CHAPTER 3

Physics and Astronomy

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3.1 Developments up to 1990

Physics in South Africa dates back to the astronomical observations of Sir John Herschel at the Royal Observatory in Cape Town in the 1830s, the introduction of geomagnetic and surveying work, and the establishment of several universities and university colleges in the second half of the 19th century. The establishment of the mining industry early in the 20th century and the subsequent industrialisation in the years before World War II significantly boosted the discipline, with physics research at several universities becoming a fully established activity. On the international scene, South Africa became a founding member of the International Union of Pure and Applied Physics (IUPAP) in 1923.

It was not until the founding of the Council for Scientific and Industrial Research (CSIR) in 1945, however, under the patronage of then Prime Minister Jan Smuts, that physics emerged as a nationwide and unified discipline. Smuts had been a member of Churchill's war cabinet, and through his active involvement in the subsequent restructuring of the world order, recognised the need for South Africa to have a strong science establishment for its development. The CSIR's National Physical Research Laboratory (NPRL) immediately created a new market for physicists, as did similar laboratories for chemistry and mathematics. In response to new research funding from the CSIR, the universities also began to strengthen their postgraduate research and training programmes.

These early developments are covered in three chapters of AC Brown's (1977) book on *A History of Scientific Endeavour in South Africa*.

In 1961, South Africa became a republic and was expelled from the British Commonwealth for its policy of apartheid. As a result, South African physics took a different route from that in other Commonwealth states. The political and economic isolation led to a centralist approach from government to use science and technology (S&T) to overcome the concerted international anti-apartheid campaign, and to meet the perceived strategic needs of the country. This development had already started with the founding of the Atomic Energy Board (AEB) in the 1950s, with the vision to utilise and enrich South Africa's uranium to make the country self-sufficient in nuclear energy. During this time, there was also an emphasis on nuclear weapons and in 1993 the government revealed that it had developed six nuclear weapons devices. Similarly, over the same period, the division of defence research at the CSIR developed into a sophisticated armaments industry, with the establishment of Armscor and its subsidiaries, to overcome the ever-strengthening arms boycott.

Physics co-incidentally prospered under these developments because most of the technologies are, naturally, physics-based. A by-product was generous funding for large physics laboratories such as the Southern Universities' Nuclear Institute (later the National Accelerator Centre, and currently the iThemba Laboratory for Accelerator-Based Sciences, or LABS). There were also extensive non-military projects at the AEB (later the Atomic Energy Corporation, AEC, and currently the Nuclear Energy Corporation of South Africa, Necsa).

Two older laboratories were those of Mintek for minerals research and beneficiation, and the Hermanus Magnetic Observatory (HMO) for geomagnetic information needed for navigation and exploration. Experimental nuclear physics and materials science research at universities directly benefited from the developments at these laboratories, performing high-quality and innovative work, especially at the level of technological physics. While it is ironic that physics in South Africa should have been strengthened by the country's isolation, there was also a down side, as much of this work was 'classified' (secret), and many scientists who wished to develop their careers submitted 'classified' MSc dissertations and PhD theses at the universities concerned. Many of them were never published again.

In 1983, the agency function by which the CSIR funded university research was transferred to the newly-established Foundation for Research Development (FRD). The FRD became independent from the CSIR in 1990, and in 1999 it became the National Research Foundation (NRF), which also had responsibility for the social sciences and humanities. Initially, the FRD vision was generally one of open or 'blue skies' research, which was meant to support and retain high-quality scholars. Physics research naturally falls into this category, and hence physics again benefited. The FRD established an evaluation or rating system by means of which scientists could be benchmarked on the basis of their standing in the opinion of international peers (see Chapter 1).

This new development came at the right moment for physics because centrally-driven physics research at large laboratories, such as the CSIR and the AEC, imploded at the time. Within the CSIR, a major restructuring exercise in the mid-1980s changed the driving force to one that was largely commercial and financial. Under its new mission, the CSIR favoured technology, engineering and applied science above basic science. At the AEC, the change was mainly due to changing strategic/political considerations leading up to the democratic dispensation of the country in 1994. These changes had a ripple effect on many other laboratories and universities. Large numbers of nuclear physicists, many of them only in mid-career, became effectively redundant. In this climate the new FRD/NRF evaluation system played a significant role to ensure that the broad academic sector of physics did not suffer the same fate, and it provided an opportunity for the subject to readjust itself within rapidly changing national priorities.

3.2 The role of the South African Institute of Physics (SAIP)

A natural consequence of the post-World War II flourishing of scientific activity was the establishment of professional scientific societies. The first attempt to establish such a society for physics happened in 1948, but did not succeed. A second attempt, launched in 1953 by C B van Wyk, eventually led to the establishment of the South African Institute of Physics (SAIP) on 7 July 1955, at the University of Pretoria, with S Meiring Naudé as its first president (see http://www/saip/org/za). The attendance register was signed by 102 practising physicists. The institute organised itself into a number of specialist groups that represented the main themes of physics practised in the country. Solid state physics and nuclear physics were natural strongholds. The institute rapidly grew to a membership of between 300 and 400, and its core activity was the annual three-day conference in July to provide a forum for progress reports in the various disciplines.

Growth was so healthy that a *South African Journal of Physics (SAJP)* was launched in 1978, as well as a quarterly newsletter called *Meson*. The *SAJP* was subsidise by the newly established Bureau for Scientific Publications. The SAIP also played a facilitating role in respect of other developments in physics. For instance, when a decision about the site for the National Accelerator Centre was needed, the decision was reached under the leadership of the SAIP council. Section 3.8 describes how the National Laser Centre (NLC) was also established under the auspices of the SAIP.

The promotion of education has always been a central concern of the SAIP. Alongside the education specialist group, where the emphasis is on research and teaching practice, the council has always had its own education portfolio to ensure that national and provincial strategies are implemented. A special feature has also been the annual heads-of-department meeting during the annual conference. While this forum has never had any decision-making powers, it has fostered sufficient debate and activity to ensure that all physics degrees awarded in the country have always been recognised by all institutions.

Even during the apartheid era, SAIP membership was open to all, and its constitution never differentiated on the basis of race or gender. It is also true, however, that the SAIP could have been more pro-active to promote change and to extend its membership. In an exchange of letters between institute presidents in 1987, the American Physical Society expressed concern about the effects of apartheid on South African physics, and proposed joint actions "to improve access to physics for all talented persons in South Africa". The SAIP president at the time responded immediately and positively, closing his letter in the hope that "this could very well be the beginning of a useful and effective collaboration". The actual benefits of this positive exchange are hard to identify, however. Towards the end of the apartheid era, a combination of the brain drain, the change in focus at the CSIR and the AEC, and much-reduced funding for research, in spite of the new FRD/NRF initiative, led to a decline in SAIP membership and in the number of students who studied the subject. A symptom of this decline was that the *SAJP* became unsustainable and the last issue was published in December 1993.

3.3 Physics and the SAIP in the post-apartheid era

The African National Congress (ANC)[1] was highly pro-active with respect to its S&T policies. Even before taking office, it commissioned a study on the state of the S&T system in 1993, and as the new government it produced a White Paper on S&T in 1996. The establishment of the Department of Arts, Culture, Science and Technology (DACST) in 1994 was a completely fresh start. Its separation into two separate departments in 2002, and the establishment of a dedicated Department of Science and Technology (DST) demonstrated the strategic importance accorded to S&T by the government. The National Research and Technology Audit of 1998 provided a comprehensive overview of the S&T system. Based on these studies, the DACST and DST initiated many new strategies.

The physics community, however, took time to react. There were several challenges at the time: student numbers were static; the new strategies had not yet had a measurable impact; SAIP membership hovered below 400; and the annual conference attendance had declined to about 300. The SAIP realised that it should entirely reposition itself in the post-apartheid era and the council launched a project called 'Shaping the Future of Physics in South Africa' in co-operation with the DST and NRF. An investigation was carried out by an eight-person panel, including five influential international scientists, and their report was published in April 2004.

The report's 15 recommendations caused a dramatic 'turn-around'. First, they emphasised the value of large and established physics laboratories and activities such as iThemba LABS and Necsa in the nuclear sciences, the NLC at the CSIR, the South African Astronomical Observatory (SAAO), the Hartebeesthoek Radio Observatory (HartRAO), and the HMO. Further, it highlighted several flagship projects in physics and astronomy that already existed or were under development. Examples are the Southern African Large Telescope (SALT), the MeerKAT radio telescope as a pathfinder for the planned huge international project, the Square Kilometer Array (SKA), the Pebble Bed Modular Reactor (PBMR) to generate nuclear energy, and the National Institute for Theoretical Physics (NITheP). The report further emphasised that the physics community should focus on such facilities and opportunities without sacrificing the smaller-scale research activities practised in university departments, which were regarded as the sustainable cornerstone of basic physics research. The report expressed concern about the grave situation in physics education, and recommended several interventions that could be made in part by the SAIP. Finally, it pointed out that a voluntary organisation such as the SAIP, with only honorary officers, could not hope to make an impact without a full-time office.

Other opportunities quickly arose from various strategic interventions by the DST. These included a Nanotechnology Strategy, an Astronomical Geographical Advantages Act, a South African Space Agency Act, a Photonics Initiative of South Africa (PISA), and the establishment of a number of centres of excellence and research chairs at universities.

The DST and NRF have also developed a focus to dramatically increase the number of high-quality PhDs in S&T in the medium term to keep South Africa on track in its development curve. Increases of up to a factor of five have been mentioned. To redress the demographic imbalance, the government naturally wants these numbers to come largely from the black community, but there is a problem of supply.

There are approximately 8 000 students each year who complete their secondary school education in science and mathematics at a sufficiently high level to gain direct entrance into science and engineering faculties at universities. Of these, fewer than 3 000 are black. About 75% of them enter the professional fields of medicine, health sciences and engineering, leaving only some 800 to be distributed among about 20 science faculties, i.e. 40 per institution. This implies that each of the four basic science disciplines of biology, chemistry, mathematics and physics at each university has a maximum annual pool of about ten black entrants at first-year university level. This hard reality underscores the key challenge facing South Africa, that of people development through effective primary and secondary school education.

The physics community reacted to the *'Shaping the Future of Physics in South Africa'* report by using it as an authoritative source to conduct its planning and to motivate funding applications. The SAIP itself took up the challenge to establish with effect from January 2008 a full-time office, funded to a large extent by government. Brian Masara was appointed as the first Executive Officer, and is supported by a core administrative and marketing/outreach staff.

With this office the new SAIP now conducts and coordinates a number of well-structured programmes that include:

- A membership drive through which the number of members has now increased to 547, a healthy 36% of them being postgraduate students. Conference attendance rose from 314 in 2002 to 540, 437 and 496 during the last three years.

[1] Known by its initials, ANC, this is the governing party of South Africa. It was formed in 1912 and is the oldest political organisation in the country.

- Women in Physics in South Africa (WiPi-SA) initiative, started in 2005, which has made such an impact that it submitted a successful bid to host the 4th IUPAP International Conference on Women in Physics in Stellenbosch in April 2011.
- BSc curriculum initiative which investigates what physics should be taught (and how) at this crucial phase. This is in response to the DST/NRF drive to increase the number of high-quality PhDs, and in view of the reality that secondary education in the physical sciences and mathematics is not demonstrably improving.
- A South African physics graduate database which aims to develop a physics graduate support system, given the very small pool of students that meet the entrance requirements in the physical/mathematical sciences.
- A Biophysics Initiative to build and strengthen this new interdisciplinary research field as a cornerstone for 21st century physics in South Africa.
- Physics for Development, which strives to implement the recommendations of the 2005 World Conference on Physics for Development. For example, a workshop on entrepreneurship for scientists and engineers from developing countries in Africa is being hosted in November 2009.
- A Pan-African Physics Forum to strengthen African networks; a meeting for heads of physical societies is planned for November 2009.
- Physics Comment, an electronic magazine to communicate with the physics community and the relevant stakeholders and decision-makers.
- The establishment of the OR Tambo Memorial Awards and Lecture Series to commemorate and honour OR Tambo's contributions as a physics teacher in South Africa and, while in exile, also in the United Kingdom (UK).
- A project called Physics 500 to promote physics in industry by publishing the careers of up to 500 industrial physicists as role models.
- A Further Education and Training (FET)[1] education project to expose university lecturers to the outcomes-based FET curriculum so that they can effectively incorporate this into their teacher-training courses.
- A revision of the 55-year old SAIP constitution, completed in 2009, to comply with modern practices.
- A History of Physics in South Africa, to be published in 2010, which will concentrate on the most recent 50 years, over the lifespan of the SAIP.

The immediate success of the office is due to the fact that it implements DST strategies and NRF programmes at the ground level. It works directly in, and with, the physics community, which the policy-making and funding agencies cannot do as easily.

The remainder of this chapter will discuss how these new opportunities for physics in South Africa are being exploited within the individual disciplines, grouped according to the current SAIP specialist groups. They are presented in alphabetical order.

3.4 APPLIED PHYSICS

Applied physics is probably the largest sector of the physics profession. It is estimated that fewer than half of all South African physicists are members of the SAIP, and that the majority of non-members are employed in industry, or use their physics expertise as S&T innovators outside the academic sphere. In view of this, there has been some debate in recent years as to the exact remit of the applied physics specialist group (APSG) within the SAIP. For a while the name 'applied and industrial physics' was used, but it was felt that this was too broad, and that this sub-group should be concerned primarily with work at research institutions in which applications of the physical principles were under development.

Applied physics naturally intersects with the interests of other specialist areas, such as nuclear physics or solid-state physics. Virtually all universities are involved in some aspect of applied physics, often in collaboration with industrial partners. Materials science is a good example of an area which includes much applied physics. Research from a conglomeration of institutes which form the DST/NRF Centre of Excellence in Strong Materials centred at the University of Witwatersrand (Wits) is much in evidence. Diamond physics has been a South African speciality for many years and continues to be important, with applications including both its strength and its novel electronic properties.

Several South African universities are working on renewable energy systems, notably the use of solar power via photovoltaic panels or direct heating, and many evaluative studies have been reported on materials and the characterisation of devices. Much attention has been given to the work on thin, light and cheap panels done at the University of Johannesburg (UJ) over the last decade, which has led to a significant production contract in Germany. Luminescent and other photonic materials are also researched, and a separate biennial conference is held locally in this area.

Another area of national importance which is very visible, both within the APSG and at other local conferences, as well as in postgraduate courses, is that of the safe handling of ionising radiation and its practical applications, either for research or for more direct benefit. The Mafikeng Campus of North-West University (NWU), for instance, has a postgraduate course in Applied Radiation Science and Technology. In this area, the APSG has recently nominated a representative to the SAIP sub-committee which liaises with the Nuclear Industry Association of South Africa.

Biophysics is small and underdeveloped in

[1] Formal education in South Africa is categorised according to three levels – General Education and Training (GET) comprising grades 1 to 9, Further Education and Training (FET) comprising grades 10 to 12 and Higher Education (HE).

South Africa, and the initiative mentioned above is an attempt to develop it as another cross-cutting aspect of applied physics, mainly in collaboration with the strong laser community (discussed in section 3.8).

In the past year, some members of the APSG have been involved in the establishment of the Physics 500 Project of the SAIP, the aim of which is to find and describe working physicists outside academia. This stems from the recommendation of the 'Shaping the Future of Physics' in South Africa project, to help students find role models and opportunities in industry, and to help industry inspire students to pursue careers in physics. In this way the creation of research collaborations between industry and academia is a continuing initiative for the benefit of the country.

3.5 ASTROPHYSICS AND SPACE SCIENCE

Astrophysics and space science (ASS) in South Africa encompass the fields of optical and infrared astronomy, radio astronomy, gamma-ray astronomy and space physics. South African scientists produce internationally recognised research output in ASS, and South Africa is a major role player because of its geographic advantage and scientific productivity.

The building of a 10-m class optical telescope called SALT, the largest in the southern hemisphere, participation in the world's foremost ground-based gamma-ray telescope, the High Energy Stereoscopic System (H.E.S.S.), and the building of the pathfinder MeerKAT for the envisaged SKA, are a few major astrophysical projects in which South Africa is involved.

Astrophysics research in South Africa is mainly optical and infrared, with the majority of researchers based in the Western Cape. The two major observatories, which are national facilities under the NRF, are the SAAO and the HartRAO. Together with H.E.S.S. in Namibia, they are the main astrophysical facilities for South African researchers, and they are financed partially or fully by government through the DST.

The SAAO is the main custodian of optical facilities and operates five small telescopes, as well as SALT on behalf of its international partners. SAAO telescopes are at Sutherland, 360 km north of the headquarters in Cape Town. The small telescopes contribute to international research and to the training of future astronomers. They are also important for the future success of SALT, either as support telescopes or in its calibration.

SALT is operated by SAAO on behalf of the international consortium which owns it and in which South Africa is the major shareholder; other shareholders include institutions from the United States (US), Poland, UK, India, Germany and New Zealand. The telescope is optimised for optical spectroscopy and has niche capabilities in spectropolarimetry and high-speed photometry. The infrared arm of the spectrograph is under construction and will make SALT an important instrument for cosmology.

Currently there are six other telescopes hosted by SAAO at Sutherland on behalf of, or in collaboration with, international partners and institutions. Some of these are run robotically by the international partner, with SAAO providing technical assistance, maintenance and services. South African researchers have access to at least some data from each of these. Other non-astronomical facilities in Sutherland include a seismograph and a geodesic observatory. Many of these facilities are part of global networks. Sutherland is important for geographical and geological reasons, as well as for hi-tech infrastructure.

HartRAO is the national facility for radio astronomy, and has operated a 26-m radio telescope near Krugersdorp, west of Johannesburg, since 1975. It was built by the National Aeronautics and Space Agency (NASA) in 1961 as part of their Deep Space Station 51, for tracking US space probes. It was transferred to South Africa 14 years later when NASA withdrew. Because of its location the telescope has played an important role in 'Very Long Baseline Interferometry' networks and geodesy. It was particularly useful in pulsar timing, interferometry, spectroscopy and radiometry. The antenna suffered a major failure in 2008 and it is currently (July 2009) inoperable. The prototype 15-m eXperimental Development Model (XDM) of the Karoo Array Telescopes (KAT) is being considered as a replacement for the 26-m telescope to continue some of the monitoring programmes until decisions are made whether to repair or replace the 26-m telescope.

South Africa has been shortlisted, with Australia, to host the SKA telescope. The KAT will be used to test technologies leading up to the development of the SKA. The first seven antennae are currently under construction, and the full array of about 80 dishes (the MeerKAT) will be operational in 2012. If the SKA is to be built in South Africa, the central array will be located near Carnarvon in the Northern Cape. The rest of the dishes may be spread out as far as Ghana and Mauritius.

Using the above optical, radio and gamma-ray facilities, postgraduate training and significant research is carried out at the University of Cape Town (UCT), University of the Free State (UFS), NWU, Rhodes University (RU), University of South Africa (UNISA) and the University of the Western Cape (UWC). In addition, theoretical cosmology is practised at UCT, the University of KwaZulu-Natal (UKZN), UWC and the University of the Witwatersrand (Wits).

South Africa is involved in ground-based gamma-ray astrophysics via the participation of NWU in the highly successful international collaboration that operates H.E.S.S. in Namibia. This university has a research chair in the field, and this forms the core of a broader participation by other South Africa institutions in H.E.S.S. II, which is currently (2009) under construction. H.E.S.S. is a system of Imaging Atmospheric Cherenkov Telescopes capable of detecting cosmic rays in the 100 GeV to 100 TeV energy range.

It is a collaboration of mainly European institutions, with South Africa and Namibia as the sole African representatives. The main goal is to explore the production, propagation and acceleration of very high energy

(VHE) particles in the universe. The extreme astrophysical sites of cosmic acceleration or sources of non-thermal radiation that produce VHE photons include supernovae, giant molecular clouds, starburst galaxies, clusters of galaxies, and supermassive black holes in active galaxies. H.E.S.S. has detected or confirmed over 50 VHE sources as gamma-ray sources.

Astronomy Advantage Areas have been declared around Sutherland and Carnarvon to protect and maintain the radio-quiet regions for the SKA and the Sutherland observatory against light and dust pollution. The Astronomy Geographic Advantages (AGA) Act was passed in 2007, to ensure that South Africa will be able to participate as a partner in global-scale science projects.

On the space science side of this main grouping, there are several activities in space and upper atmosphere physics, extending to Antarctic research. In this field and its related technologies, South Africans have worked historically in the fields of geomagnetism, ionospheric physics, heliophysics, and plasma physics. The birth of space-weather research in Africa and the increased human dependence on space technology have added to the interest. The HMO specialises in fundamental space physics research, as well as the development of research infrastructure, promotion and marketing of space physics.

The HMO is responsible to the international science community for a number of infrastructure networks that extend as far as Antarctica and deep into Africa, where space physics collaborations are being established. In particular, it is one of four observatories worldwide whose observations are the basis of the Dst index, a measure of variation of the earth's magnetic field, e.g. due to solar activity. The South Atlantic Anomaly has a strong effect on the main geomagnetic field in Southern Africa, and studies by the HMO of its temporal variation are yielding interesting results. The HMO also carries out ionospheric tomography using Global Positioning System (GPS) satellite data. RU has a long history of research in ionospheric physics. Currently, in conjunction with HMO, it operates a network of ionospheric observatories.

As one of the original 12 signatories of the Antarctic Treaty in December 1959, South Africa has maintained a scientific base in Antarctica since 1960. The treaty sets aside the continent for research purposes, and South Africa celebrated its 50th anniversary in Antarctic research at a mid-winter function on 17 June 2009 at the South African National Antarctic Programme (SANAP) headquarters in Cape Town. The current South African National Antarctic Expedition (SANAE) base is situated on a rocky outcrop 240 km from the edge of the ice shelf. The proximity to the magnetic pole and the auroral zone means that measurements in upper-atmosphere physics provide a ground-based 'window into geospace'. The flagship project of SANAP at SANAE is the Southern Hemisphere Auroral Radar Experiment (SHARE) high frequency (HF) radar, which probes a large region of the ionosphere over Antarctica, and it is part of the international network known as SuperDARN (Super Dual Auroral Radar Network). It was developed as a project of the former Universities of Natal (now UKZN), responsible for data management, and Potchefstroom (now NWU), who carried out the construction from 1994 to 1996, and who were responsible for engineering operations for the subsequent eight years. The SHARE group and HMO have a long history of working on ultra-low frequency (ULF) geomagnetic pulsations arising from solar-terrestrial effects. Observations of naturally-occurring very low frequency (VLF) waves by UKZN and HMO are related to particle precipitation effects in the auroral region. Cosmic-ray neutron monitors at SANAE have been operated by the research group at NWU (Potchefstroom campus) continuously since 1964, providing a valuable long-term data resource which contributes to valuable insights into the modulation of cosmic rays.

Since 1974, the group at NWU has focused strongly on the theoretical side of cosmic-ray transport in the heliosphere. Their models are based on numerical solutions of the cosmic-ray transport equation, and they provide explanations for the observations made over many decades, ground-based as well as by spacecraft throughout the heliosphere, of how the sun modulates the cosmic-ray intensity. These insights are applicable to new so-called astrospheres that are being discovered and to cosmic rays created in the remnants of supernova explosions.

For many years there has been a strong involvement at UKZN in theoretical research on linear and nonlinear waves in plasmas. Their interests in space plasma physics include studies of electrostatic solitons, dusty plasmas, waves in kappa distribution plasmas, and geomagnetic field line resonances.

This discipline as a whole strongly experiences the enabling effects of government policy and legislation to provide South Africa with world-class facilities for astrophysics and space physics. The Space Agency Bill of 2008 strives to integrate the space applications more strongly with the basic space sciences. The big challenge remains to educate more South Africans to a level where they can make full use of these facilities.

The ASS group has a specific focus on student training and development. The National Astrophysics and Space Science Programme (NASSP) was formed in 2003 to address the problem of shortage of South African astronomers that are capable of using SALT, and the extreme lack of black South African astronomers. The programme has been quite successful in producing postgraduate students with various skills that can also be applied in a range of other fields and industries. The primary problem so far has been attracting sufficient black South Africans into the programme, but this is addressed with the introduction of an extended programme that caters for South African students with disadvantaged educational backgrounds.

3.6 CONDENSED MATTER PHYSICS AND MATERIALS SCIENCE

Materials physics is the most widely practised branch of physics in South Africa, and also one of the oldest and most established. Researchers such as FRN Nabarro and JH Van der Merwe pioneered the field in the 1950s and 1960s, and currently there are established groups at about ten universities, together with research laboratories at the CSIR, iThemba LABS, and Mintek, as well as Element 6 in industry.

Recent years have also seen a stronger overlap with research in other physics sub-disciplines (applied physics, optics and spectroscopy, and theoretical physics), and even with other disciplines (chemistry, biology and engineering) and research areas (nanosciences, biotechnology, and microscopy). Details are given under the descriptions of each of the respective fields.

A research chair in nanotechnology was awarded in 2008 to the physics department of Nelson Mandela Metropolitan University (NMMU) for work on thin-film semiconductor materials. The NRF has also established a National Centre for High-resolution Transmission Electron Microscopy (TEM) in the same department. It will operate the first double-corrected atomic resolution TEM in Africa. This facility is, however, only the most high-profile of a series of similar facilities established throughout the country for research on nanomaterials and other interdisciplinary science. Only three years ago, near-atomic resolution microscopy in South Africa was a dream, with researchers and students having to use their scarce resources for travel. Now there are facilities at UWC, UCT, Wits and the CSIR. The same pattern has been repeated throughout the recent investment in interdisciplinary research equipment. The major share has been used to purchase analytical equipment for materials characterisation, and it is these tools of condensed matter physics and materials science which are driving the resurgence of applied and interdisciplinary research.

This cross-fertilisation with other disciplines and investment in much-needed infrastructure has led to an equal growth in human capacity. Almost every university in the country now has either an active research group in the field, or a successful postgraduate programme, often in collaboration with other institutions and disciplines. In this respect, the new teaching and research activities at the UFS's Qwa-Qwa campus, and at the University of Zululand (UZ) in collaboration with UWC and the materials research group at iThemba LABS, are particularly noteworthy. Even the established universities and the science councils have seen a resurgence in an interdisciplinary approach to materials research, with the establishment of the Centre of Excellence for Strong Materials at Wits, and the National Centre for Nano-structured Materials at the CSIR. The UFS has established, through its applied and basic research on nanophosphors, strong collaborative links with chemistry departments. Both NMMU and UCT have a broad programme of research, ranging from the fundamental physics of nanomaterials through to the applied physics of solar cells – one being based on thin-film compound semiconductors and the other on printable nanoparticulate silicon. While not formally having a solid-state physics group, Stellenbosch University (SU) is actively pursuing the study of materials using femtosecond laser techniques, specifically second-harmonic generation at semiconductor interfaces and ultra-fast electron diffraction. The University of Pretoria (UP) has maintained its traditional strength in semiconductor materials and ion beam analysis, while developing industrial links to conduct research on the materials for the PBMR. Theoretical and computational solid-state physics, traditionally the preserve of the Materials Modelling Centre at the University of the Limpopo (UL) and the Wits physics department, has been enhanced by the activities of the theoretical physics community, namely the establishment of NITheP and the Centre for High Performance Computing in Cape Town. UJ, UCT, UFS and UZ are now actively conducting research in this area. On the experimental side, UJ has become the *de facto* national centre for studies of the magnetic properties of materials.

3.7 EDUCATION

Physics education activities within the SAIP take place at four levels – curriculum, pupils, teachers and undergraduate. In the past few years, South Africa has introduced new secondary school curricula that are designed to be modern and based on the principles of outcomes-based education. The focus is on what students know and can do, rather than on what the teacher teaches. The curriculum for Grades 10 to 12 was phased in between 2006 and 2008. Members of the SAIP were centrally involved with designing the physics component of the physical sciences curriculum. There are three physics, two chemistry and one integrated strand, each of which is taught in each of the three years of secondary school. The selection and sequence of physics topics were intended to facilitate conceptual progression, while helping students see the relevance of physics to everyday life. Applications related to South African-based science were also included, such as the SALT and laser physics.

Between 2005 and 2009, the SAIP received funding from the DST to support teachers in implementing the new Grade 10 to12 physics curriculum. Since the new curriculum required greater depth of understanding of the physics content, it was essential that physicists were involved in in-service teacher development. DST funding has been used to develop materials for workshops for teachers to be run by physics university lecturers. The national Department of Education (now the Department of Basic Education) has also called on SAIP members to run workshops for subject advisers and teachers. In addition, physicists at several universities are involved in teaching formal teacher education programmes, to both pre-service and in-service teachers. Greater involvement of physicists in teacher education and professional development will lead to greater understanding of subject matter amongst teachers, as well as greater appreciation amongst physicists of the background of incoming students at university level.

In order to stimulate interest and nurture talent in physics amongst pupils, the SAIP has been working with DST to establish a physics olympiad. In 2009 it will be written by a subset of pupils writing the more general science olympiad. In the future there are plans to expand participation and performance in the physics olympiad by offering training camps.

South African physicists have conducted research in physics education for more than 30 years. In the 1970s and 1980s, much of the research focused on students' alternative conceptions and reasoning difficulties, in line with international physics education research at the time. In the 1990s there was a strong political and social imperative to provide access to science degrees for students who came from economically and educationally disadvantaged backgrounds. Several universities created programmes that extended the BSc degree by one year and included additional components to help overcome gaps in students' background knowledge and to explicitly develop their cognitive and metacognitive skills. A great deal of research was carried out during this time by physicists specialising in physics education research. The impetus behind much of the research in physics education was to identify obstacles to success for students in foundation programmes and interventions to overcome them. This led to research focused on students on the one hand, and the learning environment on the other. The research topics encompassed the identification and evaluation of appropriate curriculum elements for foundation and extended courses; the interplay between language and conceptual understanding (the great majority of South African students study in a language that is not their mother tongue) and between writing and learning; the effect of metacognition on enhancing learning; student understanding of the nature of scientific measurement; strategies for enhancing problem-solving skills; and effects of peer-group learning. The research has yielded insights into aspects of curriculum, teaching approaches and student learning environments that can lead to more effective physics learning.

Today, most universities in South Africa provide some form of foundation physics course that is offered as part of an extended BSc degree. These courses are intended to provide access to university science-based degree programmes for students who have been academically disadvantaged. Over the past two decades, physics education research led to the identification of key concepts, cognitive skills, mathematical tools and philosophical elements that need to be explicitly incorporated into physics curricula at the foundation and introductory levels. Physics education research continues to inform the design and development of the content, philosophy and teaching approaches for these courses. In several universities, this research is also influencing the content and teaching approaches in the introductory courses, including the design of introductory laboratory work.

A few studies have also been carried out over the years on physics teachers. Such studies have identified teachers' conceptual difficulties, which are likely to be passed on to students. Others were about the relationship between teachers' content knowledge, teaching approaches and professional attitudes.

A more recent line of research involves the relationship between indigenous knowledge and traditional physics. This is aimed at identifying aspects of indigenous knowledge that can be directly related to physics concepts and then incorporation into physics curricula. It is hoped that the effect will be to both preserve indigenous knowledge and to help students value it. Furthermore, the use of local contexts may make the physics concepts more accessible to students.

3.8 LASERS, OPTICS AND SPECTROSCOPY

South Africa has a long history of optical spectroscopy, and it continues to be an important field in the country, both as a tool and in terms of fundamentals. Examples are the research undertaken at the NPRL of the CSIR and at SU and UKZN (Pietermaritzburg campus). This expertise led to South Africa being an early adopter of laser technology, the first lasers being built in the 1960s at the NPRL and at UKZN. Despite this early introduction, there was little activity in photonics in the country until the early 1980s, when the AEC started investigating the process of Molecular Laser Isotope Separation (MLIS) as an alternative to the ubiquitous centrifuge technology for uranium isotope separation for enrichment. This required a large investment in laser and photonic technology in terms of both infrastructure and equipment, as well as in competency. It is estimated that several hundred millions of Rands were spent on this chimera.

South Africa is often praised for its voluntary halting of all nuclear enrichment programmes, but this left the photonics community in South Africa in a quandary, when in 1997 the MLIS programme, with a staff of more than 300 well-trained scientists and technicians, and an estimated R20 million worth of laser and photonic equipment, was terminated. Interventions from the SAIP with the then DACST led to the inauguration of the NLC in 2000, but more importantly, a nationally co-ordinated programme (Rental Pool Programme) to promote lasers, optics and spectroscopy in South Africa.

The outreach activities of the SAIP lasers, optics and spectroscopy (LOS) specialist group members, together with that of the Rental Pool Programme, has seen photonics in South Africa enjoy significant expansion from 1998 onwards. Technical, scientific and infrastructural support has meant that any university in South Africa can now consider photonics research regardless of lack of experience or equipment. This approach has seen photonics adopted across disciplines, whereas previously it was predominantly the domain of physicists, and has seen the LOS group become one of the largest and most active in the SAIP community. There has been a concomitant increase in publication outputs and student involvement in photonics research, with four of the research chairs appointed in photonics: photonics, ultra-fast and ultra-intense laser science (SU); quantum information processing and communication (UKZN); medicinal chemistry and nanotechnology (RU); and nanophotonics (NMMU). The main research centres in photonics are concentrated at the NLC and SU, where both basic and applied research is undertaken in a wide range of fields, including a growing activity in ultrafast science. Extensive application of photonics is to be found at other institutions such as Wits (materials), UJ (biology), UKZN (quantum optics), NMMU (fibre optics and photonic materials) and RU (chemistry).

The extension of activity into the rest of continental Africa is strong and well-focused, with the recent establishment of the African Laser Centre which currently has 19 partner countries and the growth of which is set to continue.

Photonics is one of the fastest growing technology fields worldwide; for the first time, in 2005, worldwide revenue from photonics exceeded that of microelectronics, heralding the so-called 'century of the photon', where photons are mooted as the electrons of the 21st century. This is apparent in everyday life, where photonic components are steadily replacing electronic components (such as communications over fibre optic instead of copper wire). The DST strongly supports laser research in South Africa, identifying it as an important emerging research area and one in which it is believed that researchers in South Africa have the potential to contribute to leading-edge global knowledge.

Ten years since the small LOS community established the NLC, the members (now numbering about 70) have again mobilised to take photonics into the future through the Photonics Initiative of South Africa (PISA). Offered as a direct intervention for flagship-type programmes as suggested in the 'Shaping the Future of Physics in South Africa' report, PISA has presented to DST a strategy for photonics in South Africa involving a R700 million investment in photonics over a five-year period, starting in 2009. PISA aims to position South Africa as a globally competitive player in photonics by strengthening human capital development, investing in pure and applied photonics research, and fostering a national photonics industry.

3.9 NUCLEAR, PARTICLE AND RADIATION PHYSICS

Since the advent of democracy in 1994, many collaborative research partnerships have been established with other countries in the fields of nuclear, particle and radiation physics. Many efforts, both experimental and theoretical, are underway in South Africa and abroad, with the overall goal being the production of a cohort of skilled, dynamic young scientists who reflect the full diversity of South Africa's population. Some of these initiatives are discussed below.

In collaboration with a considerable number of South African universities, accelerator-based academic and applied nuclear research is carried out at the Cape Town and Gauteng sites of iThemba LABS, at Necsa, and at UP. This represents a substantial research infrastructure that is a key asset to the country as it seeks to develop the skills required by the nuclear power and medical industries, as well as delivering other potentially beneficial spin-offs.

In the Cape, iThemba LABS makes use of its two main accelerators, namely the K=200 Separated Sector Cyclotron (SSC) and the single-ended 5MV Van de Graaff. The SSC produces 200 MeV protons for research and proton therapy, up to 250 μA of 66 MeV protons for isotope production and neutron therapy, and a wide range of ion beams from ^{3}He to ^{136}Xe for academic research. A new 'beam-splitter' has been installed so that high and low-current production of radio isotopes can be carried out simultaneously. In addition, new electron cyclotron resonance ion sources are currently being installed to enhance the opportunities for cutting-edge academic research. The challenge remains as to how best to divide the SSC accelerator's beam-time between the nuclear power and medical sub-disciplines. Clearly, the only long(er) term viable solution would be to have dedicated accelerators for the medical and isotope production functions, which would free the SSC to be used exclusively as a research tool.

Of the suite of smaller accelerators, the 5 MV van de Graaff at iThemba LABS South is mainly used for materials, nanoscience, geological and biological research. The accelerator located at the iThemba LABS Gauteng site is a 5 MV EN tandem which has recently been refurbished by grants from the DST. Currently, some of the equipment required for a commercial service for Atomic Mass Spectrometry (AMS) is being installed for ^{14}C dating and the studies of many trace materials. There is also apparatus for materials and nuclear research. The major facility at Necsa is the SAFARI reactor with a variety of thermal neutron beams and activation facilities. UP has a 1 MV single-ended Van de Graaff accelerator, used mostly for implantation and channelling studies.

The largest investment in human and technical capital in pure nuclear physics research in South Africa resides at iThemba LABS in the western Cape. A long-standing collaboration with the Research Centre for Nuclear Physics RCMP in Osaka, Japan, has resulted in the very large magnetic spectrometer at iThemba LABS becoming one of only two spectrometers in the world to achieve an energy resolution of better than 20 KeV for protons above 100 MeV. This has produced the first measurements of the fine structure in giant dipole resonances, measured with inelastic proton scattering, in a collaboration including Wits and the Technical University in Darmstadt, Germany. The latter study has made use of wavelet analysis in which different energy-scales of the fine structure of the GDR can be uncovered. The use of the spectrometer in the operationally challenging, but scientifically rewarding zero-degree mode has recently been harnessed over an extended running period. Such measurements will become more common if the applied and medical applications of the iThemba LABS SSC are moved onto dedicated accelerators.

The 'African Omnipurpose Detector for Innovative Techniques and Experiments' (AFRODITE) gamma-ray spectrometer at iThemba LABS South is amongst the ten most powerful instruments in the world for the investigation of the quantum structure of nuclei. These spectrometers can be used in a wide variety of experiments, often in conjunction with additional specialised detectors. Many experiments have been carried out using AFRODITE, including collaborative measurements with physicists from Australia, Bulgaria, China, France, Hungary, Italy, Sweden, Slovenia, Turkey, and the UK. For example, there is a formal collaboration with the ATOMKI Institute in Debrecen, Hungary, under the auspices of a governmental bilateral agreement. This has resulted in the ATOMKI DIAMANT array of charged-particle detectors being available for experiments with AFRODITE. Both AFRODITE and DIAMANT are in the process of being connected to a state-of-the-art 'triggerless' data-acquisition system. These developments, along with the in-progress procurement of the first high-volume, highly segmented TIGRESS-type clover germanium detector will boost the detection sensitivity for the study of weakly populated structures of significant and cutting-edge physical interest. Of particular relevance to this is the desire to study exotic nuclear species with large neutron excesses which can be produced in the fragmentation of intense, fast beams of stable nuclei. Such beams will be available from the new Grenoble Test Source (GTS) electron cyclotron resonance ion source which is under assembly at iThemba LABS.

There is a formal agreement with the Joint Institute for Nuclear Research (JINR) at Dubna in Russia, where South African physicists have joined in experiments within the associate membership framework. Tangible benefits to the nuclear physics infrastructure in South Africa have resulted from this membership, both in terms of knowledge sharing and technological developments.

A number of world-leading projects in particle physics are underway at the European Organisation for Nuclear Research (CERN) in Switzerland to which South Africa makes significant contributions. Recently, a South African team successfully tested their software for the fast di-muon trigger of the ALICE (a large ion collider experiment) detector on the Large Hadron Collider.

Sources of positrons from 22Na, manufactured by the radio-nuclide production group at iThemba LABS, have been used to produce anti-hydrogen at CERN. UCT is a world-leader in the application of thermodynamic approaches to understanding the properties of the Quark Gluon Plasma (QGP) that is thought to be produced by the collisions of very energetic heavy nuclei. A group at UJ is taking part in the ATLAS (a toroidal LHC apparatus) experiment, which is aimed at obtaining a definitive determination of the mass of the Higgs particle.

The Centre for High-performance Computing (CHPC) in Cape Town is an important facility that grew out of a physics proposal in this specific field. Most of the flagship projects that are listed in their brochure are physics-based. It obviously has a much broader user base, and it is another example of DST investment in S&T infrastructure.

3.10 THEORETICAL PHYSICS

Theoretical physics has a long and productive history in South Africa. The first formal structure to promote research and training in theoretical physics was created in 1974 at the founding meeting of the Organisation of Theoretical Physics (OTP). A committee was elected, with CA Engelbrecht elected as the chair, and thereafter re-elected every year until 1989. In the first year, 35 members joined the organisation, and within a few years it grew to about 60 members, which then included staff and students from all universities. The first success of the OTP was in 1976 when the CSIR president, C van der Merwe Brink, agreed to sponsor a regular summer school series through which theoretical physicists and university students could become acquainted with important developing areas in modern physics. After the death of Engelbrecht in 1991, the OTP felt that it was appropriate to name this summer school series after him as initiator of this initiative. The Chris Engelbrecht Summer School series, later sponsored by the NRF, has become known internationally, and has attracted numerous high-profile lecturers, including a number of Nobel laureates. (A list of previous summer schools can be found at http://www.nithep.ac.za.)

Another initiative of the OTP was a series of theoretical physics seminars. From the inception of the OTP in 1974 until 1980, this annual series became the major organised activity of the OTP. It obtained official status within the SAIP, and in the annual SAIP conference programme a dedicated session was established for these OTP seminars.

The April 2004 report on 'Shaping the Future of Physics in South Africa' contained among its recommendations the following: "The state of theoretical physics is characterised as internationally competitive in some areas, but there is fragmentation and a coherent policy is needed. We recommend the establishment of a national theoretical physics facility (either real or virtual); the theoretical physics community will then be able to respond nimbly to national science policy initiatives."

The theoretical physics community was able to respond quickly, and in July 2004 a working committee was elected to draft a formal proposal in response to this recommendation. In consultation with the broad community of stakeholders in theoretical physics, consensus was reached that the model of a geographically distributed National Institute for Theoretical Physics ('hub-and-spokes' model) would best serve the needs and interests of the physics community. In a proposal to DST and NRF in November 2004, and formally endorsed by the SAIP council, it was accordingly recommended that NITheP (the National Institute for Theoretical Physics) be established with its main centre at the Stellenbosch Institute for Advanced Study (STIAS), and with regional centres at Wits and UKZN. This proposal was formally approved by the DST and NRF in February 2006. Finally, in April 2008, after an interim phase in which progress was monitored by a management committee, the first full-time director, FG Scholtz, five full-time researchers and a number of postdoctoral fellows were appointed.

The inauguration of NITheP at STIAS took place on 13 May 2008 with Minister M Mangena of the DST delivering the opening speech. The inauguration was attended by Stephen Hawking, who gave a personal message of support, as well as by Nobel laureates David Gross and George Smoot.

NITheP is now firmly established and is earmarked to become a national facility in the near future. It supports around 90 postgraduate students in theoretical physics and closely related fields, and has around 30 associate members from all South African tertiary institutions. NITheP aims to create a national, African and eventually international network of researchers that will drive research and training in theoretical physics in a coherent and sustainable way throughout South Africa and Africa.

Currently, the main research thrusts in the South African theoretical physics community, which are also reflected within the NITheP network through researchers and associates at various universities, are in the broad fields of statistical and condensed matter physics (SU), fundamental high-energy physics and classical and quantum gravity (Wits and UCT), quantum computing and information (UKZN), high-energy phenomenology (UCT and Wits), cosmology and astrophysics (UCT and UKZN), space plasma physics (UKZN), and computational physics (UL, UP and Wits).

More information on NITheP's structure and activities are described at http://www.nithep.ac.za.

3.11 ASSESSMENT AND THE FUTURE

The discipline of physics and astronomy in South Africa is clearly healthy, and core to the National System of Innovation. From a slow and sometimes uncertain start 15 years ago, the physics community has learned how to focus on the needs and the expectations of the new democratic South Africa, and how to build on the existing S&T infrastructure. The government underscored the importance of this infrastructure with its strong and sustained investment in new equipment and opportunities such as telescopes, analytical equipment, research chairs, centres of excellence, new national institutes and interdisciplinary science and technology facilities. This has already had a significant effect, most notably in the increase in the number of practising physicists, as reflected by the rapid growth of SAIP membership and the annual conference attendance. The age of this membership has dramatically reduced due to the increase in the number of postgraduate students, and the demographic balance amongst these students is becoming more fully representative each year.

The challenge for the future is twofold. The mission statement of the SAIP is to be the 'voice of physics in South Africa', and through its list of initiatives, it finds itself in a continuing learning curve of how to stimulate the subject. The much bigger challenge is the poor state of science and mathematics teaching in many secondary schools, leading to too few entrants at the tertiary level, thus threatening the long-term sustainability of the basic sciences. The science and mathematics communities are continually addressing this challenge, but a much larger intervention at the national level is needed.