Institution: University of Cambridge

Unit of Assessment: UoA 8: Chemistry

a. Overview

Chemistry in Cambridge aims to support fundamental science of the highest quality in a first class physical environment. The Department includes a large number of internationally recognised research groups covering an exceptionally broad spectrum of chemical science. Our enthusiastic research culture embraces new challenging areas, including strong collaborations with other academic disciplines and institutions, while maintaining a powerful presence in the traditional core areas of chemistry. We attract substantial research funding from many sources in the UK, Europe and globally, including Research Councils, charities, the European Commission and industry. Transformational technological developments that originated from the Department include Solexa gene sequencing and Astex's fragment-based drug discovery.

The UoA hosts around 200 postdoctoral research staff and over 250 postgraduate students, a slight increase from the 2008 RAE. This submission covers a wide range of staff, including 9 Fellows of the Royal Society, 5 Fellows of the Academy of Medical Sciences, research fellows and newly independent researchers.

The Head of Department and Chair of the Senior Management Team is Daan Frenkel, with Jane Clarke and David Wales as Assistant Heads. Steve Ley is Chair of the Research Strategy Committee. The Head of Department reports to the Head of the School of Physical Sciences (Jeremy Sanders 2009–11, Rob Kennicutt 2011-present). The Department's research structure is now organised around five Research Interest Groups (RIGs) described below, whose role is to formulate, support and deliver research strategy.

Examples of our discoveries that have transformed their fields of research, changed public perception or have been translated to products or tools that benefit society include:

- Elucidation of the mechanism of amyloid aggregation (Knowles/Dobson).
- Demonstration of the biological relevance of G-quadruplexes (Balasubramanian).
- Opening of new synthesis routes based on novel C-H bond functionalization (Gaunt).
- New quantum chemistry based on Slater-determinant quantum Monte Carlo (Alavi).
- Exact quantum transition-state theory (Althorpe).
- A method for sequencing which includes epigenetic modification (Balasubramanian).

b. Research strategy

Achievement of strategic aims since 2008

In the 2008 RAE the Department identified **materials, energy and sustainability**, **medicinal chemistry**, and **atmospheric science** as areas of strategic importance for future investment.

To strengthen research in **materials, energy and sustainability**, we have made major investments to recruit Clare Grey (2009), a recognised world leader in the use of solid state nuclear magnetic resonance, to the Moorhouse-Gibson Professorship to study structure and function in inorganic materials (FRS 2011). We have also recruited Erwin Reisner (Lecturer 2010), who works on the harnessing of solar energy to convert water and carbon dioxide catalytically to hydrogen and carbon monoxide, and Stephen Jenkins (Lecturer 2009) to strengthen our research in surface science and catalysis. In 2013, we appointed Oren Scherman, who works on non-covalent polymers, as Director of the Melville Laboratory. Silvia Vignolini will join the Department in December 2013 to work on photonics and biomaterials. Other staff also contribute increasingly to materials and sustainability research, transforming our inorganic practice.

Chemical biology and medicinal chemistry was strengthened by the appointment of Shankar Balasubramanian to the Herchel Smith Professorship of Medicinal Chemistry (joint with the Clinical School 2008), who explores the fundamental chemistry and biology of cancer (FRS 2012); Jason

Chin (2010), whose goal is to re-programme the genetic code to produce new molecules and materials *in vivo* (part-time post in Chemistry to promote cross-fertilisation with the MRC Laboratory of Molecular Biology); and Lucy Colwell (2013) to focus on data analytics, particularly as applied to biological or medical systems. Other key appointments in the Chemistry of Health area are Tuomas Knowles (Lecturer 2010; Reader 2013), who develops physical chemical techniques to probe the early stages of protein aggregation, Andreas Bender (Lecturer 2010), an expert in molecular informatics, and Peter Bond (Lecturer 2010), who performs large-scale simulations of medically important drug targets.

Our commitment to **atmospheric science** was demonstrated by recruiting Markus Kalberer (2008) as a Lecturer (now Reader in Atmospheric Science), whose research focuses on atmospheric aerosols, including their health effects; and the award to Neil Harris of a NERC Advanced Research Fellowship (2010) for his work on the atmospheric chemistry of the tropics, supplementing the work of John Pyle (appointed to the 1920 Chair of Physical Chemistry in 2007), one of the world's most respected chemistry-climate modellers.

Strategic aims and goals for research 2013-2018

Looking to the future, our **Research Strategy Committee** identified the need for an assessment of research strategy, and in 2012 invited an external **Scientific Advisory Panel** (SAP) to review the Department's research portfolio and strategic vision. The SAP, chaired by Michael Klein with representatives from both academia and industry, will continue to review our strategy biennially, which will help us to continually evolve and refine the direction of research in the Department.

As a result of the first SAP review in 2012, we have identified **three strategic collaborative research areas** that unify the development of research within the Department:

- **Chemistry of Health** aims to advance the understanding of health and disease in a number of areas that are of global importance: these include ageing, cancer and infection.
- **Sustainable Energy, Environment and Climate** aims to increase understanding of impact of chemical processes on the environment and to develop sustainable energy systems.
- **Innovative Molecular and Materials Design** aims to transform the development and assembly of important functional chemicals to produce new high-value products that will lead to novel applications in health care, agriculture, energy and consumer products.

In order to underpin our fundamental research base, we have recruited (to arrive in 2014) Chris Hunter FRS, as successor to Sir Alan Fersht FRS in the Herchel Smith Chair of Organic Chemistry. This appointment will reinforce our leadership in physical organic chemistry and provide fundamental underpinning science relevant to synthesis, biology and materials science.

To promote collaborative research, we have re-organised into five **Research Interest Groups** (RIGs). Most staff participate in more than one RIG; this interaction benefits research in all the groups. The RIG Chairs are members of the Research Strategy Committee and thus contribute to higher level research strategy, providing feedback from group members. All RIGs have their own web page that sets out their research plans, recent publications and members.

Biological RIG

Senior members: Jackson (Chair), Abell, Balasubramanian, Barker, Bender, Bernardes, Bond, Chin, Clarke J, Colwell, Dobson, Duer, Fersht, Gaunt, Glen, Klenerman, Knowles, Lee, Leeper, Ley, Reisner, Spring, Vendruscolo, Wales.

Bio-related research in the Department spans the full range from chemical biology to molecular and cellular biophysics. Our aim is to contribute novel tools (characterization, modelling and chemical intervention) to the life sciences e.g. research into protein aggregation, protein folding, epigenetics and various methodologies for drug discovery. Conversely, we aim to introduce tools from the life sciences into chemistry e.g. synthesis of unnatural proteins. Our research is well integrated with biology and medicine via collaborations within and external to Cambridge. Areas of research that support the Department's strategic collaborative research aims are:

- The study of protein folding and misfolding. Key objectives are to elucidate the pathogenic

action of misfolded proteins and to help develop intervention strategies.

- The synthesis of small bioactive molecules using structure-, fragment- and in silico-based design, to probe biological mechanisms and therapeutic targets. A key objective is the exploration of bioorthogonal chemistries for bio-imaging.
- Novel synthetic biology for the creation of modified proteins.
- The development of techniques to detect and characterize proteins, metabolites and nucleic acids (including epigenetic modifications) in living systems. This research focuses on the development of new microfluidics systems and chemical and physical tools for imaging and characterization. A specific aim is to design and build a 3D super-resolution single molecule microscope for cellular imaging with a resolution of 20 nm in all three dimensions.

In order to achieve these objectives, and to further the Chemistry of Health research theme, the Department is fundraising to invest £20M in infrastructure, and has recently recruited Lucy Colwell, a specialist in bioinformatics, and is hosting Gonçalo Bernardes and Steven Lee as Royal Society URFs.

Materials Chemistry RIG

Senior members: Grey (Chair), Bampos, Barker, Clarke S, Duer, Elliott, Frenkel, Jefferson, Jenkins, Jones W, Ley, Nitschke, Reisner, Scherman, Sprik, Wales, Wheatley, Wood, Wright.

One clear trend in chemistry is the integration of synthesis and materials design. Focus areas include the design and characterization of novel structures by self-assembly, the design and characterization of materials for chemical energy storage and conversion, solar fuel production and the structural biology and/or materials chemistry of mammalian tissues and pharmaceutical solids. The Melville Laboratory for Polymer Synthesis aims to explore novel macro-molecular materials with applications in a wide range of disciplines, ranging from conservation science to medical science. As part of the strategy to strengthen the industry/academia interface in the area of sustainability, the new £63M inter-disciplinary Maxwell Centre, supported by the Research Partnership Investment Fund, will be constructed in the coming two years. Part of the space in the Maxwell Centre has been allocated to our collaborative research projects. In order to broaden the scope of our innovative materials chemistry, the Department has recruited a lecturer (Vignolini) in the area of photonics and biomaterials. We aim to strengthen the physical infrastructure that will be required for this and our wider material research activities by building a departmental materials characterization facility, housing a broad range of instrumentation.

Physical Chemistry RIG

Senior members: Pyle (Chair), Clarke S, Elliott, Grey, Harris, Jefferson, Jenkins, Jones W, Jones R, Kalberer, Klenerman, Knowles, Lee, Scherman, Taraskin.

Our research will focus on the development of new physico-chemistry tools and techniques that are relevant to the key strategic research aims and have huge societal relevance ranging from climate change to DNA sequencing and neuro-degenerative diseases. Understanding atmospheric chemistry change on scales from the local, where we are developing high density, low cost measurement networks, to the global, is a key research area. We have a particular focus in the tropics, where we have extensive local collaborations, with projects in the tropical rain forest and a joint NERC-NSF-NASA project exploiting the high-flying Global Hawk drone. In the coming years, the Department aims to support the Physical RIG in strengthening its role in the National Centre for Atmospheric Science by appointing a lecturer, co-funded by NCAS, in the area of atmosphere modelling. We aim to establish a multi-disciplinary Centre for the physico-chemical characterization of greenhouse gases and we are fully engaged in the £3.3M Cambridge British Antarctic Survey Innovation Centre. Another important research focus will be the extension of single molecule microscopy and spectroscopy techniques, originally developed for the sequencing of nucleic acids, to the study of protein molecules in highly heterogeneous complexes. Knowles has just received an ERC starting grant that will enable him to develop micro-fluidic based tools to probe (*in vitro*) the early stages of protein aggregation diseases. Our collaboration with Castrol will be a key component development in our surface science research. The 1920 Physical Chemistry Chair will become vacant in 2018, opening up the opportunity to explore new directions.

Theory, Modelling and Informatics RIG

Senior members: Glen (Chair), Alavi, Althorpe, Bender, Booth, Bond, Clarke S, Cohen, Colwell, Elliott, Frenkel, Goodman, Grey, Jenkins, Pyle, Sprik, Taraskin, Thom, Vendruscolo, Wales.

Strategy in this area is based on the dual realisation that all aspects of chemical research have become more data intensive and that better predictive tools are needed to guide experiments. As modelling spans many different fields, Chemistry has taken the initiative to establish the multi-department Lennard-Jones Centre for Computational Materials Science. This provides a unified structure for interactions with industry and for training in new computational-science tools. We have therefore moved towards a closer integration of model building, simulation and data mining with experiment. One research aim is to capitalise on the breakthrough achieved in Slater-determinant quantum Monte Carlo and in quantum rate theory. Lines of research that offer exciting links with experiment are the modelling of complex self assembly and the *ab-initio* modelling of redox reactions. Much of the molecular informatics research is organised in the Unilever Centre, directed by Glen. In 2014, our current agreement with Unilever ends, allowing the Department to diversify its activities in this area. As a strategic commitment, the Department has made two key appointments (Bender and Colwell) in molecular informatics, cheminformatics and data analytics. The 1968 Chair will provide a recruitment opportunity in 2018.

Synthetic Chemistry RIG

Senior members: Gaunt (Chair), Barker, Balasubramanian, Bampos, Galloway, Goodman, Ley, Leeper, Longbottom, Nitschke, Paterson, Reisner, Sanders, Scherman, Spring, Wheatley, Wright.

The focus of chemical synthesis in the Department has changed to developing novel methodologies, both at the instrumental level (flow synthesis of new classes of compounds) and through the discovery and development of novel chemical functionalities. Catalysis research will be at the heart of our vision in the next five years, through the Centre for Transformative Catalysis for Molecular Synthesis – a strength of this Centre will be its strong links with research that will be carried out in the biological, materials and modelling areas and will involve a series of joint workshops with industry. The research in this Centre will enable us to develop new strategies for C-H bond activation, enantioselective catalysis, the conversion of renewable resources to new feedstocks and fuels and for energy-efficient synthesis routes. An important line of research aims to combine the power of chemical and biocatalysis, both in the context of biomedical research and in the area of sustainable energy, to develop sustainable chemical synthesis that avoids toxic by-products. We plan to make both a senior (BP Chair) and Lecturer appointment in synthesis over the next five years.

c. People, including:

i. Staffing strategy and staff development

Relation of staffing strategy to research strategy and physical infrastructure

The RIG Chairs meet regularly with their members to discuss research progress and strategy. As members of the **Research Strategy Committee**, the Chairs use this feedback when considering how their research goals, in conjunction with the three strategic collaborative research areas, can be supported through staff recruitment. These discussions consider the advice of the Scientific Advisory Panel, and the wider strategic goals of the University. The RIGs' strategic recruitment plans are discussed in the RIG paragraphs above. Relation of staffing strategy to **infrastructure** is discussed in Section D.

Chemistry has also developed its own **Next Generation Fellowship Scheme**, which has proved a successful strategy for recruiting—and keeping—the most talented young researchers. In this scheme, donors provide £250k over five years as a start-up package for **early-career academic staff**. Since its inception in 2006, Robinson (now in Oxford), Gaunt, Scherman, Nitschke, Spring, Klenerman, Knowles and, most recently, Vignolini, have all been recipients of NGF awards.

We train, develop and encourage researchers to move into important positions: over a dozen Royal Society, EPSRC and BBSRC Research Fellows have moved to academic roles in the UK, Netherlands, and the USA during the REF period. Numerous college research fellows have

followed a similar path.

We host around 40 independently funded research fellows who are not on the payroll and who have gained prestigious personal awards through open competition. Additionally, during the REF period, 14 people have been awarded Royal Society URFs or Research Council Fellowships. We are proud to host 8 to 10 new Marie Curie individual fellowships annually.

Academic staff

We aim to enhance the personal development of all staff, through programmes such as the University's **Emerging Leaders Programme, Career Management Programme**, and the **Senior Leaders Succession Programme**. Other leadership training is also available to all staff, including staff with senior roles in the Department and the University. Additionally, the **Pathways in Higher Education Practice** is a University scheme that offers personal, flexible orientation and professional development during the probationary period of **newly appointed lecturers**. We also offer a **sabbatical leave** scheme to academic staff, which provides one term sabbatical leave on full pay for each 6 terms of service.

We are committed to promoting the career development and progression of all academic staff. Senior colleagues have moved on to major roles elsewhere, notably Robinson to Oxford and Huck to Nijmegen, as a result of the career development opportunities provided by Cambridge.

The University's annual promotions exercise is a highly structured competitive exercise, and promotion requires demonstration of a significant international research reputation, based on objective criteria and strong external support. The Head of Department meets individually with those eligible for promotion to explain the criteria and provide help throughout the process. Final decisions are made by a Committee chaired by the Vice-Chancellor. The international reputation of the Department's academic staff is demonstrated by the success of its staff in earning promotion: over half hold professorships (mostly personal chairs), and several hold personal readerships.

Additionally we provide leadership training to **early career researchers** through **Cambridge Personal and Professional Development,** and we offer both **Management** and **Leadership** training (developed by Chemistry in 2013) to younger academic staff to help them build successful research groups. All academic staff are offered **mentors** on appointment.

Research staff

In 2012 postdoctoral research workers became the largest staff group in the University (now over 37%; in Chemistry they are 57% of staff). In response to this growth the University has embarked on a major property development in **North West Cambridge**, with Jeremy Sanders (Pro-Vice-Chancellor) as the lead academic. In the first £300M phase, due to open in 2016, high-quality and sustainable housing will be provided for over 500 postdocs and their families, together with retail and social facilities, homes for 300 graduate students and also private sector housing. In addition, the University has created the new role of **Director of Postdoctoral Affairs**: the first Director, Chris Abell (Chemistry) will coordinate and develop strategy for the entire postdoctoral community, spearhead fund-raising for further North West Cambridge facilities, and act as an advocate for postdocs in the governance machinery of the University. The aim is to transform the postdoctoral experience across the University. Also see below (**(ii) research students**) for details on the University's **Researcher Development Programme**.

A new Departmental **Post Doc Affairs Committee** (PDAC) acts as a forum to consider issues of importance to postdocs in the Department. PDAC's remit includes: employment (contracts, probation, mentoring, redundancy, maternity/paternity rights, etc.); dignity at work and equality; welfare (induction, safety training, access to support services); training (on-the-job training, availability and suitability of training courses, training for supervisory roles taken on within research groups); career development (review, career advice and mentoring); staff review and development; and representation and communication within the Department, for example, they represent postdocs at the staff management committee and on the Athena SWAN working party. This Chemistry initiative has been emulated by many other Departments in the University.

Career Development Support for Researchers and Implementation of the Concordat

To consolidate our efforts to provide a vital and sustainable working environment, in 2010 we appointed Jane Clarke to the new position of **Assistant Head of Department,** with responsibility for staff management issues. She chairs the Department's **Staff Management Committee**, which monitors and reviews our HR policies to ensure excellence in recruitment, support and development. All categories of staff, including assistant staff and early career researchers, are represented in the committee and contribute to decision-making.

We have streamlined recruitment procedures and given recruitment training to all PIs. We are now in the process of collecting data to ensure that our practices are fair and transparent - we will pay close attention to the results of this exercise, and we have the flexibility and commitment to make any changes deemed desirable. We have also developed a new induction programme for all staff, who can additionally access a wealth of information on-line, including information on pay scales, guidance on progressing through pay grades, and clear role descriptions.

All our planning for recruitment and development is guided by the principles of the Concordat to Support the Career Development of Researchers, and supported by both University and Departmental initiatives. We have a School-based HR advisory team provided by the University, and advisors from the **Cambridge Personal and Professional Development** and **Careers Services** attached to the School of Physical Sciences. The University has been awarded the "HR Excellence in Research" badge by the EC, for fostering good working conditions and career development for researchers.

All researchers have a structured probationary period with support provided to both researchers and supervisors to make it successful, and with a clear framework for induction, probation and appraisal developed through the University's **Employment and Career Management Scheme** (implemented in 2011). We have also introduced a new, custom-adapted, **Career Development Review** (CDR) procedure, with reviews held yearly for all contract researchers and biennially for academic staff.

Equality and diversity

The Department is proud of receiving the **Athena SWAN bronze award** in April 2013, but is not complacent, and we have a working party actively addressing the actions required to achieve a Silver award before the end of 2015. The University's **Athena SWAN bronze award** was renewed in 2013; it is also aiming for a Silver award before the end of 2015. As part of our Athena SWAN initiative, we have formalised our **family-friendly working practises.** For example, we have policies to allow flexible or part-time working, and departmental events take place within core office hours, to make it easier for those with parental or caring responsibilities to attend. Staff can also access the University's newly introduced **Returning Carers Scheme** - open to both men and women - which provides grants to individuals returning after periods of parental or carers' leave, to facilitate their return to research.

We place great emphasis on all aspects of equality and diversity, and promote the **Dignity@Work** policy to all new staff, which sets out University procedures for dealing with harassment, bullying and other inappropriate behaviours, and has specialist advisors. In 2009 the University appointed **3 Equality Champions** (around Gender, Disability and Race) to provide leadership in equality and diversity matters and support the **University Diversity Networks**. We have pushed strongly for all staff to complete the University **equality and diversity on-line training modules,** which have already been completed by all members of the Senior Management Team, all chairs of appointments panels and the REF UoA team. The University's Personal and Professional Development team also run two **gender-specific staff and graduate student training programmes**: Springboard for women and Navigator for men.

The University has a number of other major initiatives on gender led by Jeremy Sanders as PVC: the **Women in Science, Engineering and Technology Initiative**, which supports women from undergraduate through to professorial level in Cambridge, and includes a CV-mentoring scheme; a new **Senior Gender Equality Network** to support the advancement of gender equality; considerably more generous maternity/paternity/adoption leave provision than required by law; and the **Returning Carers Scheme** mentioned above.

In 2012 the University won the **Employee Engagement Award** from the Employers Network for

Equality and Inclusion, and in 2012 and 2013 the University was ranked 11th on the **Stonewall** Top 100 Employers workplace equality list, the highest for any UK HEI. The University won a number of other awards (2011-2013) for engaging and working with staff.

To ensure accessibility to all, we have added a wheelchair lift to the front door (2012) and accessible card readers to all doors. We make sure that any staff or students who have a disability know that they can be assessed by the University's **Disability Resource Centre** (DRC), who then liaise with us to help us accommodate any special needs. The DRC also lends specialist equipment, and coordinates the University's network of **Departmental Disability Liaison Officers**, who provide information about disability to staff. We also provide information to students and staff about the University's **Occupational Health** service, which promotes the physical and mental well being of staff, and provides a free counselling service to University staff.

International staff appointments

The Department hosts a very large array of international scientists. Many of the 70 or so post-doctoral researchers and research fellows appointed every year are recruited from outside the UK. Approximately 25% of appointments are British, 45% from elsewhere in the EU, and 30% from outside the EU. Since 2008, we have been fortunate in recruiting the following high calibre academic staff from outside the UK: Grey (Stony Brook, USA); Kalberer (Paul Scherrer Institute, Switzerland); and Bender (University of Leiden).

We benefit enormously from many visiting overseas academics. As well as numerous ad hoc visits, the Department has an endowed visiting professorship and a number of visiting lectureships, which enable visiting academics to stay here up to a month, giving lectures and networking with research groups. Holders since the last RAE include:

- *Linnett Professor:* Susan Solomon (Colorado), Peter Wolynes (Rice), Richard Zare (Stanford).
- *Lewis Lecturer:* Fraser Armstrong (Oxford), David Milstein (Weizmann), Daniel Nocera (MIT), Chad Mirkin (Northwestern).
- *BP Lecturer:* Avelino Corma (Valencia), Helmuth Möhwald (MPI Potsdam), Jean-Marie Tarascon (Picardy), Akira Harada (Osaka).
- *GSK Lecturer:* Erick Carreira (ETH Zürich), Michael Krische (Texas).
- *Melville Lecturer:* Samuel Stupp (Northwestern), Dennis Discher (Pennsylvania), Geoffrey Coates (Cornell), Laura Kiessling (Wisconsin), Jeffrey Moore (Illinois).
- *Alexander Todd Visiting Professor:* William A Eaton (NIH, Maryland).

ii. Research students

Quantitative information on admissions and nationality

Over the assessment period the Department admitted annually on average 80 postgraduate students (chiefly PhD students, but also including up to ten research MPhil students per year). Just under 50% of admissions were UK nationals, 17% were from elsewhere in the EU, and 34% from outside the EU. The number of fee-paying PhD and MPhil students (excluding most 4th year and above students) enrolled at the start of each academic year was as follows:

2008/09	2009/10	2010/11	2011/12	2012/13
229	208	232	245	258

A significant proportion of our international students are supported through highly competitive Cambridge-based trust funds such as the Cambridge Gates Trust, Herchel Smith Fund and Oppenheimer Fund, to name just three. These offer either full scholarships (fees and maintenance) or bursaries, which can be combined with other sources of funding. A major part of the University's fundraising over the next five to ten years will be to increase funding opportunities for postgraduate education.

Training and support

We offer a **PhD course** (over 3, 3.5 or 4 years, depending on the sponsor) and a 1-year, research-only, MPhil through our dynamic graduate training programme. In autumn 2013 we appointed a **Graduate Studies Co-ordinator** to support our plans to significantly expand the range and number of graduate courses. The Chemistry Department will also play a major role in several doctoral training programmes commencing in 2014:

- "The Cambridge Earth Science DTP: Multi-disciplinary studies of the solid Earth, its atmosphere, oceans, cryosphere and biosphere," funded through NERC. Chemistry will be involved in all three themes of climate, solid earth and biology, with a leadership role in climate.
- "The EPSRC Centre for Doctoral Training in Computational Methods for Materials Science", which will integrate training across the Physical Sciences and Engineering to create a large cohort of highly skilled computational scientists.
- "The EPSRC Centre for Doctoral Training in Graphene Technology," aligned to the recently established Cambridge Graphene Centre and involving the schools of Physical Sciences and Technology.

We also lead the Graduate Training Programme in Medicinal Chemistry supported by CRUK, and are partners in the EPSRC Doctoral Training Centre in Nano Science and Technology (started 2009) and the BBSRC Doctoral Training Programme in Biosciences (started 2012). These integrated programmes place a great emphasis on multi-disciplinarity, so a key requirement for a student is a willingness to study in a collaborative environment.

The **Departmental Postgraduate Committee** has oversight of all matters concerning postgraduate training, and provides guidance and support to academic supervisors, who have responsibility for reviewing academic performance both formally and informally. The supervisors (with other members of the research team) help students identify their initial training requirements, and guide them to relevant undergraduate lecture courses and research seminars. Additional training needs are discussed at the beginning of each academic year (or more frequently, if needed) as the student progresses and research broadens. Training can also be given in project-based technical skills in other University departments, labs of collaborators or external workshops, and there is always an extensive induction course on safety procedures. Research Council-funded students also attend week-long graduate schools.

More formally, PhD students submit a dissertation on their research at the end of their first year, and undergo an oral examination by two academics (other than their supervisor), which gives them an opportunity for oral examination and third party feedback on progress with their research. Supervisors submit a report (which the student may read) at the end of each term to the Department and University. The PhD dissertation is assessed by two examiners, at least one external, who will make a recommendation to the Degree Committee regarding the award of the PhD degree.

The **RIGs** play a key role in postgraduate support and development: all have thriving seminar, conference and workshop series that integrate students, postgraduates and academics. For example, the Materials RIG has an annual "BP day" where BP representatives give prizes to third years for their talks, and second years on their posters. The Biological RIG hosts frequent symposia for student and PI research presentations, accompanied by a forum for research discussions, and organises training for chemists to learn bio-techniques via workshops and lectures. The TMI RIG has established joint postgraduate teaching programmes with a range of other departments, to offer introductory and advanced courses in theory and simulation.

We continue to adhere to recommendations in the Roberts Report, the University's **Researcher Development Programme** having an annual spend of £1.1M. For example, we provide a comprehensive rolling programme of **transferable skills training** for all our graduate students and researchers. This includes Personal Development Planning, a formal process in which students reflect upon their own learning and performance, and plan for their personal, education and career development. Students (as well as other staff) also have free access to the **University Computing Service**, which offers IT training in person and on-line; the **University Careers Service**, which gives careers advice and courses including CV-writing and interview techniques; the **Cambridge Entrepreneurship Centre**, which offers seminars and courses related to entrepreneurship and

business skills; and the **Cambridge University Library**, which offers a Research Skills Programme. The University's **Office of External Affairs and Communications** runs the "Rising Stars" public engagement programme, which offers students training and practical experience in delivering outreach events.

d. Income, infrastructure and facilities

Provision and operation of specialist infrastructure, facilities and investments

The programme of refurbishment for the Lensfield Road laboratories that was started in the late 1990s has continued, with a total investment of over £60M from a diverse range of funders such as SRIF, CIF, the University, the Royal Society, charities, industry and private donors. Our strategic plans for developing laboratory space continue to be considered in conjunction with new academic appointments, because offering modern laboratory space as part of an attractive start-up package is a major element in drawing international stars to the Department.

For example, the appointment of Grey as Moorhouse-Gibson Professor prompted complete transformation of part of the basement into a research centre for new materials, including batteries and other low-carbon applications. A major part of Grey's work involves solid-state NMR and X-ray diffraction techniques; grants from SRIF, the European Commission, the Royal Society and Research Council UK have provided a world-class facility for the characterization of solids. Total investment for the Grey lab amounted to £4.7M. The estimated cost of laboratory upgrading for Hunter's appointment as Herchel Smith Professor of Organic Chemistry is £1.75M, which will be met from University and Departmental funds. We have also expanded the Melville Laboratory for Polymer Synthesis, which now provides a state-of-the-art facility for the development and characterization of novel functional materials.

We have also commissioned a feasibility study to explore the possibilities of refurbishing or replacing our building on Lensfield Road completely within the next 10 to 15 years. This study will allow us to develop an informed strategy for funding and the time frame for completion.

We continue to fund major new pieces of research equipment. For example, through CIF we purchased a 700MHz NMR spectrometer (£1.02M) for research into energy materials, a mass spectrometer (£745k) for the study of the chemistry of atmospheric aerosols and their effect on health, and a £100k equipment start-up package for Knowles. More recently, funds from EPSRC and University central funds have allowed us to upgrade single-crystal X-ray diffraction facilities (£444k) and to strengthen the Department infrastructure in the fields of solution and solid-state NMR spectroscopy (£650k and >£1M, respectively) and mass spectrometry (>£800k).

As well as dedicated equipment based in research groups, our communal facilities promote the efficient use of funds, with the added benefit of encouraging inter-disciplinary research. One example of this is the establishment of the **Centre for Biological Chemistry,** a shared, maintained equipment centre, which is used by all relevant research groups and also serves as a forum for sharing technical expertise. This in turn helps with strategies for planning future equipment needs. A recent grant from the Wellcome Trust of £200k will enable us to start an equipment replacement programme in the Centre.

We continue to support a range of widely used analytical services available to all groups in Chemistry and to other departments. Facilities include 6 (soon to be 7) solid-state (up to 700 MHz) and 11 solution-state (up to 700 MHz) NMR spectrometers, mass spectrometry (7 systems for general access, with a further two being purchased, along with more than 12 systems held by individual research groups), X-ray diffraction (7 single crystal and powder diffractometers) and electron microscopy (2 transmission electron microscopes and 1 scanning electron microscope). We are seeking funding for major upgrades for mass spectrometry and electron microscopy. A rolling programme of smaller scale upgrades has maintained the technological cutting-edge in NMR spectroscopy and the biological sciences, funded by public and private sector sources.

Several members of staff use international facilities as a key component of their research; notably the ILL (France), ISIS (UK), HMI (Berlin), Swiss Light Source, DIAMOND (UK) and more recently the Advanced Photon Source (USA). We have been particularly successful in gaining access to these facilities: for example, since 2011 we have had approximately 61 days at ISIS, which is

estimated to be worth €0.7 to €1.2M. Clarke S has a key role in allocating access to these facilities and in planning future facilities for the international community.

Chemistry will be a major beneficiary of the **West Cambridge Data Centre**, opening in 2014. This £20M investment will provide an energy-efficient home for the **High Performance Computing Service**, and intensive research computer clusters, reducing our carbon footprint and releasing departmental space for research. We access integrated shared resources such as **CamGrid**, via local clusters of high performance computers. We will also contribute to and benefit from the **Cambridge Advanced Imaging Centre** (a £1.6M MRC grant), based in the Department of Physiology, which aims to develop and adapt state-of-the-art high resolution imaging methods for application to biological and biomedical problems throughout the University.

We also benefit from the University Library, a legal deposit (copyright) library with over two million volumes and a digital library which provides access to over 21,000 electronic journals, 400 databases and a growing collection of electronic books, which supplements our comprehensive departmental library.

The research funding portfolio (including future plans)

Our current portfolio of grants (August 2013) includes almost 200 awards, with a value of nearly £92M. Around 38% (by number) are from Research Councils (EPSRC, BBSRC, NERC, MRC and STFC), 19% from the European Commission, 18% from industry, and 14% from UK charities. Annual expenditure from research grants has increased from £18.6M in 2008/09 to £21.3M in 2012/13, which shows growth in research activity despite the adverse financial climate. We have seen a trend towards fewer but larger grants, usually to consortia of academics rather than individuals, and an increase in multidisciplinary grants involving several institutions.

Pharmaceutical funding is increasingly in the form of large grants and donations from industry and medical charities (Wellcome Trust, CRUK, BHF) and the EC. Expenditure on EC grants held in the Department has more than doubled between 2008 and 2012, mainly due to our success with ERC grants. Since 2008, we have been awarded 7 Advanced Investigator grants (Balasubramanian, Frenkel, Grey, Huck, Pyle, Wales and Wright) and 9 Starting Investigator grants (Bender, Ciulli, Day, Gaunt, Kalberer, Knowles, Nitschke, Scherman and Spring). Three recipients have now used these grants to start up research elsewhere.

The stature of individual academic staff is also evident from the number of senior Research Council fellowships awarded: Nitschke, Gaunt, Reisner, Spring and Alavi all hold EPSRC Leadership Fellowships. Clarke J. holds a Wellcome Trust Senior Research Fellowship.

Other than the ERC and Research Council Fellowships, grants with a value of over £1M have been awarded to Abell (Seeding Drug Discovery Grants, Wellcome Trust, £1.37M and £2.4M - the only 2 held by the University), Balasubramanian (Chemical Biology of the Genome, Wellcome Trust, £1.69M), Dobson (Neuro-degenerative Disease, Elan Pharmaceuticals, US $10M; Protein Misfolding, Wellcome Trust, £1.15M; Protein Chemistry, BBSRC, £1.98M), Frenkel (Self-Assembly, EPSRC, £2.74M), Glen (Molecular Informatics, Unilever, £3.2M), Ley (Organic Synthesis, two EPSRC grants, £3.42M and £2.56M), Pyle (NCAS, £4M), Reisner (Sustainable SynGas, Christian Doppler Foundation, €1.63M), Sanders (Dynamic Combinatorial Chemistry, EPSRC, £1.51M), and an EPSRC Core Capability in Chemistry equipment grant (£1.06M).

During the REF period, yearly expenditure in the Department from trust funds and donations has amounted to around £750k. This is additional to external research income and is not reflected in the External Research Income table.

Consultancies and professional services

With strong encouragement from the University, most of the Department's staff are regularly invited to give lectures at other HEIs, at national and international conferences and to industry. As detailed further in our Impact Template, 9 members of staff currently serve on company **Scientific Advisory Boards (SABs)** and 4 hold **Company Directorships.** We have several significant joint projects with industry and embedded laboratories, and we have supported numerous secondments both to and from industry during the census period. Additionally, many staff have formal paid consultancies.

e. Collaboration or contribution to the discipline or research base

The RIGs are involved in joint workshops with other Departments and Schools within the University, with a view to developing new collaborations with overseas academic partners (e.g. the developing economies of China, India, Singapore, and Brazil) and with industry (e.g. Schlumberger, BASF, BP, Dow, Unilever, SABIC, Elan, Sumitomo, Astra Zeneca). We have instigated a series of industrial forums via **Cambridge Enterprise**, the University's research commercialisation arm, where representatives from the Department (academic and research staff) meet with scientists from a selected company to brainstorm a number of chosen topics.

We are a partner in the recently established $100M BP International Centre for Advanced Materials (BP-ICAM), which will lead research in the fundamental understanding and use of advanced materials across a variety of oil and gas industrial applications. It has a 'hub' located in the University of Manchester and 'spokes' in Cambridge, Imperial College, and the University of Illinois at Urbana-Champaign.

Our involvement with the Pfizer Institute for Pharmaceutical Materials (established in Cambridge, 2002) encompasses the Department of Materials Science, the Cambridge Crystallographic Data Centre, and other pharma companies, with a focus on developing a better understanding of the materials aspects of drug delivery. Chemistry researchers participate in the University's Strategic Initiatives and Networks, including the following: **Conservation**, **Global Food Security, Cardiovascular Research, Synthetic Biology, Energy** and the **Nanoforum**, which promote cross-disciplinary projects to tackle research challenges in these areas, many of which dovetail with our Department's key strategic collaborative research themes.

Some awards in collaboration with other UK universities include:

- Abell, a partner on EPSRC grants (microdroplets) with Imperial College (£5.9M).
- Duer, two bio-materials grants from MRC and the British Heart Foundation in collaboration with Kings College London (£547K).
- Frenkel, lead investigator on an EPSRC grant (self assembly) in collaboration with Oxford and Birmingham (£2.74M).
- Grey, a partner on three major energy grants from EPSRC, coordinated respectively by St Andrews, Bath and Imperial College (total value £10.9M).
- Harris, leading a UK consortium project which is the first to collaborate with NASA using their high-flying drone platforms to study remote regions of the atmosphere (£4.5M).
- Klenerman, a partner on Wellcome and MRC grants (imaging on cell surfaces) with Imperial College and Oxford (£1.1M).

Members of the Department belong to a number of multi-disciplinary activities:

- The Melville Laboratory for Polymer Synthesis is a joint enterprise with Physics, Materials Science and Engineering Departments, based in Chemistry.
- The BP Institute for Multiphase Flow includes Chemistry, Applied Mathematics, Chemical Engineering, Materials Sciences and Physics, based in Earth Sciences.
- The Cambridge Centre for Climate Science involves Earth Sciences, Plant Sciences, Geography and Applied Mathematics as well as the British Antarctic Survey, supporting our strategic collaborative research theme of sustainable energy, environment and climate.
- The Lennard-Jones Centre for Computational Materials brings together research groups across Chemistry, Physics, Materials Science, Engineering and Chemical Engineering.
- MINIARE, with Chemistry and the Fitzwilliam Museum at its core, is developing an internationally leading Centre for the scientific application of sensing technologies to a wide range of art objects, including illuminated manuscripts, paintings and printed matter.
- Balasubramanian has contractual duties in both Chemistry and the Clinical School, and is developing research themes in nucleic acid chemistry and the molecular basis of cancer.
- Chin has a joint appointment with Chemistry and the MRC Laboratory for Molecular Biology, with a remit to build links between them.
- Grey is a member of the multi-department £6.8M EPSRC-funded Graphene Centre.
- Catalysis@Cambridge is a virtual centre that links catalysis research in Chemistry, Chemical

Engineering, Materials Science, Biochemistry and the MRC Lab of Molecular Biology.

During the REF period, the Department has been a coordinator of 6 EC networks or consortia with a total value of over €27M: SCOUT, Stratosphere-Climate Links with Emphasis on the UTLS; EMBIO, Emergent Organisation of Complex Biomolecular Systems; DCC, Dynamic Combinatorial Chemistry; NATAMA, Nano-engineered Titania Thin Films for Advanced Materials Applications; DYNAMOL, Dynamic Molecular Nanostructures; and SASSYPOL, Hierarchical Self Assembly of Polymeric Soft Systems.

Excluding Marie Curie fellowships and networks, the Department has been a partner in 31 EC Collaborative grants, with funding of £8.3M being received by Chemistry.

How research collaborations with research users, including industry users, have informed research activities and strategy

In order to facilitate and expand our successful collaborations with outside users detailed in the section above and in the Impact Template, the Department is planning major investments in a new building for the Chemistry of Health, and will vigorously pursue the establishment of an industry-academia interface in the Maxwell Centre (described earlier on page 3). We also aim to expand our programme of industry-academia workshops that have proven to be a powerful tool to initiate cutting-edge research in areas of great societal relevance.

Exemplars of leadership in the academic community

We have submitted 9 Fellows (and one foreign member) of the Royal Society, three of whom (Grey, Klenerman and Balasubramanian) have been elected since 2008. We have also submitted 2 foreign honorary members of the American Academy of Arts and Sciences (Fersht and Frenkel), 5 Fellows of the Academy of Medical Sciences, 3 of whom (Clarke J, Abell and Balasubramanian) have been elected since 2008, and 1 foreign associate of the US National Academy of Sciences (Dobson, elected 2013). Pyle is Chief Scientist of NCAS, a NERC research centre made up of three science directorates (climate, weather, atmospheric composition), with facilities distributed across many UK universities and related institutions; and, since 2008, one of 4 international co-chairs of the Science Assessment Panel, who advise parties to the Montreal Protocol. Sanders served as Chair of the national RAE Chemistry sub-panel throughout 2008.

Amongst the many top medals, awards and other recognition from UK and international bodies within the REF period, we highlight two Royal medals (Dobson and Ley) and the Davy Medal (Sanders) from the Royal Society, and the Tetrahedron Award twice (Ley and Balasubramanian).

In 2013 alone our staff have received the following awards and recognition: Balasubramanian (Tetrahedron Prize, as above; Heatley Medal), Chin (European Inventor Hall of Fame, Solvay Public Lecture, Brussels), Jane Clarke (RSC Interdisciplinary Prize), Dobson (US National Academy, as above), Frenkel (Hinshelwood Lectures, Oxford), Gaunt (RSC Corday-Morgan Medal), Glen (Novartis Chemistry Lectureship), Goodman (RSC Bader Award), Grey (Günther Laukien Prize), Ley (French–British Prize of Societe Chimique de France; RSC Longstaff medal), Scherman (RSC Hickinbottom Award), Wothers (RSC Nyholm Prize for Education), Vendruscolo (RSC Soft Matter and Biophysical Chemistry Award).

Finally, we list a selection of other awards for our younger and newly-appointed staff given over the REF period: Balasubramanian, BBSRC Commercial Innovator of the Year 2010, Mullard Award; Bender, Bayer Young Scientist Excellence Award in Chemistry, Young Medicinal Chemist of the Year, CEFIC Long-Range Research Initiative Award; Bernardes, EFMC Prize for a Young Medicinal Chemist in Academia; Chin, EMBO Gold Medal, Louis-Jeantet Foundation Young Investigator Career Award, Corday-Morgan Medal, Royal Society Francis Crick Prize and Lecture; Gaunt, Novartis Early Career Award; Grey, Ampere Award, IBA Research Award, Kavli Medal and Lecture, RSC John Jeyes Award; Knowles, Harrison-Meldola Medal; Nitschke, Cram Lehn Pedersen Prize in Supramolecular Chemistry; Reisner, Anton-Paar Science Award, Career Acceleration Fellowship, Talents Sponsorship Award; Scherman, Macro Group UK Young Researchers Medal, Harrison-Meldola Medal, CBI McBain Prize.