exposed to its strong magnetic field, all the axes line up with that field. Next, a pulse of radiofrequency (RF) energy is applied, exciting the protons enough to make them temporarily tip out of alignment. As the protons return to the resting, aligned state they emit energy, which is recorded as an RF signal. Different tissues yield different signal intensities, which are processed by software in the MRI machine and displayed as shades of grey. The slice-by-slice scans are used to build a 2D or 3D image of the body part.

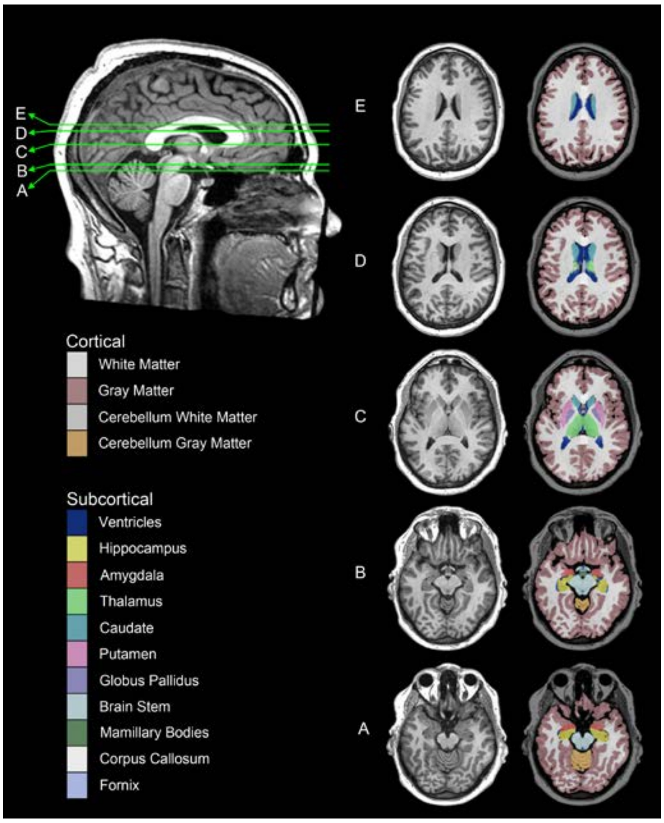
Various MRI ‘sequences’ are used to obtain images showing specific structures or problems. These sequences are particular settings of RF pulses and gradients, such as changing the repetition time (TR) between successive pulses or the echo time (TE) between a pulse and receipt of the signal. The most common MRI sequences produce T1-weighted or T2-weighted images. T1-weighted images use short TR and TE times, which results in protons from some tissues not having relaxed back into the aligned state before the next measurement is made, nor having returned to spinning out of phase with one another. This yields a high signal for fat but a low signal for water, whereas the converse applies for T2-weighted images, which use longer TR and TE times. The different intensity and contrast levels mean that cerebrospinal fluid, for example, appears black on T1-weighted images but white on T2-weighted images.

Patients undergoing a T1-weighted scan are often injected with a contrast agent containing the rare earth metal gadolinium, which increases the speed at which protons realign with the magnetic field. By highlighting areas with increased blood flow, gadolinium-enhanced images make identification of tumours, abscesses, and sites of inflammation and infection easier.

A variation of a T2-weighted sequence known as diffusion-weighted imaging (DWI) uses differences in the random motion – or Brownian motion – of water molecules in tissues to generate contrast. Since diffusion is restricted both by cell death, as occurs in a stroke, and by rapid proliferation of cells, typical of a malignant tumour, DWI is an important tool for rapid diagnosis of brain-related emergencies as well as long-term management of cancer cases. Some MRI sequences are optimised to image bones

Florey Institute, CC BY-NC-ND 2.0

Advanced software allows greyscale MRI data to be visualised as colour 3D imagery.



Tracy Abildskov, CC BY-NC-ND 2.0

Axial T1-weighted MRI slices of the brain, showing greyscale and colorised versions.

University of Pretoria

The Onderstepoort Veterinary Academic Hospital of the University of Pretoria's Faculty of Veterinary Science recently acquired its own 1.5 T MRI scanner. Here, Sister Sinazo Nikelo prepares a sedated patient for a scan.

and joints, and are often used to assess sports injuries such as shin splints, stress fractures, torn ligaments and meniscal tears in the knee.

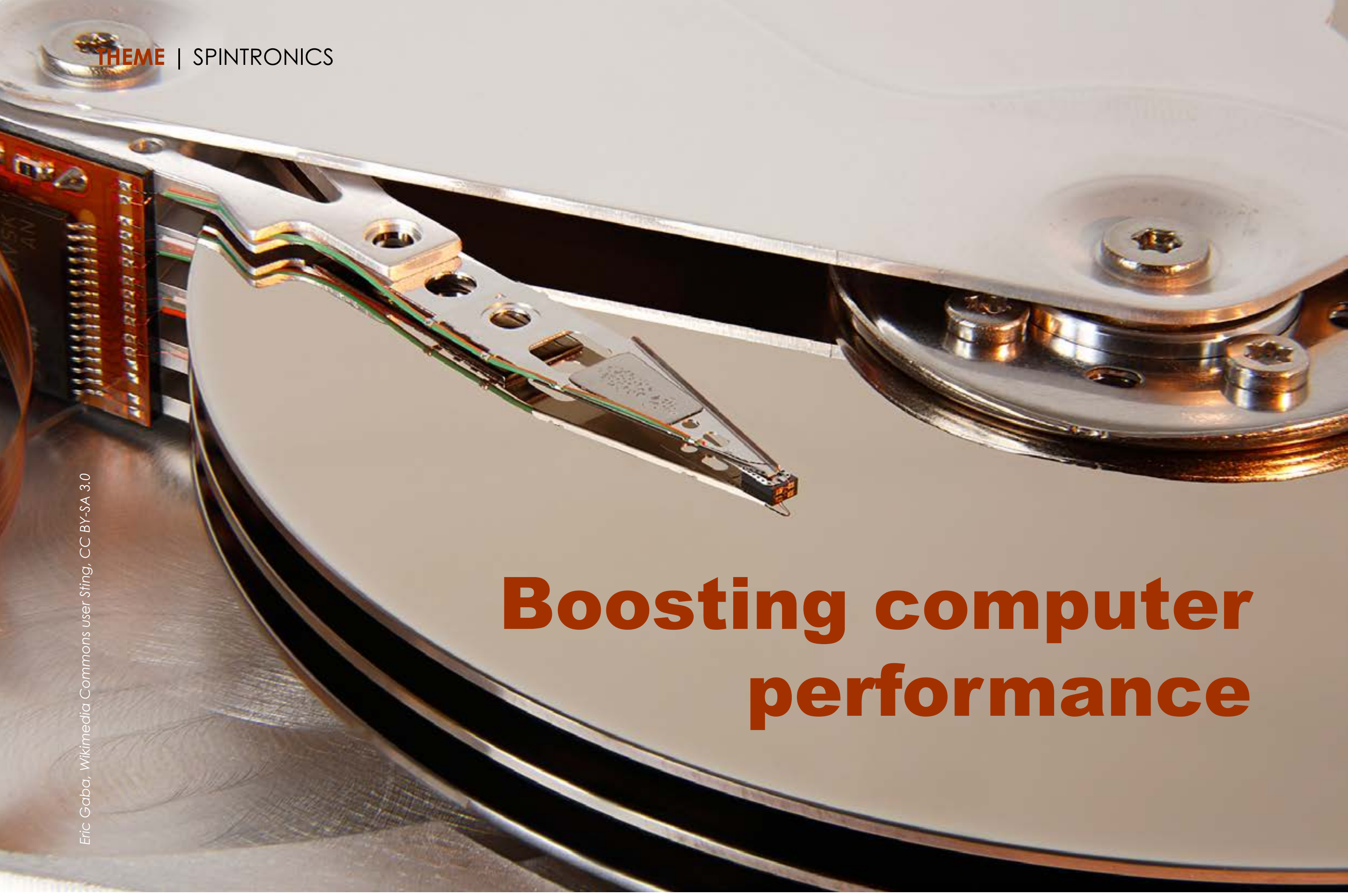
Rather than imaging body structures, or anatomy, functional MRI (fMRI) measures and maps brain activity by detecting changes in blood flow. It uses the MRI sequence known as BOLD – for blood oxygenation level dependent – which relies on the fact that areas with active neurons require more oxygen, causing a shift in the ratio of oxyhaemoglobin and deoxyhaemoglobin in red blood cells. Haemoglobin contains iron, giving it magnetic properties, but the oxygenated form is diamagnetic, meaning it is repelled by a magnetic field, while the deoxygenated form is paramagnetic, being attracted to a magnetic field. These differences are reflected in the MRI signal.

Patients might be given an fMRI prior to surgery to remove a brain tumour or repair an aneurysm, for example. By asking them to move their hands, speak or solve a simple problem while undergoing the fMRI, areas of the brain involved in these functions can be pinpointed so that the surgeon can try to avoid damaging them. The method is also widely used in research, with the aim of allowing accurate early detection of neurodegenerative disorders such as Alzheimer's disease, or diagnosing developmental disorders like autism. In the United States, the Adolescent Brain Cognitive Development (ABCD) study, launched in 2016, has enrolled nearly 12 000 youth aged 9 to 10 countrywide, and will track their development through repeated MRI scans over a decade. The data has already revealed which brain regions are involved in a range of psychological processes, including cognitive control, reward processing, working memory and social/emotional function.

MRIs are painless procedures and, unlike X-rays and computed tomography (CT) scans, they involve no ionising radiation. Some people may feel claustrophobic and anxious inside the MRI, and the 'stronger' machines can cause vertigo – the dizzying sensation of falling or being in moving surroundings – apparently due to the magnetic field pushing on the current of charged particles in the inner ear fluid. Most MRIs are either 1.5 T or 3 T (tesla; a fridge magnet is about 0.01 T), but in the past few years some 7 T machines have been approved for clinical use. These provide a higher signal-to-noise ratio and increased resolution, allowing structures less than a millimetre to be visualised. Stronger machines are used for research on human volunteers, cadavers and animals. The world's most powerful is a 21.1 T MRI at the US MagLab headquarters in Tallahassee, Florida, but since the interior space is a mere 10.5 cm, it can only be used to study small animals like lab rats, mice and birds.

These machines are tremendously heavy – the largest that can accommodate an entire human body is the 11.7 T one at NeuroSpin in France, and the magnet alone weighs about 120 tonnes. In common with most MRI machines, it is a superconducting magnet, in this case made from 182 km of niobium-titanium alloy wire wound in coils. To maintain its superconducting state, it must be kept in 7 000 litres of helium to ensure the temperature does not rise above −271°C, but it allows exploration of the human body at a resolution of one-tenth of a millimetre!

Written by Quest Editor, Sue Matthews



Boosting computer performance

Atsufumi Hirohata explains how the shift from electronics to spintronics opens up possibilities of faster data

Electronics is based on measuring the tiny electrical charge of electrons passing through electronic circuits. An alternative approach under development is spintronics, which instead relies not on electrons' charge, but on another of their fundamental quantum-mechanical properties: spin.

Spin can be visualised as the Earth turning on its own axis while rotating around the sun. In the same way, an electron spins on its own axis while rotating around an atom's nucleus. Spin is either 'up' or 'down'. In the same way traditional electronics uses charge to represent information as zeros and ones, the two spin states can be used to represent the same binary data in spintronics.

Spin can be measured because it generates tiny magnetic fields. Ferrous metals such as iron become magnetic, for example, when enough particles have their spin set in the same direction, generating a magnetic field of the same polarity as the spin.

Spintronics has several advantages over conventional electronics. Electronics require specialised semiconductor materials in order to control the flow of charge through the transistors. But spin can be measured very simply in common metals such as copper or aluminium. Less energy is needed to change spin than to generate a current to maintain electron charges in a device, so spintronics devices use less power.

Spin states can be set quickly, which makes transferring data quicker. And because electron spin is not energy-dependent, spin is non-volatile – information sent using spin remains fixed even after loss of power.

Upgrading hard disks using spin

The first application of spintronics to computers saw Professors Albert Fert and Peter Grünberg awarded the 2007 Nobel Prize in Physics for their discovery of giant magnetoresistance (GMR). They realised it was possible to use electron spin to increase the rate at which information could be read from a hard disk drive and developed ground-breaking technology to harness this feature.

A hard disk drive stores data as ones and zeros encoded magnetically on rotating disk platters within the drive. The magnetic field is generated when electrons flow through wire coils mounted in the drive write heads that move across the face of the platters, changing the alignment of the magneto-sensitive particles on the platter surface. Reversing the electron flow reverses the field; the two directions represent one and zero. To read from the disk the process works in reverse.

A GMR drive head consists of two ferromagnetic layers, one with a fixed magnetic field direction and the other free to align with the magnetic field encoded on the disk, with a non-magnetic layer sandwiched in between.

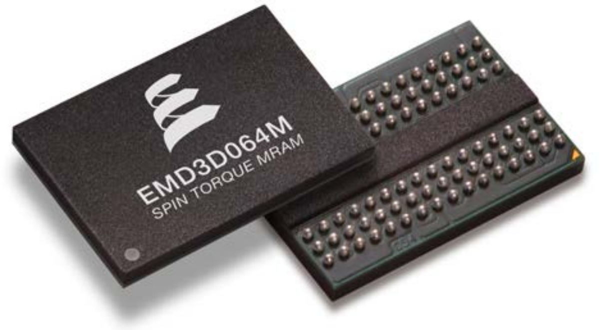
When an electron passes through a magnetic field its spin state may change, known as scattering. Where electrons have random, scattered spin states this creates greater resistance to electric current. By aligning electrons' spin state to that of the magnetic field in the layers of the drive head, GMR technology dramatically reduces resistance, speeding up data transfer. First introduced by IBM in 1997, GMR technology has led to faster and higher-density drives than was previously possible.

Putting a fresh spin on memory

Spintronics researchers have since been working on introducing the same technology to computer memory, aiming to replace electric current-based dynamic random access memory (DRAM) with 'magnetic' RAM (MRAM). The first commercial product by Everspin was used in Airbus aircraft and BMW motorbikes due to its reliability under heat stress or cosmic-ray exposure – something that affects aircraft cruising at high altitudes.

MRAM exploits the same spin-based magnetic field approach, but uses a magnetoresistance cell to store data rather than a spinning disk platter as in a hard drive. While it is not as fast as DRAM, magnetic cells are able to maintain their stored spin orientations, and so the data they represent, without power. MRAM is likely to replace commonly used flash memory such as SD cards and compact flash first, as it is faster and doesn't suffer from flash memory's limited lifespan.

Other manufacturers such as Intel, Qualcomm, Toshiba and Samsung are developing MRAM to use as processor cache memory, where by virtue of their smaller size MRAM chips of greater capacity can be incorporated into smaller packages that will be faster, and use up to 80% less power than current cache memory.



Everspin

Everspin is the world's leading developer and manufacturer of magnetoresistive random access memory (MRAM). See Everspin's website for graphical explanations of spin-transfer torque MRAM and toggle MRAM technology, along with case studies of applications in automotive, aerospace, medical and Internet of Things sectors, among others.

As electronics approaches the limits of silicon, spintronic components will play an important role in ensuring we enjoy steady performance gains, and faster, higher-capacity storage at lower power and cost.

- For more detail, see the recent open-access paper by Hirohata et al., 2020, Review on spintronics: Principles and device applications, in the *Journal of Magnetism and Magnetic Materials*. https://doi.org/10.1016/j.jmmm.2020.166711

Prof. Atsufumi Hirohata is a professor in the Department of Electronic Engineering at the University of York, United Kingdom.

Eric Gaba, Wikimedia Commons user Sting, CC BY-SA 3.0

A Seagate 3.5-inch hard disk drive (HDD), showing the circular platters and read/write head mounted at the tip of the arm.

iThemba LABS

Magnetism in accelerator-based science

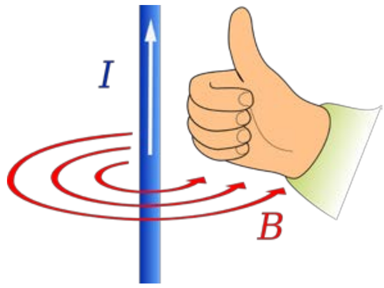
Gillian Arendse reports on the relevance of magnetism at iThemba LABS

At iThemba LABS, which stands for Laboratory for Accelerator Based Sciences, we make small things go *very* fast using strong magnetic fields. The research done at iThemba LABS uses beams of charged particles to study the origin of matter, but also to understand the interaction between radiation (energy as particles or waves) and biological systems. Apart from research activities, we also produce nuclear medicine such as radiopharmaceuticals to diagnose and treat cancer. Magnets and magnetic fields are used in a variety of ways here, but let's focus on three aspects:

- How we produce magnetic fields
- The role played by magnetic fields in the acceleration of charged particles
- How magnetic fields are used to help us 'see' the sub-atomic world and conduct research.

Producing magnetic fields

If you have ever been close to a powerline whilst listening to AM-radio and your radio went crazy, that was the magnetic fields created by the powerlines interfering with your reception. In electromagnetism lessons at school we learn the right-hand rule, which helps us understand that if we point our thumb in the direction of current flow, the magnetic field is indicated by the curl of our fingers. We use this principle at iThemba LABS by designing coils that will produce a magnetic field meeting our requirements when current (or electricity) is passed through them. The effect of the field can be enhanced by wrapping the coil around iron, also known as an iron yoke – rather like those school experiments to make an electromagnet by coiling wire around a nail and then connecting it to a battery for a current!



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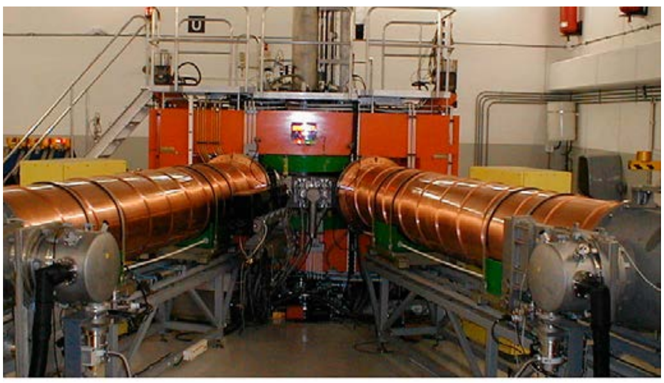
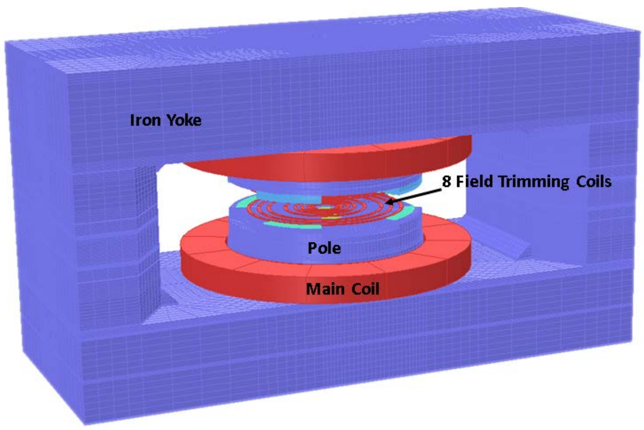
The right-hand rule states that our fingers show the direction of the magnetic field (B) when we point our thumb in the direction of current flow (I).

Accelerating particles

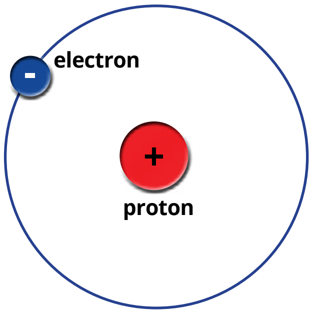
The charged particles used in accelerators are either protons, electrons or ions. The most common isotope of



iThemba LABS



The green parts of this injector cyclotron are the coils, depicted in red on the schematic.



Hydrogen atom

hydrogen is the simplest of all atoms, consisting only of a proton in the nucleus and an electron. So, all we need to do is remove the electron through a process called ionisation, and we are left with the proton, a positively charged particle.

A charged particle experiences a force when it is exposed to an electric field. The direction of the force will be in the direction of the field if the charge is positive and opposite if the charge is negative. This means that electric fields can be used to make the charged particles go faster or slower. Dr Muneer Sakildien, representing Accelerator Operation and Technical Support at iThemba LABS, explains that the simplest version of an accelerator is a linear accelerator, the so-called LINAC, which accelerates charges in a straight line. The oldest (and biggest) accelerator at iThemba LABS is the Separated Sector Cyclotron, usually just called the SSC. A cyclotron accelerates particles in a circular manner, with the radius of acceleration linked to the speed at which the particle travels. This is much like a roundabout, where the distance from the axle determines how fast you travel.

At the heart of the circular motion is the interaction between moving charged particles and magnetic fields. The force exerted by a magnetic field on a charged particle is always perpendicular to the plane defined by the magnetic field and the motion of travel. This implies that a magnetic field can change the direction of travel, but it cannot accelerate the particle. That's where the electric field comes in. The electric field makes the particle go faster whilst the magnetic field changes its direction so that it keeps travelling in a circle. The SSC is capable of accelerating a proton to a maximum kinetic energy of 200 MeV (megaelectron volts). A proton with that amount of energy is able to travel a distance equivalent to four times around the Earth in one second!

In addition to their involvement in the acceleration of charged particles, magnetic fields are crucial in steering or bending and changing the profile of the beam. The beam of particles can be focused through the introduction of magnetic fields. The basic idea is that in much the same way we use lenses to focus light, we can use magnetic fields to confine the space within which the charged particles travel. The acceleration and delivery of the accelerated particle beams to the end-user forms part of the activities of the Accelerator Operation and Technical Support Department.

Using magnetic fields for research

When walking late at night we need a flashlight, or torch. The flashlight beam sheds light on objects and the reflected light is detected by our eyes, making it possible to see. This is essentially what scientists at iThemba LABS do when they conduct research. They use a beam of fast-moving particles (the probe) to illuminate a target, and a detector to see. The choice of probe, target and detector is informed by the specific study that is undertaken.

Dr Retief Neveling is one of our research scientists who works in the field of sub-atomic physics, and uses a magnetic spectrometer as his detector of choice.

Let's think about the basic process for a bit. How do you determine what is inside a gift-wrapped box without opening the box? You could shake it and listen to the sounds, or you could smash it and collect all the pieces. Putting the pieces back together allows you to reconstruct the contents of the box. Likewise, Dr Neveling allows a fast-moving beam of particles to smash into a thin target, and then he collects all the reaction products using a detector in order to investigate the structure and behaviour of particles.

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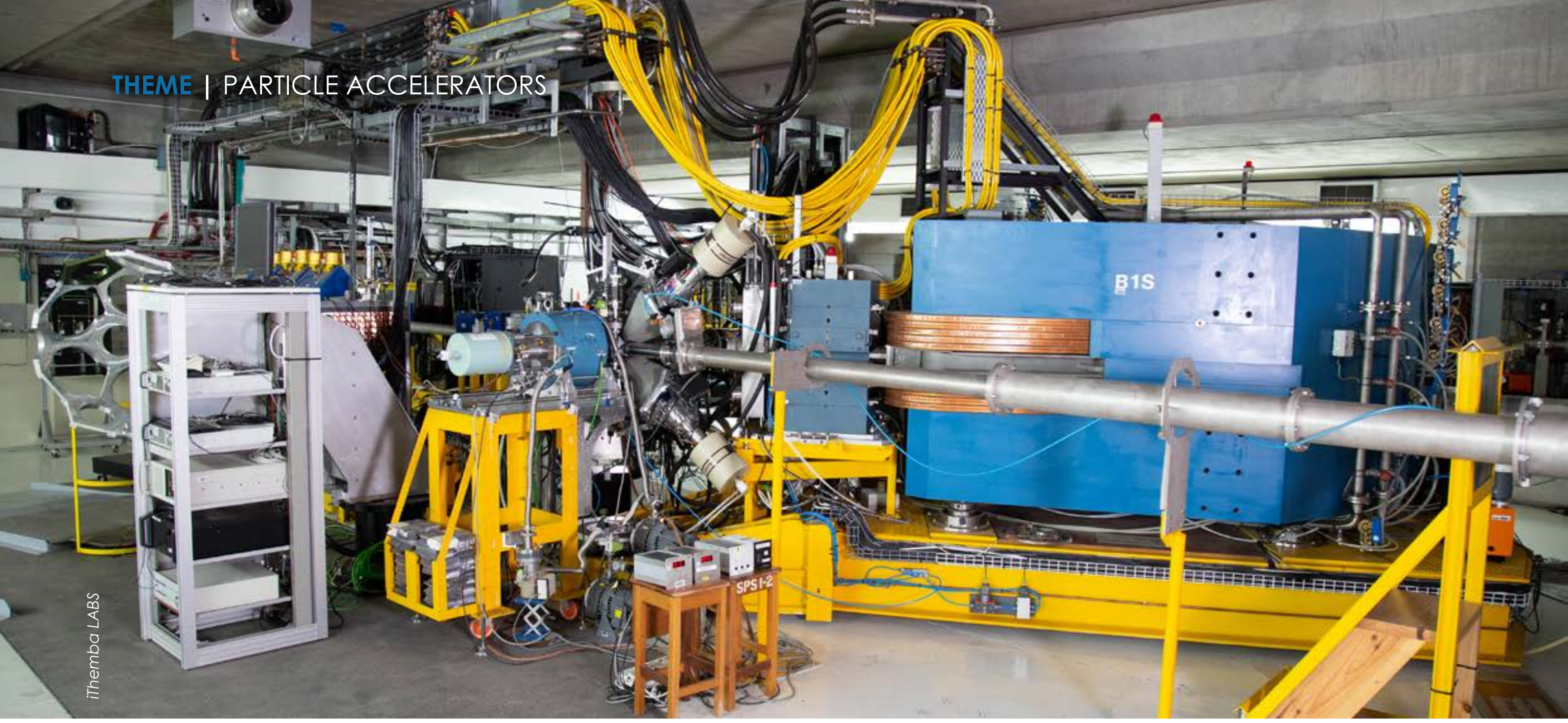
The Separated Sector Cyclotron (SSC) is the largest accelerator at iThemba LABS. The magnetic fields are largely contained within the yellow sectors of the accelerator.



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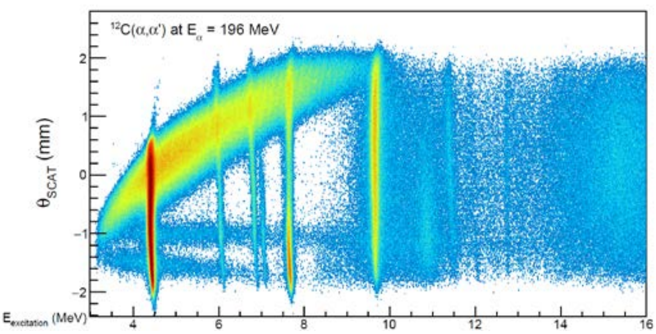
The k600 magnetic spectrometer is capable of measuring inelastically scattered particles and reactions at extreme forward angles, including 0°. This makes it one of only two such facilities in the world capable of measuring at 0°.

One of the biggest detector set-ups at iThemba LABS is the k600 magnetic spectrometer. This 100-tonne detector can generate a relatively strong magnetic dipole field of up to 1.64 Tesla, which is approximately 30 000 times stronger than the Earth's magnetic field at the surface. The field is strong enough to bend protons moving at 56% the speed of light through a radius of just 2.1 m.

Magnetic fields make it possible to manipulate fast-moving charged particles when the particle's mass, speed and charge are known. These three quantities can be rolled up into one concept, namely the particle's rigidity (R). The higher the rigidity, the more difficult it is to change the particle's direction – in other words the more rigid its trajectory is. For example, it is more difficult to change the direction of a faster/heavier particle than a slower/lighter particle. Similarly, a particle with more charge is affected more by a magnetic field than a particle with less charge.

Dr Neveling makes use of this concept to measure, with high accuracy, the kinetic energy of fast-moving reaction products following a nuclear reaction. With sub-millimetre precision, he detects where the particles exit the spectrometer and, in this way, determines their rigidity. The type of particle is identified by measuring the time it takes the particle to traverse the magnetic field (to better than 1 nanosecond accuracy), as well as the amount of energy deposited in the detector at the spectrometer's exit. All these bits and pieces allow him to reconstruct the interaction between the energetic projectile and the target.



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Typical experimental results obtained with the k600 spectrometer for the inelastic scattering of alpha-particles off ^{12}C. Each vertical line represents a specific excited state in a nucleus. The majority are from ^{12}C, with a few contamination states seen due to the presence of ^{16}O in the target. The strong diagonal line represents alpha scattering from hydrogen.

One such study concerns the structure of the Hoyle state. This is an excited state in carbon-12 (^{12}C) at 7.654 MeV, which plays a pivotal role in the creation of carbon in stars and – by extension – the existence of carbon in the universe. The nuclear structure of this famous state is not yet understood, nor is the character of states in ^{12}C around 10 MeV fully explored. A possible way of studying the Hoyle state in ^{12}C is through inelastic scattering of alpha-particles, which consist of two protons and two neutrons, making them identical to the nuclei of helium atoms. This entails allowing fast-moving alpha-particles to interact with a ^{12}C-target and detecting the alphas after the collision at a reduced energy. The reduction in energy is related to the energy absorbed by the nucleus, and allows the researcher to extract information about the structure of ^{12}C, and therefore the Hoyle state. The strong dipole magnetic field in the magnetic spectrometer results in particles with different energies exiting the magnetic field at different places. The highest-energy particles, which imparted the smallest amount of energy to the ^{12}C nucleus, will be bent less than the lower-energy ones which excited the ^{12}C more.

By detecting and studying such phenomena at the sub-atomic level, iThemba LABS is truly a place where all the science we are taught at school comes to life!

- For more detailed information, read the laboratory portrait published in *Nuclear Physics News*. https://tlabs.ac.za/wp-content/uploads/pdf/iTL_portrait.pdf

Dr Gillian Arendse is the head of communications and stakeholder relations at iThemba LABS, and a well-known motivational speaker. He completed his PhD in experimental nuclear physics at Stellenbosch University in 1996.

Large Hadron Collider

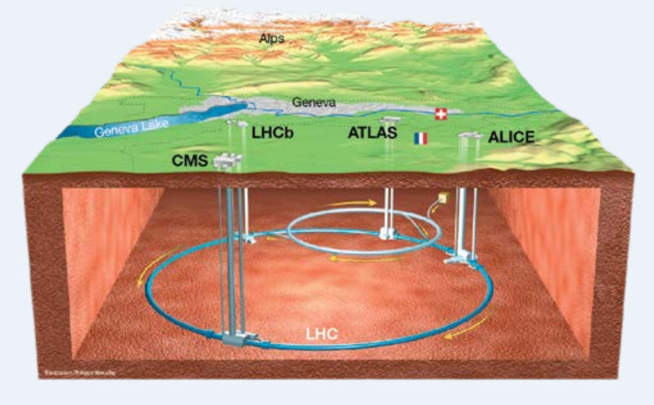
The world's most powerful particle accelerator is the Large Hadron Collider at CERN – the European Organisation for Nuclear Research. Referred to by scientists as the LHC, the accelerator is in a circular tunnel located 100 m underground at the French-Swiss border near Geneva, Switzerland. Its full name refers to:

- 'Large' because its circumference is about 27 km
- 'Hadron' because it accelerates quark-containing particles called hadrons, such as protons
- 'Collider' because the particles form two beams travelling in opposite directions, which are made to collide at four different points.

The beams travel at close to the speed of light, which means that a proton goes round the LHC circuit more than 11 000 times per second! The beams are in two separate beam pipes, or tubes, kept at ultrahigh vacuum with a pressure similar to that of the moon's atmosphere. Thousands of magnets of different varieties and sizes – many of them 15 m long – direct the beams around the accelerator.

There are seven experiments installed at the LHC. Construction work on the first four began between 1996 and 1998. These are located in huge underground caverns built around the four collision points of the LHC beams and are called A Large Ion Collider Experiment (ALICE), A Toroidal LHC ApparatuS (ATLAS), the Compact Muon Solenoid (CMS), and the Large Hadron Collider beauty (LHCb) experiment. The smaller Large Hadron Collider forward (LHCf) experiment, TOTal Elastic and diffractive cross section Measurement (TOTEM) experiment, and Monopole and Exotics Detector at the LHC (MoEDAL) were added later.

The experiments use detectors to analyse the particles produced by collisions in the accelerator. In July 2012, CERN announced the discovery in both the ATLAS and CMS experiments of the Higgs boson, a fundamental particle predicted to occur by Peter Higgs, François Englert and other theorists. Following this confirmation of its existence, Higgs and Englert were awarded the Nobel Prize for Physics in 2013.



CERN, CC-BY-4.0

Schematic view of the Large Hadron Collider (LHC), with the four largest detectors.

SA-CERN programme

The LHC experiments are run by collaborations of scientists from institutes all over the world, including South Africa. The SA-CERN programme is a national programme hosted by iThemba LABS and funded by the Department of Science and Innovation (DSI) and the National Research Foundation (NRF) to provide South African researchers, students, engineers and technicians with an opportunity to participate in the activities at CERN. This includes taking part in the ATLAS and ALICE experiments, as well as those at CERN's radioactive ion beam facility called ISOLDE, which stands for Isotope Separator On Line Device. In addition, South Africans contribute to theoretical physics related to the research at CERN.

The SA-CERN programme makes a limited number of bursaries available for MSc and PhD studies in CERN-related research. South Africans can also apply for international funding, such as the ATLAS PhD Grant offered by the CERN & Society Foundation. In December 2020 it was announced that a physics PhD student at the University of the Witwatersrand, Humphry Tlou, was one of two recipients of the 2021 ATLAS PhD Grant, the other being a female PhD student from Portugal. Tlou is the first South African to have been awarded this grant, and he has also received financial support through the SA-CERN programme, having been involved in ATLAS activities since 2015 as a final-year undergraduate student and then travelling to CERN for the first time in 2017.

ATLAS Collaboration, CERN

Humphry Tlou is the first South African to be awarded the ATLAS PhD Grant.

Currently the LHC is in a 'long shutdown', which started in December 2018, for maintenance and upgrades before the next 'run' period, due to start in early 2022. Tlou explained during the grant award ceremony, held online, that he is contributing to the upgrade, development and management of the data acquisition software for the ATLAS Tile Calorimeter, a sub-detector of ATLAS. This will allow the 'TileCal' group to operate the detector and collect data for physics analysis, including for his own PhD focusing on the search for a new boson, heavier than the Higgs boson.

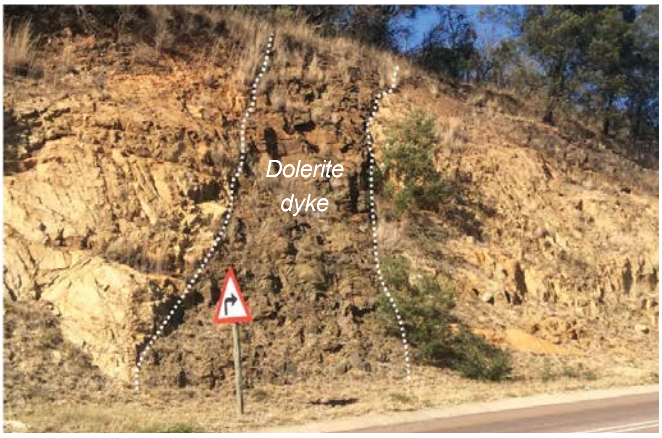
Tlou's PhD supervisor is Prof. Bruce Mellado, Director of the Institute for Collider Particle Physics (IPP) in the Wits School of Physics, and a senior scientist at iThemba LABS. In May, Mellado was elected Chairperson of ATLAS TileCal's Institutional Board by representatives of 25 research institutes worldwide.

For more information about CERN facilities and science, refer to: https://home.cern/resources/brochure/knowledge-sharing/lhc-facts-and-figures

Tracking continents in deep time

Michiel de Kock reveals how the Earth's magnetic field is recorded in rocks, providing the basis for the palaeomagnetic dating method

Michiel de Kock



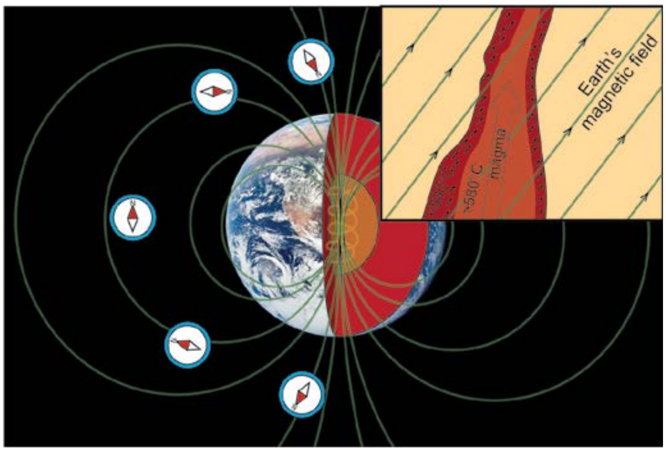
Palaeomagnetic core samples are collected from dolerite dykes, which are approximately 1 850 million years old.

The chainsaw engine pushes back with a whine as the diamond-tipped bit cuts deeper into the dolerite rock. My PhD student, Cedric Djeutchou, is ensuring that the bit stays cool by maintaining a steady flow of water from a small pump can. I need to cut another centimetre or so to complete the core.

Cedric and I are palaeomagnetists, and we are interested in the record of the Earth's magnetic field in rocks. We have collected over 372 cores from 61 separate dolerite dykes. Each of these cores is 2.5 cm in diameter, nearly 8 cm long, and oriented according to the direction and angle that it was drilled. The dykes are remains of an ancient 'plumbing system' of mostly northeast–southwest running cracks that fed molten rock called magma – subsequently cooled and solidified to dolerite – to the surface some 1 850 million years ago.

Geologists know from the rock record that continental fragments were assembling to form the supercontinent Columbia at that time. Most people have heard of the last supercontinent, named Pangea, which broke apart to form the modern continents. Unlike Pangea, we only have a vague idea of what Columbia looked like, and no idea where the ancient landmass of southern Africa – known as the Kalahari craton – was located. Cedric is hoping to change that, and was lead author of a recent paper outlining some of our findings (Djeutchou et al., 2021).

Michiel de Kock

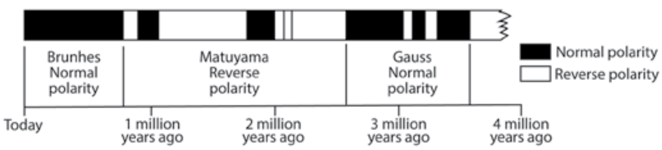


Earth's magnetic field is dipolar, produced in the outer core, and aligned with the spin axis. Magma that contains magnetite will record the Earth's magnetic field if it cools below 580°C.

Magnetic declination and pole-flipping

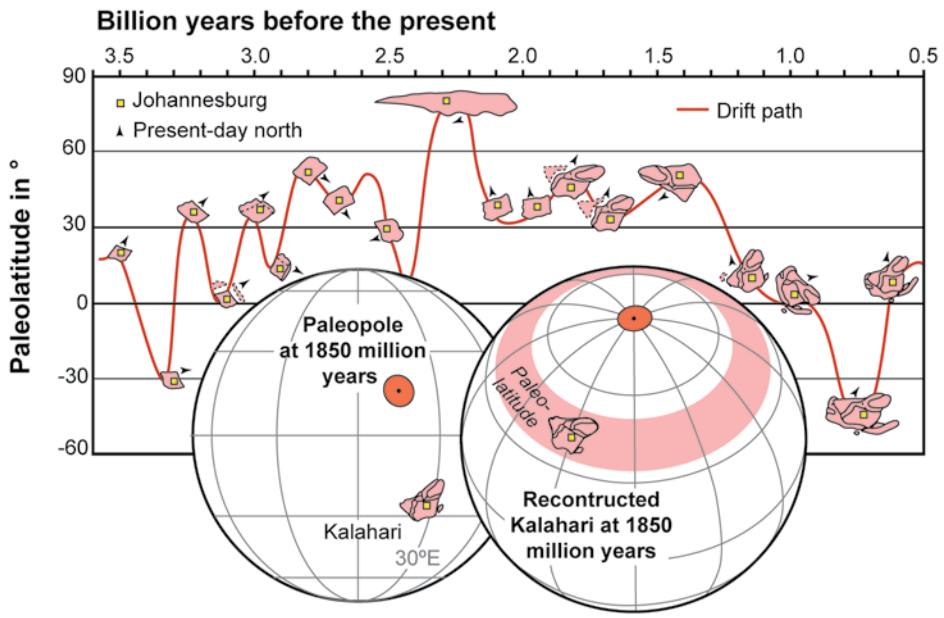
Electric currents in the molten iron-nickel outer core of the Earth produce a magnetic field according to Faraday's Law. The molten outer core gets whipped into helical flow due to cooling of the outer core and the Earth's fast rotation. This produces a looping current and an induced magnetic field that comes out of the loop in a doughnut shape. Magnetic field lines emerge steeply near the South Pole, become flatter towards the equator, and steepen up again near the North Pole. On the surface, a compass needle aligns with these field lines to point to magnetic north, which differs from the spin axis – the imaginary line passing through the North and South Poles – by an amount known as the magnetic declination.

The angle at which the magnetic field lines exit or enter the surface is called the magnetic inclination. The magnetic



Michiel de Kock

Polarity of the Earth's magnetic field for the past four million years. The current polarity interval, the Brunhes interval, started 780 000 years ago. Before that, during the Matuyama interval, a compass would have pointed south instead of north.



Michiel de Kock

Drift and growth of the Kalahari craton. The inclination at a specific time, here 1 850 million years ago, reveals the location of the North Pole relative to the craton. The craton is reconstructed by moving the 1 850-million-year-old pole to the spin axis while keeping the distance between the craton and the pole locked.

field is the result of dynamic processes, and the position of magnetic north oscillates around the spin axis. However, when averaged over long periods of time, this variation disappears, making magnetic north and the spin axis the same. Magnetic inclination varies depending on where it is measured and can be expressed as Tan(I) = 2Tan(λ), where I is the inclination and λ is the latitude.

The polarity of the Earth's magnetic field can flip and has changed many times in the past. These polarity intervals occur irregularly, sometimes flipping in quick succession and sometimes remaining stable for millions of years. The sequence and tempo of magnetic polarity reversals is unique for any specific time interval – kind of like a barcode – and can be used to date rocks.

Remanence and the Curie temperature

Rocks can become magnetised and retain a record of the Earth's magnetic field. This is known as a remanent magnetisation or remanence. A rock records and retains remanence for a long time if it contains minerals of the right chemical composition, and if those minerals are of the right size. Magnetic minerals such as magnetite (Fe_3O_4) or hematite (Fe_2O_3) are needed, and crystals should not be too small or too big. Both size extremes would result in an unstable remanence that can easily be overwritten. Luckily for geologists, many rock types contain these and other magnetic minerals that are also of the desired grain-size to retain remanences for millions to billions of years.

When an iron- and magnesium-rich magma cools in a crack near the surface from its initial 1 200°C to below 580°C, small crystals of magnetite will become magnetised in the direction of the Earth's magnetic field. The temperature where specific minerals become magnetised (and above which they lose their magnetisation) is called the Curie temperature. For small and pure crystals of magnetite, this is 580°C. As the magma cools and solidifies to form dolerite, the magnetic record becomes 'frozen in'. The dolerite will only lose this remanence if it is remagnetised through crystallisation of new magnetic minerals, through later heating of the rock to above the Curie temperature, or by exposure to a very strong magnetic field.

Reading the magnetic record

To read the magnetic record in rocks, the collected core samples must be returned to our palaeomagnetic laboratory at the University of Johannesburg. The laboratory is equipped with a sensitive superconducting rock magnetometer that can measure very weak magnetisations like those recorded in rocks. Our laboratory is the only one on the African continent with this equipment.

The prepared cores are slowly stripped of their magnetic record in a process known as demagnetisation to reveal the most stable kernel of the dolerites' remanence. The inclination of this remanence reveals where the Kalahari craton was when the dolerite intruded 1 850 million years ago. This allows palaeomagnetists to turn back the clock and to reconstruct the Kalahari craton to its original latitude. Using rocks of different ages, we can track the movement of the Kalahari craton back 3.5 billion years.

- Djeutchou, C, De Kock, MO, Wabo, H, Gaitán, CE, Söderlund, U & Gumsley, AP, 2021. Late Paleoproterozoic mafic magmatism and the Kalahari craton during Columbia assembly. *Geology* v. 49, https://doi.org/10.1130/G48811.1

Prof. Michiel de Kock is the head of the Department of Geology at the University of Johannesburg. He supervised Dr Cedric Djeutchou, who completed his PhD in 2020 and is now conducting postdoctoral research at the University of Johannesburg.

Johny Goerend, Unsplash

Observing the Earth's magnetic field

Pieter Kotzé discusses the role of the geomagnetic observation network operated by the South African National Space Agency

The Earth's magnetic field has its origin in the molten core located ~3 000 km below the planet's surface. Without it, the Earth's atmosphere would be eroded over millions of years by the solar wind – the plasma stream of charged particles constantly escaping from the Sun. The so-called 'geomagnetic' field shields our planet from this damaging radiation and allows life on Earth as we know it to exist.

Convection in the molten core means that the geomagnetic field changes gradually in space and time. These changes, known as secular variation, have practical implications for navigation, geological magnetic surveys and various applications dependent upon precise orientation. Continuous monitoring is therefore conducted by geomagnetic observatories around the world, and the results used to build or update global and regional models of the geomagnetic field.

The geomagnetic observation network operated by SANSA consists of observatories at Hermanus and Hartebeesthoek in South Africa and at Tsumeb and Keetmanshoop in Namibia.

The observatories also play a crucial role in space weather monitoring. The interaction between the solar wind and the geomagnetic field may cause disturbances under certain conditions, with particularly intense magnetic storms occurring where the magnetic field associated with a coronal mass ejection is oppositely directed to the geomagnetic field. These storms can damage electronics and electricity networks, affect navigation and communication systems, and expose astronauts, airline crew and passengers to dangerous levels of radiation.

The geomagnetic observation network operated by the South African National Space Agency (SANSA) monitors the behaviour of Earth's magnetic field in southern Africa over a wide range of time scales, from seconds to several decades. Apart from research and data provision for regional and international use, the information is used to characterise magnetic storms and determine their strength and duration during space weather events. The magnetic field disturbance at a particular point and time is especially important where the broad scientific objective is to understand the sources and processes internal and external to the Earth's surface. The geophysical exploration industry, for example, needs accurate geomagnetic data for directional drilling, which orientates the drill bit deep underground using the Earth's magnetic field – yet this may vary considerably even on a normal day, and much more during a magnetic storm.

Observations past, present and future

The requirements of navigation, rather than any scientific interest in geomagnetism, originally prompted the recording of data of magnetic field components in

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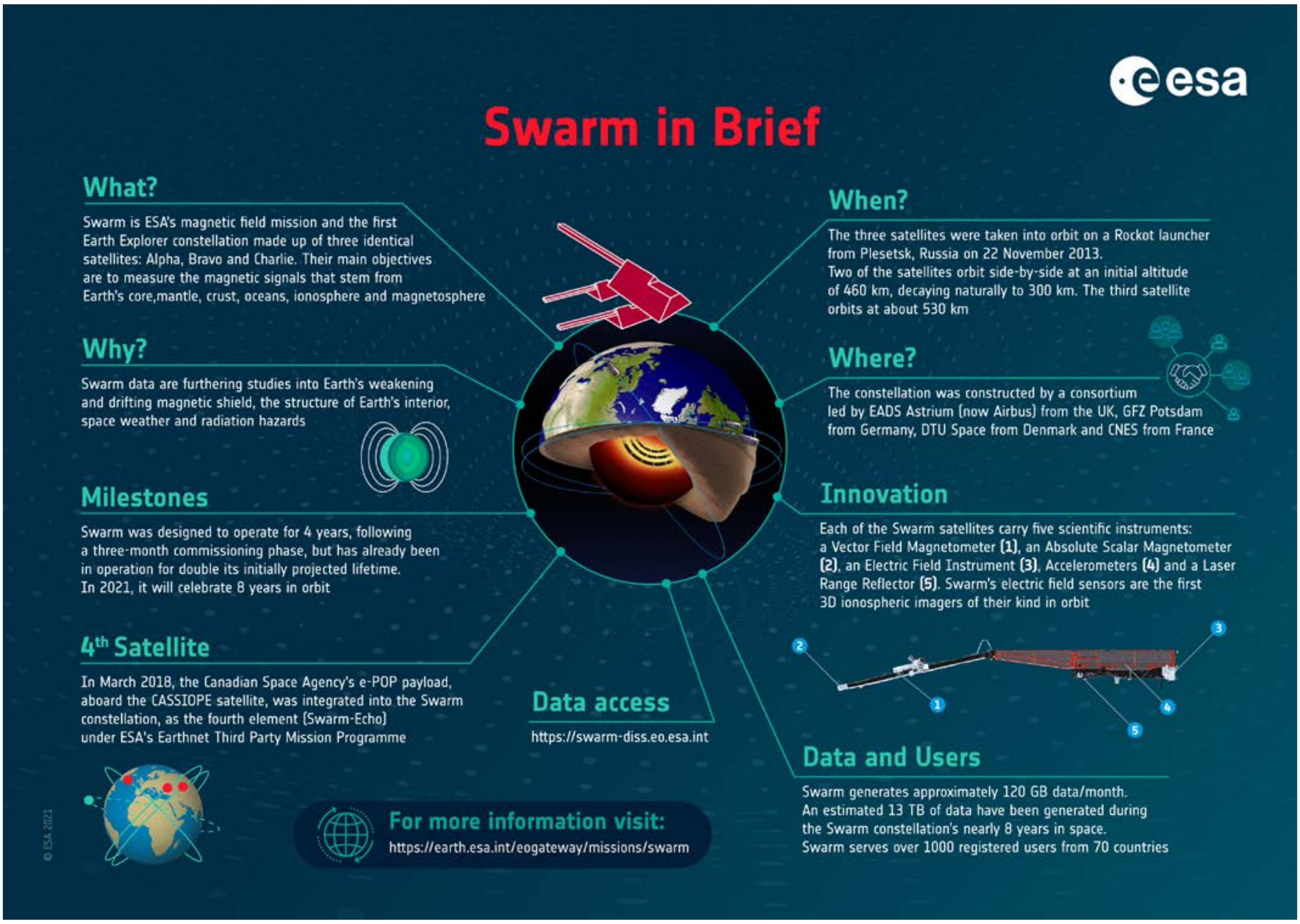
SANSA is in the process of upgrading its Hermanus facility to a 24-hour operational space weather centre.

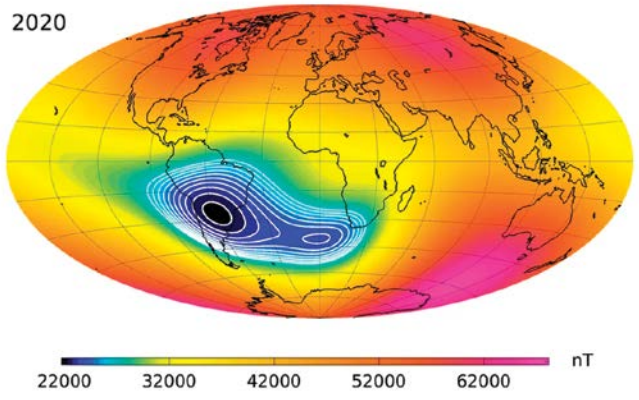
southern Africa. Even before 1600, seafarers were making magnetic field observations at places close to the coast to check the accuracy of their magnetic compasses. The first systematic observations in South Africa resulted from the establishment in 1841 of a worldwide network of geomagnetic observation stations. One of these stations was built on the grounds of the Royal Observatory at the Cape of Good Hope, where observations were carried out intensely for some years and then – after the station burnt down in 1953 – only sporadically until 1870, when the Observatory's director, Sir Thomas Maclear, retired.

The first magnetic survey of southern Africa was carried out by Professors Beattie and Morrison between 1898 and 1906. In 1932, in celebration of the International Polar Year of 1932–1933, a magnetic observatory was established at the University of Cape Town. But the subsequent electrification of the suburban railway network created a disturbing influence, to the extent that accurate observations were becoming almost impossible. A new site was identified in Hermanus because it was sufficiently remote from such disturbances and had been proved by a magnetic survey to be suitable in other respects.

Over the years following the establishment of the Hermanus Magnetic Observatory in 1941, various institutions have administered the facility, but in 2011 it became part of SANSA's Space Science Programme. The observation network in southern Africa has also been expanded since the 1960s, and now includes additional observatories at Hartebeesthoek in South Africa and at Tsumeb and Keetmanshoop in Namibia. This SANSA-operated network is integrated into the International Real-time Magnetic Observatory Network (INTERMAGNET), an organisation dedicated to promoting the operation of geomagnetic observatories according to modern-day, high standards.

Given sufficient resources like funding and human capacity, SANSA may expand the network in the future, the eastern part of Botswana having been identified as a potential





The splitting in two of the South Atlantic Anomaly can be clearly seen in this depiction of the field strength of Earth's magnetic field, as measured by ESA's SWARM satellite constellation.

candidate for a new INTERMAGNET observatory. Some regional space weather projects, such as those focused on potential hazards for the local electric power grid industry, as well as mineral survey companies operating in southern Africa, may benefit from the addition. The expansion could perhaps be achieved through international collaboration, as was the case for the establishment of the Keetmanshoop observatory through the support of the GFZ German Research Centre for Geosciences. SANSA could also expand the time domain of data collection by moving to continuous monitoring at sampling frequencies of 10 Hz or higher, which can be utilised for high time-resolution research and applications.

Currently, SANSA is in the process of upgrading its facility in Hermanus to a 24-hour operational space weather centre. In terms of an agreement with the International Civil Aviation Organisation, this will serve as a regional centre providing space weather services for the African region. The official ground-breaking ceremony for a new, state-of-the-art facility took place on 9 March 2021.

South Atlantic Anomaly

South Africa is also uniquely positioned to study the South Atlantic Anomaly (SAA), where the geomagnetic field is weaker by about 40% relative to other places at equivalent latitudes, due to processes in the Earth's core. Although originally detected by satellite missions in the late 1950s, data from the European Space Agency's Swarm satellite constellation, launched in November 2013, have revealed that the SAA has split in two since 2014. It is also moving westward at a rate of 20 km per year, which increases the anomaly's area of influence demonstrated by an observed weakened magnetic field over southern Africa.

A weaker field means that the shielding effect is severely reduced in this area, allowing high-energy particles to penetrate deeper into the upper atmosphere here than anywhere else on Earth. Although the SAA is no cause for alarm at ground level, most satellites and spacecraft crossing this area at altitudes below 1 000 km have experienced some level of malfunctioning or degradation. For example, their solar panels and computer chips can get damaged, and astronauts are vulnerable to radiation exposure here.

By the year 2100 the SAA will cover most of South America, the southern part of Africa, and the South Atlantic Ocean south of 25°S to the Scotia Sea and Antarctica. The size of the SAA will have increased by a factor of four, suggesting that the radiation hazard to humans in space may be increased by a corresponding amount.

It is unknown where the turning point of this migration is, but it is suspected that it might culminate in a polar reversal, when the north and south magnetic poles switch places, most probably in the next millennium. During the Earth's history, these poles have reversed many times at intervals ranging from about 120 000 years to 660 000 years. Since the last known reversal was 780 000 years ago, such an event is long overdue!

- Read more about space weather monitoring in the article 'SuperDARN' in *Quest* Vol. 16 No. 2, which focused on early warning systems.

Dr Pieter Kotzé retired from SANSA in 2020 but remains active as a researcher through his association with the Centre for Space Research at North-West University and the Physics Department at Stellenbosch University.

CURRICULUM CORNER

PHYSICAL SCIENCES: GRADE 10
Magnetism: Earth's magnetic field

Raphael Rychetsky, Unsplash

Birds, brains and magnetic fields

Betony Adams and Francesco Petruccione share current theories of how birds use magnetoreception to navigate during long-distance migration

"We can only see the universe," wrote Einstein, "by the impressions of our senses reflecting indirectly the things of reality." Our senses are the interface between ourselves and our environment; they mark the boundary between our inside and our outside world. The progress of science has to some extent been the progress of artificial sense organs – the invention of telescopes and microscopes, lenses that outstrip our eyes, membranes that magnify vibrations beyond the capacity of our ears. But what if this progress identifies more than the five senses we are accustomed to: touch, sight, hearing, smell and taste?

A recent experiment revealed that, even though we may not be aware of it, humans can sense the Earth's magnetic field, known as the geomagnetic field. By having human subjects sit silently in a completely dark chamber and then flipping the direction of a simulated geomagnetic field around them, scientists demonstrated that some of the subjects experienced corresponding changes in alpha rhythms – a specific frequency of brain activity. A different experiment found that hungry men, but not women, could orient themselves in the geomagnetic field in response to cues about food. There is also some evidence that disruptions caused by magnetic storms can affect human health on both a physical and mental level.

A number of other animals possess a magnetic sense. Perhaps the most impressive usage of this sense is for migration, allowing for accurate navigation across great distances.

Turtles, sharks and birds are just some of the animals that make long journeys thought to involve magnetoreception. Turtle hatchlings have been shown to change direction according to the magnetic field they would encounter in different parts of the ocean, and it may be this that enables them to return as adults to the beaches where they hatched. Sharks also respond to magnetic fields and it has been suggested that they use special electromagnetic receptors, called ampullae of Lorenzini, to navigate, although this is still a matter of debate.

Many bird species undertake impressive feats of navigation during annual migrations. Some weird and wonderful theories about bird migration have arisen throughout history. The gathering and seasonal disappearance of particular species led some to believe that birds flew to the moon or the bottom of dams and ponds. And the fact that redstarts migrate south to Africa at the same time that robins arrive in Greece prompted Aristotle to conclude, more than 2 300 years ago, that redstarts became robins as the season changed.

Amur falcons are small birds of prey, or raptors, which breed in south-eastern Siberia and Northern China. At the start of autumn in the northern hemisphere, they set off in large flocks to the north-eastern Indian subcontinent, where they gather in enormous numbers. After a stopover of a few weeks to feed and rest, they continue their journey, crossing the Indian Ocean to reach Africa. They then fly south to arrive in southern Africa in early summer, after a total trip of about two months. This is the longest migration of any raptor worldwide.

By now, the incredible journeys of many bird species have been mapped and studied in great detail, traditionally through bird-ringing programmes but more recently incorporating radio-, satellite- or GSM-tracking technology. While birds use a number of environmental cues to navigate, including the sun and the stars, it is generally agreed that they primarily use the geomagnetic field. There are two main theories as to how they do this. The minerals magnetite and maghemite – forms of iron oxide with magnetic properties – are found in the cells of numerous animals, including humans. Directional behaviour due to magnetic minerals has been observed in certain bacteria, which align themselves according to applied magnetic fields. It has also been suggested that animals such as fish, turtles and birds might use the action of these iron oxides to navigate and orient themselves. Magnetite in cells, responding to a magnetic field, mechanically opens ion channels, changing nerve signals and acting as a magnetic sense.

While magnetic materials such as magnetite are responsive to the poles of a magnetic field, researchers in the field of quantum biology have suggested an alternative avian compass that responds to the inclination of the geomagnetic field. Although there are still many questions to be answered, there seems to be some agreement that both mechanisms might be important. The inclination compass, which depends on how the magnetic field lines are inclined relative to the Earth, is called the radical pair mechanism, and is based on the science of spin chemistry. This is where it crosses paths with quantum theory.

Quantum theory was developed to describe how matter behaves at the atomic – extremely small – scale. Atoms are made up of a positively charged nucleus of protons and neutrons surrounded by negatively charged electrons. Protons, neutrons and electrons all have an intrinsic property called spin. Other intrinsic properties of matter are more familiar, such as mass and charge. But just as mass describes how matter will respond to a gravitational field, and charge describes how matter will respond to an electric field, spin describes how matter will respond to a magnetic field. This is the basis of the radical pair mechanism of avian magnetoreception, which depends on the paired spins of two electrons and how they respond to the Earth's magnetic field.

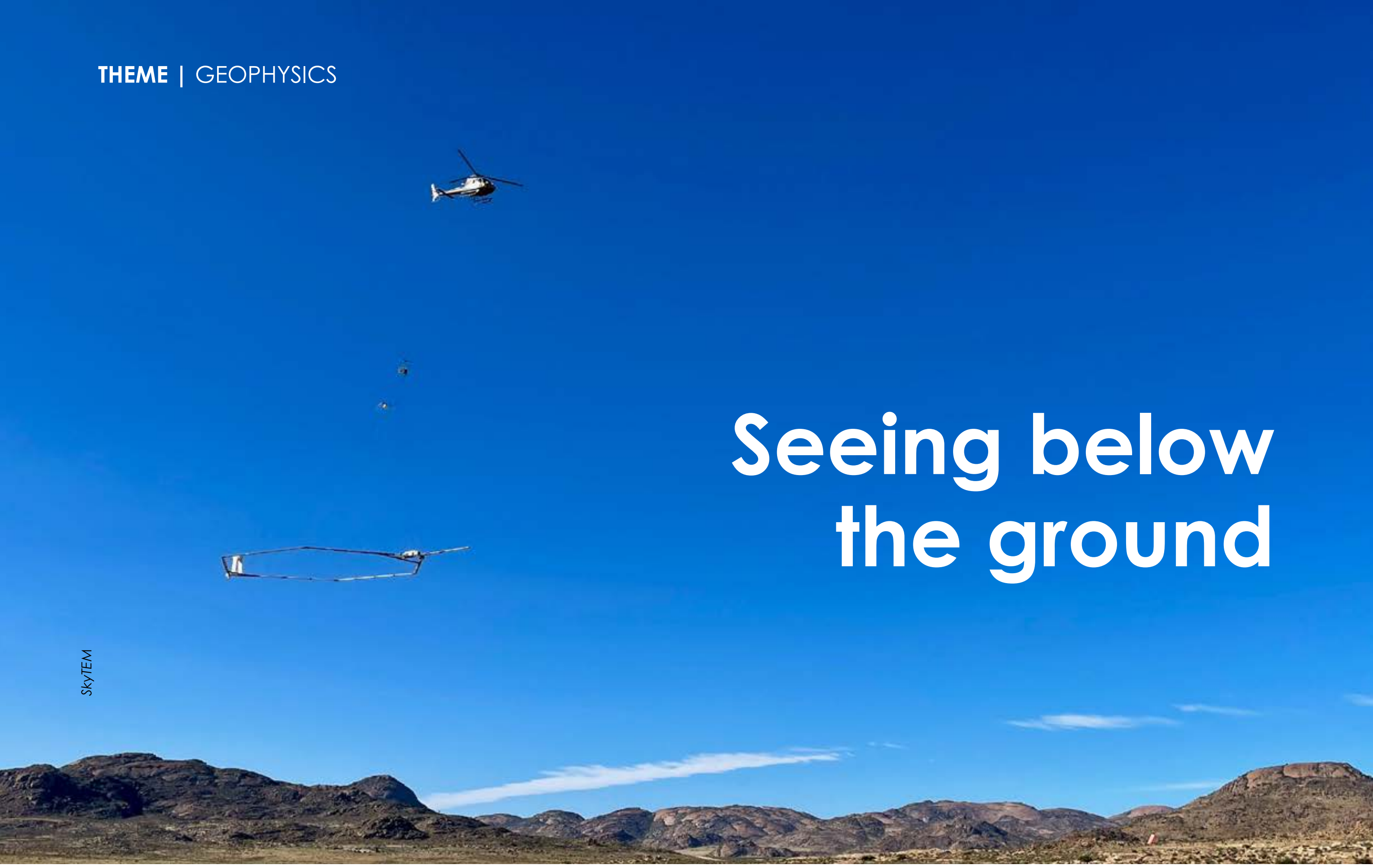
There is some evidence that a protein called cryptochrome, found in the eyes of birds, is the site of this radical pair compass. Cryptochrome is sensitive to light, especially blue light. Light entering a bird's eye can transfer its energy to one of a pair of electrons in cryptochrome, causing this electron to be excited and forming the spatially separated but spin-correlated electron pair that is called the radical pair. This electron pair starts out in what is called a singlet state, which means that the spins of the two electrons are arranged in a specific way with respect to each other. However, the spins can also be arranged in a different way known as a triplet state. Singlet and triplet states can interconvert under the influence of the nuclear spins of the other atoms in the surrounding protein as well as the Earth's magnetic field. Whether the paired spins are in a singlet or triplet state determines what chemical product is made, which then supplies directional information to the bird's brain.

Behavioural evidence supports the possibility of spin-dependent magnetoreception in various ways. Birds display migratory behaviour even when confined to cages, and their seasonal restlessness favours the direction in which they should be flying. By attaching carbon paper to the walls of these cages and examining the marks made by the birds as they attempt to escape, scientists can interpret the activity in specific directions under different conditions. It appears that bird migration is light-dependent and that the frequency of this light matters. It has also been demonstrated that radiofrequency electromagnetic radiation, which can influence the radical pair mechanism by modulating the singlet-triplet conversion, disrupts the accuracy of avian magnetoreception.

The scale of an electron is far beyond what we can see with our own eyes. Electrons are so small that it is difficult to measure their size accurately. Bird migration, on the other hand, happens on the scale of hundreds of kilometres. The Arctic tern flies from pole to pole and back. It is incredible to consider that the response of an electron to the geomagnetic field might shape something as impressive as a tern's journey.

Betony Adams is a physics PhD student at the University of KwaZulu-Natal (UKZN), where her doctoral research explores quantum processes that might take place in the human brain. She was awarded her MSc by UKZN in 2016 for her thesis investigating an open quantum systems approach to avian magnetoreception.

Prof. Francesco Petruccione is head of the Centre for Quantum Technology, a research group within UKZN's School of Chemistry and Physics.



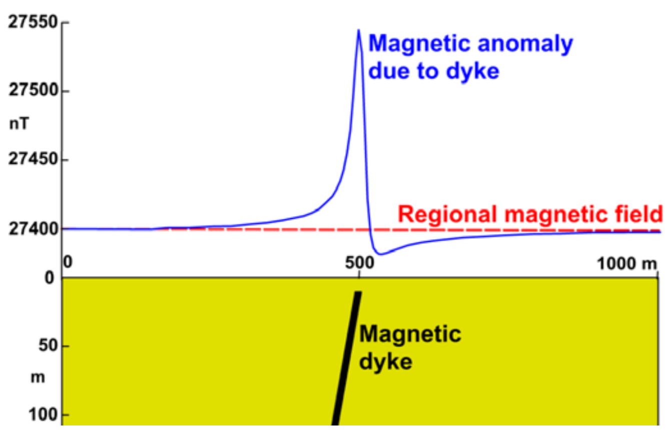
SkyTEM

Seeing below the ground

Francois Fourie tells us how magnetics and electromagnetics are used to investigate the Earth's subsurface

Geophysics is a branch of the Earth Sciences that involves the use of physics to study the physical properties of the subsurface, allowing us to gain insight into the distribution of different rock types and the presence of geological structures. This information may be used to improve our understanding of the Earth's internal structure (pure geophysics) or to explore for resources, such as mineral deposits, oil and groundwater (exploration geophysics). Geophysics is also widely used in engineering, as well as archaeological, agricultural and environmental studies (applied geophysics).

There are many different geophysical methods, each sensitive to different physical parameters. What all geophysical methods have in common is that they require a contrast in some physical property of the subsurface materials. For example, the gravimetric methods are sensitive to mass density contrasts in the subsurface, while the resistivity methods focus on contrasts in the ability of subsurface materials to conduct electrical current.



Example of the magnetic anomaly recorded across a magnetic dyke (a sheet-like rock formation).

Several geophysical methods involve or make use of magnetism, including the magnetic induced polarisation, magnetometric resistivity, and nuclear magnetic resonance methods. Two of the most commonly used groups of methods are the magnetic methods and electromagnetic methods.

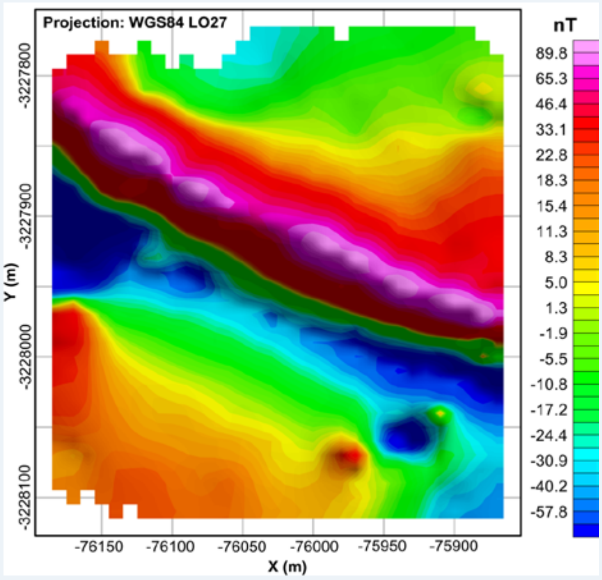
Magnetic methods

As the name implies, magnetic methods depend on contrasts in the magnetic properties of subsurface materials. Many rock formations contain magnetic minerals and therefore become magnetised by the Earth's magnetic field. These formations thus acquire their own induced magnetic fields, which are superimposed on the Earth's regional magnetic field. The resultant (combined) magnetic field in the vicinity of these magnetised rock units therefore exhibits departures from the regional (inducing) field, which are called magnetic anomalies. The shapes and sizes of the magnetic anomalies depend on many factors, including the direction of the Earth's magnetic field; the dimensions, depths and orientations of the magnetic bodies; and the magnitudes of the magnetic contrasts.

During magnetic surveys, geophysicists measure the resultant magnetic field using sensitive instruments called

Groundwater exploration

The city of Bloemfontein was named after a strong spring that sustained growths of beautiful flowers. Geologists in the 1950s first suggested that the spring was associated with a circular dolerite dyke (a ring-dyke), which was referred to as a barrier reef at the time. The city of Bloemfontein has since expanded and now overlies the ring-dyke, concealing its presence. Due to a nationwide drought, a project was launched in 2014 to investigate the possibility of augmenting the municipal water supply from groundwater resources. Geophysical surveys were conducted within the municipal boundaries in areas where the presence of surface and subsurface infrastructure allowed such surveys. In an open area in the south-eastern parts of the city, a very prominent magnetic anomaly was recorded. This anomaly has been interpreted to be due to a dipping dolerite dyke, which is thought to be the ring-dyke underlying the city. Boreholes will soon be drilled along the margins of the dyke, and strong yields are expected. However, since the ring-dyke underlies urban and industrial areas of the city, numerous sources of contaminants could have adversely affected the groundwater quality. Groundwater pumped from this resource will therefore probably have to undergo robust treatment before incorporation into the municipal water supply.



Contour map of the residual magnetic field (in nanoTesla, nT) recorded across part of a large dyke partially underlying the city of Bloemfontein.

magnetometers. Magnetic surveys are typically done on profiles across the survey area or on grids covering the survey area. The recorded magnetic data are then processed to remove the regional field so that only the anomalous (or residual) field remains. This residual field contains information on the positions, depths, geometries and orientations of the magnetic bodies responsible for the observed anomalies. Geophysicists use specialised software to derive models of the causative bodies and interpret these in terms of the geology of the area.

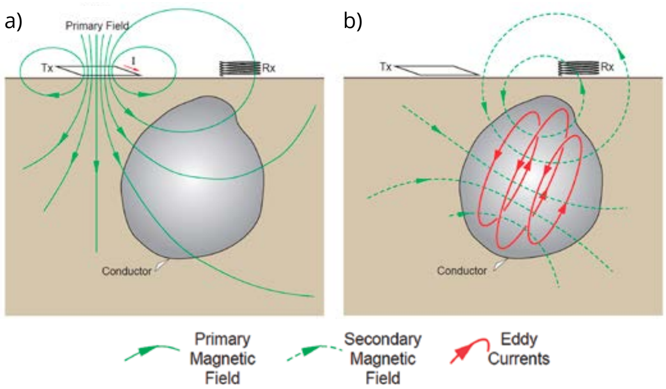
Magnetic surveys can be done on the ground, in boreholes, from airborne platforms such as helicopters and drones, and even from satellites.

Electromagnetic methods

Geophysicists use electromagnetic (EM) methods to investigate the electrical conductivity distribution of the subsurface. These methods are based on the fact that EM waves travelling through conductive media cause electrical currents to flow in those media. These induced electrical currents are called eddy currents, and their behaviour depends on the conductivities of the media in which they flow. The eddy currents set up their own magnetic fields, which can be measured and analysed to obtain information on the subsurface conductivities.

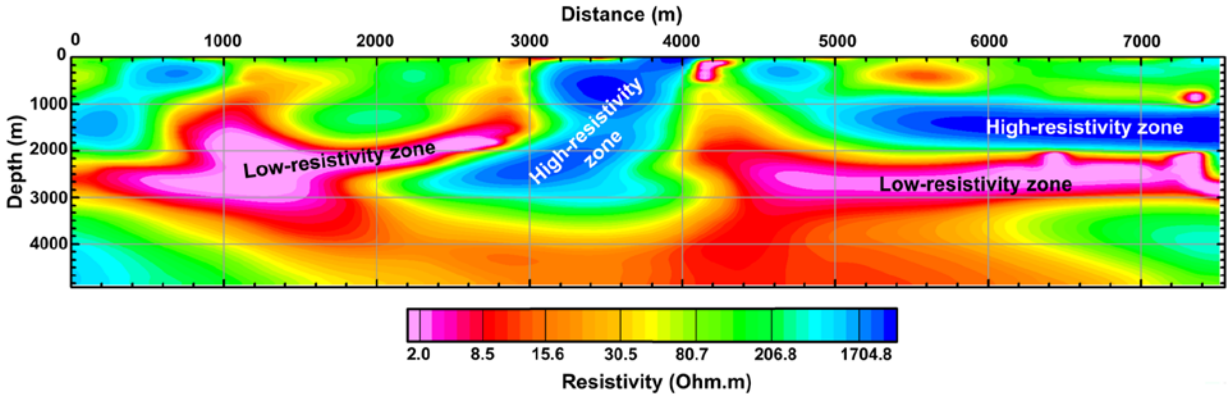
EM systems typically employ a source (transmitter) loop in which a time-varying electrical current is made to flow. This current gives rise to a magnetic field, called the 'primary' magnetic field. Receiver loops are then used to measure the 'secondary' magnetic field due to the eddy currents in the subsurface. Similar to magnetic surveys, EM surveys can be performed on the ground or from airborne platforms.

Depending on the nature of the electrical current in the source loop, EM methods are divided into two broad categories: frequency-domain and time-domain methods. Frequency-domain methods use an alternating current (AC) in the source loop, and measure the phase shift (time delay) between the primary and secondary magnetic fields. This phase shift contains information on the subsurface conductivity. Time-domain methods, on the other hand, employ a direct current (DC) that is quickly terminated to create an impulsive EM wave, which travels through the subsurface, inducing eddy currents along its way. These eddy currents, and their associated magnetic fields, decay over time. The decay rates depend on the conductivities of the subsurface materials: faster decay rates occur for lower conductivities.



Dentith & Mudge, 2014

a) During EM surveys a time-varying electrical current is made to flow in a transmitter loop (Tx) to create a primary magnetic field. b) The primary magnetic field induces eddy currents in subsurface conductors. These eddy currents give rise to their own secondary magnetic fields, which may be measured using a receiver loop (Rx).

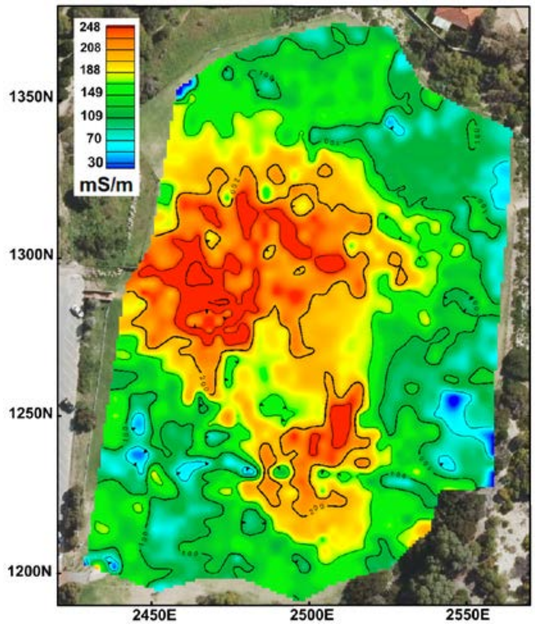


Two-dimensional resistivity model of the subsurface, obtained from a magnetotelluric survey near Beaufort West as part of a groundwater exploration project conducted by the Council for Geoscience.

An important property of EM waves is that the depth of penetration of the wave into a conductive medium is inversely related to the frequency of the wave: waves of higher frequencies have smaller penetration depths. This property allows geophysicists to investigate the subsurface at different depths by using EM waves of different frequencies. Frequency-domain systems employ individual frequencies from a few hertz (Hz) to tens of kilohertz (kHz), while the impulsive EM wave used in time-domain methods contains a broad spectrum of frequencies, allowing depths of investigation ranging from tens to thousands of metres.

Apart from the active EM methods, which use artificial sources of electromagnetic energy such as current-carrying wire loops, there are also passive methods, which employ natural electromagnetic waves as their sources of energy. Natural EM waves of low frequency (<1 Hz) are generated when the solar wind (plasma and charged particles streaming from the sun) interacts with the Earth's magnetic field. Higher-frequency natural EM waves are caused by lightning strikes. The magnetotelluric method is an EM method that uses these natural EM waves to investigate the subsurface to depths of tens to hundreds of kilometres. For deep measurements, the response from waves of very low frequencies has to be measured. This means that the recording time can last several days to weeks to ensure that data of good quality are recorded.

One limitation of EM methods is that they are affected by sources of EM noise, such as the energy grid. In South Africa, electricity is distributed at a frequency of 50 Hz along overhead and underground power lines. The EM radiation from these power lines can strongly affect the measurements taken during an EM survey, even making it impossible to record useful data. During a recent groundwater exploration project near the drought-stricken Gqeberha (Port Elizabeth), using the magnetotelluric method, the electricity supply had to be switched off for six hours to allow the survey to be completed. However, the inconvenience of temporarily being without electricity was a small price to pay because the results of the survey allowed a major fault zone at a depth exceeding 200 m to be pinpointed. Five very strong boreholes were drilled in the fault zone, with a total yield of more than 350 litres per second.



An EM survey is conducted to map the spatial extent and thickness of a buried waste site, using the Loupe time-domain system. The front operator's backpack holds the transmitter loop, while the following operator's backpack holds a coil that acts as the receiver. The system is equipped with a GPS, which allows it to record the location of each conductivity measurement while the operators walk across the survey area. The output shown above is a contour map of the apparent conductivities at a depth of 0.5 m below the surface.

Dr Francois Fourie is a senior lecturer at the University of the Free State's Institute for Groundwater Studies, where his research focuses on groundwater geophysics.

MAGLEV

Quest explores the use of magnetic levitation in cutting-edge transportation systems

The fastest commercially operating train in the world relies on magnetism to travel at up to 431 km/h, but this record 'rail' speed could almost triple if ambitious plans for hyperloop systems come to fruition.

Maglev trains

China's Shanghai Maglev Train provides a shuttle service between the Pudong International Airport and a station on the outskirts of the vast Shanghai Metro system of interconnecting lines, doing the 30 km trip in about eight minutes. It used to have a morning and afternoon slot to show off its maximum commercial speed of 431 km/h, but currently sticks to a more sedate 300 km/h for the duration of its daily operating hours.

Maglev is short for magnetic levitation, a technology that allows trains to rise, or levitate, above the track and be propelled along by magnetic forces. Without the friction of rail-wheel contact or the need to carry heavy engines and braking systems, maglev trains require less maintenance, offer a smooth ride, and can reach tremendous speeds. The world record for conventional high-speed rail was set at 574.8 km/h by a TGV electric train in France in 2007, but in normal operation the TGV trains travel at a top speed of 320 km/h. A maglev Series LO train developed for the Central Japan Railway Company – known as JR Central – was clocked at 603 km/h during a test run on the experimental Yamanashi Maglev Line in 2015, a feat recognised as a Guinness World Record.

There are plans to extend the 43 km experimental line in both directions to form the Chuo Shinkansen maglev line between Tokyo and Osaka. An initial 286 km section between Tokyo and Nagoya was scheduled to open in 2027, but delays caused by the pandemic as well as environmental concerns about tunnel construction mean

A Series LO train using SCMaglev technology reached a record-breaking speed of 603 km/h on the experimental Yamanashi Maglev Line in Japan in April 2015.

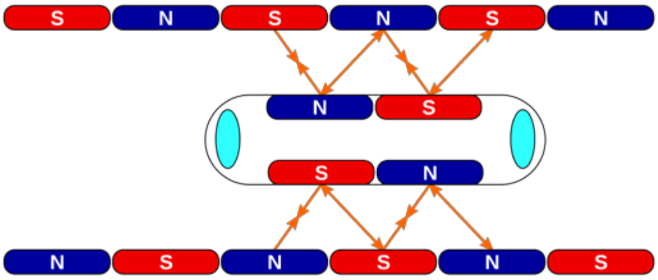
The Shanghai Maglev Train in China is the world's fastest train in operational service, with a maximum commercial speed of 431 km/h.

that this will not be possible. In normal operation the trains will travel at a maximum speed of 500 km/h, and this – together with the more direct, mostly underground route – would shorten the train journey from two hours to just 40 minutes.

The system uses the Japanese-designed SCMaglev technology, which relies on superconducting magnets installed on the sides of the train and two types of electromagnetic coils on the sides of the U-shaped track, called the guideway. The attraction and repulsion forces created by the interaction of these magnets levitate the train by 10 cm, keep it aligned in the centre of the guideway, and propel it forward. Adjusting the frequency of the alternating current supply to the propulsion coils – in other words, the rate at which the current changes direction per second – changes the rate of polarity switching between north and south, allowing control over the train's speed. This is an electrodynamic suspension system, requiring the train to have wheels that only retract once a certain speed is reached and the current induced in the coils creates a magnetic force strong enough to achieve levitation.

The superconducting magnets are essentially electro-magnets made from coils of niobium-titanium wire. To become superconducting – a state where there is no electrical resistance – the wires must be cooled during operation to −269°C. Without the problem of resistance-induced heating, the wire can conduct much larger electric currents than ordinary wire, allowing the creation of intense magnetic fields. Liquid helium is used to achieve this cryogenic temperature within a circulation system that incorporates liquid nitrogen for cooling too.

Research is being conducted on so-called high-temperature superconductors made from materials that do not require



Cool Cat, CC BY-SA 3.0

In magnetism, opposites poles attract and like poles repel. In the SCMaglev system, superconducting magnets on the sides of the train interact with electromagnetic coils on the guideway walls to pull and push the train along, creating propulsion.

Andreas Heddergott, TUM

Teams from the Technical University of Munich have won each of the four hyperloop pod racer competitions held to date. This 2019 prototype, TUM Hyperloop Pod Four, holds the competition record at 482 km/h.

cooling with liquid helium. In January 2021, China unveiled a prototype of a high-temperature superconducting maglev train and claimed that it would be able to reach 620 km/h. This is only a design speed based on modelling by the technology's developers – a research team from Southwest Jiaotong University – as the track built for the prototype is just 165 m long.

By contrast, the Japanese SCMaglev system is proven technology, and is being considered for adoption elsewhere. In the United States, an environmental impact assessment process is under way for a high-speed SCMaglev route between Washington, DC and Baltimore, Maryland, and in Australia it has been promoted for a route linking Sydney, Canberra and Melbourne.

Nevertheless, since there are no SCMaglev systems in commercial operation at this stage, the Shanghai Maglev Train in China, which has been in commercial operation since 2004, is still the fastest 'running' train in the world. It uses the Transrapid electromagnetic suspension system developed in Germany by Siemens and ThyssenKrupp, relying on attractive forces between the track and ordinary electromagnets on the wrap-around bottom of the train.

This was not the first maglev system to be implemented – the technology was invented in the 1960s and a number of smaller and much slower versions have either been discontinued or are still in operation. The very first such service was in England, where a shuttle with a top speed

Minseong Kim, CC BY-SA 4.0

The Ecobee is operated on a 6 km route at Incheon Airport in South Korea.

of 42 km/h covered the 600 m between Birmingham International Airport and the nearby railway station from 1984 to 1995. Today, a similar service known as the Ecobee is operated on a 6 km route at Incheon Airport in South Korea, and in Japan the Linimo, built for Aichi Expo 2005, covers a 9 km route near Nagoya. Both are driverless systems with maximum speeds of around 100 km/h.

Hyperloop

Hyperloop could take maglev to a new level. The term was coined by Elon Musk in 2012 and he elaborated on the concept the following year in a 'white paper' written with assistance from engineers at SpaceX and Tesla Motors. He noted that while the idea of travelling in either a pneumatic tube with air-propulsion or a vacuum tube with electromagnetic suspension was not new, neither were practical. He proposed instead a low-pressure (partially evacuated) tube system to minimise aerodynamic drag, with pods levitated on a cushion of compressed air and propelled by a magnetic linear accelerator at various stations along the tube. The pods would travel at up to 1 220 km/h, allowing a 35-minute trip between Los Angeles and San Francisco in California on a preliminary route mapped on Google Earth.

Musk 'open sourced' the hyperloop concept and encouraged others to contribute to the design process to help bring the idea to a reality. In January 2015, he tweeted that he would be building a hyperloop test track and was thinking of running an annual hyperloop pod racer competition for students. The competition, hosted by SpaceX, was subsequently announced in June 2015 and began with a design phase. Suspension could be via wheels, air bearings or magnetic levitation. About 120 designs from teams around the world were judged in January 2016 and 30 teams were selected to build prototype pods. Construction of the 1.6 km test track, called the Hypertube, was only completed in October 2016, so the first year's entries were put to the test in January 2017, with subsequent on-track competitions later that year and in 2018 and 2019. Musk announced plans to build a longer, 10 km track for the 2020 competition, but this was called off because of the pandemic.

The first four competitions were all won by a team from the Technical University of Munich (TUM) in Germany. Their initial pod prototype reached a top speed of 94 km/h in the first competition, but by the 2019 competition this had increased to 482 km/h, using a much smaller pod weighing only 69 kg. The TUM Hyperloop team is currently building a full-scale demonstrator consisting of a 24 m-long tube and a human-sized passenger pod.

Some of the other student teams have also formed companies to continue working on hyperloop, and a few start-ups were initiated soon after Musk released his white paper. Some have folded or gone quiet, but two have made significant advances. The most high-profile, perhaps, is what started out as Hyperloop Technologies and then became Hyperloop One and then Virgin Hyperloop One – after Richard Branson invested in the company and joined the board of directors in October 2017 – and then just Virgin Hyperloop from June 2020. It completed construction of a 500 m low-pressure test track, called DevLoop, in the Nevada Desert outside Las Vegas in 2017 and has done more than 500 tests since then. The highest speed achieved with the full-scale pod to date is 387 km/h, but this is on only 500 m of track; Virgin Hyperloop estimates that a fully developed system will transport cargo or passengers at 1 080 km/h. In November 2020 the first test with human passengers was conducted in a two-seater pod, and this was done at a top speed of 172 km/h, but Virgin Hyperloop envisages a system with 28-seater pods departing a station together, travelling in convoy and splitting off to different destinations. A concept video released in August 2021 describes battery-powered pods gliding smoothly and safely using Virgin Hyperloop's "proprietary magnetic levitation and propulsion".

The other major player is Hyperloop Transportation Technologies (HyperloopTT), which was started in the United States with crowdfunding in October 2013 but now has offices in North and South America, the Middle East and Europe. Rather than hiring employees, HyperloopTT set up a network of expert contributors who work in exchange for shares in the company. Currently there are more than 800 of such contributors and 50 full-time employees, interacting in 52 multidisciplinary teams with corporate and university partners. The company unveiled a passenger pod in 2018, completed construction of a 320 m test track at its R&D Centre in Toulouse, France, in early 2019 and began running tests a few months later. Its proprietary maglev technology is based on the Inductrack system developed at the US Lawrence Livermore National Laboratory in the 1990s and optimised for a low-pressure environment by HyperloopTT. It uses arrays of permanent magnets – called Halbach arrays – on the pod, and is a passive system that does not require electromagnets or superconducting coils to achieve levitation over an unpowered but conductive track. HyperloopTT believes its fully developed system with pods seating 28 to 50 passengers will be capable of reaching speeds of 1 223 km/h.

Neither Virgin Hyperloop nor HyperloopTT are exploring Musk's proposed Los Angeles to San Francisco route, but both are in negotiations or have signed agreements with various companies, regional partners and governments in the United States and other countries, and feasibility studies for different routes have been completed or are under way. Both also made presentations to the US Congress subcommittee dealing with railroads in May 2021, as part of a hearing on 'The benefits and challenges of high-speed rail and emerging rail technologies'. In August the US Senate passed the Infrastructure Investment and Jobs Act, which mentions hyperloop technologies. If the legislation is passed by the House and signed by President Biden, US-based hyperloop projects would be eligible for government loans and grants.

Virgin Hyperloop

Virgin Hyperloop

Virgin Hyperloop's two-seater XP-2 (Experimental-Pod-2) is prepared for loading into the DevLoop tube for the world's first passenger hyperloop test in November 2020. Larger pods seating 28 passengers and travelling in convoy are envisaged for full-scale implementation.

Déjà vu

Maglev projects have already been eligible for such funding for some time. In June 1998, the Maglev Deployment Programme for high-speed transportation was authorised by the US Congress in the Transportation Equity Act for the 21st Century, and the first round of applications for funding closed in February 1999. The Department of Transportation's Federal Railroad Administration ultimately selected two projects – in Maryland and Pennsylvania – for additional studies including engineering design and site-specific environmental assessment, with the aim that one of these would be given capital assistance for construction, subject to the appropriation of funds by Congress.

The Maryland one was a 64 km route from Baltimore to Washington, DC, with a stop at the Baltimore/Washington International Airport, and was going to use the German

Hyperloop TT

The HyperloopTT pod, or capsule, is designed to seat 28 to 50 passengers.

Hyperloop TT

HyperloopTT's test track at its R&D Centre in Toulouse, France, is 320 m long.

Transrapid maglev technology. In 2003 Maryland halted the project, but when the Federal Railroad Administration issued a call in 2015 for funding applications under a new Maglev Deployment Grants Programme, the concept was revived by a private entity, Baltimore-Washington Rapid Rail, this time relying on SCMaglev, as previously mentioned. The Grant Programme has awarded funding for only one project in each of the three funding rounds in 2015, 2019 and 2020, and in every case it was the Baltimore-Washington SCMaglev Project that was successful, with grants totalling US$53.8 million.

Meanwhile, Elon Musk has apparently abandoned his plan to dig a tunnel covering the same route. In July 2017 he tweeted that he had received verbal approval to build a hyperloop tunnel connecting New York, Philadelphia, Baltimore and Washington, DC. In October of that year the Maryland state government confirmed that it had issued a conditional permit to Musk's The Boring Company to begin digging a 16.5 km tunnel on its land beneath the Baltimore-Washington Parkway, the 56 km-long highway between the two cities. By April 2019 a draft environmental assessment had been completed for The Boring Company's so-called Washington DC to Baltimore Loop Project, the concept having been changed to parallel, twin tunnels through which passengers would be transported in autonomous, battery-powered electric vehicles at speeds of up to 240 km/h. The underground tunnels would potentially serve as corridors for hyperloop pods travelling at 1 120 km/h in the future. Two years later, in April 2021, news media reported that the project had been removed from The Boring Company's website, and appeared to be 'dead'.

It's highly likely that if a hyperloop system is eventually implemented anywhere, the first one is not going to be in the United States, given the existing transport systems, land-use rights, funding constraints and more pressing socio-economic priorities. Although considered an environmentally friendly technology because of its lack of direct CO_2 emissions, the elevated tubes would have high visual impact. Its proponents say hyperloop will be safer than road, rail and air travel because it will not be affected by adverse weather conditions and, in the case of road travel, high rates of human error and reckless driving, but there are concerns about sabotage and earthquakes, not to mention the inherent risks of travelling at such great speeds. Implementing it for freight alone is not feasible, owing to its high construction cost and ongoing energy demands, which could be at least partly offset by covering both the tubes and stations in photovoltaic technology for solar power. In January 2021, the US Department of Energy released a report on its analysis of the 'Effect of hyperloop technologies on electric grid and transportation energy', which showed that hyperloop transport of freight would be less energy-efficient than all other modes of freight transport except for air.

High-speed maglev trains, too, are prohibitively expensive to build, have high energy demands, are quite noisy due to air displacement, and are impractical to implement, given the difficulty of integrating them with existing railway networks. To be financially feasible, they'd need enough passengers travelling between cities and able to pay the high ticket price, but preferring to take a train rather than a plane.

Low- to medium-speed maglev trains within cities are suggested by some analysts to be more promising, having the benefits over existing urban transport systems of no emissions and low noise. Back in 1999, the US Federal Transit Administration initiated the Low-Speed Urban Magnetic Levitation Programme and funded five projects to develop such systems. A 'lessons learned' report evaluating the programme was published a decade later, and by that time only two of the project teams were still working on maglev. Although a few short test tracks were built by these or other projects, no maglev train system has been implemented in the US to date – a fact that brings about a 'déjà vu' feeling that we've been here before.

For a better understanding of the technology, JR-Central has an interactive animation explaining the SCMaglev system: https://scmaglev.jr-central-global.com

HyperloopTT have a set of diagrams depicting the principles of the Inductrack-Halbach array technology at the bottom of this webpage: https://www.hyperlooptt.com/technology/

Virgin Hyperloop released a short video explaining their concept in August 2021. Search YouTube for 'Virgin Hyperloop Explained': https://youtu.be/6hXNXL9PiYk

Written by Quest Editor, Sue Matthews

THE INNOVATION TRAIN

Mike Bruton pays tribute to Elon Musk and other South Africans who made train-related innovations

South African-born Elon Musk is credited with reviving the Hyperloop concept (see preceding article, 'Maglev'), and is recognised as one of the most influential innovators of today. His vision is no less than to change the world, reduce global warming through sustainable energy production and consumption, and minimise the risk of human extinction by setting up a colony on Mars!

Steve Jurvetson, CC BY 2.0

South African-born Elon Musk at the unveiling of the Hawthorne test tunnel in California in December 2018.

Educated at Pretoria Boys High School, Musk taught himself computer programming and – at the age of 12 – developed and sold the code for a BASIC-based video game, 'Blastar'. At 17 he emigrated to Canada and started an undergraduate degree there in 1989, but subsequently transferred to the University of Pennsylvania in the United States. He later enrolled at Stanford University with the intention of doing a PhD in applied physics, but after just two days he decided to benefit from the internet boom and left to pursue a business career. He co-founded the software company Zip2 with his brother Kimbal and sold it four years later to Compaq for US$307 million.

Musk then started X.com that later became PayPal, which was bought by eBay for US$1.5 billion in 2002. In the same year he founded SpaceX, which over the years has developed a number of Falcon rockets, the reusable Grasshopper rocket and the Dragon spacecraft. The maiden flight of the unmanned 'Dragon 1' was in December 2010, but in May 2020 the first crewed flight took place on 'Dragon 2', which carried two astronauts to the International Space Station. Musk is also the brains behind Starlink, the SpaceX constellation of thousands of low-Earth orbit satellites designed to provide a high-speed, low-latency broadband internet system with global coverage.

He provided some of the initial funding for the electric car company Tesla Motors when it was founded in 2003, then chaired the board from 2004 and became CEO in 2008. The company has since been renamed Tesla, Inc, having expanded into energy generation and storage, such as solar panels and roof tiles and new-age batteries. This was after Tesla's acquisition in 2016 of SolarCity, which Musk helped his cousins start in 2006 and remained involved as Chairman.

Musk also co-founded OpenAI, an artificial intelligence research laboratory, in 2015 and Neuralink, a neurotechnology start-up to integrate the human brain with AI, in mid-2016. At the end of 2016 he came up with the idea for his tunnelling venture, named The Boring Company, which aims to allow commuters to avoid city traffic on underground freeways. Currently, there is only the Hawthorne test tunnel in Los Angeles County and – as of April 2021 – a 1.83 km, dual-tunnel 'loop' providing a shuttle service in Tesla cars at the Las Vegas Convention Centre, but there are plans for this to be extended and negotiations are under way for more.

Jim Linwood, CC BY 2.0

A statue commemorating engineer James Greathead was erected in London in 1994. The inscription on the plinth reads, "Inventor of the travelling shield that made possible the cutting of the tunnels of London's deep level tube system."

Long before Musk's involvement in the Hyperloop revival and tunnel construction, however, other South African-born innovators were making important inventions relating to tunnels or trains. One of the earliest was James Greathead, who was born in Grahamstown (Makhanda) in 1844. He attended St Andrews College from when it opened in 1855 and also spent a short period at Diocesan College ('Bishops') in Cape Town, but completed his schooling in London after the family moved to England in 1860. He subsequently apprenticed to a civil engineer there and became involved in the development of new railways.

At the age of only 24, he successfully tendered for a contract to construct the Tower Subway, the second tunnel under the Thames River. When it opened in 1870, it was the first underground tube railway in the world. Greathead later patented his Greathead Shield for underground tunnelling and the Greathead Grouting Machine. He was the resident engineer for the world's first underground electric railway (the City and South London Railway), joint design engineer for the first overhead electric railway (the Liverpool Overhead Railway), and was involved in three more tunnelling projects before he died of cancer in 1896 at the age of 52. He is commemorated in a towering bronze statue that was unveiled by the Lord Mayor of the City of London in 1994.

Another notable early inventor was John George 'Jack' Rose (1876–1973), an analytical chemist and accomplished cyclist before he joined the Cape Cyclist Corps during the South African War (1899–1902). Together with champion cyclist and bike builder, Donald Menzies, Rose developed a Rail-Mounted Bicycle Reconnaissance Vehicle using pairs of bicycles with flanged wheels riding on railway lines. These 'war cycles' were so successful for railway track inspections, espionage and dispatch riding that over 50 were built. Rose also mounted a small, air-cooled Ariel car onto one of his war cycles, thus creating the first motorised vehicle to operate on a military warfront.

During World War I he developed a Rail-Mounted Motor Tractor with a REO truck engine as well as small troop-carrying trains powered by Model T Ford engines that ran on narrow gauge railway tracks. In his 60s, Rose further distinguished himself during World War II by coordinating a massive campaign to mobilise the Allied forces in East and North Africa. When he died at the age of 97, he was celebrated as one of South Africa's most decorated sportsmen, inventors, engineers and military heroes.

City Cycling Club

In the 1970s the South African Railways (SAR) engineer Herbert Scheffel re-designed the bogie, the four-wheeled undercarriage at either end of a railway carriage, so that it could run more efficiently on our relatively narrow-gauge railway tracks. He replaced the rigid, rectangular chassis that was previously used with a flexible, cross-anchor chassis that allows the wheels to adjust their position on corners, thus reducing lateral forces, vibrations and wear.

Champion cyclist Jack Rose worked with the 'Springbuck' bike builder, Donald Menzies, to develop 'war cycles' that could travel on railway lines during the South African War ('Anglo-Boer War').

The Scheffel Bogie was introduced to the SAR fleet of ore wagons in 1975 with great success and has saved the country millions of Rands in maintenance and repair. It is also used on railways in eastern Europe and south-east Asia.

Transnet

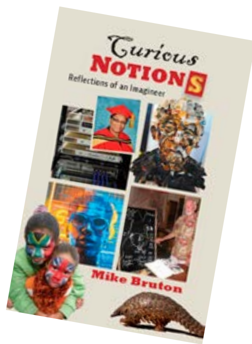
Transnet's Trans-Africa Locomotive (TAL) is the first locomotive to be designed, engineered and manufactured in Africa.

In 2016 a South African company, DCD Rolling Stock, revolutionised the manufacture of railway bogies by moving away from traditional casting-based construction to fabrication using hot-rolled steel. This has resulted in significant weight reductions as exactly the right steel thickness is used to deliver the required strength without over-engineering.

South African parastatal Transnet has developed its first home-grown locomotive, the Trans-Africa Locomotive (TAL), specifically for African conditions. The diesel-powered locomotive, which was launched in 2017, offers a cost-effective solution for the majority of Africa's railway lines that are currently unused, and Transnet plans to sell the TALs to other African countries to promote rail traffic on the continent. Transnet Engineering also makes and sells railway bogies, passenger coaches and goods wagons that are suited to African conditions.

The CSIR has refined the Ultrasonic Broken Rail Detector (UBRD) to detect breaks in train rails and remotely communicate this information to rail engineers. Work began in 1996 when the Institute of Maritime Technology was contracted to develop the first version, which used the CSIR's piezoelectric ultrasonic transducers. UBRDs operate off solar power and scan lengths of rail up to a thousand metres long every three minutes. They are made from robust, rust-free components and can be installed without interrupting rail traffic.

- Read more about South African inventions in Mike Bruton's latest book, *Curious Notions. Reflections of an Imagineer*, published by Footprint Press. For further info, contact him at mikefishesbruton@gmail.com.



Prof. Mike Bruton was formerly head of the Department of Ichthyology and Fisheries Science at Rhodes University, Director of the then JLB Smith Institute of Ichthyology, and founding Director of the MTN ScienCentre (now the Cape Town Science Centre) in Cape Town. He currently operates a consultancy called Mike Bruton Imagineering, writes popular articles and books, and makes regular appearances as a guest speaker.

The ancient AFRICAN plant that captured GIORGIO ARMANI'S attention

Plant Stress Lab, UCT

Prof. Jill Farrant with the resurrection plant *Myrothamnus flabellifolia*.

The resurrection plant *Myrothamnus flabellifolia* – believed to be one of the most ancient plants on the planet – is widely used in African traditional medicine. Known in isiZulu as *Uvukakwabafile*, which translates roughly to 'awake from the dead', it can dry out almost completely and survive.

Professor Jill Farrant, from the University of Cape Town's Department of Molecular and Cell Biology, says that the plants can lose up to 95% of their water and appear completely dead, but bloom back to life in as little as 12 hours after rain. Farrant holds the SARChI Chair in 'Systems biology studies on plant desiccation tolerance for food security', leading research into the mechanisms that allow plants to tolerate extreme water loss, with the ultimate goal of introducing such characteristics into crops for improved food security in the face of climate change.

The phytochemicals that enable the plants to survive extreme conditions are also powerful antioxidants that can be used in pharmaceuticals and cosmetics. *M. flabellifolia* contains the greatest number of antioxidants Farrant has ever seen in a plant – more than so-called wonder plants like rooibos and aloe vera – and its major antioxidant has been shown to protect cell membranes from damage at the microscopic level. This is partly why designer Giorgio Armani chose it as the main ingredient in his only skincare range, Crema Nera.

"Antioxidant activation can defend cells against damage caused by pollution, UV rays, dehydration, free radicals and temperature extremes, all of which accelerate skin ageing," says Farrant. She was approached to be the scientific advisor on the product after Armani and his team had identified the plant as a possible candidate. They had been looking for a plant with an interesting story that is also on the list of ingredients allowed in skincare products in China, so as to capitalise on the huge Chinese market.

"Armani's cosmetics operate through L'Oréal," says Farrant, "and when they reached out to me, I had just found out I was going to win the L'Oréal UNESCO Women in Science Award. The Armani team had no idea, so they were surprised and delighted at the news and it made for great marketing."

As yet, South Africa does not export *M. flabellifolia* and Armani sources the plant from Zimbabwe, largely because that country sells the product internationally at a very reasonable cost. As a condition of her role as scientific advisor, Farrant has requested that the plants are not sourced from South Africa unless there is investment into studies for sustainable harvesting. She is also working to ensure the farmers who will grow the plant are remunerated in accordance with its value, and that royalties are paid to the elders of the communities who first discovered its medicinal properties.

Although the plants can be cultivated in greenhouses, studies have shown that when grown in such 'comfortable' conditions they do not produce the strong antioxidants they need to survive in the wild.

Based on a press release issued by UCT Communication and Marketing Department, which summarised an article by Natalie Simon: https://www.news.uct.ac.za/article/-2021-09-07-the-ancient-african-plant-that-captured-armanis-attention

View a video featuring Prof. Farrant, called 'The miracle resurrection plant' on YouTube: https://www.youtube.com/watch?v=9MLe3G_ODdQ

Umuthi Uvukakwabafile, osetshenziswa kakhulu kwezokwelapha ngamakhambi esintu, uyinxenye yomkhiqizo wesikhumba odayiswa umlkami wasentaliyane u Giorgio Armani.

Translated by Zamantimande Kunene

Climate Change:
the IPCC's latest assessment report

Francois Engelbrecht and Pedro Monteiro present five 'take-home' messages for southern Africa

The Intergovernmental Panel on Climate Change (IPCC) Assessment Report Six Working Group I report was released in August and has been described as a 'code red' for humanity. The report makes it clear that climate change is widespread, rapid, intensifying and unprecedented in thousands of years. The requirement for climate stabilisation is immediate, strong, and sustained reductions in greenhouse gas emissions. Here we examine the report through a southern African lens, and – as two South African lead authors of the report – identify five messages key to the southern African region and its people.

We are close to exceeding dangerous thresholds of global warming

Humanity's delay in taking strong climate change action, that is, in drastically reducing greenhouse gas emissions, means that dangerous thresholds of global warming may soon be exceeded. The report gives as the best estimate value of global warming to date the value of 1.1°C – precariously close to the thresholds of 1.5°C and 2°C that define 'dangerous climate change'.

Note, in this regard, that the 'Long Term Global Goal' of the Paris Agreement on Climate Change is to restrict global warming to values well below 2°C above pre-industrial levels, preferably to below 1.5°C. These thresholds are directly informed by the physical science base of climate change; above these levels aspects of climate change become increasingly dangerous in terms of impacts, while aspects such as the melting of large ice sheets may become irreversible, with costly risk consequences for coastal infrastructure.

The report assesses that under strong and immediate climate action, with deep cuts in CO_2 emissions in the 2020s, followed by continued mitigation to achieve net zero emissions by 2050, it is likely that the 2°C threshold will not be exceeded. However, even with these best-effort mitigation efforts, it is more likely than not that the 1.5°C threshold will be exceeded by a small margin. The report further assessed that crossing of the 1.5°C threshold may likely occur in the early 2030s (as defined in terms of the midpoint of 20-year averages of the global surface temperature). This is a sobering finding: it means that we are probably already living in the first 20-year period that will have an average temperature of 1.5°C above the pre-industrial temperature.

Every bit of warming matters

The report details that climate change, including changes in extreme weather events, can already be detected in every region of the world. Southern Africa is no exception. The immense human tragedy of tropical cyclone Idai in March 2019 (more than 1 300 people lost their lives in Mozambique, Zimbabwe and Malawi), the infamous Cape Town 'day zero' drought of 2015–2017 and the 2015/16 El Niño drought in the interior (the 2015/16 El Niño is the strongest ever measured) are all examples of unprecedented climate impacts in southern Africa.

Further increases in global warming will result in further increases in the frequency and intensity of extreme events across the globe (e.g. heatwaves, heavy precipitation, tropical cyclones and, in some regions, the frequency and intensity of drought). Every bit of global warming matters. For example, increases in extreme events will be substantially larger at 2°C compared with 1.5°C of global warming.

Southern Africa is a climate change hotspot

One of the advances of AR6 compared to earlier IPCC assessments is the great deal of detail available in terms of regional climate change. This includes an analysis of the likely changes in the climate of the southern African region.

In this respect, the assessment has not changed compared to previous assessments: southern Africa is likely to become generally drier – in fact, reductions in precipitation can already be detected. Periods of drought are projected to occur more frequently already at 1.5°C of global warming, and more so as the level of global warming increases. It has also long been known that the region is warming drastically, at about twice the global rate of warming.

Further strong regional warming with associated increases in heatwave events will continue to occur for as long as global warming continues. This points towards significant future challenges in terms of adaptation in the region (to be assessed in the upcoming Working Group II (WGII) report; keep an eye on its release in February 2022): when a region that is naturally warm and dry becomes warmer and drier, the options for adaptation are limited.

Net-zero emissions for climate stabilisation – every tonne of carbon emitted adds to global warming

Carbon dioxide is the main driver of global warming, so it is also the most effective lever to reduce and later reverse it. The IPCC assessment shows that limiting global warming to the temperature threshold of 1.5°C is still possible, but requires that all countries achieve net-zero emissions within a calculated remaining carbon budget by mid-century.

Maintaining the global temperature below 1.5°C then requires negative emissions that remove CO_2 from the atmosphere in the second half of the century to offset the delayed warming impact of historical emissions and any small overshoot above 1.5°C. Both are audacious, but necessary to stabilise global and regional climate to avoid dangerous climate change, and partially reverse ocean acidification.

Net-zero emissions and the remaining carbon budgets are science-based policy metrics derived from a planetary physics relationship between warming and cumulative CO_2 emissions, which is largely controlled by the ocean. This relationship is the basis for two fundamental ideas that are critical to stabilising climate.

First, that every tonne of CO_2 that we emit adds to global warming: this leads to the corollary that if we stop emitting, then temperature stops rising, which is the basis of the net-zero concept. Second, it allows us to calculate with confidence the amount of carbon that can still be emitted and remain below the 1.5°C target. Both net-zero and the remaining carbon budgets are necessary to achieve and sustain the global surface temperature below a given threshold.

South Africa is globally one of the top five countries in terms of carbon emitted per unit of energy. To meet net-zero global objectives, the challenge will be to transform its carbon-intensive economy, and simultaneously meet its development needs and objectives through a just transition. It is both an enormous challenge and an unprecedented opportunity for the modernisation of the country.

However, reaching net-zero by 2050 by cutting emissions is not sufficient.

Negative emissions for climate stabilisation beyond 2050

To ensure that global warming remains below the 1.5°C level until the end of the century and beyond, the IPCC assessment shows that an additional global-scale intervention beyond net-zero emissions is necessary: the active reduction in atmospheric CO_2 through negative emissions. Negative emissions through carbon dioxide removal (CDR) reduce the amount of CO_2 in the atmosphere to reduce global surface temperatures and begin to reverse ocean acidification.

The global challenge is that at this stage it cannot be done at the required scale. While there are several promising technologically intensive CDR approaches with large-scale potential on land and in the ocean, at this stage all are at an early conceptual to pilot-scale level of readiness.

There will be no single approach that will solve the negative emissions challenge globally. Linked to these methods will be land and ocean observational technologies and remote sensing to assess the effectiveness of the integrated global effort. CDR is likely to drive a new wave of global science and technological innovation, and South Africa needs to make sure that its institutions are not left behind.

Opportunities range from no-regrets approaches such as restoration of soil carbon in agriculture, restoration of ecosystems, particularly wetlands, to more technologically intensive geochemical methods, bioenergy with carbon capture and storage as well as direct air capture. These options to achieve negative emissions are explored in more detail by the IPCC WG III assessment to be released in 2022.

Prof. Francois Engelbrecht is a climatologist at the University of the Witwatersrand's Global Change Institute, and was Lead Author of Chapter 4, 'Future global climate: scenario-based projections and near-term information', of the IPCC Report.

Dr Pedro Monteiro is an oceanographer at CSIR's Southern Ocean Carbon & Climate Observatory (SOCCO), and was Coordinating Lead Author of Chapter 5, 'Global carbon and other biogeochemical cycles and feedbacks'.

The IPCC Working Group 1 report, titled *Climate Change 2021: the Physical Science Basis*, is the first instalment of the IPCC's Sixth Assessment Report (AR6), which will be completed in 2022. The report was co-authored by 234 scientists from 66 countries.

Animal home-building habits may provide clues to climate change adaptation

Birds build nests to keep eggs and chicks safe and warm, but they may also adjust nest insulation in very hot conditions to reduce the risk of overheating. Some mammals, such as rabbits and ground squirrels, construct burrow systems in which the temperature stays relatively constant, so they can avoid the more extreme temperatures that prevail above-ground. And termites – the master builders of the insect world – make mounds with their own solar-powered air-exchange system to control the temperature, humidity and concentration of oxygen and carbon dioxide inside the colony's nest.

Paying closer attention to how animals modify their 'home structures' to alter the microclimates within them may help us understand how they will respond to climate change. This was the crux of a recent paper published by a group of four researchers in the journal *Trends in Ecology and Evolution*.

"It's crucial that we continuously improve our ability to predict and mitigate the effects of climate change," says Professor John Terblanche from Stellenbosch University's Department of Conservation Ecology and Entomology, who was part of the group. "One of the ways we can do this is by gaining a better understanding of how animals influence their own small-scale experience of climate at the level of individual members in a population."

The African paradise flycatcher builds a cup-shaped nest made from both coarse and fine plant material, held together with spider web and camouflaged with lichen. Many bird species are known to reduce nest insulation in very hot conditions to prevent overheating of eggs or chicks.

Lead author of the paper, Professor Art Woods, is from the University of Montana in the United States, while the other authors are Dr Sylvain Pincebourde from the University of Tours in France and Associate Professor Michael Dillon from the University of Wyoming in the United States. Asked how these far-flung scientists came to team up for the paper, Prof. Terblanche explains that each member of the group had already collaborated with two of the others before they all got together for a week in Tours when he was on sabbatical there in 2019. They met up specifically to discuss mutual interests and propose some topics that they felt needed further consideration in the climate change literature.

"We all got along extremely well and this paper spun off naturally from our discussions. For the past two years we've had monthly group Zoom meetings to discuss books, papers and ideas – and have even nicknamed our little group 'Thermal Warriors' in honour of a classic book of the same name by one of the forefathers of insect thermal biology, Bernd Heinrich!"

The paper's title, 'Extended phenotypes: buffers or amplifiers of climate change?', refers to a concept that was introduced by the British evolutionary biologist Richard Dawkins in his 1982 book, *The Extended Phenotype: The Long Reach of the Gene*. Over the last decade, the concept has spawned a major research field, partly due to developments in next-generation sequencing technology that allow the entire genetic code of an organism to be read in a matter of days, but also because of its relevance to medicine, agriculture and conservation.

But what exactly is an 'extended phenotype'? A phenotype is an organism's observable characteristics or traits, determined by its collection of genes – its genotype – and environmental influences. Dawkins argued that genes have an effect that extends beyond just the organism's own body, because by influencing behavioural traits they may cause the organism to have an effect on the surrounding environment or other organisms. For example, beavers build dams on rivers to create sheltered ponds for their own benefit, but this 'ecosystem engineering' has a considerable impact on hydrology, nutrient dynamics and local biodiversity. And many parasites can manipulate their hosts, changing their behaviour to increase their own chance of survival and reproduction. Internal parasites in the form of fungi or flukes, for instance, may turn their invertebrate

At the end of July, Stellenbosch University launched its School for Climate Studies, the first school of its kind in South Africa that has the status of a faculty. The vision is for the School to be a world-class institution for interdisciplinary and transdisciplinary climate-related studies in and for Africa, and to support and encourage research partnerships with other entities, both nationally and internationally. The School will conduct research, coordinate curricula development and facilitate postgraduate training, advice and consultancy as well as technology transfer in the multiple fields of climate studies.

intermediate hosts into 'zombies', causing them to move into positions where they are more likely to be eaten by the definitive host, such as a bird or fish. The cuckoo takes this manipulation a step further, with 'action at a distance'. It fools other bird species into raising its chick by laying its egg in the nest of the host, and has evolved to ensure that both the egg and sometimes even the hatchling resemble those of the host.

These three examples represent the three categories of extended phenotype defined by Dawkins. Like beaver dams, bird nests, burrow systems and termite mounds are extended phenotypes because they are modifications that animals deliberately make to their local environment

Cape ground squirrels live in the hot, dry parts of southern Africa, but can retreat to their cool burrows for short intervals during the day to reduce body temperature.

to maximise the survival of their own genes. What is not known is whether animals will be able to make further modifications that will allow them to withstand the possibly harsher environmental conditions they could be exposed to with climate change. In other words, how much plasticity do extended phenotypes exhibit, and how rapidly can they evolve to 'keep up' with climate change?

The researchers call for a renewed effort to understand the role of extended phenotypes in animals' experience of climate variability. This information could enhance the predictive ability of climate change models that aim to forecast the effects of climate change, including how species' ranges may shift, what the relative risks of extinction are for different animal groups, and which species will thrive, all of which have important implications for human food security and disease risk.

Written by Quest Editor, Sue Matthews, using press releases from three of the universities as well as other sources.

Solar radiation on African termite mounds drives a natural ventilation system that ensures an optimal microclimate within the underground nest.

CURRICULUM CORNER

LIFE SCIENCES: GRADE 12

Genetics and Inheritance: genotype and phenotype

Starting out on a STEM career

The importance of developing science, technology, engineering and mathematics (STEM) skills in South Africa is widely acknowledged. Here, *Quest* explores two initiatives that aim to help achieve this – one giving graduates an opportunity to gain experience in their field of study, and the other providing learners with a platform to find out more about different careers.

Data sciences

For the past nine years, analytics leader SAS has been running a technical internship programme that provides graduates with the opportunity to gain workplace learning and experience. The year-long programme encompasses several functions – from consulting, customer advisory and marketing to finance and sales – and the interns can attain specific SAS qualifications to help them further their careers. At the end of the year, every attempt is made to find a placement for each intern, either within SAS or at its customers and partners.

Recently, SAS asked three of its current interns what motivated them to pursue a STEM career and what excites them most about data and analytics.

For Kgopotso Magabjane, a technical intern at SAS, it was a passion for maths at school that led her to study BSc Mathematical Science and then BSc Honours in Science Statistics at the University of Limpopo. Her honours project opened her eyes to the power of working with data, which in turn led her to pursue her ambition of becoming a data scientist.

Magabjane's view of the importance of data and analytics encapsulates the value of it, as she explains that she believes knowing how to leverage data provides her with legitimate skills in the world. She adds that learning to work with data will empower people to better understand information and make informed decisions. "We live in a digital world, which is why it is hard to find people without a computer or a phone at hand. Everything is now connected, the digital world is growing and the best part about it is that data is engraved in it," she says.

Nkhensani Khoza's path to data and analytics was similar to Magabjane's. She too found her curiosity being stoked by mathematics at a young age, culminating in her attaining a BSc degree with a specialisation in mathematics and applied mathematics from the University of Johannesburg.

"I initially intended to enter into the field of statistics and use my degree to solve business concerns. However, upon being introduced to data science, I soon realised that I could instead use what I was learning to solve real-world problems," she says.

Kgopotso Magabjane believes data analysis can empower people to make informed decisions.

Nkhensani Khoza says working with data and analytics is like searching for hidden treasure.

Khoza views working with data and analytics as akin to searching for hidden treasure, where the possibilities are endless, and one never knows what one will discover. She explains that it was SAS's leadership in the field of analytics that drew her to apply for an internship. "I knew that if I wanted to be a specialist, then SAS was one of the top companies in South Africa that would provide me with the necessary training I needed to pursue my dream. The company's brand and message of 'We believe curiosity is at the heart of human progress' really spoke to me."

For Shannon Arendse, an intern in the Customer Advisory team, it was the prospect of creating value-added solutions from numbers and data through technology that drew her to data sciences. "I like the idea of being able to transform what most people would call 'nothing' into something valuable," she explains. While she obtained a BSc in Mathematics and Statistical Science for her undergraduate qualification and BSc Honours Statistical Science for her postgraduate degree, she notes that she is creatively inclined, with a love for drawing and painting. For her, creativity is part and parcel of a career in data and analytics.

Arendse was initially intent on pursuing a career in academia majoring in mathematics, but once she explored the capabilities of SAS when doing her honours research project, she discovered that she enjoyed writing programs and coding to answer questions out of curiosity. In her internship, she is being given the necessary skills to code programs more efficiently. "Data and analytics, to me, is the future. It enables us to achieve better results for almost anything and with technology improving every day, it can only get better," she says.

Shannon Arendse enjoys writing computer programs but loves indulging her creative side too.

While all three interns have a strong academic background in mathematics, they highlighted curiosity, passion and creativity as primary components in their chosen career path, along with a desire to use data to solve problems. In an era where data is king, they're likely to find their career choice highly fulfilling, knowing they can help make a difference in solving problems.

Based on a press release by Catlin Hawken of INK&Co for SAS

STEMulator

The STEMulator is an interactive exploration platform designed to stimulate learner curiosity in the world of science, technology, engineering and mathematics. Its 'virtual landscape' is crammed with educational content on the built world, living organisms – including the human body – and complex systems such as the water cycle.

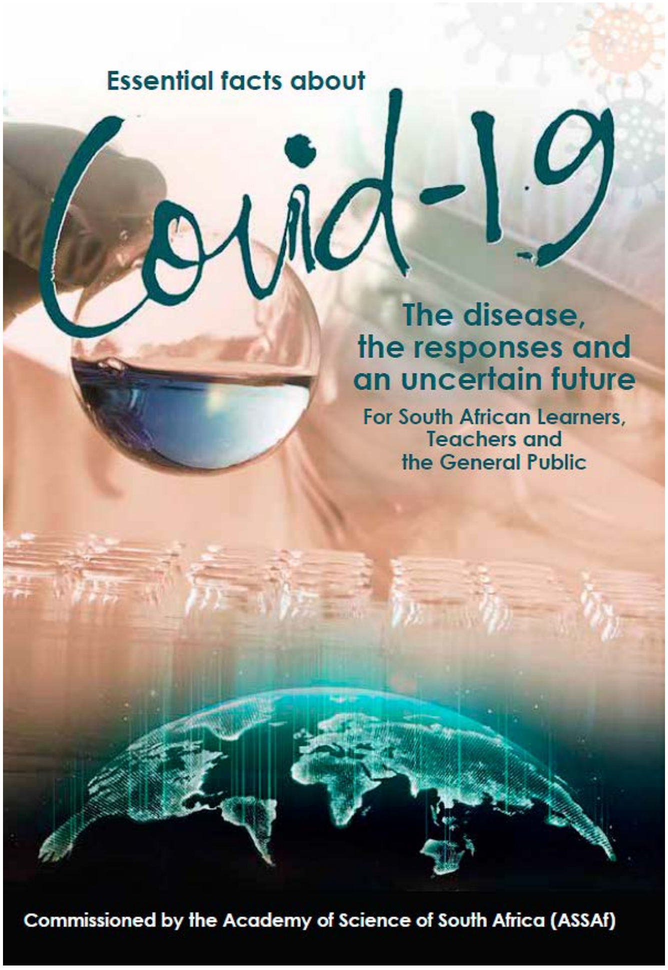
The opening image, serving as the main menu, has clickable areas that yield more information on subject-specific layers. Clicking on the Energy area, for example, reveals separate sections on nuclear power, hydropower, coal-fired power stations, wind turbines and photovoltaic energy, each with accompanying text, images, animations and video. Apart from learning about the technology, users can find out about relevant career options, such as electrical or mechanical engineering, and which institutions offer these fields of study.

Try out the STEMulator at www.stemulator.org.

The STEMulator Car unpacks into various parts, allowing users to explore the workings of an engine or steering system. Other options currently covered include Plane, Satellite, House, Construction, Nature and Agriculture. The STEMulator is still in beta-testing phase, and the development team is looking for contributions to flesh out the content of some areas.

The STEMulator is an initiative of proSET, the membership sector of the National Science and Technology Forum (NSTF). Its 'Chief Instigator', Richard Gundersen, reports that it has been distributed to rural schools on memory sticks called STEM-seeds, and there is another version that can be hosted by an off-line server.

Essential facts about Covid-19



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The Academy of Science of South Africa (ASSAf) recently launched a booklet it commissioned to educate learners, teachers and the general public about the Covid-19 crisis.

Essential facts about Covid 19 – The disease, the responses and an uncertain future is a collective effort by ASSAf Members, staff and invited scholars to help understand some of the basic scientific facts that are needed to understand the current crisis and the various options available to respond to it. The booklet emphasises that the threat of infectious diseases is not a new phenomenon, and pandemics have occurred for centuries. Scientists had warned for years of the need to prepare for the next one.

The first cases of a new coronavirus, SARS-CoV-2, were identified toward the end of 2019 in Wuhan, China. Over the following months, this infectious agent spread to everywhere in the world, and by now no country has been spared the loss of lives from the coronavirus disease, or Covid-19, nor the economic and social impacts of responses to mitigate its impact.

Covid-19 remains a major challenge worldwide. On the positive side, the scientific effort to develop vaccines against the disease has been immensely successful, and by mid-September 2021 vaccination campaigns were being rolled out in some 200 countries. However, in South Africa and elsewhere, there are many who are hesitant to be vaccinated, and this is a major impediment to slowing down and stopping the disease.

This situation highlights the importance of disseminating basic knowledge about science and medicine to the broader public. It is not sufficient to have a high level of scientific knowledge concentrated among a small group of experts. This is even more true today, when so much false information is being disseminated via social media and other internet-based platforms. Consequently, the ability to distinguish reliable information from less trustworthy information is an extremely important skill.

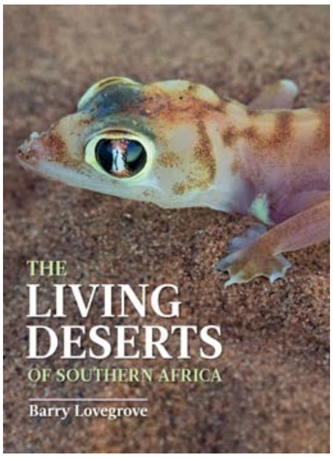
The booklet aims to enrich knowledge with some of the basics of medicine, viruses and epidemiology. Beyond the immediate Covid-19 crisis, South Africa faces a number of other major health challenges: highly unequal access to quality healthcare, widespread tuberculosis, HIV infection causing AIDS, a high prevalence of mental illness, and a low life expectancy. It is essential that young people, also learn about the nature of these new challenges, so that they may contribute to finding future solutions.

The booklet is available at the following link:
http://dx.doi.org/10.17159/assaf.2021/0072
and on the *Quest* website at https://questonline.org.za/issues/

Books

The Living Deserts of Southern Africa

By Barry Lovegrove, Struik Nature



Prior to the publication of the first edition of this book in 1993, it was anticipated with great excitement by members of the zoology and botany communities who were aware that it was coming. Lovegrove's 'labour of love' promised to open a window to a world that few had been privileged to get well acquainted with, and in that sense it did not disappoint. Focusing largely on the adaptations that allow animals and plants to cope with life in arid environments, it was packed with information, but many felt that this was also to its detriment. It was rather too cramped, too technical, and therefore risked not appealing or being readily accessible to the broader public. And raising awareness about these often overlooked, seemingly 'barren' landscapes was – and still is – important for their conservation. Although the Desert Biome, Arid Savanna Biome and Succulent Karoo Biome in southern Africa are well protected within large state and private parks, the same cannot be said for the Nama-Karoo Biome, where only 1% of the land area is under state conservation management.

But Lovegrove heeded the criticisms when – after retiring from the University of KwaZulu-Natal, where he retains Emeritus Professor status – he began revising the content. He has reduced the number of scientific diagrams and graphs, and instead has provided discrete references (via endnote numbers corresponding to a list of publications at the back) for the benefit of those wanting more detailed information. Some chapters needed more updating than others, with the final one, 'The future of the deserts', having been given a major overhaul to incorporate new developments in conservation and climate change. An extra chapter called 'The ancient Karoo' has also been added to provide an overview of the proto-mammals and dinosaurs that once inhabited the Nama-Karoo. Now, Lovegrove has succeeded in creating an informative and interesting book that comfortably straddles the 'key reference work' and 'coffee table' genres.

The designers, Janice Evans and Neil Bester, should be congratulated too, as the attractive, 'clean' and spacious layout has increased the book's readability immensely. The recommended retail price (RRP) for the hardcover version is R450, but there is also an eBook for R360.

Struik Nature recently released two new pocket guides. *Mushrooms of South Africa*, by Marieka Gryzenhout, is a new edition of a book first published in 2010. It features a selection of species most commonly found in the region, and will enable mushroom 'hunters' and natural history enthusiasts to identify them in the field. Each entry includes informative species accounts highlighting distinguishing characteristics, with full-colour photographs, and edibility at a glance.

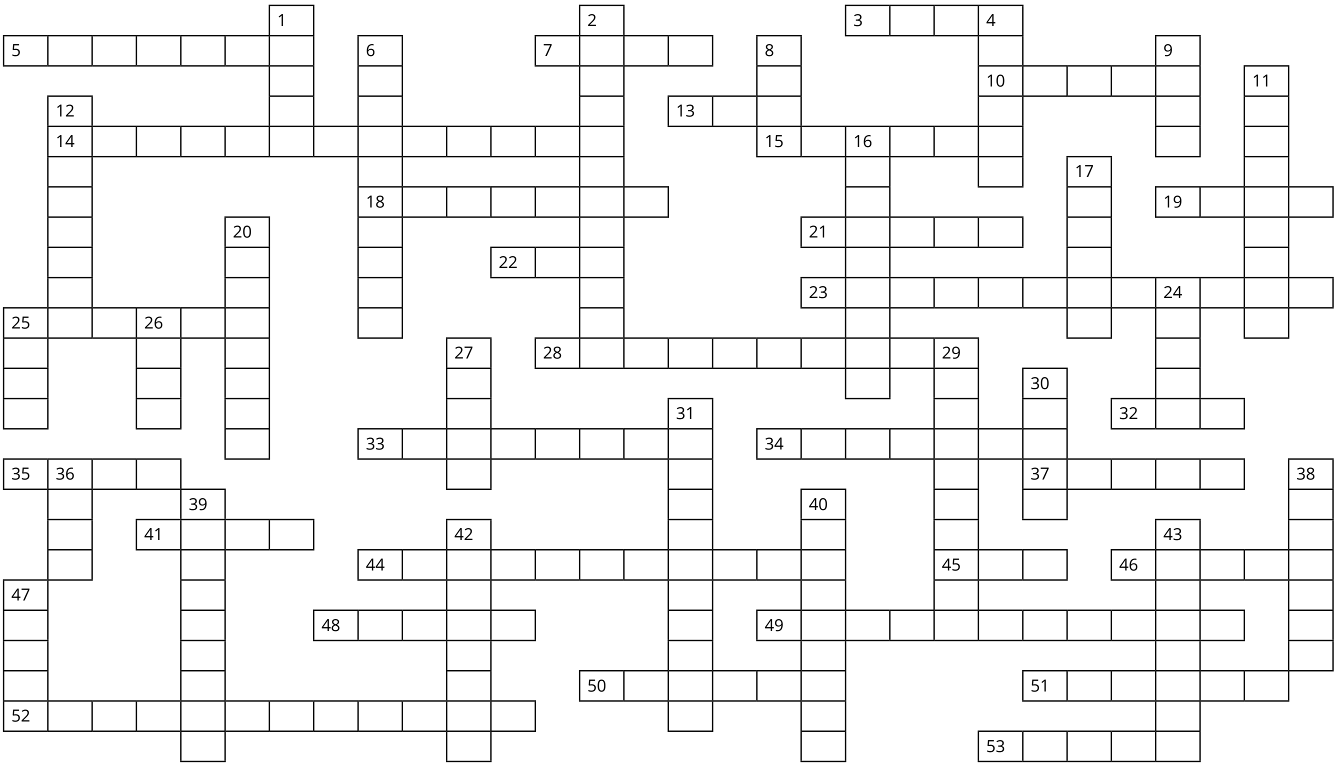
Gryzenhout is a lecturer in the Department of Genetics at the University of the Free State and a member of various mycological associations. She is the author and co-author of numerous scientific papers and books on fungi, including the popular *Field Guide to Mushrooms and other Fungi of South Africa*. She shares her passion for the subject on her website, www.themycologyblog.com. The book's RRP is R200.

A Pocket Guide to Sharks of the World, by David A. Ebert, Marc Dando and Sarah Fowler, is also a new edition of a previously published book, this one in 2015. This expanded edition presents richly detailed colour images, information on newly discovered species, and updated text throughout. It is apparently the only field guide to identify, illustrate and describe every known shark species. Apart from species accounts, it has fin guides and teeth guides, allowing for some level of identification on the basis of these parts. It also includes sections on shark biology, ecology and conservation.

Lead author Ebert is programme director of the Pacific Shark Research Centre in California, USA, and a research faculty member at Moss Landing Marine Laboratories, Dando is a scientific illustrator and publisher based in the United Kingdom, and Fowler is a scientific advisor to the Save Our Seas Foundation, co-founder of the Shark Trust and the European Elasmobranch Association, and a member of the IUCN Shark Specialist Group. The book's RRP is R340.

Test your knowledge

All of the answers can be found in this issue of *Quest*



ACROSS

3 Acronym for device using ultrasonic signals to detect breaks in rail tracks
5 The South Atlantic ___ is a weak spot in the Earth's magnetic field
7 Magnetite is a form of ___ oxide with magnetic properties
10 A type of particle that is identical to the nuclei of helium atoms
13 Acronym for the largest accelerator at iThemba LABS
14 The University of Pretoria's Faculty of Veterinary Science is based here
15 A bird famous for being a brood parasite, fooling other species into raising its young
18 Arrays of permanent magnets used in the Inductrack system
19 Acronym for a type of imaging that measures brain activity
21 A time-domain system used in electromagnetic surveys to map geological features
22 Acronym for a magnetoresistance effect used in hard disk drives
23 Plants that can dry out almost completely and spring back to life when watered
25 The Kalahari ___ represents the ancient landmass of southern Africa
28 The branch of the Earth Sciences that uses physics to study the subsurface
32 A data analytics company offering internships to South African graduates
33 An innovative mode of rail transport used during the South African War
34 Japan's record-holding train uses an electro___ suspension system
35 This falcon has the longest migration of any raptor worldwide
37 The ___ -hand rule helps us learn about electromagnetism
41 A sheet of rock that cuts through the layering of adjacent rocks
44 Advanced electronics making using of the spin of electrons
45 Acronym for Africa's first 'home-grown' locomotive
46 The Higgs ___ is a fundamental particle confirmed to exist in 2012
48 The frame carrying the wheels underneath a train carriage
49 A global network of observatories monitoring the Earth's magnetic field
50 A subatomic particle with a positive charge in the nucleus of every atom
51 Used as a coolant for superconducting magnets
52 Substances that can protect cells from damage
53 An excited state of carbon-12, involved in the creation of carbon in stars

DOWN

1 Bird nests and termite mounds are examples of extended pheno___
2 A protein found in the eyes of birds, involved in navigation
4 A SpaceX vehicle for carrying cargo and astronauts to the International Space Station
6 Carbon dioxide is an example of a ___ gas causing global warming
8 Acronym for the United Nations body for assessing the science related to climate change
9 The radical ___ mechanism is thought to facilitate magnetoreception in birds
11 A proposed high-speed transportation system involving pods in low-pressure tubes
12 The Hadron ___ is the world's most powerful particle accelerator
16 Refers to temperatures that are ultra-cold
17 A transportation system that uses magnetism to 'float' above the track
20 The South African-born innovator behind The Boring Company
24 A unit of measurement for magnetic field strength
25 The European Organisation for Nuclear Research
26 Nickname for the London Underground train system
27 The European Space Agency's satellite constellation measuring the Earth's magnetic field
29 An interactive platform to explore science, technology, engineering and mathematics
30 The ___climate in burrows may be very different from the above-ground surroundings
31 The amount of deviation of a compass needle from true north
36 A type of computer memory that uses a magnetoresistance cell to store data
38 The Earth's current polarity interval that started 780 000 years ago
39 An accelerator that propels charged particles in a circular path
40 MRI stands for magnetic ___ imaging
42 The higher a particle's ___, the more difficult it is to change its direction
43 Rock formed from magma that flowed up from deep within the Earth
47 South Africa's government agency that monitors space weather

For magnetism-related games, demos, lesson plans and more, check out the Magnet Academy, brought to you by the National High Magnetic Field Laboratory in the United States.

https://nationalmaglab.org/education/magnet-academy/

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