Institution: University of Glasgow
Unit of Assessment: B9: Physics

a. Context

The School of Physics and Astronomy comprises six Research Groups: *Astronomy and Astrophysics, Institute for Gravitational Research, Materials and Condensed Matter Physics, Nuclear Physics, Optics and Imaging*, and *Particle Physics.* The School is one of seven that make up the College of Science and Engineering, formed following major university restructuring in 2010.

During this assessment period, the School has worked with 40 UK and international companies, using consultancy, collaborative research, licensing and company creation to enhance their competitiveness and economic impact. State-of-the-art instrumentation developed for research has been diversified for commercial applications. For example: detectors developed for nuclear and particle physics have been transferred to clinical applications, commercial x-ray diffractometers and for radioactive monitoring in the nuclear industry; precision optical interferometry used in gravitational-wave detection has been transferred to laser-system and device manufacturers and algorithms have been adapted for military applications; optical-control technology has been licensed to scientific-device and system manufacturers; nanoscale-imaging technology has been incorporated into commercial electron microscopes. Optical imaging research has been transferred to manufacturers of consumer, military and ophthalmic systems and remote-sensing techniques have been developed for oil prospecting and transport monitoring. School research facilities have provided expertise and measurement services to industry, particularly in materials characterisation, for sensor and magnetic storage applications and to manufacturers of precision optical devices.

Our research is a critical enabling technology for product sales of more than £20m per annum by UK and international industries. Key examples of companies capitalising on our research include: in aerospace and defence, *Thales*, *Selex, Qioptiq*; in photonics, *M^2 Lasers*, *Toptica, Newport* and *Gooch & Housego*; in medical imaging, *Optos*; in electronic devices: *STMicroelectronics*, *Amec, Honeywell* and *Seagate*; in instrumentation: *Gatan*, *PANalytical*, *Findlay Irvine, Boulder Nonlinear Systems* and *Elliot Scientific*; in energy resources: *Shell* and the *National Nuclear Laboratory*. Through engagement with public bodies School staff have also had impact on government policy in education and on Women in STEM issues, and have enhanced public engagement with science.

b. Approach to impact

The School has enhanced Knowledge Exchange (KE) through diversifying the use of our research infrastructure, and through our institutional and external mechanisms, to build long-term partnerships with companies. This approach includes the following components:

(i) **Research infrastructure:** Investment in facilities has enhanced the ability of the School to work with industry. Key services and facilities are available to non-academic users through a centralised University facility (http://tinyurl.com/GUlabs) and include: the *Kelvin Nanocharacterisation Centre,* enhanced by a recent £2.4m electron microscope for atomic-scale imaging and £0.4m pulsed-laser deposition facility and strongly linked to the College's James Watt Nanofabrication Centre; device characterisation facilities in the *Institute for Gravitational Research* (£1.3m new investment) and the *Glasgow Laboratory for Advanced Detector Development* (£0.4m). These facilities have been used by more than 20 companies, ranging from SMEs to internationals such as *Freescale*, *Coherent* and *Texas Instruments*, and public organisations such as DSTL. An additional £0.7m investment in imaging laboratories has enabled us to build new collaborations with *Optos*, *Selex*, *Qioptiq, STMicroelectronics* and *Findlay Irvine.*

(ii) **Institutional and external mechanisms:** Using the range of mechanisms detailed below, the School has collaborated in applied research valued at £2.8m in period, involving 40 companies.

The School has won and exploited substantial external funding to support KE activity. An STFC *Innovation Partnership Scheme* (IPS) fellow has been embedded within the School to identify research with potential for economic impact. Following the success of this model, Business Development Managers (BDMs) were embedded within the College in 2010, leading to a step-change enhancement in KE activity. The BDMs and IPS fellow provide support and guidance on schemes (both institutional, *e.g. First Step*, and external, *e.g.* TSB) designed to achieve impact and facilitate opportunities for collaborations (*e.g.* industry open days, company visits and creativity workshops). They have worked with academics to further develop research partnerships, employing mechanisms such as STFC Innovation Partnerships (one funded, £460k), Knowledge Transfer Partnerships (three funded, £516k), contract research, industrial studentships (12 funded), EngD students (two funded) and industrial exploitation or company spinout. Industrial PhD and EngD studentships are funded by the EPSRC Doctoral Training Grant and through our partnership in the EPSRC *Optics and Photonics Industrial Doctorate Centre*. BDMs also provide support for developing and delivering impact plans. The School has also benefitted from the university Innovation Network, including its £5k Innovation Vouchers (5 awarded) to enable SMEs to work with academics on feasibility studies.

In 2009 Glasgow University was one of only two Scottish universities to be awarded an EPSRC Knowledge Transfer Account. Together with the subsequent Impact Acceleration Account (2013-16), with an aggregate value of £3.8m, this has funded 10 collaborative R&D projects in the School with a value of £199k. These projects include support leading to the spinout of *Anacail* for cold-plasma sterilisation technology and for KE: with *Coherent* for laser-stabilisation technology; with *Optos* for biomedical-imaging technology and for product integration of our optical-tweezers technology by *Elliot Scientific* and *Boulder Nonlinear Systems*.

The School was also the originator of an innovative approach to Intellectual Property (IP) management known as Easy Access IP (http://www.easyaccessip.org.uk). This approach maximises partnerships with industry and the transfer of university knowledge for public benefit, by providing free IP using rapid and simple agreements. An early example was the licensing of our optics IP, led by **Padgett**, to *Boulder Nonlinear Systems*. The company invests in the University on ongoing projects. Easy Access IP has been adopted by every institution in Scotland, under the direction of the Scottish Government, and 18 universities and research organisations globally.

The School's industrial relationships and KE expertise have been key factors driving our sensors KE activity, the success of which is manifest in the £3m College sensors initiative; the £2.2m *Scottish Sensor Systems Centre* (initiating two industry partnerships); and in 2013, the Scottish Funding Council (SFC)-funded £10m, Glasgow University-led CENSIS *Innovation Centre for Sensor and Imaging Systems*. CENSIS aims for a culture-change enhancement to university/industry partnerships, employing a training programme designed by **Harvey** that involves industry-university secondments, 20 Masters-level training positions per year and 25 EngD studentships. **Harvey** leads physics involvement in CENSIS across Scotland.

Two further funding mechanisms enhance the long-term interaction between industry and our staff:

- The £3.25m investment by Glasgow University, EPSRC/STFC and the SFC in the new International *Max Planck Partnership for Measurement and Observation at the Quantum Limit* has a core objective to generate economic impact through KE with industrial partners.
- *SU2P*, a £2.4m initiative funded by RCUK, the SFC and Scottish Enterprise, delivers an innovative, entrepreneurial-focused teaming of leading photonics researchers (including ECRs) in Scottish universities and companies with Stanford University and Caltech – thus linking our academics to the California innovation environment. Two SU2P Entrepreneurial Fellows, (Bassiri and Mathieson), following secondment from our School to Stanford, have transferred technologies in optical coatings to *MLD Technologies* and retinal prosthesis to *Pixium*. In parallel, School retinal oximetry has been developed by **Harvey** with *Optos*.

Spinout of the company *Anacail* from the School, led by **Diver**, illustrates our approach to impact generation. *Anacail* manufactures food decontamination systems using techniques inspired by solar plasma physics research and identified with the help of an STFC IPS fellow in 2009. College

BDMs helped obtain initial development funding which was followed by funding from STFC and a KTA fellowship. The School provided staff time and space as in-kind support. Spinout of the company, in 2011, was followed by TSB funding, a Scottish Universities Physics Alliance (SUPA) fellowship and Scottish Enterprise funding (including a 2013 SMART award) leading to £750k of seed-capital (including support from Glasgow University-partnered venture-capitalists *IP Group*) and a move to incubation premises in 2013. Contracts from three major food producers have been obtained; they expect to obtain Food Standards Agency approval for commercial sales in 2014.

Finally, KE and Impact are weighted equally with traditional publication and research-income metrics that inform staff annual Performance & Development Reviews and hence promotion and reward. Support for staff also includes flexible timetabling of teaching and administrative duties.

(iii) **Industry partnerships:** Underpinned by our significant investment in research infrastructure, the School has fostered long-term relationships with key industrial partners. This approach is exemplified by our collaboration with *JEOL* and *Gatan* who have incorporated our innovations in electron-microscopy instrumentation into their commercial equipment, giving us world-leading capability at a substantial discount Our unique magnetic-imaging capabilities, supported by *Seagate,* have improved understanding of the operation of recording heads to improve production reliability. With *Shell* we developed sensitive ethane detection for oil prospecting which we adapted for clinical applications. Other key examples of industry partnerships include: working with the *National Nuclear Laboratory* in a £1.8m, 4-year programme to adapt our muon-detector technology for monitoring intermediate-level radioactive waste; an ultra-high bandwidth computer network developed in partnership with *Extreme Networks*, which was commercialised and nominated for an industry prize; transfer to the photonics industry of optical-interferometer technologies developed by the *Institute for Gravitational Research* - *e.g.* optical-bonding technology to *Gooch & Housego*; on-going collaborations (dating from 2005 and transferred to Glasgow University by **Harvey)** with *Qioptiq, Selex, STMicroelectronics* and *Optos* for exploitation of computational imaging – *e.g.* miniaturisation of consumer imaging and aberration-free military imaging.

(iv) **Schools and public engagement and policy:** For decades the School has invested significant infrastructure and personnel in support of schools – as demonstrated by our on-going accommodation of the regional STEMNET office 'Science Connects' and since 2008 the enrolment of 38 research students and ECRs in the STEMNET Science Ambassador scheme. Other examples of our activity include the award in 2010 of an STFC Science-in-Society Fellowship to **Hendry**, and the delivery of typically more than 150 presentations/year by School staff at public and schools events, attended by many thousands of people annually across the UK.

During 2008-13 the School has influenced government policy in the area of science education. **Hough** is a member of the Scottish Science Advisory Council (SSAC), Scotland's highest-level science advisory body to the Scottish Government, and led the publication of the SSAC report "Science Education: Enhancing Support for Schools Through Collaboration". This report resulted in the appointment of an Industry/Academic Schools Liaison Coordinator for Sciences funded by the universities and industry and, further, stimulated *Education Scotland* to appoint an education officer in this area. **Davies** played a key early role, through leading site visits and chairing the Institute of Physics Diversity Committee (2007-11), in the IOP Project Juno scheme which has improved the working environment of university physics departments. **Hendry** represents the Royal Society of Edinburgh on the Scottish "Curriculum for Excellence" Physics Qualifications Design Team, developing new curriculum content for the revised Higher and Advanced Higher that has improved pupil engagement (Case Study *Public Engagement*). We have also enhanced the profile and reach of our schools and public engagement through strengthening its linkages to our international research leadership. **Hendry** chairs the public outreach working group of the LIGO Scientific Collaboration – a global network of more than 900 scientists leading the quest to detect gravitational waves – and in this role is PI on a major international exhibition on gravitational-wave astronomy (Case Study *Public Engagement*). **Robson** has led the delivery of a programme of *Particle Physics Masterclasses* to more than 650 pupils and to Physics teachers, and pioneered a high-impact, widening-participation programme of schools' visits to CERN.

c. Strategy and plans

Our future impact strategy is focused on three strands: (i) investing in key technologies (ii) engaging closely with existing institutional and national support mechanisms, (iii) providing new staff development opportunities that embed impact more firmly in the School's strategic plans.

(i) **Investing in key technologies:** The School will build upon its leadership of the *International Max Planck Partnership (IMPP) in Quantum Technologies.* Beyond our investments in academic leadership with the key recent appointment of **Barnett**, the growth of our College Business Development Team will enable effort to be directed towards exploitation of the emerging field of Quantum Technologies. This dedicated support will deliver joint academic/industrial workshops, create formal links to the CENSIS *Innovation Centre* and *Fraunhofer Centre* (see below) and initiate projects exploiting the 50% College support of industrial studentships (see below). This additional investment by the College will grow our collaborations with colleagues in Engineering, both within Glasgow University and overseas, thus meeting a primary objective of the IMPP.

(ii) **Mechanisms for engagement:** The School will increase its engagement with the wide range of KE support mechanisms within the College, University, SUPA, nationally and internationally. We will continue to encourage staff to engage with funding schemes, including the Impact Acceleration Account (now extended to non-EPSRC funded areas using University funds). Where appropriate, our staff will transfer knowledge and IP via the *Easy Access IP* scheme, the co-ordination and administration of which is fully supported/funded by Glasgow University. We will work closely with the CENSIS *Innovation Centre* and with the *Fraunhofer Centre for Applied Photonics* (Scottish funded and based at Strathclyde University) to promote long-term partnership with industry via EngD and PhD studentships, staff secondments and joint projects; and with the SUPA Industrial Placement Scheme for ECRs. We are also partners in a new EngD-based CDT in *Applied Photonics*. Across the full range of academic activity, the College has committed additional resource to support 50% of any joint PhD studentship with an industrial collaborator. Through these sources and others, we plan to support 20 further EngD, CASE and industrial PhD studentships in the School in the period to 2019. The University has also committed a further 3 years of funding to support the SU2P collaboration between Scottish Physics, Stanford and Caltech.

(iii) **Staff Development:** At all grades of academic appointment/promotion Glasgow University's new HR policy places KE activity on an equal basis to academic publications and grant income. Similarly, KE and related activities are fully recognised in the School's workload model. We will continue to encourage our staff to participate in activities such as the Scottish and College Crucible, designed to develop their creative ideas. Participation in the Scottish Crucible is competitive: **D. Maclaren**, **Hild**, **Seitz** and **White** have won selection since 2009. The College Business Development team will expand its ongoing program of industrial sandpits where specific companies are invited to be the focus of joint workshops (recent examples include *Optos* and *Tullow Oil*). Within these future workshops we will increase participation by ECRs. We will work with the College, GU and SUPA to set up KE mentoring of new staff, and in particular ECRs, by our growing pool of senior staff with experience of leading KE and commercial activities. More generally, to form a better interface to these mechanisms the School has formed an External Liaison Team to identify and foster new industrial and other end-user partnerships.

d. Relationship to case studies

Our impact case studies have all benefitted directly from the research environment, management support mechanisms and infrastructure investment within the School, College and University. These are all designed to foster impact generation and KE alongside research excellence. Our flexible approach to the allocation of teaching and administrative duties enabled the field trials necessary for case study *LightTouch* and the award and operation of the Science in Society fellowship that supported *Public Engagemen*t. Long-term investment in laboratory research facilities underpinned case studies *LightTouch, Ultra-stable Lasers, DualEELs and Medipix*. Targeted studentships supported the development of *DualEELs* and *Medipix*. The variety of case studies submitted – with underpinning research that spans optics, materials, particle physics and astrophysics, generating impact that has benefitted a wide range of stakeholders – indicates the School's ongoing commitment to supporting KE across the full spectrum of its research activities.