Institution: University of Cambridge

Unit of Assessment: UoA 8 (Chemistry)

1. Unit context and structure, research and impact strategy

Context

(Category A submitted staff in bold)

The Department of Chemistry has a thriving research culture. We host a large number of internationally leading research groups and collaborate with many University departments and companies, locally and internationally. We have 56 permanent academic staff, and a continuously cycling population of about 20 independent research fellows, 200 postdoctoral researchers, and 300 postgraduate students. Several retirements within the REF period have given us opportunities to refresh and diversify our research portfolio. We have appointed two established researchers to named Chairs (**Hunter,** Herchel Smith Professor of Organic Chemistry; **Gaunt**, Yusuf Hamied 1702 Chair), and ten Early Career Researchers to lectureships (**Archibald**, **Bernardes**, **Bronstein**, **Forse**, **Giorio**, Jack, **Lee, Reinhardt**, Schmidt, **Thom**). Many of our distinguished Emeritus Professors (JClarke, Frenkel, WJones, Ley, Sanders) are still research active, publishing and making important Departmental contributions through mentoring and fund-raising.

Our research embraces challenging new fields while maintaining a powerful presence in the traditional core areas of chemistry. We have strong collaborations with industry, international bodies, and other scientific disciplines, because we believe these are the best way to tackle vital global challenges, from climate change and renewable energy to ageing and disease. Examples of important discoveries made in the Department during the REF period include:

- Discovery of the role of secondary nucleation in the aggregation of misfolded proteins that lead to Alzheimer's and Parkinson's diseases (**Knowles, Vendruscolo,** Dobson).
- The first directly observed fragmentation of a prion protein, which is a key process in the replication and spreading of prions in disease (**Klenerman**).
- Elucidation of the role of G-quadruplex structures in the progression of cancer (**Balasubramanian**).
- Identification of the molecular mechanism behind hardening of the arteries (**Duer**).
- Total synthesis of *E. coli* with a recoded genome, a defining milestone in synthetic genomics (**Chin**).
- Detailed characterisation of the relationship between chemical structure and dynamics and the functional behaviour of lithium-ion and sodium-ion batteries (**Grey**).

- Development of new hybrid photoelectrochemical cell architectures that efficiently convert solar energy into chemical fuels (**Reisner**).
- Discovery of a new high-strength, self-healing supramolecular polymer (**Scherman, Abell**).
- Creation of new and general processes for alkylamine synthesis **(Gaunt**).

Review of plans described in 2014

The major strategic objectives outlined in REF2014 have been achieved as follows:

- The £24M Chemistry of Health building, funded jointly by the UK Research Partnership Investment Fund, private investors and benefactors, opened in 2018. It houses the Centre for Misfolding Diseases and the Chemistry of Health Incubator, one of the first start-up incubators to be completely integrated into a UK department.
- The £63M interdisciplinary Maxwell Centre opened in 2016 in West Cambridge. It houses the Centre of Advanced Materials for Integrated Energy Systems, which provides state of the art facilities for Department researchers to work on projects involving solar cells, thermo-electrics, fuel cells and batteries.
- We have strengthened our international position in atmospheric chemistry research and our role in the National Centre for Atmospheric Science (NCAS) by appointing three new Lecturers (**Archibald**, **Giorio,** Schmidt) and securing NCAS funding for two Senior Research Associates (**Abraham**, **Griffiths**). We have also significantly expanded our instrumentation for characterisation of greenhouse gases, including a network of high precision field instruments deployed around London.
- We have strengthened research in organic chemistry through three appointments that span biological, polymer, and supramolecular chemistry (**Bernardes**, **Bronstein**, **Hunter**).
- We have enhanced our materials characterisation instrumentation by establishing a new facility for electron microscopy, which has both SEM and TEM with EELS and cryo-capability, and an integrated facility for powder and single-crystal X-ray diffraction. Three new posts (**Bond** and two technicians) have been created to ensure that we have appropriate expertise to fully exploit these facilities.

Research structure

Our research is organised around five research interest groups (RIG). We believe this structure promotes collaboration and exchange of ideas both within and between the RIGs, and enables effective planning of research strategy, infrastructure and staffing. The RIGs also provide an important conduit for interdisciplinary collaboration with other University departments and industry.

In order to free academic time for research, we also have five full-time teaching-only staff. The major administrative leads are Keeler, who is Head of Department (HoD), and his Deputy, **Bampos**. We regularly consult an experienced international Scientific Advisory Panel, who provide external perspective.

Biological RIG

The major focus of research in the Biological RIG is the development of new tools for investigating and manipulating biological systems. Chemical and biochemical methods are being developed for introducing new functionalities into proteins in cells, either by re-engineering of cellular genetic codes or by chemoselective bio-orthogonal labelling strategies. New microdroplets platform technologies are being developed for single cell selection and sequencing. New approaches that are being developed for sequencing chemically modified DNA bases will have a major impact in biology. The appointment of **Bernardes** in the REF period expands the applications into antibody therapies. Drug development is at the heart of many research programmes, including improving the approaches to fragment-based drug discovery, identifying novel DNA structures as potential drug targets, designing synthetic molecules that interfere with the mechanisms essential for cancer cells, and developing methods to modify protein therapeutics.

The Centre for Misfolding Diseases (CMD) provides a focus for research into the molecular processes underlying protein misfolding diseases, including Alzheimer's and Parkinson's (**Vendruscolo**, **Knowles**). The CMD is located in the new Chemistry of Health building, which brings together researchers from a wide variety of scientific backgrounds, and includes the Chemistry of Health Incubator, creating a seamless interface between research and practical applications. The Incubator is currently host to Wren Therapeutics, a start-up company developing small molecule therapies for degenerative diseases.

Materials RIG

The Materials RIG is developing synthetic routes and applying state-of-the-art characterisation techniques to a range of new materials with applications from renewable energy to medicine. Highly interdisciplinary approaches are being used to monitor structural changes that occur during the long-term operation of batteries, and to study solid-state electrolytes for fuel cell membranes. Work on artificial photosynthesis and solar fuels aims to develop sustainable energy carriers and chemicals, and **JZhang** brings new expertise in implementation of the photosynthetic machinery of biological cells for renewable fuel synthesis and biosensors. The appointment of **Bronstein** (joint with Physics) and **Forse** in the REF period broadens the scope into conjugated polymers for organic solar cells, and new materials for CO_2 capture. Research programmes at the interface

with medicine are focused on the development of novel materials for drug delivery, and understanding how disease changes the properties of tissue, important in both ageing and cancer.

The Melville Laboratory for Polymer Synthesis provides a focus for research on polymeric materials (**Scherman**, **Vignolini**). Researchers here are developing new synthetic polymers for bespoke applications, from self-assembled nanoconstructs for the delivery of therapeutics to sustainable, recyclable biopolymers for pigments and sensors.

Physical RIG

Researchers in the Physical RIG have a shared emphasis on gaining insight into chemical systems through quantitative measurement. Research spans the range from nanoscale phenomena in catalysis and corrosion to global climate change; from single-molecule studies relevant in biomedical research to the development of innovative sensors for the monitoring of pollution or clinical diagnosis. Advanced surface science techniques are being used to study real-world problems in corrosion, catalysis, oil refining, and engine lubrication.

The Centre for Experimental Biophysical Chemistry brings together physical chemists, biophysicists, optical engineers, and computer scientists with a shared interest in experimental biophysics (**Klenerman**, **Knowles**), who are combining tools from chemistry and physics to develop new approaches to probe the behaviour of biomolecules, including single-molecule fluorescence techniques that directly image biological processes with unparalleled resolution. The appointment of **Lee** in the REF period has expanded the scope of this work into multidimensional super-resolution imaging.

The Centre for Atmospheric Science is a joint venture with the Departments of Applied Mathematics and Theoretical Physics and Geography (**Pyle, RJones, Griffiths, Kalberer, Abraham**). State-of-the-art modelling and data analysis are combined with laboratory and field measurements to probe the ways in which natural and anthropogenic chemistries influence the atmosphere at local and global scales. Networks of low-cost ultra-small sensors are being used to monitor urban air pollution and provide evidence regarding its effect on human health. The appointments of **Archibald**, **Giorio** and Schmidt (joint with Geography) in the REF period have expanded capabilities in global atmospheric and climate modelling, volcanology, and the effects of particles in the atmosphere on climate and public health.

Synthesis RIG

Research in the Synthesis RIG focuses on developing state-of-the-art methods for the assembly of functional molecules that are important in medicine, crop science and materials. The

development of new catalytic processes for small molecule synthesis focusses on C-H bond activation, photoredox chemistry, and enantioselective catalysis. Diversity-oriented synthesis continues to be a major activity, providing small molecule libraries for biological collaborators to screen for drug leads or biological tools. The use of self-assembly for the construction of large porous containers promises to solve problems of chemical purification in new energy-efficient ways. In the REF period, **Gaunt** was appointed to the Yusef Hamied 1702 Chair, the recruitment of **Hunter** has opened new directions in physical organic chemistry and sequence polymers, and **Phipps** brings new expertise in supramolecular catalysis. Advances in the development of flow reactors, high throughput synthesis and analytical platforms underpin much of this research, while there is an increasing emphasis on computational chemistry to provide understanding and predictive tools.

Theory RIG

The Theory RIG aims to advance fundamental understanding and computational tools in all areas of molecular science in soft and condensed matter. Active research projects cover quantum dynamics and electronic structure, statistical mechanics, electrochemistry, drug discovery and energy landscapes. Researchers work on new algorithms for global optimisation, enhanced thermodynamic sampling, and rare event dynamics, with applications to structure prediction and analysis of emergent observable properties. Novel methods to compute fundamental quantities such as configurational entropy and tunnelling splittings will provide new insight into complex systems including granular materials and water in clusters, liquids and solids. The appointment of **Thom** in the REF period strengthens research on electronic structure and simulation, and the appointments of **Reinhardt** and Jack (joint with Applied Mathematics) bring expertise that will help tackle problems difficult for conventional methods to treat, such as glassy materials, self-assembly, and addressable complexity.

The Centre for Chemical Informatics brings together a unique collection of expertise and provides a focus for research in the rapidly emerging area of artificial intelligence and data analysis as applied to chemistry (**Colwell**, **Goodman**, **Glen**, **Bender**). New computational tools are being developed and applied to drug design, chemical toxicology and medical diagnostic support, and there are strong interactions with the pharmaceutical industry.

Interdisciplinary Research

Our Departmental structure encourages cross-fertilisation of ideas and promotes interdisciplinary research across the Department, University, and other institutions. A number of our staff hold joint appointments and have a second research laboratory located in another department:

Balasubramanian (Cancer Research UK Cambridge Institute), **Bronstein** (Physics), **Chin** (MRC Laboratory of Molecular Biology), Jack (Applied Mathematics), **Klenerman** (UK Dementia Research Institute), Schmidt (Geography), **SClarke** (BP Institute for Multi-Phase Flow). In addition, there are a large number of less formal collaborations between the Department and other research institutes across Cambridge. For example, the Cambridge Epigenetix spin-out, which forms Impact Case Study B_UoA8_CS-08-1555, is a direct result of one such interaction with the Babraham Institute.

Many of our researchers belong to the **Lennard-Jones Centre for the Development of Computational Methods for Materials Modelling,** which connects researchers across the University who have an active interest in materials modelling and has a particular strength in method development (**Alavi, Althorpe, Bender, Colwell**, Elliott, Frenkel, **Glen, Goodman, Jenkins, Sprik, Thom, Vendruscolo, Wales**).

In addition to the research council Centres for Doctoral Training (CDT) and Doctoral Training Programmes (DTP), which are described in section 3, our researchers connect to cross-school and interdisciplinary research in key thematic areas through the University's Strategic Research Initiatives and Networks (SRI, SRN) and Interdisciplinary Research Centres (IRC). Multiple members of the Department play an active role in each of the following:

- CamBridgeSens SRN for sensor technology
- Cancer Research UK IRC
- Cardiovascular Disease IRC
- Centre for Data-Driven Discovery IRC
- Energy Transitions at Cambridge IRC
- Global Challenges SRI
- Immunology SRN
- Infectious Diseases IRC
- Neuroscience IRC
- Synthetic Biology IRC

Further interdisciplinary collaborations are listed in section 4.

Research strategy and goals for the next five years

Our overall aim is to support fundamental science of the highest quality in a first-class physical environment, with a recognition that the global problems we face require collaborations across scientific areas as well as with the public and private sector. The two key objectives that shape our research strategy are:

- to recruit talented scientists and provide them with the research environment and infrastructure that they require to flourish,
- to maintain a diverse research portfolio by leading new developments in both fundamental chemistry and at the interface with other disciplines.

Recognising the need to accommodate different ideas, methods and directions that will come with the future recruitment of world-class researchers, the three broad areas outlined below form the basis of our current research strategy:

- **Chemistry of Health** aims to advance the understanding of health and disease in a number of areas that are of global importance, including ageing, neurodegenerative disease, cancer and infection. This area combines chemistry, biology, biochemistry, bio-engineering and medicine and addresses the UK Industrial Strategy Grand Challenge of Ageing Society.
- **Sustainable Energy, Environment and Climate** aims to increase understanding of the impact of chemical processes on the environment and to develop sustainable energy systems. This area combines atmospheric chemistry, computer modelling, engineering and materials science, and addresses the UK Industrial Strategy Grand Challenge of Clean Growth. Cambridge Zero is a new umbrella organisation that will coordinate research across the University in this area, and our Department will make a major contribution.
- **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 healthcare, agriculture, energy and consumer products. This area combines synthetic chemistry, materials, physics and engineering, and addresses the UK Industrial Strategy Grand Challenges of Future of Mobility and Clean Growth.

These three areas will continue to be underpinned by strong interactions with one of the UK's largest theory, modelling and informatics groups. Research in the area of theory will address the UK Industrial Strategy Grand Challenge of Artificial Intelligence and Data.

Several senior members of staff are due to retire in the next REF period, and succession planning is one of the major priorities in our action plan:

- With the sad loss of Dobson, and more recently **Abell**, we will make appointments in chemical biology to secure our leading position in this important area for the longer term.
- We will appoint a new 1968 Professor of Chemistry (Michaelides).
- To fill the upcoming vacancy in our 1920 Physical Chemistry Chair**,** we will recruit a world-class researcher to take a leadership role in tackling climate change.

- We will appoint a new Professor of Molecular Sciences Informatics to bring a new vision to the Centre for Molecular informatics and exploit the new opportunities in chemistry that machine learning opens up.
- The development of close links with other departments will continue through joint appointments. For example, a new lectureship appointment joint with the Department of Genetics will be made (Collepardo).
- We will strengthen the Synthesis RIG with two new lectureship appointments.

We have a strong track record of attracting and supporting young scientists to establish world-leading research groups (see Section 2), and we will continue to make opportunistic lectureship appointments of talented ECRs.

We will continue with our programme of upgrading existing facilities and creating new ones as our research portfolio evolves, and ensuring we have expert technical support to maintain and use them efficiently. Clusters that share funding and resources are important for increasing the range and availability of equipment to researchers across disciplines, and we will continue to lead on cross-departmental initiatives. This strategy underlies our plan to refurbish several labs for synthetic chemistry as part of a £5M ERDF Innovation Centre in Digital Molecular Technology, and to seek UKRPIF funding to support research in chemical biology by further developing the instrumentation in our purpose-built facility, the Molecular Production and Characterisation Centre.

To continue our provision of world-class training for research students, we aim to attract more graduate student funding by leading in the development of Research Council DTPs, long-term industry collaborations and endowed studentships sponsored by alumni.

Impact strategy

We support the development of innovative ideas from inception through commercialisation by creating opportunities for researchers at all levels in the Department. Our impact strategy has three main strands:

Inception. Our RIG structure and interdisciplinary environment create a fertile atmosphere for the regular and robust interchange of ideas often crucial to generating new business concepts. We hold a biennial Chemistry Networks event to showcase our research and promote relations with industry. We have a full-time Departmental Knowledge Transfer Facilitator, as well as an Enterprise Champion (**Knowles**), who actively help researchers develop their ideas into products, apply for funding, and connect with entrepreneurs and the business sector for collaboration and support. As a result, the EPSRC Impact Acceleration Account awarded £1.5M in the REF period to researchers in the Department to support early-stage development of technology and industry

collaborations. Our commitment to impact is embodied in the **Chemistry of Health** Incubator, which is deliberately located inside the Department to promote interactions between researchers and embryonic spin-outs. Its first occupant Wren Therapeutics (**Knowles, Vendruscolo,** Dobson) has raised an additional £18M since its creation.

Training. The University offers entrepreneurship courses throughout the year to researchers at all levels, providing the knowledge and confidence to make the transition from initial concept to concrete business idea. For example, EnterpriseTECH offers a three-month course on commercialisation pathways and early-stage business development. Since 2018, 31 PhD students and postdocs from the Department have completed the programme, several members of staff have submitted projects, and two start-up companies have been created by students from Chemistry. Accelerate Cambridge is a 10-week intensive programme that combines entrepreneurship training, regular coaching, mentoring, and access to shared workspace. In the REF period, five Chemistry spin-out companies have come from this programme. We are now integrating these types of entrepreneurial training programmes into our PhD courses. For example, all of the SynTech CDT students will receive training from Accelerate.

Commercialisation. Cambridge Enterprise (CE) supports researchers whose ideas are ready for commercialisation through regular webinars and training events; advice on writing business plans; help with obtaining patents, securing IP and licencing ideas; supplying board members; providing seed funding; and guiding through fundraising rounds. CE has played a key role in supporting numerous spin-out companies from the Department.

The eleven spin-outs generated by the Department in the REF period testify to the success of this strategy. Some highlights are:

- Xampla (**Knowles**) is developing single-use biodegradable plastics made from plant protein and has raised £2M in investment.
- PharmEnable (**Bender, Spring**) uses artificial intelligence to design drug candidates and has raised £1.8M in investment.
- Kalium Health (co-founder postdoc Hutter) has developed a fast, accurate and low-cost home blood-testing kit for kidney patient potassium levels and has raised £950K in investment.
- ChemInventory (postgraduate Fitzpatrick) has developed database software licensed to 2500 institutions in 90 countries. Fitzpatrick won the ACS Talented 12 Competition for developing this technology.
- Cambridge Oncology (**Duer)** is developing novel glioblastoma treatments and has raised £550K from private investors.

How case studies are related to our approach to achieving impact

Our REF impact case studies are a direct consequence of the entrepreneurial environment fostered by our impact strategy:

- Solexa (B_UoA8_CS-08-1551). The technology behind Solexa was developed through the regular opportunities within the Department for **Klenerman** and **Balasubramanian** to become familiar with each other's work. CE (then known as Wolfson Industrial Unit) administered the spin-out, held a Board seat, and helped the University invest.
- Astex (B_UoA8_CS-08-1537). **Abell** benefited from close links with other departments, which led to a collaboration with Blundell in Biochemistry. CE invested to help through the early stages of the company.
- Aqdot (B_UoA8_CS-08-1540). This company resulted from a collaboration between **Scherman** and **Abell** within the Department. CE provided series A financing and held a seat on the board.
- Sphere Fluidics (B_UoA8_CS-08-1558). Regular interactions within the Department brought **Abell** and Huck together to form a collaborative microdroplets research group, which led to this technology. CE obtained IP filings, developed business propositions, and held a board seat.
- Cambridge Epigenetix (B_UoA8_CS-08-1555). **Balasubramanian** benefited from the wider collaborative Cambridge environment by working with Reik at the Babraham Institute. CE obtained IP filings, developed business propositions, and provided $30M in series C financing.

In a different arena, the Department has achieved impact through the development of national and international collaborative networks, which play an important role in influencing policy. For example, **Pyle**'s work with the National Centre for Atmospheric Science and the Scientific Assessment Panel to the Montreal Protocol has directly influenced governmental policy on climate change (B_UoA8_CS-08-1561).

Open research environment and research integrity

We share the University culture of support for Open Research, and actively encourage all researchers to upload their publications into the University Open Access Repository, Apollo. Our five Chemistry Data Champions (who include our Librarian and **Griffiths**) are experts on research data management and sharing. They handle researcher queries and speak at Departmental meetings. Extensive support, training and advice on organising, sharing and looking after research data is provided by the University Research Data Management Team. Our Librarian

provides regular training for Department researchers and facilitates access to the online courses and electronic resources provided by the University.

We provide internal and external online research ethics training to all researchers and a twice-termly face-to-face course on Research Integrity. All first-year postgraduates take an Integrity and Ethics in Research course; further guidance is provided by RIGs and the University Research Integrity website. The University Research Strategy Office provides clear policies, procedures and training courses, and the Misconduct in Research Policy sets out a transparent, robust and fair process to deal with allegations of misconduct should they occur. The Department upholds the commitments in the Concordat to Support Research Integrity and requires all researchers, whether staff, students or visitors, to abide by national, European and international standards of research integrity.

2. People

We view training, regular appraisals, open communication, and of course the opportunity to take part in high class research as the foundations of a healthy environment for our staff. This nurturing environment has not only resulted in world-leading researchers, but in highly motivated staff, who interact well at all levels.

Staffing and research strategy

Our strategy is to hire and support the best people, who can bring new research directions that strengthen or complement the three strategic areas described in Section 1. The Senior Management Team (SMT) which is composed of the RIG Chairs, Head and Deputy Head of Department and senior administrators, is responsible for implementing our research and staffing strategy through staff recruitment and infrastructure investment. With advice of the external international Scientific Advisory Panel, the SMT has developed a five-year plan to fill the key positions which underpin these research areas, as discussed in Section 1.

Philanthropy is an increasingly important strand in our staffing strategy. Our Next Generation Fellowship (NGF) scheme provides up to £250K over five years to new appointments, for immediate funding for equipment and researchers. As a result, the first recipients of this scheme were rapidly promoted to professor (**Jackson**, **Gaunt, Klenerman**, **Knowles, Nitschke, Spring, Scherman, Vignolini**), and the NGF scheme has also led to longer-term relationships with the donors. For example, the Frances and Augustus Newman Foundation, which sponsored **Knowles** as an NGF**,** made a further donation in 2016 for a new microfabrication laboratory and a postdoctoral position. Endowments of £1M from the Walters-Kundert Trust and £2M from BP will fund three NGFs in perpetuity. Over the REF period, these donations together with the Isaac Newton Trust have provided NGF funding for **Archibald**, **Forse**, **Giorio**, **Lee** and **Thom**.

Support for academic staff

In 2016, we tailored the University Staff Review and Development Scheme to respond to the specific pressures and expectations unique to academics in our Department. The collaborative process is designed to address individual needs, aspirations and successes, and to facilitate career development. It runs on a two-year cycle (after probation) and the HoD reviews the outcomes and handles specific requests or issues. Its success is highlighted by the fact that it is now being adopted by other science-based departments across the University.

The University Senior Academic Promotions Scheme sets out a clear and transparent procedure for applications for promotion to University Senior Lecturer, Reader and Professor. Over the REF period, **Althorpe Archibald, Bender, Bernardes, Bronstein, SClarke, Duer, Goodman, Jackson, Jenkins, Knowles, Lee, Leeper, Nitschke, Reisner, Scherman, Spring, Wheatley** and **Vignolini** have all received promotions through this scheme.

We encourage academic staff to expand their networks and build external research collaborations through sabbatical leave, accrued at the rate of one term in seven and used exclusively for research activities. For example, **Duer** used her sabbatical in 2018 to found spin-out Cambridge Oncology. **Scherman** established ongoing collaborations in supramolecular hydrogels with Tsinghua University during his 2014 sabbatical in China. **Althorpe** shared his sabbatical in 2015 between the Chinese Academy of Sciences in Beijing and Caltech in California. **Knowles** used his 2019 sabbatical to develop a new line of research in liquid-liquid phase separation of proteins. **Grey** used her sabbatical to establish the interdisciplinary Centre of Advanced Materials for Integrated Energy Systems in the Maxwell Centre, which opened in 2016.

We also support secondments with industry and the government sector. For example, in a unique opportunity to access machine learning expertise and software engineering skills, **Colwell** has a secondment at Google. **Archibald** has a part-time secondment with the Met Office, where he is helping develop a long-term strategy for atmospheric chemistry. **Bender** combined sabbatical leave with a secondment at AstraZeneca, where he leads the Computational Toxicology group.

During the REF period **Abell, SClarke, Grey, Pyle, Spring** and **Wales** have all participated in the University's senior leadership programmes for academics at all career stages. The University's Inclusive Leadership Programme launched in 2019, supports the University's strategic priorities in reducing the risk of explicit or implicit sex, race or other discrimination when making management decisions. All those with responsibility for the performance, behaviour and development of others, including leaders of research groups have been encouraged to attend.

Support for postdoctoral researchers

We value our postdocs, who play an integral role in the research activities of the Department. We have put a number of mechanisms in place to ensure they get the most out of their research time here, and our Postdoc Affairs Committee keep the HoD and SMT informed of postdocs' concerns. In consultation with them, we have implemented a mentoring scheme for new postdocs, which uses a pool of academic volunteers to offer support on work-related issues, career development, work-life balance, motivation, confidence and inspiration. The University has implemented the Concordat to Support the Career Development of Researchers and retained its HR Excellence in

Research award in 2015, which recognised a commitment to improving the working conditions and career development of research staff. We provide an induction, so new postdocs can learn not only about Departmental and safety policies, but also about dignity at work, family-friendly hours, and the many University resources available for career and personal development. We give clear information to postdocs on how to prepare for their annual review under our Staff Review and Development Scheme, where they can discuss achievements, challenges, targets, training and personal development with academic staff members, who receive training on how to conduct reviews.

We train postdocs in key skills they will need for their future careers. Postdocs take responsibility (with appropriate training) for day-to-day operational issues in research laboratories, such as safety, procurement and use of key equipment. With guidance from academic staff, postdocs can develop teaching skills by delivering small group undergraduate tutorials or acting as senior demonstrators in the undergraduate teaching laboratories. They supervise postgraduate students, and devise and supervise undergraduate research projects. Many are College Research Associates, which provides them with further opportunities to develop interdisciplinary research networks as well as skills such as interviewing for the admissions process. Postdocs are regularly invited to present lectures on their research to a wider audience as part of the RIG seminar programmes.

Our impact strategy (see Section 1) provides a range of mechanisms to help postdocs develop entrepreneurial skills and an appreciation of the business world. Many of the Department's spin-out companies are led by former postdocs, who were involved from inception to commercialisation. Visitors from industry to the Department range from representatives of major international companies to local start-ups, and we use these occasions to organise networking events that enable postdocs to develop contacts and explore future possibilities for a career in relevant industries.

The Department offer careers training and workshops, and the University provides courses on transferable skills, leadership development, time management, career planning, staff review and professional development. Between 30 and 40 postdocs from Chemistry enrol annually on the University Researcher Development Programme. Most of our postdocs use the Postdoc Careers Service, which has specialised careers advisers who arrange one-to-one meetings to discuss career choices, to review applications, or to help prepare for interviews.

In the wider University community, the Postdoc Academy offers programmes such as its Mentoring Scheme, which focuses on developmental mentoring and arranges formal matching with mentors from academia or industry. All members of staff, including postdocs, get shopping

discounts through the employee benefits scheme (CAMbens); and the CAMbens Cars and Cycle to Work salary sacrifice schemes help save money on transport costs. Many postdocs from the Department have benefited from subsidised housing at the Eddington development in North West Cambridge, where the University has recently built high-quality accommodation specifically for postdocs. The Postdocs of Cambridge Society also contributes actively to this rich environment of support through its many social events.

The Department not only hosts many externally funded research fellows, but also supports our most talented postdocs to take the next steps to independence through internal fellowship schemes such as Herchel Smith, Oppenheimer, Borysiewicz or College Research Fellowships. The number of postdocs from the Department who have moved into important positions in other institutions is an indicator of the success of the training we provide. Since 2014, over 100 of our research fellows and postdoctoral researchers have moved on to academic positions at prestigious institutions across the world including the USA, the European Union, Australia, Canada, China, India, Israel, Japan, Korea, Mexico, Switzerland, Thailand, Turkey and the UK.

Support for research students

We host around 300 postgraduate research students (PhD or MPhil candidates), as well as around 50 students who carry out a research project as part of the Masters programme, admitting 14-25 MPhil and 65-75 PhD students each year. Almost all of our PhD students complete within four years. During the REF period, we awarded 484 PhD degrees. Funding for PhD studentships comes from a wide variety of sources, as detailed in Section 3.

We see the wellbeing of students as key to their (and our) success. All postgraduates are assigned a supervisor and an academic mentor (in addition to their college tutor), as well as having access to our pool of postdoc mentors. The Departmental support team provides pastoral support, and our buddy scheme teams up the new intake with postgraduates who have just completed their first year. Supervisors review the progress of every student each term. Reports are submitted through the Postgraduate Feedback and Reporting System, which provides channels for review and evaluation by students and their tutors. At the end of their first year, students submit a thesis for probationary review, and undergo an oral examination by two academics. These processes provide multiple pathways for students to obtain independent feedback on progress, and mean we can identify and tackle any problems at an early stage.

The postgraduate training programme consists of compulsory, elective, fundamental and specialist academic courses, resulting in many transferable and interdisciplinary skills. We plan training in consultation with students through feedback surveys and via student representatives on

the Postgraduate Education Committee. First years take the School of Physical Sciences Core Skills Training Programme, which identifies existing skills and gaps. All first years give a talk in cross-RIG peer-to-peer sessions, second years present posters, and third years give a lecture to a wider audience at the annual Chemistry Showcase Week. We follow the Cambridge Researcher Development Framework to help students develop into professional researchers, and the RIGs help students become confident members of the Department through weekly seminar programmes, internal conferences and workshops that integrate postgraduates, postdocs and academics.

We also encourage students to enroll in University training programmes, which include personal development and computer skills courses. Students can take language courses at the University Language Centre, and non-native speakers can take the Academic Development and Training for International Students. Postgraduates interested in policy can participate in workshops at the Centre for Science and Policy. Many of our postgraduates also benefit from the unique training and interdisciplinary networking opportunities provided by the multiple CDTs, DTPs and Marie Curie ITNs that we are involved in (see Section 3).

The Department's careers programme for postgraduates includes talks, workshops and careers events hosted by the University Careers service. We also invite industry representatives to the Department to discuss careers. For example, postgraduates meet senior researchers from BP and present their research in talks and posters at our annual BP Day. Our annual Merck Sharp & Dohme (MSD) Lecture is always attended by representatives from the company, who run workshops and presentations for those interested in pharmaceutical careers. In 2017, three senior female scientists from MSD ran an event to highlight the opportunities and challenges for women in industry.

We actively aim to recruit postgraduates from a wider base by encouraging members of all communities to apply. We run an annual Open Day to promote our PhD programme as widely as possible, explain the opportunities available, and clarify the application process. We make sure that students from underrepresented backgrounds are encouraged to apply for relevant scholarships offered by the Cambridge Trust. We can also access the £100M Harding donation to fund excellent students who otherwise could not afford to study here. The University is committed to raising the profile of researchers with protected characteristics in order to inspire others to apply, and the achievements of two of our postgraduates were highlighted as part of Black History Month in 2018.

Equality and Diversity

Equality and diversity is of paramount importance at all levels in the Department and is integral in all decision-making processes. Training is mandatory for all staff, and equality and diversity are specifically considered in planning how the Department is organised and run, in recruitment of technical staff, graduate students, postdocs and academic staff, in career progression, in providing suitable access to facilities and training, support for securing research grants, access to internal funds, conference attendance and sabbaticals, and in the promotion of role models, for example through a balanced programme of diverse seminar speakers.

The Department and the University both hold Athena SWAN Silver Awards. We have policies to allow flexible or part-time working, and both male and female staff access the Returning Carers Scheme. For example, Schmidt used this scheme to take her family with her while she worked at the National Center for Atmospheric Research in Colorado in 2019. We are by no means complacent, and continue to institute new ideas and methods gathered through meetings and staff surveys to improve equality and diversity. For example, all committee meetings, seminars and group meetings are now restricted to core office hours to make it easier for those with parental or caring responsibilities to attend. The University has a number of other major initiatives on gender including 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, generous maternity/paternity/adoption leave, and a scheme called My Family Care, which gives employees access to a network of emergency childcare, school holiday cover, and backup adult and elderly care.

All of our academic staff have completed the University Equality and Diversity training. We promote the Dignity@Work policy to all new staff, which sets out University procedures for dealing with harassment, bullying and other inappropriate behaviours. As a University Equality Champion, **Bampos** provided senior leadership in equality and diversity matters. We run regular Department-wide events to raise awareness of diversity issues. For example, we ran an all-day event called Celebrating Women in Chemistry in 2019 and a similar Diversity in Chemistry event in 2020.

The University LGBT+ Staff Network supports all University staff who identify as LGBT+. The BAME Staff Network similarly gives voice and visibility to BAME staff. Both networks organise monthly social and other events throughout the year to raise awareness and celebrate diversity. The University's three-year action plan on race and racism was acknowledged in 2019 with a Race Equality Charter Bronze award. The University also belongs to a number of diversity organisations such as the Stonewall Diversity Champions and Business Disability Forum.

To ensure accessibility to all, we have a wheelchair lift to the front door and accessible card readers to all doors. Our Departmental Disability Liaison Officer ensures that any staff or student can request assessment by the University's Disability Resource Centre, so that they can be provided with specialist equipment. We also inform students and staff about the University's Occupational Health service, which promotes physical and mental wellbeing, and provides a free counselling service.

The Department recognises the importance of mental health in the workplace and has enthusiastically adopted the University's Wellbeing Initiative. We have created a calming wellbeing area in the library, for use by anyone who needs time out. Our Human Resources team organises weekly Pilates classes, workshops on mindfulness and tackling stress, quizzes, charity coffee mornings, and regular talks about aspects of wellbeing that have become a much-admired feature of Departmental life. Many of these activities moved online during the Covid-19 lockdown, and additional coffee mornings and webinars on relieving stress and anxiety were arranged.

We are explicit in the criteria we use to reach hiring, tenure and promotion decisions, and are fully committed to the University's implementation of the San Francisco Declaration on Research Assessment. We assess research on its merits and do not use journal-based metrics as a surrogate measure of the quality of research articles when assessing researchers. We seek to recruit the most diverse pool of applicants possible, and include the following wording in all academic recruitment advertisements:

> "We particularly encourage women and/or candidates from a Black, Asian and Minority Ethnic background to apply for this vacancy as they are currently under-represented at this level within our University. Applications are welcomed from researchers that are either internal or external to the University. The University actively supports equality, diversity and inclusion and encourages applications from all sections of society."

Our REF committee has followed the fair and transparent processes for output and staff selection, including appeal procedures and data protection, laid out in the University Code of Practice and our own Working Methods document. All our committee members have taken courses on Equality and Diversity and on Unconscious Bias to mitigate potential bias in decision-making. Our Equality lead (**Hunter**) ensures the application of equality principles in all decision making. We do not consider REF to be an appropriate mechanism for staff appraisal, and staff progression is not influenced by whether someone has met the REF criteria for research independence.

3. Income, infrastructure and facilities

Research income

The total value of our research grant portfolio was £100-120M through the REF period, and currently stands at £109M with 276 active grants. Annual expenditure on research funded by grants from external sources is normally £20-22M but dipped slightly last year, due to the constraints on research activity imposed by the Covid-19 epidemic. In addition, external funding for the Chemistry of Health building augmented the expenditure in 2015/2016. Research in the Department is supported by a healthy range of different funding sources: Research Councils (30%), European Commission (24%), industry (17%), charities (19%), and other sources (10%). None of the figures on income or expenditure include trust funds and donations, which contributed an additional £1M per annum to research in the Department and increased our total research expenditure by 5%.

We have increased multidisciplinary collaborative grant applications to take advantage of the trend toward fewer but larger grants to academic consortia, and we participate in many of the most significant UK-wide research clusters, which often provide opportunities to pool major instrument facilities and act as hubs for interactions with industry. Highlights include:

- **UK Dementia Research Institute (£250M MRC, Alzheimer's Society, Alzheimer's Research UK)**: **Klenerman** is a Foundation Professor with a new laboratory on the Cambridge Biomedical Campus in this collaboration across six universities.
- **BP-ICAM (£100M BP):** A 15-year project across four universities to investigate novel material developments (**SClarke**, **Wright,** Frenkel).
- **Faraday Institution (£65M Industrial Strategy Challenge Fund): Grey** leads a £12M collaboration with nine other universities and ten industry partners to examine how environmental and internal battery stresses damage batteries over time.
- **Interdisciplinary Research Collaboration on Hard to Treat Cancers (£10M EPSRC):** This Cambridge-led collaboration brings together academics from five universities with clinicians and industry (**Scherman**).
- **Sir Henry Royce Institute (£10M EPSRC)**: The Cambridge spoke of this Manchester-based Institute provides equipment-sharing for state-of-the-art experimental facilities for energy materials characterisation and deposition, developing strong modes of collaborative working between researchers and industry (**Grey**).
- **Cambridge Graphene Centre (£7M EPSRC):** A Synergy group with the Graphene National Institute in Manchester and the University of Lancaster, whose mission is to

investigate the science and technology of graphene, carbon allotropes, layered crystals and hybrid nanomaterials, and to promote alignment with industry (**Grey, Nitschke)**.

- **Prosperity Partnership (£6M BP/EPSRC):** A collaboration between four institutions to investigate and mitigate the processes that cause surface degradation (**SClarke**).
- **Centre of Advanced Materials for Integrated Energy Systems (£4M EPSRC): Grey** is director of this four-university partnership focusing on development of advanced materials for energy conversion and energy storage (**Bronstein, Grey, Wright**).
- **UK Chemistry and Aerosol (£3M NCAS, Met Office): Archibald** is Science Director of this Joint Climate and Weather Research Programme, whose partners include the Hadley Centre, and two other universities. Its objective is to develop, evaluate and make available an atmospheric chemistry-aerosol global model suitable for a range of topics in climate and environmental change research (**Pyle, Archibald, Abraham, Griffiths**).
- **RaNT (£6M EPSRC):** A collaboration between four institutions and partnering companies to identify diseases and treat them in a single, effective non-surgical procedure using light and nanoparticles (**Scherman**).

Our staff have also been highly successful in attracting individual grants for projects and fellowships that allow them to focus full-time on research. ERC grants in the REF period include:

- eleven Starting Grants (**Bender**, **Kalberer**, **Knowles**, **Nitschke**, **Vignolini**, **Bernardes**, **Bronstein, Gaunt**, **Phipps, Scherman**, **Spring**)
- two Consolidator Grants (**Reisner**, **Scherman**)
- eleven Advanced Grants (**Balasubramanian, Chin,** Frenkel, **Grey** x 2, **Hunter**, **Klenerman, Nitschke, Pyle**, **Wales, Wright**)

Individual five-ten year research fellowships in the REF period include:

- two Royal Society Research Professorships (**Grey**, **Klenerman**)
- two EPSRC Established Career Fellowships (**Gaunt**, **Spring**)
- two EPSRC Leadership Fellowships (**Gaunt**, **Nitschke**)
- four Royal Society University Research Fellowships (**Bernardes**, **Lee**, **Phipps**, **Thom**)
- an EPSRC Early Career Fellowship (**Bronstein**)
- two BBSRC David Philips Fellowships (**Vignolini, JZhang**)

Other major grants in the REF period include:

- **Abell**, £1M Wellcome Trust “Fragment-Based Lead Discovery Against the Protein-Protein Interaction between Aurora A and TPX2 for the Treatment of Cancer”
- **Balasubramanian,** £2M Wellcome Trust “The Chemical Biology and Function of Natural Modified DNA Bases in Genomes”

- **Balasubramanian,** £2M Wellcome Trust "The Chemical Biology of the Genome and the Epigenome"
- **Balasubramanian,** £1M CRUK "Structure, Function and Chemical Biology of Nucleic Acids"
- **Grey**, £1M EPSRC "Next Generation Solid-State Batteries"
- **Hunter,** £2M EPSRC "The Non-Covalent Chemistry of Complex Systems"
- **Klenerman**, **Hunter**, £1M EPSRC "PET markers of oligomeric misfolded proteins in neurodegenerative disorders"
- **Nitschke, Hunter,** £5M EPSRC with Manchester "Molecular Robotics"
- **Scherman,** £2M Leverhulme Large Grant "Natural Materials Innovation"
- **Scherman,** £5M EPSRC "Nano-Optics to controlled Nano-Chemistry"
- **Wales,** £1M EPSRC "Intrinsically Multifunctional Energy Landscapes"

As detailed in Section 4, our strong links with the chemical industry and industry-funded collaborations are an important element of our research grant portfolio. For example, Apollo Therapeutics is a collaborative venture between Imperial, UCL and Cambridge and three global pharmaceutical companies (AZ, GSK, Johnson and Johnson Innovation), which provides translational funding and drug discovery expertise for novel therapeutics and has funded **Spring, Abell** and **Klenerman** (£4M). Other examples of industry funding held in the REF period include:

- OMV Group: £1M contribution to the £2M Christian Doppler Laboratory for Sustainable Syngas Chemistry led by **Reisner**.
- Shell: £1.2M for **SClarke** to investigate the properties of ions on surfaces that led to external paint failure.
- GlaxoSmithKline: £420K for **Bender, Colwell** and **Goodman** to develop predictive tools for the relationship between chemical structure and adverse side effects.
- Astex Therapeutics: £490K for **Colwell** to develop artificial intelligence technologies for fragment-based drug discovery.
- Novo Nordisk: £790K for **Vendruscolo** to develop *in-silico* screening algorithms for protein therapeutics.
- Dyson Technology: £810K for **Grey** to investigate magnesium ion batteries.
- Medimmune: £800K for **Scherman** to develop hydrogels for treatment of glioblastoma.

Our successful increased focus on philanthropy resulted in these major research donations during the REF period:

- £18M for research in the Centre for Misfolding Diseases (Elan Pharmaceuticals).
- £2.5M to endow the Yusuf Hamied 1702 Chair (Dr Hamied).

- £6M to create the Una Finlay Laboratory for research on protein misfolding diseases, the Yusuf Hamied Laboratory for Chemical Synthesis & Catalysis, and the Sir Rodney Sweetnam Microfabrication Laboratory for microfluidics research.

The re-endowment of the 1702 Chair by Dr Hamied has allowed us to redeploy the original BP endowment to support two Next Generation Fellows in perpetuity and to create a fund to improve diversity and inclusion.

Postgraduate research student funding

Approximately 65-75 PhD students are admitted to the Department every year, and although funding sources vary, they are generally as follows: 30% UKRI; 30% research grants from industry, Royal Society, Marie Curie, and ERC; 20% University (e.g. Gates, Harding, Cambridge Trust, Chinese Scholarship Council awards administered by Cambridge Trusts, and named philanthropic scholarships administered by the Colleges); 10% self-funded; and 10% other sources (e.g. home government).

Many of our postgraduates are funded by interdisciplinary CDTs and DTPs:

- SynTech EPSRC CDT in Automated Chemical Synthesis Enabled by Digital Molecular Technologies (**Bernardes, Gaunt, Glen, Goodman, Hunter, Lee,** Ley, **Nitschke, Phipps, Reisner, Scherman, Spring, Thom, Vendruscolo, Vignolini)**
- NanoDTC EPSRC CDT in Nanoscience and Nanotechnology (**Vignolini, Scherman, Nitschke, Reisner, Knowles, Bronstein, Forse, Grey, Jenkins, SClarke**)
- Sensor CDT EPSRC CDT in Sensor Technologies for a Healthy and Sustainable Future (**Jackson, Klenerman, Knowles, Lee, Scherman, Vignolini)**
- EPSRC CDT in Graphene Technology (**Grey, Reisner, Scherman, Vignolini, Wright)**
- EPSRC CDT in Computational Methods for Materials Science (**Thom, Althorpe, Reinhardt)**
- C-CLEAR NERC DTP in Cambridge Climate Life and Earth (**Giorio,** Schmidt**, Vignolini)**
- AI4ER UKRI CDT in Artificial Intelligence for the Study of Environmental Risks (**Archibald, RJones,** Schmidt)
- Connected Electronic and Photonic Systems (**Lee)**

Industry-sponsored PhD studentships over the REF period came from Alphasense, AstraZeneca, BP, DSTL, Cambridge Display Technology, Elan, Eli Lilly, GlaxoSmithKline, Heptares, MedImmune, Mitsubishi, Novartis, Philips Electronics, Procter and Gamble, Schlumberger, Shell, Syngenta, and Unilever. In addition, the AstraZeneca Cambridge PhD Programme is a ten-year undertaking by AZ to provide funding for a minimum of nine annual four-year PhDs in Chemistry, Biochemistry and Pharmacology, worth about £2M to the Department during the REF period.

Organisational infrastructure

Our new Chemistry of Health building and investment in our existing laboratories and facilities will ensure that we continue to provide world-class facilities for the foreseeable future. Support for infrastructure has come from a diverse range of funders: UKRPIF, the University, the Royal Society, charities, industry and private donors.

The Chemistry of Health building and associated infrastructure was funded by £18M from UKRPIF, £18M from Elan Pharmaceuticals, and a £5M private donation. The 2018 opening significantly expanded our footprint and freed up lab space for refurbishment in the Department. The associated Incubator**,** which will nurture spin-out companies from inception through early growth, maximises opportunities for the Department to interact with the industrial and entrepreneurial expertise drawn to the health-related research institutes burgeoning in and around Cambridge, and also provides a favourable environment to develop skills in research translation and entrepreneurship with the aim to increase research impact.

Our strategic plans for developing laboratory space continue to align with new academic appointments, because offering modern laboratory space as part of an attractive start-up package is a major element in drawing international talent to the Department. The University has invested a total of £7M in laboratory refurbishment and infrastructure to support new appointments in the REF period. The basement was transformed into the Dudley Williams Laboratory for the appointment of **Hunter**, the former Whiffen Laboratory was upgraded for the appointment of **Gaunt**, and an ongoing laboratory refurbishment programme aimed at attracting new ECRs currently provides state-of-the-art space for **Forse** and **JZhang**. We have also used £6M in philanthropic donations to create new laboratories for existing research groups working on chemical biology, catalysis, and microfluidics.

Operational and scholarly infrastructure

We have a well-organised and enthusiastic technical and administrative staff, who provide a range of support services across the Department, ensuring that researchers can focus on research.

The eight Computer Officers manage computers, services, computer security, website and extensive wi-fi infrastructure. The Department is a major beneficiary of the £20M West Cambridge Data Centre, which provides an energy-efficient home for the High Performance Computing Service (HPCS) and research computer clusters. The Department has nine racks of dedicated computer equipment in the HPCS and four racks in a similar facility in the Department of

Engineering. The relocation of this equipment has freed up space for research and led to considerable savings in power usage.

Our eight Research Laboratory Technicians and three Senior Technical Officers ensure every laboratory is run safely and maintained to a high standard. The nine technicians in our Technical Services Centre provide electronics, electromechanical, mechanical, and glass blowing services to all researchers. Capabilities include PCB assembly, wiring, repairs, bespoke electronic design, PIC programming, manufacture and repair of glassware, grinding, milling, vacuum sealing and quartz work, sheet-metal manufacture, 3D printing using Rapid Prototyping, repair of rotary vacuum pumps, and Computer Numerical Control milling and turning. Our five Stores Officers ensure an efficient flow of equipment and goods. Our three-member Photography and Reprographics team print posters, theses, teaching material, and provide many related services.

Our comprehensive library has computer terminals providing access to extensive online materials, and quiet spaces for work. Two Department Librarians ensure smooth access to online chemistry databases such as Reaxys, provide training, and implement requests for new materials. We also benefit from the University Library, a legal deposit (copyright) library with over two million volumes and access to over 21,000 electronic journals, 400 databases and a growing collection of electronic books.

Equipment

As well as dedicated equipment based in research groups, we have a range of communal facilities run by experienced technicians, who also provide training to individual researchers wishing to become expert users. These Departmental services ensure that we always have access to the latest instrumentation and techniques, promote the efficient use of funds, and encourage collaborative research. Each of the core analytical facilities listed below is subject to a continuous review and investment programme. In addition to new equipment funded on grants, we invested a total of £8.6M in the REF period in upgrading the instrumentation in our Departmental services.

Microscopy. We have two scanning electron microscopes, and in 2017 we secured a £2M EPSRC multi-user facility grant for a transmission electron microscope (TEM) equipped with EDX, tomography, EELS, and a cryo-holder. We appointed a new Technical Officer who runs the instrument and provides a service for researchers across the University. We also have access to a high-resolution Thermo Scientific Titan Krios cryo-TEM funded by a £3M Wellcome Trust grant in 2016, joint with the Department of Biochemistry.

NMR spectroscopy. We have a comprehensive suite of modern NMR spectrometers (up to 700 MHz) with capacity for the full range of solid-state and solution-phase experiments and extensive automation of routine data acquisition. The instruments are run and maintained by two dedicated technicians. We have invested £740K in a rolling programme of upgrades to improve our seven solid-state and eleven solution-phase NMR spectrometers. In 2018, we acquired an AVANCE III NEO 400MHz spectrometer with a cryoprobe, and completely refurbished our solution phase 700MHz spectrometer, so that it can now run with both solution phase and solid-state probes. In 2020, we bought a new £1.7M DNP solid-state spectrometer.

Mass spectrometry. We have invested £2M to upgrade our mass spectrometry facility, which now has ten instruments. The facility is run and maintained by three dedicated technicians, who also provide support for the 12 additional mass spectrometers that are located in the laboratories of individual research groups.

X-ray crystallography. We have five single crystal and two powder X-ray diffractometers, along with access to powder-diffraction equipment in Earth Sciences and in Physics. Our service is run by **Bond** and a dedicated technician.

The Melville Laboratory maintains a wide range of polymer and materials characterisation equipment including an automated peptide synthesizer, several rheometers, a DLS/zetasizer, a bank of five GPCs, two AFMs, contact angle apparatus, DSC, TGA, both analytical and semi-preparative HPLCs, and an ESI-MS. The Melville technician oversees the smooth running of this equipment.

The Molecular Production and Characterisation Centre was established in the Chemistry of Health building in 2018 and houses an array of modern biological and biophysical facilities available to internal and external researchers. It vastly expands and improves the former Centre for Biological Chemistry, in addition to freeing up research space previously occupied in the Department. The user-membership scheme enables researchers to access fully equipped biological laboratories and state-of-the-art equipment including AKTA PURE systems, Octet, UV-vis, fluorescence and circular dichroism spectrometers, ITC, microscale thermophoresis, real-time PCR and an EVOS 5000 imaging machine. Nidus Laboratories is contributing £1M per year to the MPACC facility.

Outside the Department. Many of our researchers regularly access external facilities. Through joint appointments or membership, staff have access to the infrastructure and facilities at the Cancer Research UK Cambridge Institute (**Balasubramanian**), the UK Dementia Research Institute (**Klenerman**), the MRC Laboratory for Molecular Biology (**Chin**), the BP Institute

(**SClarke**), the Cambridge Advanced Imaging Centre (**Klenerman**, **Lee**), and the Faraday and Henry Royce Institutes in the Maxwell Centre, where **Grey** has coordinated the building of the first UK facility capable of fabricating lithium-containing solid-state batteries, and which includes the Royce Ambient Processing Cluster Tool, a custom-built tool that comprises ten glove box modules and includes thermal evaporation, sputtering, pulsed laser deposition, chemical vapour deposition and atomic layer deposition, and gives access to a wide range of functional materials.

Research income in kind

National facilities. We make regular use of the EPSRC UK National Mass Spectrometry Facility and the EPSRC UK National Crystallography Service. **Grey** and **Duer** use the UK high resolution solid-state NMR facility at Warwick (**Duer** is Co-I on the £2.6M award to provide this service). **RJones** and **Pyle** use the NERC Facility for Airborne Atmospheric Measurements, and **Pyle, RJones** and Schmidt use the NERC HPC and ARCHER computers. We have been particularly successful in gaining access to ISIS (**SClarke, Grey, Scherman)**, where we have had over 60 days estimated to be worth £2.3M, and time in Diamond Light Source (**Bond, SClarke,** Elliott, **Grey, Knowles, Nitschke, Reisner**, Sanders**)** worth £2.3M.

International facilities. Grey, SClarke, Vignolini and Dobson have used international facilities over the REF period, including the ILL (France), ESRF (France), Swiss Light Source, and the Advanced Photon Source and Spallation Neutron Source (USA).

Covid-19 Response

During the national lockdown, the Department closed to protect staff and students. We were able to maintain essential infrastructure (instrumentation, computer connectivity, refrigeration) and prevent potential setbacks to research by preserving critical samples, so that the Department was well-placed to reopen efficiently in June. A variety of measures were implemented to ensure safe working conditions: shiftwork limited lab occupancy to 30% to ensure social distancing, masks were required in all communal areas, and those who could work from home did so. Special consideration was taken for the circumstances of at-risk minorities to allow flexible working arrangements. This approach minimised research downtime to a few months, and from June, researchers and students were able to continue their research with conditions as close to normal as could be achieved under the government guidelines.

4. Collaboration and contribution to the research base, economy and society

Collaboration with industry

Our research is integrated with the international chemical and pharmaceutical industries through a range of different types of interaction as detailed below, and industry funding is a key element of our research income (see Section 3). We have a successful track record of major long-term partnerships with multinational companies, which fund academic posts and infrastructure. We are engaged in various Cambridge-based organisations that facilitate the formation of academic-industry research consortia. There are multiple one-to-one project-specific interactions between scientists in industry and Department researchers, and many of our staff are also engaged by industry as external consultants. In addition, we maintain close research links with the numerous spin-out companies generated by the Department.

Our successful track record of major long-term industrial partnerships includes BP, Johnson Matthey, Shell, Sabic, Unilever and Pfizer. For example, **SClarke** is a faculty member of the BP Institute for Multiphase Flow, which was permanently endowed with £22M from BP and hosts an interdisciplinary team of almost 40 academics, postdoctoral researchers and students to focus on fluid mechanics and surface science. With our commitment to a zero-carbon future, we are transforming our relationship with BP into one of support for sustainable research. For example, the BP funding re-deployed from the Yusuf Hamied 1702 Chair now supports a Next Generation Fellowship for **Forse** to develop new materials that can reduce greenhouse gas emissions. We have also developed a strategic alliance with AstraZeneca as part of their move to Cambridge. AstraZeneca have funded a ten-year PhD studentship programme in order to develop closer research interactions, and **Gaunt** has been appointed to their External Advisory Board for Chemistry. In addition, AstraZeneca fund multiple one-to-one collaborations with our researchers (**Bender**, **Colwell**, **Spring**, **Vendruscolo**, **Scherman**, **Jackson**, **Goodman, Gaunt, Hunter, Phipps, Bernardes**).

Over the REF period there have been other numerous industry-funded collaborations in the Department that cover all major application areas of chemistry: Apollo Therapeutics (**Klenerman**), Astex Therapeutics (**Colwell**), Ceylon (**Wales**), Jaguar Land Rover (**Grey**), Maxeler Technologies (**Thom**), AB AGri Ltd (**Scherman**), AXA **(Kalberer**), Cambridge Display Technology **(Scherman**), Cosma (**SClarke**), Eli Lilly (**Bender),** GlaxoSmithKline (**Bender**, **Gaunt**, **Phipps, Spring**), Huawei (**Grey**), Johnson Matthey (**Grey**), Lhasa (**Bender**), Lubricants UK (**Casford**), Medimmune (**Jackson, Klenerman, Scherman, Vendruscolo**), Mitsubishi (**SClarke**), Murata (**Grey**), Novo Nordisk (**Vendruscolo**), Otsuka Pharmaceuticals (**Gaunt**), Philips Electronics (**Spring**), Procter &

Gamble (**Wright),** Schlumberger (**Grey**), Shell (**SClarke, Grey**), Syngenta (**Abell, Phipps**), Talga (**Grey**), and Unilever (**Bender, Casford, Goodman**, **Hunter**). To support our new SynTech CDT, we have established industrial partnerships with a range of global and SME pharmaceutical and data-science companies, which each make an annual contribution of £40K-200K (AstraZeneca, Astex, Elsevier, BASF, Heptares, Arcinova, Cambridge Display Technology, Computational Modelling Cambridge, Sentinel, Vertex).

Our entrepreneurial culture encourages the translation of research into practical applications, and eleven spin-out companies were founded by Department members during the REF period (highlights in Section 1). The founders often continue productive relationships with their spin-outs as consultants or as members of Scientific Advisory Boards. The first company to occupy our Chemistry of Health Incubator is Wren Therapeutics, and with the success of this interaction, we envisage using this facility to foster new relationships with industry in the future.

Collaborative networks and partnerships

The value, breadth and reach of our research is enhanced through collaborative ventures, which can accelerate results, broaden funding streams and widen access to facilities. In addition to the numerous individual external collaborations that all of our research groups are engaged in, there are more formal arrangements through secondments, virtual networks, or as part of multi-institution consortia.

Secondments:

- **Archibald** has a secondment to the Met Office to develop a strategy for air quality science.
- **Colwell** has a secondment at Google to work with their experts on machine learning.
- **Bender** has a secondment at AstraZeneca to head the Computational Toxicology group.

Cambridge-based networks for interdisciplinary collaboration between academia, industry and the wider policy and service community:

- The Cambridge Centre for Climate Science brings together research groups from Chemistry, Applied Mathematics and Theoretical Physics, Archaeology, Earth Sciences, Geography, Plant Sciences, the Scott Polar Research Institute and the British Antarctic Survey (**Abraham, Archibald, Griffiths, Pyle, Giorio,** Schmidt).
- The Lennard-Jones Centre connects groups from Chemistry, Physics, Materials Science, Engineering and Chemical Engineering who have an active interest in materials modelling (**Alavi, Althorpe, Bender, Colwell, Glen, Goodman, Jenkins, Thom, Vendruscolo, Wales**).

- The Cambridge Circular Plastics Centre includes Chemistry, Zoology, Engineering, Physics, Biochemistry, Materials Science and Metallurgy, Chemical Engineering and Biotechnology, and the Judge Business School, and engages a wide academic, industry, service provider and policy community (led by **Reisner**).
- The Innovation Centre in Digital Molecular Technology will be located in the Department and will bring together industry with the Departments of Chemistry and Chemical Engineering and Biotechnology to develop new molecular synthesis technology platforms.
- The Cambridge Academy of Therapeutic Sciences (CATS) works with industry to tackle research and policy challenges to improve delivery of therapeutic medicines. CATS is home to the Cambridge Alliance on Medicines Safety, an industry partnership for sharing research on toxicology, which led to an on-going collaboration between **Bender, Colwell**, **Goodman** with GlaxoSmithKline and AstraZeneca to predict the safety of current and future medicines.
- The Milner Therapeutics Institute facilitates collaborations with the pharmaceutical industry through its therapeutics consortium, which led to **Colwell**'s collaboration with Astex on the use of artificial intelligence in fragment-based drug discovery.

See also our membership in the University's Strategic Research Initiatives and Networks and Interdisciplinary Research Centres described in Section 1.

Major research clusters:

- **Grey** is director of the Centre of Advanced Materials for Integrated Energy Systems, a partnership of four universities, which focuses on the development of advanced materials for energy conversion and energy storage.
- **Grey** leads the Faraday Institution's project to examine how environmental and internal battery stresses damage batteries over time, a collaboration between ten universities and ten industry partners.
- **Klenerman** is a Foundation Professor of the UK Dementia Research Institute, a collaboration across six universities funded by MRC, the Alzheimer's Society and Alzheimer's Research UK.
- **Scherman** leads the Interdisciplinary Research Collaboration on Hard-to-Treat Cancers, a collaboration between five universities, clinicians and industry.
- **Grey** and **Nitschke** are part of a Synergy group involving three universities, which will investigate the science and technology of graphene and hybrid nanomaterials.
- **Abraham, Archibald, Griffiths** and **Pyle** are members of the National Centre for Atmospheric Science, a NERC collaborative research centre with over 200 members of staff in 12 UK research institutes and universities.
- **Archibald** is science director of the UK Chemistry & Aerosol NCAS-Met Office programme, a collaboration between the Hadley Centre and three universities to develop a new atmospheric

chemistry-aerosol global model, which will form part of the UK's flagship contribution to the next IPCC report.

- **RJones** is part of Breathe London, a multi-partner project involving King's College London, Cambridge Environmental Research Consultants, National Physical Laboratory, Google, Mayor of London, C40 Cities, the Children's Investment Fund Foundation and Clean Air Fund, which has a network of 100 air pollution sensors across London.
- **Reisner** directs the EPSRC-supported UK Solar Fuels Network (SFN), which coordinates national research activities in artificial photosynthesis.
- **Ley** led the EU Future and Emerging Technologies One Flow programme aimed at green process design, involving eight institutions in five countries.

Outreach

Engaging with diverse communities is fundamental to the sustainability of the discipline. We promote chemistry to the general public through open events held in the Department, external visits to schools, and national exhibitions. Staff and students at all career stages are encouraged to participate in Department and University programmes aimed at developing skills in public engagement. For example, the University Rising Stars public engagement course is part of transferable skills training for research students and ECRs.

Postgrads, postdocs and academics all volunteer to create projects for our annual Chemistry Open Day, held as part of the Cambridge Science Festival and funded by a £400K endowment from the Walters-Kundert Charitable Trust. The day gives local, national and international visitors an opportunity to learn about science in an engaging way, and the number of children who attend has grown from 744 in 2014 to 1369 in 2019. We host the annual Salters' Institute Festival of Chemistry, providing teams of school children from years 7, 8 and 9 with hands-on practical experience. For older students, our popular Cambridge Chemistry Challenge offers online resources for students and teachers worldwide. Informally, many of our staff, postgrads and postdocs visit local schools to talk about chemistry and provide hands-on science demonstrations. For example, in the REF period 17 postgrad ambassadors have taken a Fourier Transform infrared spectrometer to local sixth forms as part of the RSC Spectroscopy in a Suitcase programme. We have also developed our own exhibitions for the general public: the **Vignolini** group presented an exhibition on the Chemistry of Colour at the National Science Museum (estimated footfall 4000); our Centre for Atmospheric Science demonstrated the interior of an atmospheric research aircraft at the 2014 Royal Society Summer Exhibition; and the **Scherman** group demonstrated how chemistry will facilitate new timber-based construction methods at the 2019 exhibition (estimated footfall 15,000).

For over ten years, Wothers has set challenging papers for Year 13 students as part of the Chemistry Olympiad programme. He is heavily involved in promoting chemistry to young students and members of the public and has fronted our Cambridge Science Festival lectures at the Department and for local schools. His contributions were recognised by an MBE for services to Chemistry in 2014.

Our outreach activities also have an international dimension. In 2019, one of our graduate students organised a Cambridge-Nigeria Outreach Programme involving three Nigerian universities, and won a Vice-Chancellor's Social Impact Award for his Africa of our Dream Initiative, which aims to provide access to quality education and medical care in sub-Saharan Africa. The University's Public Engagement Starter Fund provided support for a postdoc from the Department to partner with Biomakespace and TeamDeploy to engage young people in India with science. A PhD student from the Department runs the non-profit Simuka-Arise Initiative in Zimbabwe to enable the economic, social and academic empowerment of young women, and co-organised a Black Legacies in STEM exhibition for Black History month in 2020. Another PhD student from the Department set up a mentoring scheme called CariScholar in 2016 to help aspiring scholars from the Caribbean reach their potential.

We run a diverse seminar programme that is advertised to the public and attracts globally renowned speakers. This programme ensures that our researchers are exposed to the latest developments across the discipline and showcases our research to leading scientists from across the world. Nobel prize winners who presented lectures in the Department during the REF period include Frances Arnold, Greg Winter, Richard Henderson, Tom Cech, Bob Grubbs and Ada Yonath. We make it a point to invite women scientists as role models for younger researchers: for example, Luisa De Cola, Charlotte Williams, Sally Price, Anne Bertolotti, Kimberly Bonger, Magdalena Titirici, Carmen Nussbaum-Krammer, Filippa Lo Cascio, Anna Krylov, Nadine Nassif, and Louise Serpell all lectured in the Department in 2019.

Leadership in the academic community

The Department hosts a number of researchers who are international leaders in their field, and who have been recognised with major awards and honours. We also make important contributions to the health of the discipline through a variety of community service and leadership roles.

During the REF period, honours were awarded to **Balasubramanian** (knighthood for services to science and medicine), Dobson (knighthood for research into Alzheimer's and Parkinson's), **Klenerman** (knighthood for his contribution to the development of high-speed DNA sequencing technology), **Pyle** (CBE for services to atmospheric chemistry and environmental science) and

Sanders (CBE for services to scientific research). An alumnus of the Department, Sir Gregory Winter, was awarded the Nobel prize in Chemistry. We have 11 Fellows and one foreign member of the Royal Society, of whom **Alavi**, JClarke**, Wales,** and **Abell** were all elected during the REF period; four Fellows of the Academy of Medical Sciences of whom **Chin** and **Klenerman** were elected during the REF period; two foreign members of the American Academy of Arts & Sciences (**Grey**, Frenkel); a foreign associate of the US National Academy of Sciences (Frenkel); and an honorary member of the Royal Irish Academy (**Hunter**).

The international standing of staff from the Department is evidenced by the numerous awards received for scientific achievement within the REF period. We highlight the following:

- two Royal Society Royal Medals (**Balasubramanian**, **Klenerman**)
- two Royal Society Davy Medals (**Pyle, Grey**)
- RSC Tilden Prize (**Wales**)
- three RSC Corday-Morgan Prizes (**Knowles**, **Scherman, Reisner**)
- two RSC Harrison-Meldola Memorial Prizes (**Bernardes, Phipps**)
- two Raymond and Beverly Sackler International Prizes (**Chin, Knowles**)
- two RSC John B Goodenough awards (**Grey**, Elliott)
- American Chemical Society Arthur C Cope Award (Ley)
- American Chemical Society Arthur C Cope Scholar Award (**Gaunt**)

All members of the Department contribute to the wider academic community through refereeing of publications and research grants, acting as members of grant awarding panels (EPSRC, BBSRC, Wellcome, Royal Society, ERC and Marie Curie), editing journals, and organising and speaking at international conferences. In addition, several staff from the Department play important leadership roles in national and international organisations including:

- **Abell:** Scientific Advisory Board Astex, Aqdot and Sphere Fluidics.
- **Balasubramanian:** Scientific Advisory Board Cambridge Epigenetix, Illumina, Max Planck Institute for Molecular Physiology, Science Advisor Haren Innovation Capital.
- **Pyle:** International co-Chair of the Scientific Assessment Panel that advises Parties to the Montreal Protocol, Chief Scientist of the National Centre for Atmospheric Science, NERC Council.
- Sanders: Chair of the Athena Forum, the national body advocating for greater diversity in STEMM on behalf of all the UK science learned societies.
- **SClarke:** ISIS Science Advisory Committee and the European Spallation Source sample environment panel.
- **Grey:** Samsung advisory group, expert panel of the Faraday Institution.

- **Hunter:** Deputy Chair REF2021 chemistry panel, REF2014 chemistry panel, Associate Editor *Chemical Science*, Series Editor *Topics in Current Chemistry*.
- **Spring**: Review Panel Diamond 104-1 beamline.
- **Gaunt:** AstraZeneca Chemistry External Advisory Panel, Associate Editor *Chemical Science*, Advisory Board of Netherlands Advanced Research Center Building Blocks Consortium.
- **Reisner**: Editorial Board *Angewandte Chemie*, Scientific Advisory Board Max Planck Institute of Colloids and Interfaces.
- **Scherman**: Scientific Advisory Board member SABIC, Editorial Board *ChemComm* and *Chemical and Biological Technologies in Agriculture.*