Physical sciences at Diamond: past achievements and future opportunities

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The start of user operation at the Diamond Light Source in January 2007 marks a major milestone for the physical sciences in the UK. The routine delivery to the UK community of ultra-bright X-ray beams from the third-generation source has provided us with capabilities that were available previously only at international sources, and indeed has created some that are unique. Here, a personal view is given of some of the achievements to date, and possible future opportunities outlined.

It is arguably that in their application to the physical sciences, the full capabilities of X-rays and their interaction with matter are realized. The spectacular success of modern macromolecular crystallography, for example, relies on the fact that an X-ray photon has an electric field, giving rise to elastic scattering from the electronic charge distribution in a molecule. To understand the wide utility enjoyed by X-ray imaging in its most commonly realized forms, to take a second example, it is enough to appreciate that an X-ray can also be absorbed.

Questions relevant to the physical sciences demand not only using these two particular aspects of the photon–matter interaction, but also the fact that a photon carries angular as well as linear momentum, has a magnetic as well as an electric field, can be inelastically as well as elastically scattered, has a polarization, etc. [1]. These photon attributes allow the myriad forms of spin, charge and orbital ordering and their dynamics to be characterized and understood. At the same time as opening up new opportunities, exploiting the full range of photon characteristics represents a formidable challenge for the provision of specialized
beamlines, each necessarily dedicated to a subset of possibilities. This challenge has been met at Diamond through three successive phases of beamline construction, with each phase seeing the commissioning of a number of beamlines for the physical sciences.

Reviews of significant achievements in the physical sciences enabled mainly by phase I and II beamlines are provided in this theme issue. (At the time of the symposium to mark the 10th anniversary of the inauguration of Diamond, the first phase III beamlines had not yet entered routine user operation.) The article by Radaelli & Dhesi [2] concerns itself with strongly correlated electron systems and materials displaying complex magnetic structures, both areas of considerable contemporary interest to condensed matter physicists, and others seeking materials with new electronic functionality. The contribution by Allan et al. [3] complements this viewpoint by focusing on structural aspects of metal–organic framework materials and their chemistry for applications in the energy sector. The breadth and depth of subjects addressed by these reviews serve to illustrate the diversity and vitality of the physical science community at Diamond.

There is little I can add to these fine reviews in the space available other than to highlight a few significant early results from one of the first phase III beamlines, and to give a further example from my own narrow area of research where they can be expected to have an impact. This is as good a way as any of assessing whether or not Diamond is on the right track for the future.

One of the most important issues in materials science is to understand the electronic states in metals and semiconductors. As the electrons are mobile in such systems, this task requires determining both the momentum and energy of the states available to them. The recently commissioned beamline, I05, is specialized for this task. It uses a technique known as angle resolved photo-emission spectroscopy (ARPES) [1]. The first branch of I05 ARPES beamline began operations in July 2013 and has already had some spectacular early successes [4–6].

The next example for assessing how set fair for the future Diamond might be is the construction of the phase III beamline I21, dedicated to resonant inelastic X-ray scattering (RIXS) [7]. The development of RIXS as a technique also nicely serves to illustrate how progress in the exploitation of X-rays in the physical sciences is achieved on different fronts. The dogma, regretfully propounded by myself and others, was that understanding the dynamics of magnetic moments in materials—by measuring the so-called magnon dispersion—would always be the preserve of neutron scattering. This viewpoint was entrenched for two reasons. Firstly, although the formal structure of the resonant X-ray scattering cross-section is well established, our understanding of how to apply it is incomplete. The remarkable truth is that more than 100 years after the discovery of the X-ray photon–matter interaction, it remains a productive research subject in its own right. Secondly, the observation of magnons with RIXS required the development of appropriate X-ray spectrometers with a resolving power of more than $10^5$. Thus, the experimental observation by Braicovich et al. [8] in 2010 of magnon dispersion in La$_2$CuO$_4$ using RIXS has opened up an entirely new research field. The start of operations on the RIXS beamline I21 in 2017 will help to drive this field forward by extending the number of elements to which the technique can be applied.

The wider international context of X-ray facilities in which Diamond operates is also in a rapid phase of development. The advent of the LCLS, the world’s first hard X-ray free electron laser (XFEL), has already produced some exquisite examples of the transformative nature of these sources in providing coherent, femtosecond pulsed beams [9–11].

XFELs, in my opinion, represent an opportunity and not a threat to synchrotron sources such as Diamond, as their capabilities are so fundamentally different, although there are of course overlapping areas of interest. The opportunities for synchrotron sources come not only from the essential role that they play in laying the groundwork for XFEL experiments (with examples given by Radaelli & Dhesi [2] in their review), but also from the challenge they are set to drive forward their technical innovation and capabilities: in a world where XFELs are a reality, synchrotrons cannot stand idly by. The emergence of low-emittance magnetic lattice designs for synchrotrons, with up to a factor of a thousand increase in source brilliance, presents a clear route forward through the construction of new sources such as MAX-IV in Sweden, and for the upgrade of existing ones. The European Synchrotron Radiation Facility, for example, has announced recently
that it will completely replace its existing lattice—in effect building a new lower emittance
synchrotron, but retaining many of the beamlines—in the period 2018–2020. The opportunity
will come for a similar upgrade to Diamond, and I for one hope that such an opportunity is
enthusiastically embraced, as it will allow Diamond to continue to flourish in the coming decades.

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