Institution: University of Birmingham (UoB)

Unit of Assessment: Physics

a. Context

Physics at Birmingham has a long and distinguished history of addressing the needs of the country and society in general. This is not only through providing well trained physics graduates and PhDs, and conducting fundamental research which generates knowledge and technology for future applications, but also through specific and more immediate contributions to industrial and national demands and opportunities.

This history is illustrated by the development of the Cavity Magnetron in the 1940s, which enabled the identification of submarines with airborne radar devices, and by the production of medical isotopes for radioactive imaging of patients in hospitals since the 1950s (we currently produce krypton generators used for medical imagining in hospitals across the UK). This ability to innovate persists to more recent developments in which our fundamental research has led to: use of superconductors in novel antennae in collaboration with the School of Electrical Engineering; the development of new photo-resists by Nanoscale Science, cluster beam instrument sales to the export market, development and sales of a new biochip platform and characterisation and development of new catalysts; new cancer treatments in collaboration with the University Hospital Birmingham. There are significant developments aimed at translating research into impact over the period until the next REF census. These include the development of quantum interferometry and metamaterials for engineering applications, and research being driven by our Nanoscale Science group to develop a massive scale-up of size-selected cluster production.

In the period considered by the REF, the underpinning research for impact can be classified into two categories: (i) purely fundamental research, as conducted by the two Astronomy groups, Particle Physics, Theoretical Physics and Nuclear Physics, where the main impact (in the REF sense) comes from Public Engagement, and impacts on the economy or health tend to arise from advanced instrumentation developments, and (ii) fundamental research in application areas, as conducted by the Nanoscale and Nuclear Physics groups. This is also the approach of School's newest groups, Quantum Matter, which unites the Cold Atoms effort set up in 2007 with the long established Condensed Matter group, and Metamaterials, established in 2010. The Case Studies submitted reflect this balance of activity.

b. Approach to impact

The School's approach to impact is driven by the key research facilities, expertise and scientific leadership coupled with maximising the potential provided by the University's well-developed Business Engagement (BE) environment and support for delivering impact through its central Research and Innovation Services (RIS). There is now an established culture of recording the impact of research projects and linking this to project funding, publications and patents. During the REF period there have been 19 records of invention (including; invisibility cloaking of visible light, the ILIAD precision interferometer, a fibre-optic mode scrambler and elements of Boron Neutron Capture Therapy, BNCT, cancer treatment and 4 patents filed. This is a step change in the attitude and approach of staff in delivering impact.

Facilities, Expertise and Scientific Leadership, Delivering Impact

The School exploits its significant scientific expertise and facilities coupled with its academic endowment to maximise its impact potential which may be crystallised into three areas:

i) Nanoscale Science: At University level RIS help lead major projects such as the Science City Research Alliance (SCRA), which brings together the West Midland's two leading research-led universities, Birmingham and Warwick, in collaborative projects across scientific themes in Advanced Materials, Energy and Translational Medicine as part of the Birmingham Science City initiative. This 10 year project has brought £3M of funding for eight new instruments to the Nanoscale Physics group, including the aberration-corrected scanning transmission electron microscope, plus £500k towards the establishment of the Cold Atoms laboratories. The associated research of the Nanoscale Physics group, has resulted in a set of complementary industrial impacts, specifically (i) cluster beam instrument sales to the export market, (ii) development and sales of a new biochip platform (iii) characterisation and development of new catalysts and (iv) the development of next generation and EUV and e-beam resists and spin-on hardmask products for

fabrication of semiconductor devices. These impacts have been achieved via licensing and knowledge transfer to the companies: Inanovate, Irresistible Materials Ltd, Teer Coatings Ltd and Johnson Matthey. The establishment of two spin-out companies Inanovate and Irresistible Materials was facilitated by RIS. Irresistible Materials has successfully raised a total of £370,000 in two financing rounds and currently has trials underway with JSR Micro (USA and Japan) on the EUV Resist and the hardmask; and with Dow (USA) on the hardmask. Additionally, Fujifilm (Japan) has entered in to an agreement to trial the EUV resist. There is a substantial and growing market for photo-resist materials, with estimated total value of $1.15bn. Inanovate developed a fully UHV compatible cluster beam source capable of a mass resolution of 130. The instrument attracted the attention of the Centre for Individual Nanoparticle Functionality (CINF) at the Technical University of Denmark in Lyngby. As a result Inanovate secured a significant export order (>£300k), delivering the instrument under license from Birmingham in 2011. CINF are focused on catalysis, e.g. for the petrochemicals and fuel cells areas.

ii) Nuclear and Particle Science: Physics has exploited collaborations across the University together with elements of its own scientific tradition and academic endowment. The presence next to the University of a large, modern teaching hospital and Medical School with a formidable research base, well established history of translational medicine and leading Medical Physics department provides a very attractive basis for identifying and adopting innovations in Physics. This has implications for health at the level of both diagnostics and treatment (e.g. the BNCT cancer treatment programme which the School is establishing with the University Hospital, Birmingham). Similarly, the development of unique applied research facilities such as the Birmingham MC40 cyclotron and the associated positron emission particle tracking (PEPT) facility has led to collaboration with groups in Chemical Engineering enabling fruitful characterisation studies of industrial processes for organisations such as Procter and Gamble and BP. The labs associated with the cyclotron and PEPT activities were refurbished within the REF period (>£500k), maintaining the significant industrial impact of the School. The history of instrumentation development, particularly within the Particle Physics group, has led to partnerships with industry. For example, there has been involvement with Aero Engine Controls (subsidiary of Rolls-Royce and Goodrich) in the prototyping of compact high temperature tolerant circuit boards. AEC are now further developing these boards for applications in aircraft engines, nuclear submarines and engineering uses such as drill heads. The long-standing links with the nuclear industry via research and educational programmes (close to 20 of the UK's leading nuclear companies fund our reactor physics course) have provided the platform for the recent development of the Birmingham Centre for Nuclear Education and Research, with the capacity to deliver 100 graduates/year into the nuclear sector. These foundations formed the basis for the recent UoB report on the "Future of Nuclear Energy", which was the result of a Commission chaired by Lord Hunt that examined nuclear energy and fission R&D in the UK, together with the future prospects for building new nuclear new-build and R&D for future fission technologies.

iii) Outreach: Building on the leading fundamental science research, the School has a well-established outreach programme (the School organises 130 outreach events per year). The unique features of this programme are the size and diversity (both in terms of types of engagement and the subject range). Engagement is via science exhibitions, development of novel practical and computer based demonstrations through to conveying science through art and theatre. This leadership is recognized through a STFC Public Engagement Fellowship (Lazzeroni). Birmingham is in the top two recipients of STFC Small Awards for Public Engagement, with 17 awards since their inception (1999), demonstrating sustained leadership. We are unique in having led two multi-institute exhibits for the Royal Society Summer Exhibition in the past three years ("Discovering Particles" in 2011 and "Understanding the Higgs boson" in 2013). We were also involved in "Cosmic 100" in 2012. Prof. Watkins represents the whole UK on the International Particle Physics Outreach Group. The groups associated with Particle and Nuclear Physics and Astronomy have developed events, hands-on demonstrations, educational software development and media work. The total number of people reached is approximately 10,000 through school visits, 5,000 through public talks and 50,000 through science festivals.

Impact Environment and Culture

RIS and BE have a number of principle activities, each supporting areas for impact. The University has its own technology transfer company (Alta Innovations Ltd), which provides expertise and resources to help academics protect their ideas and identify routes to commercialization, including

IP licensing and spin-out (e.g. the School's spin-outs *Inanovate* and *Irresistible Materials*); Alta also manages consultancy services. It is via Alta that "Alta Cyclotron Services Ltd" operates, through which Physics commercially produces medical isotopes for hospitals across the UK. The income from the operation of the cyclotron is then reinvested in research. RIS also has a team of professionals supporting Strategic Research Projects, i.e. large scale multi-disciplinary projects frequently involving collaboration with business (for example, Science City Research Alliance which has led to significant KT opportunities for the School). This team manages Knowledge Transfer Partnerships (KTPs) and KT Secondments. The BE Directorate has responsibility for the development and maintenance of strategic bilateral partnerships; these are mainly with industrial and commercial organizations providing an important route to impact (for example with Procter and Gamble who utilise our PEPT facilities). Support for the College-wide research is provided through an embedded team of Research and Knowledge Transfer plus Business Development Managers. A Manager is assigned to each School and works closely with central RIS and BE to identify opportunities to generate impact from research through industrial partnerships, sponsored research and outreach to the public in general.

Within Physics this multi-scale, highly integrated, structure, combined with the research strengths of the College and its research facilities, has been used over the REF period to create what one might call our "impact environment and culture", containing the three elements:

(i) **IPR development and protection:** In respect of opportunities for economic impact, whether purposeful or unpredicted, we try to capture relevant IPR at the earliest possible stage, to allow rapid publication both for academic purposes and further to protect the invention against competing claims, and to establish a basis for license negotiations. Just one example of successes here is the development of high resolution resists by the Nanoscale physics group which have the potential to enhance the precision to which microelectronics may be manufactured. The University's IPR company, Alta Innovations, files an initial UK patent application while expecting that we will find an exploitation partner to help meet the IPR costs during or at least after the Patent Cooperation Treaty (PCT) phase. The process and the rules for allocation of reward (the share assigned to the inventors and the School for example) are transparent, as is our 30-day standard limit on consultancy without buy-out. The positive environment and stability established over a long period also means that staff new to the business of exploitation can quickly get up to speed from colleagues who have been there before.

(ii) **Facilitating Translation**: The University has a stated ambition to promote academic research in collaboration with SMEs within the West Midlands and new business ventures through Birmingham Science City (a public, private and HE sector partnership to develop, use and promote science, technology to stimulate innovation). Research from the Nanoscale Physics group has resulted in two spin-out companies; Irresistible Materials and Inanovate.

(iii) **Funding Innovation**: The establishment of "soft VC" funds by government, notably in our case the regionally orientated, Mercia Fund, has provided a valuable source of very early stage financial support for technology demonstration projects and spin-out companies with realistic views about the returns that can be expected as small companies make the transition into, ideally, larger and self-sustaining enterprises (e.g. Irresistible Materials Ltd and Inanovate). We have also been successful in capturing Follow-on-Funding, e.g. for the application of nanotechnology techniques to the development of high speed shutters for IR cameras, where there have been subsequent negotiations regarding sale of IP.

c. Strategy and plans

The School's overarching impact strategy seeks to enhance areas of current strength and support those which are currently promising impact, but above all create an environment in which potential impact from fundamental science is accelerated. This last strand is our "knowledge escalator", translating fundamental discoveries through to industrial innovation by exploiting close collaboration with Engineering Schools across the College. Specific developments which are expected to maximise impact into the next REF period include: (i) the on-going development by Cold Atoms/Quantum Matter group of the Gravity Gradient technology, which is utilising cold atom physics to find underground voids revealing the range of services that lie hidden under the streets (in collaboration with Civil Engineering), which is currently funded by EPSRC (£2.5M). Metamaterials is already collaborating with Samsung on acoustic metamaterials, and has developed broadband extreme acoustic refractive indices. This collaboration is now moving to

device fabrication. Both of these areas illustrate the developing "knowledge escalator"; (ii) further the exploitation of the potential of current facilities such as the MC40 cyclotron and Dynamitron. To this end an ion-irradiation facility is being developed on the cyclotron for the characterisation of current and future generation nuclear materials. Taking advantage of the proximity of the Medical School, the Dynamitron is being upgraded for BNCT cancer studies, and eventual therapy at Birmingham. Such a high flux neutron source may also lead to new opportunities in nuclear materials characterisation and the development of high power targets; (iii) the Nanoscale Physics group has begun a major new project (EPSRC Fellowship plus four further grants including TSB with Johnson Matthey and Miba, total funding >£3M) aimed at massive scale-up of size-selected cluster production, by 5+ orders of magnitude, for advanced materials and advanced manufacturing, with diverse potential applications in e.g. catalysis, biosensing, coatings and photonics; (iv) we are continuing to explore how expertise in grid computing and management of distributed data may be applied to diverse sectors where there is transformational potential linking to a new University-wide initiative on bioinformatics.

To facilitate further impact awareness and impact opportunity the School will:

(i) Broaden the base of the research groups contributing to economic impact by the establishment and growth of high quality new research groups doing fundamental research in areas which also have good potential to lead to applications, as reflected in the recent formation and planned growth of our new Cold Atoms/Quantum Matter and Metamaterials research areas. Here there are concrete plans, and already progress, to connect the fundamental research being performed in Physics with the Engineering Schools of Electrical, Mechanical, Civil, Materials and Chemical Engineering – key elements of the *knowledge escalator.*

(ii) Exploit the industrial contacts of the College of Engineering and Physical Sciences Research Support and Business Engagement teams to provide opportunities arising from the newly established research groups.

(iii) Maintain the thriving impact culture, while making all staff in the School, and students, aware of the support and opportunities available to exploit discovery and invention and promote our recent success stories (in the last 2 years there have been 2 records of invention filed from undergraduates). PhD training is to contain entrepreneurship and IP awareness courses.

(iv) Review and expand that component of our Public Engagement activities that focuses on recent research to which Birmingham has made a leading and distinctive contribution, as illustrated by the case study submitted herewith. This will be coupled with the University's "Heroes" publicity campaign which recognises through national and international publicity research achievements of the School.

(v) Incorporate into our staff workload model the vital contributions made by impact activities.

d. Relationship to case studies

The Case Study submitted in Nanoscale Physics reflects the "approach to impact" and specifically IPR, the University took a positive view of the long term potential economic impact of the group right from its establishment in 1994, such that the expectations to secure external investment or collaboration by the end of the PCT phase were relaxed. In this regard the availability of very early stage VC funding from the Mercia Fund was very helpful. This forward looking approach has been rewarded by the formation of several spin-out companies and the agreement of licences or access contracts with established companies exemplified by the Nanoscale Case Study – this a clear example of successful nurturing. The Case Studies submitted in Nuclear Physics derive from the imaginative and outward-looking research programs conducted by the former Applied Nuclear Physics group (now integrated into the Nuclear group), specifically the program which led to medical isotope production and the work which led to the invention and application of the PEPT technique. These traditions were instrumental in establishing the impact culture in the School from which newer, e.g. Nano, research activities have benefitted by convincing the University of the financial, societal and reputational benefits of exploiting fully the technical innovations in Physics. The Public Engagement Case Study demonstrates the primary contribution which our big physics groups make in the impact arena, reflecting the dynamic approach to external engagement found in our "approach to impact" and "strategy and plans".