Institution: University of Sussex

Unit of Assessment: UoA8 Chemistry

1. Unit context and structure, research and impact strategy

Overview of context and structure

Sussex Chemistry is a Subject Group within the School of Life Sciences. Chemistry comprises 18.3 FTE of REF eligible faculty (including one independent research fellow, Derudas). The School of Life Sciences adopts a unified structure with no formalised departments, in order to enhance collaborations between the five Subject Groups: Chemistry; Neuroscience; Evolution, Behaviour and Environment (EBE); Genome Damage and Stability; and Biochemistry and Biomedicine. The research synergy across the School is a particular strength of Sussex Chemistry, demonstrated by the establishment of the Sussex Drug Discovery Centre (SDDC) in 2011, with research spanning medicinal chemistry and biological sciences. The close collaborations between subject groups in the School specifically enabled the development of the REF2021 impact case study by Prof. E. Hill, focussing on the development of new, highly sensitive, mass-spectrometry methods to detect neonicotinoids and other pesticides in collaboration with EBE (Prof. D. Goulson).

REF2014 coincided with a period of restructuring at Sussex, resulting in a disappointing performance for Chemistry. In response to this, a new research strategy was implemented during the REF2021 period, leading to measurable increases in grant income and to demonstrable impacts of research during the current REF period. These improvements have been achieved by the implementation of a strategy that has promoted and enabled the development of staff appointed in the REF2014 period (Bagley, Spencer, Brown, Vargas, Kostakis) and the appointment of new staff at early career (Greenland, Pubill Ulldemolins) and more senior (Layfield, B.Cox, Nokhodchi) levels.

Current and future research strategy

Current strategy targets three research themes:

- Organic and medicinal chemistry (including SDDC)
- Materials and catalysis
- Fundamental chemical processes and interactions

The new research strategy has developed excellence in these areas by enhancing inter-disciplinary research and collaboration within the School and elsewhere (internal/external to Sussex). This strategy has enabled a resilient, sustainable and outward-looking research base in Chemistry, while promoting impact generation. Particular strengths of Sussex Chemistry include medicinal chemistry/drug discovery, and organometallic chemistry and molecular nanomagnetism. Many aspects of this research are aligned with the objectives of University-level strategic research programmes, notably the Sussex Programme for Quantum Research (Layfield is a member of the SPQR Steering Committee) and the Sussex Sustainability Research Programme.

Organic and medicinal chemistry research includes the development of new drugs (Bagley, B.Cox, Pubill Ulldemolins, Spencer, Ward, Derudas); harnessing new and emerging technologies for organic synthesis and medicinal chemistry, including flow, thermo-, photo- and mechano-chemistry (Bagley, B.Cox, Spencer); new synthetic methods (Bagley, Spencer); organic and bio-inorganic catalysis (Spencer, Viseux); and smart polymers, adhesives, bio-responsive materials and drug delivery systems (Greenland, Nokhodchi). Strengths in this area are demonstrated by the impact case based on Photodiversity, a start-up company at Sussex. The company develops complex, sp^3-rich, scaffolds and libraries for drug and product discovery in the pharma and agrochemical industries, using photochemical synthesis. Other highlights include Spencer and Bagley's research in medicinal chemistry/chemical biology and the award of an EU Interreg programme (~£500k at Sussex) in reagentless, green technologies. This grant provides substantial investment in novel equipment for flow and mechanochemistry. This area has been strengthened by the early career appointments of Greenland (polymer chemistry) and

Pubill Ulldemolins, whose research focuses on designing bioactive peptides as novel therapeutics for Alzheimer's Disease. Bio-organic chemistry research is key to the BBRSC-funded South Coast Biosciences Doctoral Training Partnership (SoCoBio DTP), including Sussex and led by Southampton, with Spencer supervising PhD students funded by the Centre and acting as the industrial liaison.

SDDC research is central to organic and medicinal chemistry at Sussex. There have been changes to the senior personnel in SDDC, with Profs. Ward and Atack moving to Cardiff in 2017. Under their leadership, SDDC attracted substantial MRC and Wellcome Trust funding. The appointment of Prof. Jeff Hill from Singapore's A*STAR as the new director (2019) has established new leadership. SDDC's place as an integral element of Chemistry is evidenced by a recently funded CRUK grant on which J.Hill and Spencer (Chemistry) are Co-Is, with West (Biochemistry) as PI. The appointment of early-career staff (Greenland and Pubill Ulldemolins) in Chemistry was also implemented to enhance SDDC collaborations.

Materials and catalysis research includes inorganic materials (Cloke, Crossley, Kostakis); molecular magnets (Layfield); energy materials (Chen, Turner); organometallic chemistry (Layfield, Crossley, Cloke); theoretical investigations of new materials and catalysis (Vargas, H.Cox); organic and inorganic catalysis (Spencer, Viseux, Cloke, Kostakis); and heterogeneous and nanostructured catalysis (Brown, Osborne, Chen). Succession planning in this area, following the retirement of Cloke in 2020, was achieved by appointing Layfield to a Chair of Inorganic Chemistry in 2018. Layfield holds an EPSRC early career fellowship and an ERC Consolidator Grant (CoG) grant and is a world leader in single molecule magnets, demonstrated by a recent publication describing the first single molecule magnet to function above liquid nitrogen temperatures. This work, led by Layfield, results from an international collaboration including scientists from China and Finland. In July 2020, Layfield secured EPSRC funding for £743k to further this work.

Fundamental chemical processes and interactions covers a range of, mainly physical, chemistry including surface reactions/interactions applied to astrochemistry (Brown); the development of new theoretical methodologies and studies of fundamental chemical physics (H.Cox); the exploration of chemical bonding in molecules (Vargas); and single molecule spectroscopy with applications to biological imaging and the photochemistry of new nanomaterials (Osborne). Reaction mechanisms are also studied computationally and experimentally (Brown, H.Cox), as is sensitivity enhancement for NMR spectroscopy, with applications to structure determination across a wide range of chemical and biological systems (Day). This latter work led to an EPSRC award in collaboration with Osborne. Computational collaborations between faculty are growing, with theoretical investigations of properties (Kostakis, Vargas), mechanism (Spencer, H.Cox, Turner) and energetics (Brown and Turner) complementing experimental work. Nanomaterials (Chen, Osborne) are an important link between Chemistry and Physics, and Osborne has synthesised novel perovskite quantum dots for 2D nanomaterials for biosensors (with A. Dalton, Sussex Physics). Strengths in this area include Osborne's work on nanocrystals and quantum dots; H.Cox's work on electron correlation, demonstrated by an EPSRC award in collaboration with Manby (Bristol); and Brown's astrochemical surface science work, demonstrated by her leadership of an STFC Consortium grant from 2015-2018.

The new research strategy has led to measurable improvements in research quality since 2014. This includes a tripling in the number of funded Chemistry post-doctoral researchers and increased grant income, e.g. BIS/BEIS research council funding has more than doubled in the current REF period, and competitive charity income has increased more than 20-fold. (**Figure 1**). Increased income has led to improved international visibility, exemplified by increasing international collaborations e.g. Brown is part of a multi-national collaboration of chemists, physicists and astronomers from the UK, Europe and the USA who have been awarded prestigious early release science time on the James Webb Space Telescope, launching in 2022. Layfield has many international collaborations with researchers from Finland, China, the USA

and Germany, as well as hosting three Newton research fellows from India and China. B.Cox has won funding from the Swiss Innovation fund.

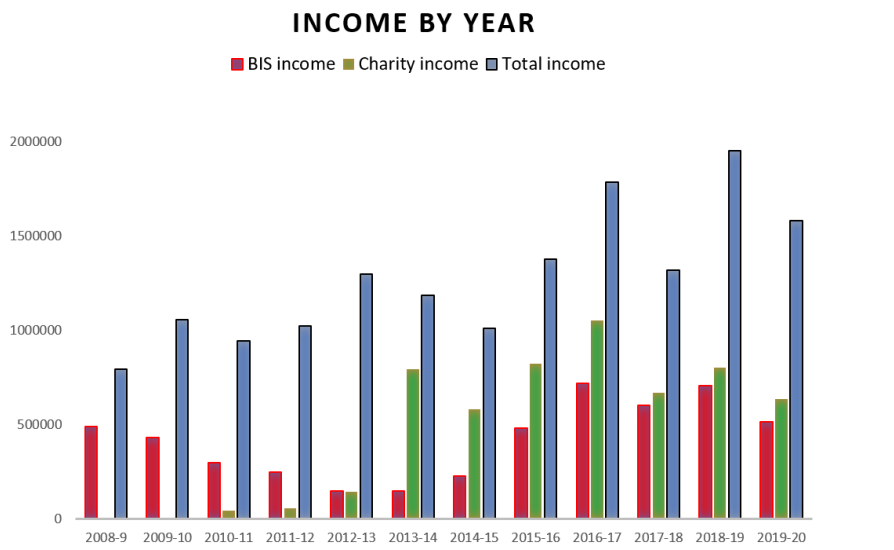

Figure 1 Chemistry income by year

The increasing international visibility of Sussex Chemistry is demonstrated by **Figure 2**, which shows the percentage of outputs involving international collaborators, as a function of publication year. The research strategy pursued during the REF2021 period explicitly encourages collaborations and this has led to increased collaborations inside, and outside, Sussex. Increased focus on impact and a positive shift towards translation of our findings into societal impacts is also part of the new strategy. The REF2021 impact case studies based on (1) the harmful effects of neonicotinoid pesticides on bees and (2) automated and photochemical methods for the synthesis of biologically active molecules, clearly demonstrate the success of this strategy. The first of these, by E.Hill, highlights the way that sophisticated, highly sensitive, analytical chemistry techniques have been used to detect neonicotinoid pesticides in plants, leading to the banning of these pesticides by garden centres to protect bees. The second impact case, by B.Cox, shows how automated chemistry methods can be used to generate new molecules with enhanced activity e.g. as anti-malarial drugs.

The new research strategy aims to create a resilient, flexible research environment, which has been demonstrated clearly during the 2020 COVID-19 pandemic. Research laboratories were re-opened and fully functional by the end of July 2020, with safety measures in place, allowing research to restart quickly and efficiently. The adaptability of our researchers is demonstrated by Spencer and Greenland who have both played essential roles in COVID-19 research. Molecules synthesised by Spencer's group have been tested as part of the COVID-19 Moonshot project. Spencer's group received a Wellcome Institutional Strategic Support Fund (ISSF) award and Sussex COVID-19 Higher Education Innovation Fund (HEIF) emergency funds for this research. Greenland's group are actively working on anti-viral polymer coatings for surfaces, partly HEIF funded.

Our future research strategy targets four areas:

- Medicinal chemistry/drug discovery for applications in cancer and dementia therapy
- Inorganic materials, particularly single-molecule and nanomaterial applications in magnetism, energy conversion and optical spectroscopy
- Green chemistry and catalysis
- Fundamental chemical processes and interactions

The further development of medicinal chemistry and drug discovery is enhanced by increased Chemistry collaborations with SDDC, following J.Hill's appointment. Pubill Ulldemolins is also building her new research group, targeting peptide-based treatments for Alzheimer's Disease and cancer, and Spencer continues to develop new collaborations e.g. a new collaboration with Giamas (Biochemistry) has recently led to the launch of a spin-off company, Stingray Bio Ltd., targeting cancer treatments.

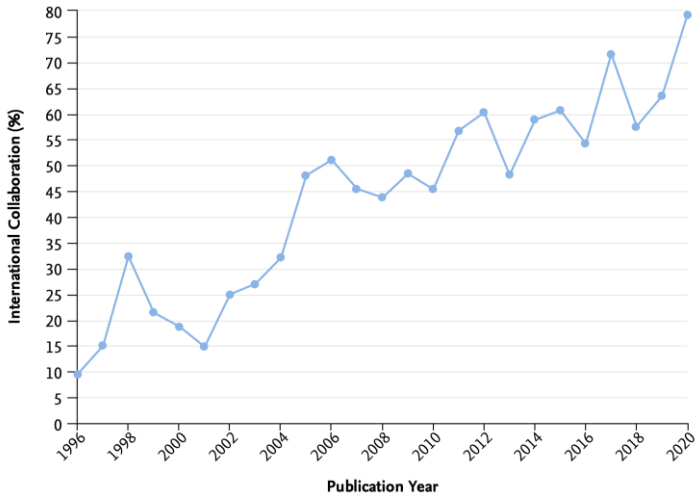

Figure 2 Output percentage involving international collaboration (Scopus, 12/20).

The development of inorganic materials research includes Layfield's expansion into new areas of molecular magnetism, such as the preparation of host-guest composite materials consisting of single molecule magnets encapsulated in metal-organic frameworks, as well as Crossley's planned development (funded by EPSRC) of new molecular-scale electro-active components for conductors and devices used as organic light emitting diodes.

Green chemistry and catalysis will be developed by the further formation of industrial links in heterogeneous and green catalysis, building on the successful Interreg programme in reagentless, green and sustainable technologies. Faculty members already have collaborative agreements or NDAs with industries in the steel, petrochemical, energy and financial sectors, e.g. new research concerning novel automotive catalysis is under development by Turner, with collaborators at the University of Brighton and Ricardo Ltd. Chen is well placed to enhance his research in the area of photo-catalysis, with recent results showing excellent photocatalytic water splitting by ZnO nanorods. A recent PhD graduate from Chen's group, Dr D. Commandeur, was awarded the inaugural School of Life Sciences Latitude prize for Sustainable Development for this work, recognising contributions aligned with UN sustainable development goals. These emerging areas in Sussex Chemistry will be enhanced by supporting and encouraging collaborations within Sussex, the UK and internationally, and with industry. Collaboration is important in its own right to broaden the science base. However, for a small Department like Sussex collaboration is vital as it provides a platform for wider economic, societal and scientific impact. It also increases the visibility and reach of Sussex research nationally and internationally.

Finally, the fundamental processes and interactions topic continues to build on strengths in physical and theoretical Chemistry. Whilst already strong, a specific aim is to appoint a member of staff in electrochemistry, to expand our capabilities in physical chemistry. The success of this strategy will be measured by continued increases in research grant income and by increased numbers of post-doctoral and PhD researchers, and publications.

Impact strategy

We have also implemented a new strategy to translate research findings into societal impacts. The strategy focuses on encouraging researchers to work with industry and/or to develop spin-outs that translate our science into demonstrable impacts, whilst also using Public Engagement to disseminate research. Chemistry has a strong, well-developed, portfolio of Public Engagement, enhanced by the School appointment of a dedicated Public Engagement Coordinator, funded by the University and the Wellcome Trust. Events provide a public platform to show how our research benefits society. Sussex chemists have participated in events including Soapbox Science in Brighton, The Big Bang Fair (South East) and the Brighton Science Festival, as well as receiving many invitations to speak at schools across the region.

The success of our strategy for translating research into societal impacts is demonstrated by the impact cases submitted to REF2021. The first of these shows how the development of sensitive mass-spectrometry techniques by E.Hill allowed a demonstration of the detrimental effect of pesticides on the bee population. This research culminated in a campaign by Friends of the Earth to persuade ten of the biggest UK garden centres to commit to removing neonicotinoids from their plants. The second impact case arises from a collaboration with the University of Bristol, supported by the Sussex Innovation Centre, which led to a start-up company, Photodiversity, created by B.Cox and Kevin Booker-Milburn (Bristol). Cox's work focusses on the design and synthesis of sp^3-rich screening libraries using photochemistry and high-throughput automated synthesis. Photodiversity has secured contracts with leading Pharma companies, biotechs and developing world disease drug development charitable organisations to make drug libraries to be tested for treating a range of diseases. The network of SMEs, developed through the Labfact Interreg programme, is also being enhanced with the Sussex Innovation Centre and the Knowledge Transfer Network, with the goal of securing translational funding from Innovate UK.

Plans are in place for developing future impact. For example, Spencer is researching Niemann-Pick disease and has recently started a new collaboration with Goulson (EBE) looking at the transfer of harmful insecticides to birds. He is also working with Prof. T. Moore (Biochemistry) on antifungal agents supporting Moore's spin-off, Alternox. Greenland is working on the development of degradable adhesives with a range of potential applications, and has recently published some of the research with collaborators at the Atomic Weapons Establishment (AWE). Layfield and Cloke have initiated discussions with the AWE relating to chemical applications of depleted uranium. Key to the implementation of our future impact strategy is an awareness of the importance of societal impact by providing support to faculty to pursue and develop impact wherever relevant. To this end, the School now has a dedicated impact champion, Prof. Paul Graham (EBE), whose role is to help researchers to nurture and develop impact cases.

Open research strategy and ethics

Research data management and dissemination are outlined by University policies. Researchers are encouraged to disseminate raw data through the University's fileshare policy and through publication in open access journals. All publications are submitted to the University repository Elements, formerly Sussex Research Online, within 3 months of acceptance and funding is available for open access publication charges. All Chemistry REF-eligible staff have an ORCID identifier. The School of Life Sciences is contributing to development of policies to embed the principles of the Declaration on Research Assessment in the career progression of researchers. All postdoctoral fellows are trained in ethics, and the School has a dedicated ethics committee to scrutinise research proposals.

2. People

Staffing strategy

To support our research strategy, there has been significant investment in new members of staff since 2014, which has allowed a >20% increase in staff from 14.4 (2013/14) to 18.3 FTE (2019/20). The appointments of Greenland, B.Cox and Pubill Ulldemolins were made to support Organic and Medicinal Chemistry, and in B.Cox's case the impact strategy. These appointments

support our aim to encourage collaborations within Sussex and outside. Layfield's appointment allowed succession planning for the Chair of Inorganic Chemistry and contributes to the strengthening research in Inorganic Materials and our international profile. Crossley's appointment was also made to support the Inorganic Materials strategy. Crossley was a Royal-Society URF and his position was made permanent in 2016, following his successful URF tenure. Previous School strategy was to appoint at Senior Lecturer level or higher. This has been revised and early career staff are now appointed, with support, mentoring and training to develop and nurture their academic careers and promotion prospects. Appointments since 2014 are:

Name	Area	Date
Prof. Brian Cox	Organic chemistry/pharmacy	November 2014
Prof. Ali Nokhodchi	Chemistry/pharmaceutics	December 2014
Dr. Ian Crossley	Inorganic chemistry	October 2016
Dr. Mohammed Maniruzzaman	Chemistry/pharmaceutics	July 2017
Dr. Barnaby Greenland	Polymer chemistry/drug delivery	September 2017
Prof. Richard Layfield	Inorganic/organometallic chemistry	May 2018
Dr. Cristina Pubill Ulldemolins	Organic/medicinal chemistry	November 2018

The research strategy in the REF2021 period has led to the award of more grants with post-doctoral researchers funded on those grants. This has led to growth in the number of research-only staff. Excluding SDDC, the number of Chemistry post-doctoral researchers has increased since 2014 (rising from 3 in 2014/15 to 9 in 2019/20). Total numbers of post-doctoral staff within Chemistry and SDDC were 29 (2014/15), 27 (2015/16), 14 (2016/17), 12 (2017/18), 13 (2018/19) and 12 (2019/20). Fluctuations in numbers have arisen due to the movement of SDDC activities from Sussex since Ward left in 2017. It is expected that numbers will increase again following the appointment of J.Hill as the new SDDC director. Recently, a number of Newton International Fellows (currently four, compared to none previously) have been awarded grants to come to Sussex, as part of our increasing international profile. One of these fellows in the Layfield group was recently appointed to an Assistant Professor position at the IISER Tirupati in India. A Marie Curie Fellow in the Layfield group was also recently appointed as a Professor at Sun Yat-Sen University in China, and his work at Sussex was recognised by the inaugural Rising Star Award of the Asian Conference in Molecular Magnetism.

Staff development

Early career faculty are appointed a mentor who is a senior member of staff with research and teaching experience. Their role is to help the new appointee to develop their skills in grant writing, research group management and PhD supervision. Whilst the mentor's role is formal, and is required by University procedures, Chemistry also assigns new faculty a "buddy". Their role is to help the new appointee navigate University systems in an informal way. Buddies arrange regular meetings with new faculty. All new faculty attend compulsory University training courses including those covering the preparation of grant proposals, PhD student supervision and research management and planning. For all faculty, grant proposals are read by two "critical friends" whose role is to provide constructive feedback, improving the quality of submissions. A measure of the success of these activities is shown by the increase in research income during the current REF period (**Figure 1**).

Staff performance is reviewed in the annual appraisal system. Appraisal is a developmental and supportive process, with discussions focusing around how faculty can build on and improve their performance and experience in particular areas. Within Chemistry, discussions also focus on what faculty need to do to be successful in the University promotions exercise. A number of promotions have been achieved since REF2014: Spencer and H.Cox were promoted to Professor in 2016 and 2018 respectively, and Day, Chen and Viseux were promoted to Senior Lecturer. More recently, Chemistry has begun a series of further staff development activities, with a research away day taking place in January 2019, and a further one planned for Summer 2021. These activities complement the annual School Away Day, in which Chemistry fully participates.

Post-doctoral researchers are included in the appraisal system, with appraisals carried out by their supervisor. The aim is to help these researchers to achieve career progression. The University and the School run various events for post-doctoral researchers, and within the School a specific member of staff has the role of overseeing these activities. Each subject group has a coordinator so that all post-doctoral researchers know who to contact if they would like to attend or organise an event. The School and University regularly holds sessions for researchers who are considering applying for externally funded fellowships, with support, advice, mentoring and peer review of proposals offered at every step. Since arriving at Sussex in 2018, Layfield, along with colleagues in the School of Mathematical and Physical Sciences and the School of Informatics, has initiated an annual University-level Early-Career Fellowship training workshop, resulting in an increase in the number of Sussex applications for major research fellowships.

Training and supervision of PhD students

PGR numbers (registered FTEs) were as follows during the current REF2021 period: 2013/14 = 40; 2014/15 = 40; 2015/16 = 45; 2016/17 = 37; 2017/18 = 32; 2018/19 = 28; 2019/20 = 27. Per head of faculty, numbers average around 2 PhD students. PGR numbers have reduced since 2013/14 due to the relocation of Ward to Cardiff. Funding for PhDs has traditionally come from a combination of School-funded studentships, and the EPSRC DTG allocated to the University, and in one case the STFC (studentship for Brown, September 2019). The School of Life Sciences was recently successful in bidding for a BBSRC DTP (SoCoBio, led by Southampton), and chemists can apply for studentships from this DTP. We have been successful in obtaining full/part funding for PhD studentships from industry, with funding being provided from Tocris Cookson (full iCASE, EPSRC), GlaxoSmithKline (full iCASE, EPSRC), and Astra Zeneca (one CASE, one full iCASE, EPSRC). We have also been successful in sourcing charity funding for PhD positions including from Worldwide Cancer Research (part funding), the Songbird Survival, DEFRA and the Leverhulme Trust. A relatively large number of International PhD students study in Sussex Chemistry, with researchers funded by the Thai, Nigerian, Chinese, Libyan, Saudi Arabian, Iraqi and USA governments all having studied for a PhD during the REF2021 period. Furthermore, EU funding in the form of an Interreg programme supports four PhD students over four years, EU Horizon RISE provides part-funding (Spencer) and Layfield's ERC grant supports three PhD students. These funding streams have enabled us to keep the number of PhD students at a healthy level. PhD completion rates are excellent, with the percentage of students submitting within 4 years being 90% (14/15); 100% (15/16); 92% (16/17); 90% (17/18) and 100% (18/19).

PhD students are assigned a primary and secondary supervisor. The second supervisor role is primarily pastoral, but they also provide research guidance as appropriate. In 2016, Sussex introduced Thesis Committees for PhD students, with the aim being to help and support students towards the successful and timely completion of their PhD. The Chair of a student's thesis committee is their second supervisor, with three other faculty members serving on the committee. Students have two thesis committee meetings in year 1, and further meetings in years 2 and 3. The first meeting in year 1 is to ascertain that the student has settled in and is making good initial progress and knows what the aims and context of their research are. All other thesis committees are accompanied by a written report, detailing progress to date. Reports on thesis committee meetings are approved by the Chemistry Doctoral Convenor (Kostakis) and are signed off by the School Director of Doctoral Studies. In this way, thesis committees ensure that students are making good progress, with the aim of catching any difficulties early, allowing the necessary support to be put into place if required. PhD students are expected to give an oral presentation within Chemistry in their final year, to give them experience in presenting their research to a broad audience. Students also give pre-viva talks on the day of their oral examination, summarising their work to the whole subject group. The success of this system is clearly demonstrated by our excellent PhD completion rates.

PhD students undergo compulsory safety training and are strongly encouraged to attend the wide portfolio of training courses offered by the Sussex Doctoral School, covering areas such as thesis writing, time management and CV writing. PhD student pastoral support is primarily *via*

the secondary supervisor and the Chemistry Doctoral Convenor. More directed support is available *via* the School Director of Doctoral Studies and the Sussex Student Life Centre. The University of Sussex Doctoral School is involved in a project to monitor and support the mental health of Doctoral students (called U-Doc) and hence excellent support in this area is readily available for PhD students.

Equality, Diversity and Inclusion

We have an international faculty, with a third of academic staff from outside the UK including Asia (China, Iran) and Europe (Spain, France, Greece). The School of Life Sciences holds an Athena Swan Silver award, demonstrating the commitment of the School to Equality, Diversity and Inclusion (EDI), and most recently the School has written and adopted a Race Equity Action Plan. Key priorities of this plan include monitoring and improving staff training around issues of cultural awareness, diversity and unconscious bias, an overhaul of recruitment literature and practices, addressing the lack of BAME role models in academia, increasing the low numbers of BAME PhD students, and remedying the BAME awarding gap.

The School's Silver Athena Swan award was renewed in 2019, with two members of Chemistry faculty participating in the renewal. The University has a Deputy Pro-Vice Chancellor for Equality and Diversity who heads up the EDI unit. This unit has set up support networks for BAME and LGBT+ staff, holding a range of events and raising awareness about issues affecting these groups. The University has published a new Dignity and Respect policy, which is fully integrated into our working culture. As part of this, the School has created a *Code of Conduct for meetings*, a campaign around email etiquette, and has instigated compulsory EDI training for all staff. The School also has a Support Network, of which Brown is a member. This network is available for all members of the School to raise any dignity and respect issues. Members of the network are trained in mediation, as well as in supporting others. The University has introduced a new flexible working procedure, with two Chemistry faculty members using this to help with child-care arrangements.

The EDI agenda is embedded within everything that we do. The Chemistry subject chair is female (Brown) and there are now three female faculty, of whom two are Professors. This is a big increase since REF2014: until Brown joined Sussex in 2013 there was only one female Chemistry faculty member. The most recent Chemistry appointment (Pubill Ulldemolins) is female. However, it is clear that gender parity within Chemistry has not yet been achieved. This is not a Sussex-specific phenomenon, as demonstrated by the 2019 RSC study of the chemical sciences diversity landscape. In terms of ethnic diversity, 16% of faculty have declared that they belong to a BAME background. Care is taken in the wording of job adverts to proactively increase diversity of staff by using inclusive language, e.g. through the use of gender decoder software and by advertising all posts on the BBSTEM website. Interview panels across the School, at all levels, must have gender and ethnic balance. All staff who undertake interviews must attend the University's Unconscious Bias and Equality and Diversity training courses.

Equalities impact assessment of REF submission

An assessment of the equalities data for REF outputs shows that 25% of all staff are female, whereas 15.8% of female staff made REF submissions. This disparity is largely due to the number of female post-doctoral researchers in Chemistry, who are not yet research-independent. All female staff on academic teaching and research contracts have made REF submissions, including one early career member of staff. 20% of all staff declare their ethnicity as BAME, and the REF submission consists of submissions from 15.8% who declare themselves as BAME. There is an over-representation of staff aged over 50 in REF submissions, who formed 47.4% of REF submissions but only 27.5% of all staff. This discrepancy can be explained by seniority – it is more likely that senior staff submit to REF than junior (especially post-doctoral) researchers.

3. Income, infrastructure and facilities

Research income

The strategy for Chemistry has led to a significant improvement in research income during the REF2021 period. This is clearly demonstrated by a doubling of overall research income in the current period (£10,399,618), compared to the previous REF period (£5,116,567). Areas in which research income has particularly improved includes BIS Research Council and Royal Society income (increased by 120% since last REF period) and UK based charity income (increased to £5.3M compared to £248,592 in REF2014), (see **Figure 1**).

Chemistry obtains research funding from a wide range of sources including the research councils, EU, charities and industry. Chemistry has also been successful in obtaining time on central facilities, such as NSCCS and FELIX (the free electron laser in Nijmegen, The Netherlands). Noteworthy grants to Chemistry during the REF period include EPSRC funding (Cloke, Kostakis, Spencer, Crossley, H.Cox, Day, Layfield); an STFC Consortium grant (led by Brown); MRC funding (Ward) and EU funding via an Interreg grant (led by Bagley) and an ERC Consolidator award (Layfield). Layfield has also been particularly successful in obtaining Royal Society Newton Fellowships, and has obtained several grants for overseas researchers to work with him at Sussex during the current REF period. Chemistry PIs have also been very successful at obtaining funding from charities including Great Ormond Street Hospital, Niemann-Pick Research foundation, Worldwide Cancer Research, Songbird Survival and the Leverhulme Trust (all Spencer); Action on Hearing Loss (Derudas); and the Wellcome Trust (Ward, Spencer, Derudas). B.Cox has also recently set up a company in conjunction with the Universities of Sussex and Bristol, Photodiversity, and has been successful in achieving major investment in this company. This latter success story forms the basis of one of our impact cases. Chemistry faculty have also been very successful in obtaining internal Sussex Research Development Funding to pump-prime future grant applications, with funds having been awarded to Brown, Kostakis and B.Cox during the REF period.

Infrastructure and facilities

Sussex has a wide range of excellent equipment to enable research within Chemistry, the SDDC and within the School of Life Sciences. This includes facilities for X-ray diffraction, NMR spectroscopy and mass spectrometry. TEM equipment is available for use by Chemists within the School of Life Sciences. Sussex has excellent facilities to perform small-molecule single crystal X-ray diffraction studies at ambient and cryogenic temperatures, including a rotating anode instrument for small and weakly diffracting crystals. The single crystal diffraction suite is run by a dedicated technical officer who provides support, advice and training to researchers. For NMR, Chemistry is well-equipped with three spectrometers operating at 400, 500 and 600 MHz, equipped with multinuclear probes allowing the study of a wide range of conventional and unconventional nuclei and experiments. The 400 and 500 MHz instruments are available on an open access basis to support inorganic and organic chemistry respectively. The 600 MHz spectrometer has 4 channels and is equipped with a triple resonance probe to support biological NMR spectroscopy. NMR is managed by a dedicated member of faculty (Day) who also undertakes research into NMR methodology. Mass spectrometry at Sussex is well-equipped and comprises 9 instruments. Of particular note are the facilities for electron impact ionisation, chemical ionisation and desorption chemical ionisation, liquid secondary ionisation mass spectrometry, matrix assisted laser desorption, electro-spray ionisation, and atmospheric pressure ionisation which allow-high sensitivity detection of a very broad range of samples. The mass spectrometry suite is run by a dedicated member of staff, Dr Alaa Abdul-Sada, whose expertise is regularly called upon to perform spectroscopy on difficult-to-detect samples. Abdul-Sada's expertise was instrumental in the high-sensitivity detection of neonicotinoids in pesticides, described in one of the Chemistry impact cases arising from research conducted by Prof. E. Hill. Abdul-Sada is also involved in the novel therapeutic detection of molecular markers in cancer patients. Mass spectrometry at Sussex also has a unique facility for accurate high resolution mass spectrometry on highly air-sensitive organometallic compounds.

Sussex Chemistry also has a wide range of highly specialist research equipment. Use of, and training on, this equipment for users outside of the individual research groups is encouraged and the School has recently compiled a database for exactly this purpose. Examples of some of the more unique equipment includes equipment for metal-vapour synthesis; ReactIR; Flash Vacuum

Pyrolysis; glove boxes for handling air-sensitive compounds, including one box with FTIR capability; ultra-high vacuum apparatus for high sensitivity surface science investigations; equipment for flow-chemistry and mechanochemistry; a peptide synthesiser; dedicated microwaves for microwave-mediated synthesis; and facilities for fluorescence correlation spectroscopy and total internal reflection fluorescence microscopy. Unique and state-of-the-art equipment is also available in the automated parallel synthesis laboratory. This facility is equipped to industry standard using cutting-edge robotic liquid handing, purification and evaporation. The equipment was purchased from Novartis UK in 2014. This laboratory enables the potential production of 250+ compounds per week, allowing for the highly efficient synthesis of chemical libraries with a range of applications (see B.Cox impact case).

The University of Sussex provides a centrally managed high-performance computing (HPC) environment into which research teams can add computer nodes and storage dedicated to their needs. Chemistry faculty make good use of this HPC environment and several of the faculty have purchased dedicated computer nodes on the HPC. Many of the high quality theoretical/computational research outputs from Sussex are dependent on this environment. Sussex IT Services (ITS) are currently developing a future strategy 'Ahead of the Digital Curve'. With guidance from the HPC User Group (which has Chemistry representation), the ITS Research Support team are designing an engagement plan that includes an 'Enabling Research' technology strategy and roadmap to support future research across the University.

A number of refurbishments and investment in high-quality laboratory space for Chemistry have taken place since 2014, many linked to the appointment of new staff. When B.Cox joined Sussex in 2014, specialist laboratory space housing facilities for parallel synthesis was provided. The total cost of this refurbishment was £140k, funded by the Sussex Development fund (SDF). Investment in high quality specialist laboratory space for Nokhodchi in 2015 was also provided, again *via* the SDF, with high specification facilities for pharmaceutical research being provided. The total cost of this investment was £16k. More recently, in 2018, refurbishments were undertaken to make a dedicated glove box room for Layfield's research group, at a cost of £45k, following their move to the Sussex from Manchester in 2018, borne by the School. The most recent refurbishment has provided a dedicated emerging technology laboratory for Interreg PhD students, providing facilities for mechanochemistry and flow chemistry, at a cost of £120k. This refurbishment was also funded by the School of Life Sciences.

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

Our research has a strong collaborative ethos in which all members of staff are engaged in projects at local, national and international levels. Collaborations span academia, industry and other sectors of the research base. Many projects have formal support from grant-awarding bodies or the private sector, whilst some of our most successful joint ventures are more informal. The reach and significance of collaborative research is reflected in the quality of the outputs, many of which are highly cited and have been published in high quality, top ranking, journals. The prominence of collaborative research reflects the quality of the expertise offered by individual members of staff and reflects the outward looking nature of Sussex research. Many of the collaborations demonstrate strong contributions to the economy and society, such as that exemplified by the two impact cases from B.Cox and E.Hill.

Collaborations within organic and medicinal chemistry

The medicinal and organic chemistry research theme provides many opportunities for industrial collaboration. Current links and active funded research are in place with Tocris Biosciences, GlaxoSmithKline and previously Oxford Nanoreportech and Astra Zeneca (all Spencer). Greenland has several consultancy agreements in place in the area of organic and medicinal chemistry with Bramble Ventures looking at drug delivery, brewery techniques and extraction technologies; with EcoBubble in the area of chemical analysis and swelling studies; with Athos Medical technology Ltd looking at new delivery systems for inhaled drugs; and with Aliaxis investigating the synthesis of degradable adhesives. Organic and medicinal chemistry research at Sussex has also led to two patents being filed in the areas of new iron chelators (Spencer)

and breast cancer prototypical drugs (Spencer with Giamas, Biochemistry). All of these demonstrate our contribution to economic and societal impact.

The position of Chemistry as a unit within the School of Life Sciences also helps to facilitate collaborations with biologists which are of clear societal benefit with respect to curing/prevention of disease. This includes collaborative research into chemical aspects of cancer and other diseases. Here Spencer has a number of collaborations including two two-year grants from Worldwide Cancer Research to investigate "rescue molecules" for the tumour suppressor P53, which plays an important role in preventing the spread of cancer. This project has collaborators at the Cambridge Laboratory of Molecular Biology (Prof. Sir Alan Fersht FRS) and at the Structural Genomics Consortium in Frankfurt (Dr Andreas Joerger), and several influential papers have resulted from this project. Spencer was also the PI on an EPSRC project to investigate molecules that can be used as treatments for melanoma. This project involves the Diamond Light Source and SGC with Co-Is (Profs Frank von Delft, Diamond Light Source and Paul Brennan, Oxford) and partners (Tocris Biosciences and California Pacific Medical Centre), and including the melanoma expert Dr David De Semir. Spencer has also received funding from the Niemann-Pick Research Foundation to work alongside Prof. Fran Platt (Oxford Pharmacology) on Niemann-Pick type C disease. This project has resulted in several important publications and has led to studies in other areas of metal dyshomeostasis, including manganese overload. The manganese research is now supported by a Great Ormond Street grant with Dr. Karin Tuschl (UCL) and related NPC work is supported by an EU Horizon 2020 RISE grant involving partners in Romania, Israel, Portugal and Chile, as described in a recent paper. In addition to his external collaborations, Spencer is Co-I on a Wellcome ISSF project and co-supervises a post-doctoral researcher in the group of Moore (Sussex Biochemistry) funded by the SDF and supporting a Sussex spin-off, Alternox Technology. To further strengthen our activities and collaborations in chemical biology, we have recently appointed Dr Cristina Pubill Ulldemolins to a lectureship in synthetic Chemistry. Pubill Ulldemolins joined Sussex from the University of St Andrews and continues to collaborate with colleagues there on the treatment of Alzheimer's disease.

Other areas of organic chemistry research at Sussex also benefit greatly from collaborations that increase the societal impact and reach of the research. A significant volume of organic chemistry research at Sussex is accounted for by an Interreg grant, funded by the EU ERDF scheme. Led by Bagley, Interreg is a French-English partnership focused on the Channel region with substantial contributions from both academia and industry. Trans-national EU cooperation is at the heart of the project, particularly with regards to improving the competitiveness and R&D capability of SMEs and chemical manufacturing in the region. This contributes strongly to the local economy around Sussex. Partner institutions include Sussex, Southampton, Pareon Chemicals, Caen University, Ensicaen, Rouen University and the CNRS. The project enables joint funding and exchange of students, staff and technology, with provision for trans-national training and knowledge exchange.

Organic chemistry research at Sussex also extends to materials and polymer chemistry, with the recent appointment of Greenland bringing further collaborations in this area, many of which lead to research with societal benefit. For example, the AWE funds research in Greenland's group focusing on making novel 'energetic' binders or glues. Greenland's research on polymers produced from sustainable sources is also supported by funding from EPSRC's Directed Assembly Network and involves a collaboration with Prof. M. Shaver (Manchester). Greenland's work also extends to rheological studies in collaboration with Prof. Clive Siviour (Oxford Engineering), with a range of joint publications. Greenland's more recent collaborative work on de-bonding adhesives received extensive media coverage because of its potential to reduce waste and allow better recycling, clearly of enormous societal benefit.

Collaborations within inorganic chemistry

Organometallic chemistry has been a world-leading area of research in Sussex since the inception of the department and remains a major activity. Cloke's work on f-element-mediated small-molecule activation has involved important contributions from computational chemists in

the UK (Prof. Jenny Green, Oxford) and France (Prof. Laurent Maron, Toulouse). More recently, Cloke has initiated a collaboration with Layfield, including work on uranium-catalysed alkene hydrogenation, which was reported by 14 news outlets and was the subject of an interview with Layfield on Heart Radio. A University press release describing this research was picked up by the Ministry of Defence, and as a result Layfield was contacted by the AWE and invited to collaborate to assist with its management of depleted uranium stockpiles. Cloke and Layfield also recently reported the single-molecule magnet (SMM) properties of a pentalene-ligated dysprosium complex, in a study that incorporated theoretical contributions from Dr Akseli Mansikkamäki at the University of Jyväskylä. Theoretical input into Layfield's research on SMMs has involved Prof. Liviu Chibotaru (KU-Leuven Chemistry) as a formal collaborator on projects funded by the EPSRC, the ERC and the Royal Society Newton Fund. Layfield also has collaborations in China with Prof. Ming-Liang Tong (Sun-Yat Sen University), which has led to publications in *Science* and *Angewandte Chemie*. Layfield is the UK host for the Newton Advanced Fellowship awarded to Prof. Jinkui Tang, a senior academic at the Changchun Institute of Applied Chemistry (Chinese Academy of Sciences) and home to the State Key Laboratory of Rare-Earth Resource Utilization. Layfield has also hosted several Newton International Fellows in his group, one of whom (Dr Arun Bar) is now Assistant Professor at the IISER Tirupati (India), with a third Fellow arriving in December 2020. Layfield also has strategic links with India through the Newton alumni fund. Layfield also collaborates with Prof. Matthias Bickelhaupt, an expert in DFT methods at the Vrije Universiteit Amsterdam, where he is a visiting Professor, and with Prof. Manfred Scheer at Regensburg University, Germany, through a Humboldt Foundation Fellowship for Experienced Researchers. Adding to the multidisciplinary nature of his research, Layfield has also initiated a collaboration with Prof. Sean Giblin in Cardiff Physics, which has led to one publication, and a grant application that was funded by the EPSRC New Horizons scheme in 2020.

Computational chemistry collaborations

Computational chemistry research is a core activity in Sussex and provides important links with experimental programmes, locally and internationally. Vargas's work has provided crucial insight into exotic and highly unusual boron compounds through his longstanding collaboration with Prof. Holger Braunschweig (Würzburg University, Germany). Further supporting experimental investigations, H.Cox has worked with Spencer in a collaboration that has resulted in seven publications, with Cox providing detailed mechanistic information into a range of catalytic transformations. Cox's contributions ultimately allowed a number of Spencer's palladium-catalysed cross-coupling reactions to be explained and optimised. More recently, Cox has a collaboration with Prof. Fred Manby at Bristol which has resulted in the award of an EPSRC grant whose aim is to design a correlation functional for use in DFT. Cox also has a collaboration with Prof. Erkki Brandas, University of Uppsala and Prof. Lawrence Dunne (LSBU/Imperial) which has resulted in a publication showing that the key to understanding the occurrence of high temperature superconductivity in cuprates is to be found in the Bohm-Pines Hamiltonian, modified to include a polarisable dielectric background.

Collaborations within physical chemistry

As well as the more traditional areas of Chemistry collaboration already described, Prof. Wendy Brown works with astronomers, chemists and physicists to support her work in the highly inter-disciplinary area of astrochemistry. Collaborations with Prof. Martin McCoustra (Heriot Watt) and Prof. Stephen Price (UCL) led to the award of an STFC Consortium grant with Brown at Sussex being the lead. Further collaborations with McCoustra and with Dr Sergio Iopollo at Queen Mary, University of London have led to the award of 4 periods of beam time at FELIX, the free electron laser in Nijmegen, to study infrared photodesorption of ices on interstellar dust grains. To allow the translation of fundamental physical chemistry data into astronomical models, Brown also collaborates with astronomers, including Prof. Serena Viti (Leiden). Brown is also part of a large consortium of chemists, physicists and astronomers from the UK, USA and Europe awarded prestigious early release science time on the James Webb Space Telescope, launching in 2022. The aim of this project, called IceAge, is to understand the formation and composition of ices in space, with an aim to better understanding the building blocks of life.

Other areas of Physical chemistry where important contributions to the research base and to societal impact are made include Dr Mark Osborne's work with Prof. Sir David Klenerman FRS and Prof. Ernest Laue (Chemistry and Biochemistry at Cambridge respectively). This work has led to the design and construction of a super-resolution fluorescence microscope for the detection, counting and tracking of single Mcm4 and PCNA, DNA-binding proteins associated with replication and repair. Osborne is also engaged in projects with Prof. Tony Carr (Sussex Genome Damage and Stability Centre) to elucidate the role of ubiquitin in post-translational modification of the chromatin associated PCNA protein in the regulation and control of DNA replication in fission yeast. Dr Iain Day also has a number of collaborations in the area of NMR spectroscopy. A recent EPSRC grant with Osborne focuses on improving NMR sensitivity and on providing NMR support to follow ligand dynamics on quantum dot surfaces. As a direct result of this collaboration, a new venture with Prof. Craig Butts (Bristol Chemistry) has been initiated which aims to improve the sensitivity of INADEQUATE spectra by improved spectral acquisition and automated analysis. This powerful method allows carbon-carbon frameworks to be determined in a single experiment. Furthermore, Day's contributions to the research of synthetic chemistry groups in Sussex is invaluable, as shown by a number of joint publications where Day provided expert analysis and interpretation of NMR spectra to aid structure determination.

The collaborations detailed above clearly demonstrate the outward facing nature of Sussex Chemistry research with collaborations adding to the impact and reach of that research, and with collaborations leading to clear examples of societal impact (e.g. in the area of disease prevention and cure). The impact and societal benefit of Sussex Chemistry research is also clearly demonstrated by the two impact cases submitted to REF2021. Public Engagement is also a key activity of Sussex Chemistry, as described in the Impact Strategy. These events provide a public platform to show how Sussex Chemistry research benefits society.

Contribution to sustainability of the discipline

Chemistry faculty actively participate in grant committees, act as journal editors, give invited keynote lectures, act on committees for learned societies and referee papers and grants for national and international journals and grant awarding bodies. For example, Crossley is a member of the Royal Society of Chemistry (RSC) Enablement grants assessment panel and a member of the EPSRC peer review college. Brown regularly serves on EPSRC panels, she chaired an EPSRC Physical Sciences panel in 2017 and regularly reviews grants for the EPSRC, the UK Space agency, the Royal Society, the DFG (German grant body), the Swiss National Science Foundation and the Danish grant awarding body. She is also a committee member of the RSC Astrophysical Chemistry group and an elected member of the RSC Heads of Chemistry UK Standing Committee. Bagley was an overseas panel member for ERC starting, consolidator and advanced grants in 2017. Layfield regularly serves on EPSRC and Royal Society panels, as well as reviewing grants for the EPSRC and several international equivalents, and was a member of RSC Dalton council from 2012-2015. He has also given numerous (15 to date) keynote lectures at national and international conferences since 2014. Layfield is a holder of an EPSRC Early career Fellowship (until August 2021) and has been awarded a Humboldt Fellowship for Experienced Researchers at the University of Regensburg and an Applied Chemistry lectureship at the Chinese Academy of Sciences. Cloke gave 5 keynote lectures over the 2014-2018 period and was a member of the Leverhulme fellowship panel. Spencer and H.Cox have both served on EPSRC panels and regularly review proposals for the EPSRC. Spencer was also a member of the Royal Society small grants committee from 2015-2018 and chaired the committee in 2018. Brown, Crossley and H.Cox were all reviewers for the inaugural EPSRC New Horizons scheme (2020).