quantum beam science

MDPI

Editorial

Facilities in Quantum Beam Science

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1. Introduction – Quantum Beam Science

The year 2017 saw the birth of the journal *Quantum Beam Science* [1] which is dedicated to the sources and properties of quantum beam radiation. In particular, it focuses on applications that probe or influence materials and matter on length scales from the interior of an atom, to crystal and molecular structures, and from microstructures to large-scale engineering or environmental objects. Similarly, time scales play a role, from the excitation of an electron, the formation of chemical bonds, the motions of atoms, diffusion, structural switching and up to applications and the aging of materials in industrial and geological contexts.

2. *Facilities*—Aims and Scope

Because large user facilities such as X-ray synchrotrons, neutron and muon sources most often act as the origin of various quantum beams, the inaugural call for contributions to *Quantum Beam Science* was dedicated to a Special Issue *Facilities*, which has developed into a continuously published Topical Collection. The aim is to assemble reviews and original articles to describe existing, upcoming, planned, and historic large user facilities for materials and life sciences from around the world. Quantum beams encompass all kinds of short-wavelength radiation for the study of condensed matter materials in the broadest sense. In particular, this includes synchrotron and neutron radiation, ion beams, positrons, muons, and to some extent lasers, where they interact under extreme conditions or are correlated with some other kind of quantum beam. While most of those quantum beams can be generated on a small laboratory scale, state-of-the-art sources are assembled in large-scale multi-user facilities, such as spallation sources, third-generation synchrotrons and nuclear reactors.

3. Contributions—*Facilities*

In 2017, the Topical Collection *Facilities* encompassed neutron beams, synchrotron radiation, muon sources, irradiation facilities and laser-driven quantum beams, represented by nine articles and showcasing the broad, interdisciplinary scope of the journal. These articles serve expert users as a primary reference for the described facilities and, moreover, supply background information to a vast base of external users, and assist exchange between groups that apply only one single kind of quantum beam.

Neutrons and Muons at J-PARC: The Japan Proton Accelerator Research Complex (J-PARC) is one of the major spallation neutron sources. In Takada et al. [2], one of four articles from J-PARC, they describe in detail their proton accelerator, consisting of a linear accelerator and a synchrotron. Negative H^--ions are brought to 0.4 GeV and then electrons stripped at insertion to the rapid cycling synchrotron, after which the bare protons are ramped to 3 GeV and fed to the transparent muon and the neutron targets. The latter produces neutrons by spallation in liquid mercury. The neutrons are then conditioned by coupled, decoupled, and poisoned, thermal and cryogenic moderators to serve up to 24 beam ports.

Nakajima et al. [3] describe the 23 beamlines within the Materials and Life Science facility (Figure 1), ranging from engineering to single crystal diffraction, chemical research to collective excitations, neutron optics to imaging, and high-pressure to total scattering, to mention but a few. Each of the beamlines has been individually designed to world-leading standards and the many peculiarities described make them unique. Neutron devices, such as choppers, optics and detectors, sample environments, and as importantly the software for data acquisition and reduction are formulated by Sakasai et. al. [4].

Figure 1. Artistic panoramic view into an experimental hall of the Materials and Life Science Facility at J-PARC [2–5]. The neutron beam ports surrounding the target station are to the far right feeding beamlinces at the right, while muon apparatus is located in the left side of the image.

The muons are produced by interaction of the accelerated proton beam with a thin carbon foil, before being dumped into the neutron target. Higemoto et al. [5] detail all muon beamlines, layouts, physical, and optical parameters for applications ranging from muon spin resonance measurements to surface sensitivity by ultra-slow muons that penetrate only a few nanometers into the sample.

Neutron Sources at the Frank Laboratory: Very complementary neutron sources are presented by Shvetsov [6] from the Frank Laboratory of Neutron Physics at the Joint Institute for Nuclear Research. Unique is the IBR-2 pulsed reactor, where criticality is obtained by passing reflectors in short time pulses, producing strong neutron pulses, and serving 18 spectrometers and diffractometers for similar applications to those mentioned in the J-PARC papers. A few unique instruments are hosted for nuclear physics, such as for reporting nuclear neutron precession and magnetic structure, or the determination of yield and decay constants in fission materials. More opportunities for fundamental and applied investigations in neutron nuclear physics are given by the IREN facility. This accelerator-based source delivers neutrons in the energy range one to hundreds of electron-volts and thus falls out of the common ranges of neutron scattering.

A bit of history—HIFAR: Neutron scattering by reactor sources had been developed from the 1950s on and was implemented in Australia with its reactor HIFAR, which ran from 1958 to 2007. Margaret Elcombe worked there as a scientist for over 40 years, from which she reports generations of technologies, such as goniometers taken from a gun mount, the beginning of computerization, hand-driven data acquisition, and other anecdotes [7]. Techniques for polarized neutrons matured here, and later famous students took their first data, such as Hugo Rietveld who developed the whole-pattern fitting for powder diffraction analysis named after him.

Ion Beams at Takasaki: A cyclotron and three electrostatic accelerators producing various kinds of ion beams, and complemented by electron and gamma irradiation for studies in materials science and bio-technology, are found at the Takasaki Advanced Radiation Research Institute and reported by Kurashima et al. [8]. Nice examples are given where, e.g., microscopic asbestos can be quantified in lung tissue by micro particle-induced X-ray emission, which is not detectable by conventional quantum beam imaging techniques. Similarly, these capabilities contribute to the vast research area on Li–ion batteries in complementary ways.

CLS—The Brightest Light in Canada: Synchrotron radiation, a highly important class of quantum beams, is reported by Cutler et al. from the Canadian Light Source [9]. It is a third generation, 2.9 GeV machine and sits in the mainstream of synchrotron light sources. Focusing on specific and unique beamlines and instrumentation makes it world-class and state-of-the-art. For example, the scanning transmission X-ray microscopy is equipped with many different experimental environments, including humidity cells and in situ catalysis. The cryo-tomography operates at spot sizes of 30 nm, setting new standards in this community. In particular, the facility is a leader in industrial applications.

High-Power Lasers at Kansai Photon Science Institute: Split off the former Quantum Beam Science Directorate at JAEA in Japan, the institute operates petawatt laser facilities, summarized by Kondo et al. [10]. This test facility offers investigations and new concepts for future state-of-the-art facilities using laser-generated quantum beam sources. The extreme strong electro-magnetic optical wave fields can accelerate electrons and ions, or create high-order non-linear processes for high-order harmonics. Developments are underway to generate γ-rays through inverse Compton scattering, coherent X-rays by relativistic flying mirrors, colliding electrons and other secondary radiation. More on these technologies, upcoming sources and applications are being compiled by Paul Bolton in a Special Issue on *Laser-Driven Quantum Beams* [11].

4. Conclusion and Outlook

The nine facilities description emphasize the necessity for *Quantum Beam Science* to produce intra- and inter-disciplinary reports on various kinds of radiation. The papers published so far form an excellent base of knowledge, supporting user experiments in a myriad of applications.

Advancing into its second year, several Special Issues on applications of quantum beams are open, including *Selected Reviews in Quantum Beam Science*, *Magnetic Materials and Magnetism* and *Strain, Stress and Texture Analysis with Quantum Beams*, and we are actively seeking Guest Editors with further ideas and contributions.

The Topical Collection *Facilities* is being recognized by a range of complementary institutions, which are planning to contribute further papers. We encourage submission by as-yet under-represented communities, such as synchrotron radiation, free-electron lasers, as well as smaller niche communities, such as those representing positron and muon sources. The aim is to emphasize the interdisciplinary nature of the journal.

Topical Collections and Special Issues will be compiled into printed books, such as *Metals Challenged by Neutron and Synchrotron Radiation* [12].

Conflicts of Interest: The author declares no conflict of interest

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