Institution: University of Bristol

Unit of Assessment: 9 - Physics

a. Context

The research scope of the School of Physics covers a broad range of activities from searching for the Higgs Boson at CERN to the development of practical high-power electronic devices, and as such the types of impact from these research activities are also broad in scope. However, our impact is predominantly focussed on areas where technology and its development play a key role, or where there is a particularly strong public interest.

In addition to the Interface Analysis Centre (IAC), a successful industry-focussed materials research facility that has been integrated into Physics during this REF period, the research groups with the strongest impact-related research activities are Nanophysics and Soft-Matter (NSM), Micro and Nanostructural Materials (MNM), and Particle Physics (PP), with a burgeoning impact profile from the Centre for Quantum Photonics (CQP) that was created during this REF period. The remaining groups Astrophysics (Astro), Correlated Electron Systems (CES), and Theoretical Physics (TP) primarily focus on fundamental aspects of physics but include research in imaging, signal processing, and superconductivity that could have significant future impact.

Technology and service based impact: Economic impact is predominantly technology or service based, and arises through engaging with business and industry, establishing spin-out and start-up companies, licensing of technologies and intellectual property, and providing consultancy and training to national, European and international industry. This is exemplified by the new companies created by the NSM group, *Infinitesima* and *NuNano* with seven licensed patents and a developing portfolio of instrumentation and products for nanoscale imaging. The MNM group, meanwhile, provides a unique Raman thermography characterisation service to the electronic industry, improving the reliability and lifetime of power and RF electronic components for nine device manufacturing companies across the UK, Europe, USA and Asia in the defence and communications industries. The IAC is an industrially focused research centre with established research directions in energy (in particular the nuclear sector), health care and aerospace. Their work has resulted in changes in policy and operation, and in demonstrating new methods, instruments or materials – for example, changes in operations procedures at CERN for the safe processing of fission waste [3]. Typical beneficiaries of the School's research impact are in the food & health, microelectronics/semiconductors, energy, and security sectors.

Outreach and public engagement. Outreach takes place across the School, with the PP, TP and NSM groups being particularly active. The School is renowned for its outreach activities and is successful in securing funding to support these activities. These activities include public lectures, TV and radio interviews on the latest research topics (from food science to quantum computing and cosmology), and talks at the British Science Festival.

b. Approach to impact

The School of Physics takes impact very seriously. The Head of School and the Impact Director are responsible for ensuring that School activities are translated into impact. To achieve this the School has implemented, as described below, a series of approaches designed to maximise opportunities for impact. However equally important has been establishing a culture where impact is high on the agendas of all members of staff. Specific practical approaches to impact are listed below.

Interactions with industry play a major role in the impacts realised by the School. Industrial CASE studentships provide a direct link with industry. The School has appointed a Director of External Relations (Schwarzacher, since 2011), and has established an Industrial Advisory Board (chaired by Prof. Peter Dobson – RCUK advisor on Nanotechnologies, with board members from e2v, AWE, IQE, Sellafield and BAESystems). Tom Scott (Physics) is the Business Fellow (since 2011) for the entire Faculty of Science. These roles, along with that of the Impact Director (Thompson, since 2011), all help to facilitate new interactions between the School and commercial partners.

There are a large number of existing industrial engagements across the different research activities within Physics, with impacts ranging from jet engine maintenance to cancer detection [1], as highlighted in the impact case studies. Four additional examples are given here.

- MNM group: The group is working with *e*.ON to develop low work function nano-diamond for use in thermionic converters for solar cells and flat panel displays.
- CES group: The Positron group in Bristol is amongst the pioneers of the application of positron annihilation to correlate the nano-scale molecular structure of synthetic polymers and their macroscopic properties, and this group is collaborating closely with the Nestlé Research laboratories in Switzerland.
- CQP group: CQP has a strong industrial collaboration with Nokia to develop quantum secure communications systems, with a joint patent and working prototype (£500k funding from Nokia). The Centre also collaborates with Toshiba, NTT, DSTL, NPL, IBM and BAE Systems and has secured four patents, all within the REF period.
- PP group: The PP group has developed reliable and cost-effective muon tomography detectors for cosmic rays using a resistive plate chamber based on coated glass and coupled to a fast readout system. These detectors are being trialled as a basic technology to detect covert movement of nuclear materials, in conjunction with AWE. The Group has used its expertise in developing radiation detectors to build strategic links with the Bristol Oncology Centre in the local NHS Trust, developing demonstrator systems that can be taken to industrial partners or to market. A patent application has been filed.

The School houses a wide range of equipment for material characterisation, such as a focused ion beam, X-ray photoelectron spectrometer, small angle X-ray scattering, high-resolution scanning and transmission electron microscope. In combination with the School's unique capability in high-speed atomic force microscopy (AFM), this suite of instruments enables research collaborations and contracts from industry, including Merck, HP, AWE, Dyson, Airbus, EDF Energy, Afton Chemical, BP, Magnox, Imerys, NNL, Sellafield and Rolls Royce.

The Bristol Centre for Functional Nanomaterials (BCFN) is a Doctoral Training Centre (DTC) within the School training an annual cohort of 20 students, and has an active and effective industrial engagement strategy within the nanoscience and nanomaterials sectors. The BCFN employs an Industrial Research Fellow (Collins) who facilitates the interaction. This involves organising Industrial Training Modules (Unilever, BASF, Merck UK) and BRIDGE think-tank exercises (Syngenta UK and International) for research training, negotiating, supervising industrial project sponsorship (Nanosight, AkzoNobel, Sasol UK, Syngenta, Heinz), and performing direct consultancy services (Heinz, LMAT).

New business creation: The School's impact strategy supports the formation of new companies to take research out of the laboratory to commercialisation. *Infinitesima* is a start-up company from the NSM group (with 12 employees) which has developed a high-speed fabricating atomic force microscopy system for silicon wafer defect review, and is currently undergoing trials with Intel. *NuNano*, a recent (2011) start-up from the same group, aims to supply custom cantilevers for atomic force microscopy whilst reducing the cost of the fabrication for these highly-specialized components. The three founding directors are Vicary, Hoerber and Miles.

Public engagement: The School of Physics is particularly active in public engagement and outreach. Members of all groups present aspects of their research and wider aspects of physics to the public and schools in the South-West and the UK. As an example, Barham's work on molecular gastronomy has received considerable media attention following the publication of his major review (*Chem*. *Rev*. **110,** 2313-2365, 2010) and his work on 'kitchen science' is of particular appeal to the general public. Barham appears frequently as the scientific advisor on Radio 4's food programmes (including "The Kitchen Cabinet"). Barham's work on animal recognition has also received significant public attention and is raising awareness of animal conservation. The BCFN DTC has driven a 3-year outreach project with local secondary schools, working with teachers, parents and pupils to promote discussion of nanoscience and nanotechnology and their impact on society and the economy. The programme has engaged with over 4,500 school children in the South West, as well as many radio shows and press coverage, winning University of Bristol Enterprise Awards in 2012 and 2013. In addition, over 40 people throughout the School have engaged in outreach, reaching out to an additional 3,600 school pupils and 2,600 members of the public.

Targeted development of groups and activities: Impact is more readily achieved in disciplines that are focused on applications; as a result the School has worked strategically to establish and support research activities that both relate to industrial concerns and deliver ground-breaking and

world-class science. These activities are often interdisciplinary and the School has made six academic appointments spanning the Schools of Physics, Electrical Engineering (EE) and Chemistry, four of which (Matthews, O'Brien, Oulton, Thompson) are associated with the CQP, a new and vibrant interdisciplinary research grouping with the goal of bringing fundamental quantum information science research out of the laboratory and towards real world application, working closely with the earlier listed industrial partners. With strong support from the University, the CQP is currently undergoing expansion whilst significantly enhancing engagement with investors and industry. This includes secondments of key support staff from Research and Enterprise Development (RED) to develop the impact strategy of the group. CQP has also used an EPSRC Impact Acceleration Account to appoint an industrial liaison officer. Finally, the IAC has joined the School of Physics during this REF period, with the aim of fostering closer ties with physics research groups and strengthening industrial connections, particularly within the Nuclear sector.

To forge stronger Physics and EE ties, and to bring fundamental physics through to application, the MNM group has formed the Bristol Power Electronic Innovation Centre jointly with the Electrical Energy Management group in EE. The Centre aims to develop the application chain for GaN power electronics from physics to engineering and exploit fully the potential impact of GaN, working with industrial collaborators United Monolithic Semiconductors, IQE, NXP Semiconductors, Selex Galileo, Thales Alenia Spaciale, TriQuint and others. In addition, the strategic appointment of Research Professor Uren, with his strong industrial background and QinetiQ connections, enhances both the academic and industrial impacts of the Centre.

University support: The University's RED office provides expert advice to the School and individual researchers who are building industry relationships. They have supported new business creation (such as *Infinitesima* and *NuNano*), provided training to engage with business and industry, and assisted with contract negotiation, intellectual property, licensing agreements, and identifying industrial partners. The University also supports the realisation of impact through a number of incentive schemes sponsored by the EPSRC, and the School of Physics has been particularly pro-active in utilising these opportunities.

Leveraging RCUK funding: *EPSRC Pathways to Impact awards* provided funds to support knowledge exchange and impact relevant activities by building on research in engineering and the physical sciences. A total of four awards were secured by Physics in the areas of: effective encapsulation (Alam); nanoparticle characterisation (Miles); quantum communications (Thompson); and the development of automated control and analysis tool for DC and time-resolved Raman thermography (Kuball).

EPSRC Building global engagement awards were granted to established and new international academic and industrial research collaborations, with ten awards (total value of £167k) to the School of Physics. The activities range from a nanomaterials graduate conference to a quantum technologies workshop in Boston MA.

EPSRC Impact acceleration account: supports awards of up to £100k over a two-year period with the aim of developing industrial engagement in a priority thematic research area. These awards provide the resources needed to ensure that ideas from the School with high impact potential reach fruition over a 5-10 year period, with a particular focus on future impact. The School of Physics has received three awards in quantum photonics (O'Brien), nanophysics (Miles) and low altitude radiation mapping (Scott). The School has also received two Enterprise Impact Development Fund awards in the area of Raman probe devices for medical diagnosis (Day).

EPSRC Enterprise Education Award: the BCFN DTC was awarded £10k (McMaster) to develop its innovative BRIDGE model of company-university dialogue. This was initiated successfully with Syngenta (UK) in 2013.

The School has also secured 3 STFC Innovation Partnership Scheme/Industry Programme Support Scheme (PIPPS) grants, totalling £414k, 2 Knowledge Transfer Network (KTN) awards and 2 Enterprise Impact Development Fund awards (EIDF) within the areas of medical diagnosis, and 2 Knowledge Transfer Network (KTS) awards, one with the National Nuclear Laboratory and one with Magnox.

c. Strategy and plans

The School of Physics has a long-term impact strategy to realise the full potential of its current and future research activities. The key goals of the School's strategy are to: (1) increase the overall

impact of research across the entire School; (2) identify and support key research areas where there is significant impact potential; and (3) further embed links with industry. The strategy is supported by an implementation plan, outlined below, which will embed a culture of impact awareness across the entire School, incentivise the pursuit of impact, create new appointments in research areas with high impact potential, enhance the methods for capturing and reporting impact, and provide mentoring to researchers within the School.

Impact awareness: The School will encourage impact awareness for every researcher by increasing its prominence within the Staff Review and Development process. This approach will also aid the School in monitoring levels of impact awareness and in capturing the impact activities of individuals across the School. The Research Steering Committee will assess potential impact opportunities and develop a specific strategy for the IAC and each of the seven research groups.

Targeted impact: While raising the impact awareness of the entire School is important, some research areas are more likely to realise impact of significance and reach, and these research areas are therefore being targeted for additional impact-related support and encouragement. For example, the CQP group has appointed a Programme Director to support the commercialisation potential of its research outputs. The School of Physics has also targeted the area of quantum engineering with the recently awarded EPSRC Centre for Doctoral Training, with strong industrial commitments and a goal of delivering impact through the training of PhD students.

The University has previously invested £11M in the interdisciplinary Nanoscience and Quantum Information building. This building has created burgeoning industrial contacts, such as with Heinz, Unilever and BASF. Later investment in Physics created the Materials Synthesis and Characterisation Facility and work has commenced on the Nano-Fabrication Facility. Both facilities will be open to industrial use, with BAE Systems showing strong interest in the Nano-Fabrication Facility, and LMAT already using the new materials facility.

Creating new appointments: The School envisages further key academic appointments in areas that strengthen industrial collaborations, including power electronics and quantum photonics.

Industrial engagement: To enhance interactions with industry, the School will host a biennial "Industrial Showcase Event" as a networking opportunity to engage local industry with both the School's research community and its final-year undergraduates. This will build on the successful BCFN Functional Materials and the Environment Conference which 17 companies and 8 strategic funding bodies attended. Further networking events will link in with Science City Bristol and the Bristol Enterprise Network, to encourage interactions with the technology business community. The School will also target intellectual property protection in specific areas, with the aim of building up patent portfolios of key technology areas that will be used to attract industrial engagement and investment. This strategy is already achieving success in the CQP group.

The School's will continue to use the Industrial Advisory Board to strengthen interactions with current industrial links and actively seek new collaborations. The Board will perform a rolling industry-focused review of School research activities and provide strategic advice aimed at increasing current industrial research funding to enhance associated impact. It will also identify and collate the latest needs of physics-related industries and professions with a view to increasing the industrial relevance of the School's undergraduate and postgraduate degree programmes.

d. Relationship to case studies

The variety of approaches taken by the School is reflected in the submitted portfolio of impact case studies. Industrial engagement that exploits the expertise and research facilities of the School is a key aspect of its research impact, and case studies 1 - 4 are good examples of how strong industrial engagement has significantly enhanced the reach and significance of the impact. Case 4 illustrates how targeted appointments (Uren, Sarua) have enhanced industrial contacts. The case studies impact the sectors of energy [2, 3], microelectronics [4], health care [1] and defence [3, 4] through contract research, providing services, and developing new technologies. Spin-out and start-up companies from the School, are highlighted well by the *Infinitesima* [5] case study.

[1] "Innovative products for microscopy and analysis provide economic and healthcare benefits in a wide range of industries". [2] "Bristol research helps extend life of nuclear power stations, with major financial and environmental benefits", [3] "Uranium storage – ensuring nuclear safety", [4] "Raman thermography – Enabling semiconductor companies to improve the reliability, performance and lifetimes of their devices", [5] "Infinitesima – pioneering atomic force microscopy applications for industry"