Institution: Imperial College London

Unit of Assessment: 09 Physics

a. Context

Research in the Physics Department at Imperial College comprises both fundamental and use-inspired interdisciplinary science delivering economic, societal and environmental impact. In this way we contribute to advances in fundamental science, and use physics to contribute to the development of technologies to improve the quality of life and address global challenges.

The Research Groups of the Physics Department are Astrophysics (ASTR), Condensed Matter Theory (CMTH), Experimental Solid State (EXSS), High Energy (HEPH), Photonics (PHOT), Plasma (PLAS), Quantum Optics and Laser Science (QOLS), Space and Atmospheric (SPAT) and Theoretical Physics (THEO). We also deliver impact through our involvement in multidisciplinary centres and institutes (e.g. the Centre for Plastic Electronics, the Institute of Shock Physics, the Grantham Institute for Climate Change). The principal beneficiaries and forms of impact include:

Industry: We engage with around 160 external companies through collaborative research, consultancy, knowledge transfer and patenting/licencing of our intellectual property. These include those within the Manufacturing (e.g. Rolls-Royce), Defence (DSTL), Energy (Carbon Trust), Healthcare (GE Healthcare), Pharmaceutical (GSK), Motor (Toyota), Electronics (Philips), Space (EADS Astrium), Chemical (Johnson Matthey), Insurance (AXA), Photonics (Carl Zeiss), Communications (Toshiba), Financial (Winton), Security (AWE) and Consumer Goods (Unilever) sectors. We have also contributed to economic growth through commercially successful spinout companies (QuantaSol, DeltaDot, Midaz lasers, Molecular Vision). In partnership with relevant companies we have created unique technologies (e.g. bioimaging in PHOT and metamaterials in CMTH) and advanced products (e.g. supercontinuum and fibre laser sources, novel high index polymer composites with SABIC), biomedicine/healthcare technology (e.g. EXSS "digital staining" infrared imaging with a US laser manufacturer). We also provide consultancy (e.g. EXSS: fuel cells with Johnson Matthey) and advise industries about their investment in infrastructure (e.g. extreme weather events for BP with SPAT).

UK Government: By working closely with government research establishments and agencies, our work informs public policy and guidelines (e.g. SPAT advice on climate change and ozone to parliamentary committees) and directly contributes to government's research and development in areas of energy, defence and national security (e.g. CMTH collaboration with CCFE, PLAS collaboration with AWE and MoD). QOLS led the "New Light Source" project for the STFC Central Laser Facility producing a Scientific Case and Conceptual Design Report, with a budget of £2M, addressing both industrial applications and economic impact.

Overseas Government: Collaborations with international and inter-governmental institutions include research that impacts decisions on fusion energy (PLAS with Sandia National Labs, USA), on new techniques for security (e.g. new high sensitivity detection techniques for US Army by CMTH) and on public service weather-forecasting (advanced instrumentation by SPAT for Eumetsat).

Health Care: Our research on new technologies for diagnosis, and on the development and delivery of therapies, is being advanced via collaborations with clinicians and industry (e.g. PHOT with Karl Storz GmbH), and has potential for enhanced healthcare efficacy and reduced costs.

Public Engagement: We engage a diverse range of audiences to ensure the widest possible understanding of our research and its benefits. Research into metamaterials ("invisibility cloak" and "perfect lens", CMTH), particle physics (the search for the Higgs boson, HEPH, THEO) and cosmology (speed of light, THEO, ASTR) have particularly attracted the world's media.

Schools: We have a dedicated programme of Outreach activities (e.g. our annual Quantum Show). We provide support to teachers (e.g. through courses) and have initiated a unique degree course in Physics with Science Education.

b. Approach to impact

Founded in 1907, Imperial College was the first UK HE institution to place the application of its work to industry and commerce as a central tenet of its mission and today research that advances

physics to the benefit of the public, government and industry is integral to the activities of the department. By celebrating examples of high impact research, and through regular discussions of impact at staff and management meetings, all academic staff and research students understand the importance of maximising the impact of their research.

The specific mechanisms used to create and promote impact include:

Imperial Innovations is a publically-listed company, combining the activities of technology transfer and company incubation with investment. During 2008-2013, activities arising from the research of the physics department included:

- 74 invention disclosures submitted and assessed for IP protection and commercialisation.
- Of these, support for patent application filings for 19 families covering more than 56 individual patent applications in different territories.
- Licensing or assignments of 8 of these patents to industrial partners, including to some of our own spin-outs. Know-how licenses include those acquired for novel antennae, magnetoresistive magnetometers, and electromagnetic cloaking.
- Companies spun-out of the department through Imperial Innovations that were active during the REF period were QuantaSol (photovoltaics, case P4, recently sold), DeltaDOT (label free intrinsic imaging P6), Midaz Lasers (diode-pumped solid state lasers P7, recently sold), Molecular Vision (clinical diagnostics P9), Duvas Technologies (advanced sensing).

Imperial Consultants (ICON) facilitate our consultancies with companies. From 2007/08 to 2012/13, ICON brokered 55 commercial consulting projects between Physics staff and 42 external clients with a total value of £3.6M.

Staff are encouraged and supported in KT activities, and in developing interactions with both Innovations and ICON, by the department's Industry Champion (*Toumi*) who is relieved of some teaching duties to enable him to carry out this role fully.

Corporate Partnerships (CP) support the formation and development of strategic alliances that lead to research collaborations of value to both partners. For example CP facilitated the Imperial-AWE relationship culminating in an Alliance Agreement**,** and the establishment in 2008 of the Institute for Shock Physics (ISP) with major investment (c£5M) from AWE. ISP carries out customised research and training for the defence sector, building national skills capability. Its existence has also resulted in new work on blast force protection for the Royal British Legion Centre for Blast Injury Studies recently established at Imperial.

Research Council, Government and European Impact schemes have supported our work. For example, a RCUK Basic Technology Translation Award (2004-8) followed by an EPSRC Translation Grant, in collaboration with Coherent (UK and Germany), allowed translation of state-of-the-art laser technology, developed in our attosecond lab, to 5 UK institutes on a commercial basis. Translation of our development of fluorescence imaging technology has been enabled by an NIHR award (2010) for developing clinical imaging technology. A Knowledge Transfer Partnership with TSB as well as a Technology Transfer Demonstrator contract from ESA supported our space magnetometer development (P8).

Our success with EPSRC Impact schemes has allowed us to win grants for 17 Knowledge Transfer Secondments (KTS) of staff into organisations, 3 KTS grants for incoming staff, 10 PhD Plus awards to enable PG students to translate their research, 11 Pathways to Impact grants and 1 Bridging the Gaps award with a total investment of >£2M over the REF period. Impact arising from these awards included: a) the development (with Life Sciences) of a bacterial sensor, informed by collaboration with Electrolux, b) Physics appointees at Flexink Ltd investigated the performance of a number of organic-based semiconducting materials resulting in commercially available products, c) diode laser technology and fibre coupling techniques were transferred to NPL and exploited in its Sr lattice clock project.

The Grantham Institute for Climate Change (Physics team led by *Toumi*) won a competition under the European Institute of Innovation & Technology to establish and lead a €390M Knowledge and Innovation Community (the Climate KIC), now Europe's largest public-private innovation partnership. It has 20 core and 91 affiliate partners across Europe delivering innovative and imaginative solutions to climate change via an alliance from academia, industry and the public sector. Under the auspices of the Climate KIC, and the Financial Services Knowledge Transfer

Network, Physics staff have set up a new company OASIS LMF producing the first open access catastrophe modelling for the insurance sector.

We have given, upon invitation, direct **Advice to Government** including oral evidence to the Secretary of State at DIUS on the ozone layer, to DECC on solar energy, to DfE on emerging science, to the Home Office on Olympic Security and to Parliamentary Committees on blue skies research, on communicating scientific uncertainty and on plastic electronics engineering.

Industrial funding for our research has been received from companies including BP, Kaust UK, Lockheed Martin, Qinetiq, Sharp, Thales, Toyota and Unilever. Our good relationships with existing industrial partners, and the development of new relationships, have been enhanced through the formation in 2010 of the department's Industry Club. We currently host 15 formally registered Visitors from industrial organisations and 15 from overseas government laboratories. We also engage with industrial users through the provision of Continuing Professional Development (CPD) short courses. Two (Applied and Adaptive Optics) have attracted about 65 participants, almost exclusively from industry, over the REF period.

We have established a number of **Interdisciplinary Centres** and formal collaborations to stimulate research areas with strong potential for technology translation. For example, the Centre for Plastic Electronics (CPE), involving staff from 4 Imperial departments, including 9 from physics, has an active international Industrial Affiliates Programme (12 corporate members) with industry workshops, short courses and training activities provided to the members. In turn they co-supervise research projects and provide wide-ranging contributions to unique professional skills development. The majority of our Masters' courses have advisory panels with industrial representation.

We have promoted PG **CASE awards**, which often involve pre-competitive research, by ring-fencing studentship funding specifically for this activity. As a result 23 CASE awards have been initiated since 2008, including 6 EPSRC Industrial CASE. CASE partners include AWE, Aurox Ltd, Cambridge Display Technology, CCLRC, UKAEA, Merck Chemicals, Met. Office, NERC Centre for EO Instrumentation and Placental Analytics (USA). In addition our 3 EPSRC Centres for Doctoral Training have collaborated with 28 companies. The success of the latter may be judged by the fact that all 28 companies have written in support of the renewal bids for these CDTs with financial commitments in cash or in kind.

Outreach to Schools: The department's excellent record of engagement with schools over many years is now facilitated by our Outreach Office (established 2009) with 2 fulltime staff, funded by the Ogden Trust, the RCUK School University Partnership Initiative, our EPSRC CDTs and the European Consortium for Outreach In Photonics. It provides training and support for staff and students as well as undertaking bespoke activities. It coordinates talks, workshops and interactive demonstrations and runs our Open Days which showcase recent research, provide insight into physics courses and examples of possible future careers (we expect 1500 attendees this year). We have presented well in excess of 120 schools talks and public lectures since 2011. The team also designs events to encourage wider participation in science from under-represented groups: e.g., supported by NASA and the US Consulate, an African American former astronaut presented to over 300 pupils from schools across UK within high ethnic minority populations and a female NASA engineer talked to an audience of 220 predominantly female school students.

Since 2012 we have run our Insights work experience scheme to able year 12 students from schools with little previous connection to the College; students spend a week in the department, much of it in research groups. With 60 attendees to date feedback from schools suggests a significant increase in university science applications, not only from attendees but also their peers.

For non-specialist teachers, who are required to teach physics but do not have a degree in it, we run an annual fully-funded Teachers' Workshop aimed to improve the teachers' understanding of the subject, boost their confidence and give them resources for the classroom, including material on current research. 75 teachers have attended the course since its inception in 2011, improving the education of an estimated 5000 school pupils to date.

In 2012, with the aim of increasing the number of specialist physics teachers, we launched a BSc in Physics with Science Education. This, the first of its kind in England and Wales, is a 3-year course providing graduates with an IOP-accredited degree together with Qualified Teacher Status. It is expanding yearly with 23 schools now participating.

With the Open Air Laboratory project (supported by The Big Lottery Fund) and the London Grid for Learning Trust (a consortium of the 33 London local authorities and 2,500 schools) we have set up the densest real time urban network of weather stations in the world, with the data openly available. The project is co-managed by SPAT and exploits expertise in detector technology and data analysis developed out of our atmospheric physics research.

Public Engagement: Our public engagement activities raise public awareness and inspire debate about our work. We have contributed to national and international media on well over 200 occasions since 2008, discussing research results and providing expert commentary on science news stories. Engagements have included, inter alia, Horizon, Material World, In Our Time, Physics World, New Scientist, The Infinite Monkey Cage and The Life Scientific.

Our postgraduate students stage an annual Quantum Show with talks and demonstrations on recent developments in quantum physics (audience of approx. 350 p.a.) and a Particle Physics Masterclass (about 100 attendees p.a.). We participate in national science events, such as Cheltenham Science Festival, the Big Bang Fair (many more than 1000 visitors to our stand over 2 days) and Science Uncovered at the Natural History Museum, as well as the annual Imperial Festival (c. 10,000 attendees) and Imperial Fringe events. Since 2008 we have engaged the public in our research by leading, or contributing to, 12 exhibits at the Royal Society's Summer Exhibition. An internet-based competition addressing the Mpemba effect was organised by PG students and attracted 22,000 entries and national media coverage.

We also host an Artist in Residence, funded by the Leverhulme Trust and EPSRC Pathways to Impact, whose activities are inspired by our research and who works with the outreach team running interactive presentations (including a solar-powered cinema inside a yurt). She has created experimental films about physics (now at the New York Museum of Modern Art) and presented the Schrödinger equation on billboards showing over busy roads in west London.

Staff Support: All departmental procedures associated with career progression, including the annual Personal Review and Development meeting, now include an assessment of the impact of the research. Delivery of impact is also taken into account in decisions on staff promotion and release from probation.

Staff can access advice from the departmental Champions. An example of the result of such an interaction is the fledgling Imperial Space Lab, involving scientists and engineers from several departments with representatives from industry and government laboratories and agencies. This arose from interactions between space physicists, the department's Industry Champion, the Director of External Liaison and the Faculty's Corporate Partnerships office.

With departmental support three staff (*Nelson, Toumi, Popov*) have been awarded Royal Society Industrial Fellowships, spending 50% of their time, over a period of 3 or 4 years, at IPG Photonics, Solar Press and BP. *Trotta* has been awarded an STFC Public Engagement Fellowship.

The Faculty organises a competition 3 times a year into which staff can bid for funding to initiate new collaborative research activities, especially those showing the potential for impact. This mechanism has provided £56K for projects led by Physics since the inception of the scheme in 2010, including, e.g., £20K for collaboration with the Dept Materials to investigate high temperature thermomagnets for power generation (*Sandeman*).

The success of our approach is evidenced by the creativity and agility with which staff identify opportunities for the application of their research to different real-world problems. For example, in response to a request from a company, through Innovations, for a water purification technique which could be used in disaster areas, PLAS staff developed a novel and cheap plasma-based ozone generator which will be used in field trials by Scottish Water in early 2014. Another example is the establishment by ASTR staff of a company, Data Fusion Consultants, which provides customized data modelling and analysis solutions to the public and private sectors.

c. Strategy and plans

Looking to the future we identify the following key emerging trends:

- Continuing innovation of disruptive technologies resulting from further blurring of traditional disciplinary boundaries and multi-disciplinary collaboration.
- Greater emphasis on translation of research into health-care technologies.
- Greater emphasis on handling of big data and the potential contributions of a number of

fundamental research areas.

To respond to these emerging challenges and opportunities, we intend to:

- Embed the new role (created in 2013), of departmental Director of External Liaison (*Cohen*), whose focus is to enhance interactions with external organisations.
- Associated with this role will be the maintenance of a departmental database of research end users/beneficiaries.
- Engage the Departmental Impact Panel whose remit is to identify opportunities where our expertise can contribute in biomed, environment, security, manufacturing, communications, tools & technology, and defence sectors.
- Continue to ring-fence funding to stimulate CASE partnerships for PhD studentships.
- Work with the Centre for Professional Development to identify and develop specific areas for impact-related staff-training.
- Set up a formal framework to ensure that all research activities are assessed and monitored for their potential to produce impact.
- Continue to have impact as a standing item on the agenda of the monthly Heads of Groups' (management committee) meetings and departmental staff meetings.
- Ensure that all departmental procedures associated with career development, promotion and sabbatical leave include impact (see §b.).
- Continue monthly meetings of the Faculty Corporate Partnerships team to identify themes that connect the department to other disciplines within College and industry.
- Introduce further measures to relieve staff of admin duties in order to give more time for R&D.

d. Relationship to case studies

The case studies are a sample of our impact activities in the broad areas of commercial application of technology, spin-out companies and government collaboration, resulting from the strategy detailed in this document. We have many fine examples of outreach and public engagement that demonstrate our commitment to communicate, influence and promote all aspects of our work but the reach and significance of our efforts, and the link between the outcomes and specific departmental initiatives, is more readily measured in the chosen examples.

Cases P1 (FLIM), P2 (Supercontinuum sources) and P3 (Fibre laser sources) arose through **industrial collaboration**, including with one of our **Industry Club** partners (IPG photonics).

Cases P4 (QuantaSol), P5 (Microcalorimetry), P6 (DeltaDOT), P7 (Midaz lasers), P8 (Space science magnetometers) and P9 (Molecular Vision) were all supported at an institutional level via **Imperial Innovations** with P9 receiving further support via a Research Council impact scheme.

Cases P10 (Aurox), P11 (Metamaterials), P12 (Ingenia), P2 and P3 reflect our policy of **supporting staff** to foster impact including through Royal Society Industrial Fellowships, collaborative industrial visits and buy-out from teaching duties.

Cases P9 and P11 each arose from a Consultancy (**Imperial Consultants**).

Case P13 (AWE) was developed through collaboration with AWE (also an **Industry Club** partner), strengthened through an Alliance Agreement.

Case P8 arose from a long-standing involvement with space agencies and support via a **Government impact scheme**, a TSB knowledge transfer partnership.

The case studies have informed our impact strategy in the following ways:

Sabbatical leave and secondments: The effectiveness of these was exemplified by P8, P11, and P12.

Industry Club: The importance of nurturing industrial links was demonstrated by P3 and P13.

Interdisciplinary research: P9 provided a successful model.

Institutional support: The value of **Imperial Innovations** was evidenced by many cases, including P4, P5, P8 and P9.

The importance of departmental/institutional support through **impact funding schemes** was exemplified by P1 (DTI/TSB Technology award), P3 (RS Industrial Fellowship), P9 (BBSRC Small Business Research Initiative scheme) and P10 (ESPRC DTA/CASE award).