Bringing physics, synchrotron light and probing neutrons to the public: a collaborative outreach

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Bringing physics, synchrotron light and probing neutrons to the public: a collaborative outreach

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Abstract
Stanley Micklavzina, a US physics educator on sabbatical, teams up with a Swedish national research laboratory, a synchrotron radiation experimental group and a university science centre to develop and create educational and public outreach projects. Descriptions of the physics, science centre displays and public demonstrations covering the physics principles involved in using photons and neutrons to probe materials are given.

Introduction

MAX IV [1] is a Swedish national laboratory for synchrotron light, and the construction of a new laboratory is driving new outreach efforts. The new facility will be the most brilliant synchrotron light source in the world. MAX IV will later be joined by the European Spallation Source (ESS) laboratory, a complementary facility using neutrons to probe material. The challenge faced in developing outreach ideas for these new laboratories is how to communicate the physics of synchrotron radiation (MAX IV) and spallation (ESS) to young students and the public.

Both of these are accelerator-based facilities, but particle physics is not part of the scientific program. The research performed at these facilities falls within any field where materials are studied down to the atomic length scale. The machines and methods used to probe these materials involve the application of a large variety of physics principles from areas such as electricity and magnetism, quantum physics, nuclear physics, and optics. Both the physics of the sources and the science that will be carried out with the light and neutrons are communicated in the outreach. A two-year collaborative project developed a set of displays at the Vattenhallen Science Center [2] LTH at Lund University, and a set of demonstrations for public science shows or smaller interactive presentations.

Vattenhallen offers a 1000 m^2 exhibit area, a 160-seat lecture presentation area and a planetarium. The exhibit developed is the latest addition to the centre and is entitled 'Shoot protons and tickle electrons'. This exhibit is an example of outreach collaboration between multiple universities, disciplines and organizations. The centre itself receives about 35 000 visitors each year. An important segment of their clientele is regional teachers, who bring an average of 100 students per school day. Pupils interact with Lund University students who are trained to show the exhibits

Figure 1. Display name and entrance.

and involve visitors with hands-on activities. On weekends and holidays Vattenhallen is open to the public.

Vattenhallen interactive displays

The research at MAX IV and ESS begins with the creation of light or neutrons to probe materials. We will call all electromagnetic radiation 'light' for ease of discussion throughout this paper. In order to create light, the accelerator staff at MAX IV accelerate electrons and then wiggle them using strong magnets. The electrons originate from a thermal electron source where they are extracted in pulses and accelerated to nearly the speed of light. The electrons are then injected into an evacuated pipe within a lattice of focusing and confining magnets called the *storage ring* where they radiate at every turn of the beam. This broad-band spectrum is then filtered to get the desired light for various experiments located at the end of individual *beam lines*. Individual wavelengths of light are selected as required for a particular experiment. For the ESS, protons originating from ionized hydrogen atoms are accelerated in a similar way to electrons, but then hit a target that releases a large number of neutrons. Neutrons are very hard to steer because they do not have any associated charge; therefore, many neutrons are needed since only the neutrons that happen to find their way to the sample create an experimental result. The exhibit begins with displays modeling the charged particle gun and linear accelerator used in these laboratories.

Figure 2. The gun model.

The gun (Kanon)

Upon entering the exhibit area (figure 1), visitors encounter the *Kanon* (figure 2). In this display ping pong balls are placed in a tall and wide transparent cylinder on top of a big drum. When visitors pound on the drum the ping pong balls bounce up, and if they bounce high enough they will be accelerated up to the ceiling (6.5 m) by a vacuum cleaner connected to a narrow clear pipe. The excitation of ping pong balls by the drum is similar to the stimulation of electrons from a heated metal surface in a real electron gun. Protons, used in the ESS, originate from ionized hydrogen gas that has been stripped of its electrons. Realistically, these charged particles undergo a selection process. This

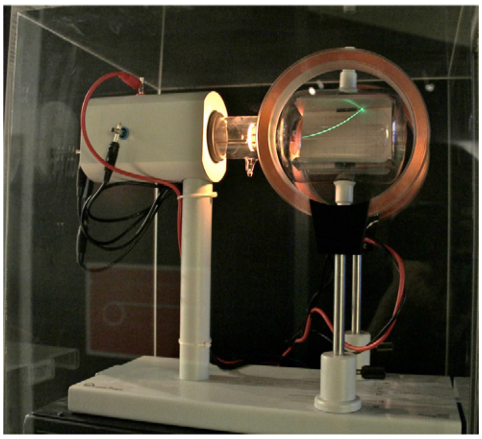

Figure 3. Electron beam in a magnetic field.

is simulated in the exhibit by the clear pipe where only ping pong balls bounced high enough in the correct direction are caught by the vacuum cleaner and accelerated away in the tube. The vacuum cleaner acts as the electric field, which ejects the charged particles from the gun. The visitors can turn off the vacuum and the balls will fall back into the original chamber. This experiment is the beginning of the display area and, as all kids love to drum, it is a playful start to the exhibition.

Cathode ray beam

At the next station, an actual electron gun can be observed. This typical instructional laboratory apparatus (figure 3) shows the heated filament and a slit that selects the electrons. The resulting electron beam is visible due to an angled phosphorous screen. Here, the visitors can see the real-life equivalent of the *Kanon* and also learn that the beam is steered, not with a plastic tube, but with a magnetic field. The visitors can bend the beam by using either a permanent magnet or a magnetic field induced by an electrical current flowing through a set of Helmholtz coils.

The linear accelerator

At this point in the exhibit, we have shown how charged particles are obtained and how they are steered by magnetic fields. After ejection from the gun, they enter the linear accelerator, where they are accelerated to about 99.9% of the speed of light by a series of electrical field cavities that are sequenced to accelerate the charged particles. Accelerator physicists manipulate the timing of electrical field cavities to produce the highest possible electron velocity.

In the interactive display model, a steel ball in a cylindrical pipe represents the charged particle, which is accelerated by a series of electromagnets in the model (figure 4). Two teams of visitors can compete on parallel tracks to make the steel balls travel as fast as possible to the other end of the pipe; to move the ball, six electromagnetic coils can be manually energized. Timing is the

Figure 4. Linear accelerator model.

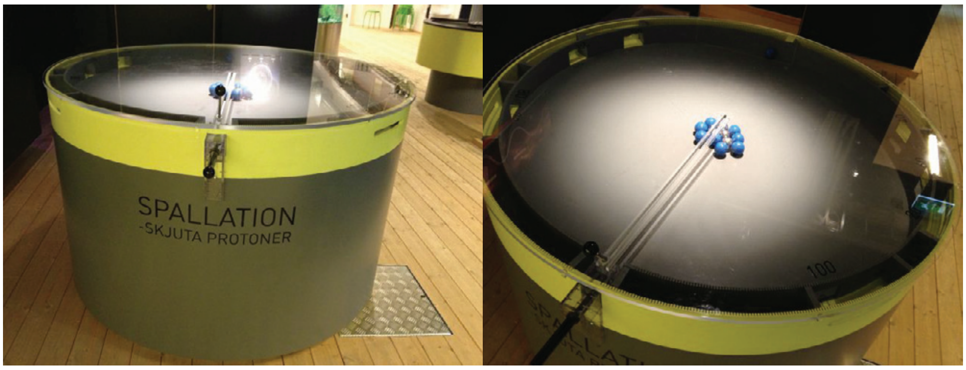

Figure 5. Spallation.

key to success. This is the reality that accelerator physicists are faced with as well! Depending on the timing, a ball can accelerate, slow down or even be turned around by the magnetic fields. The timing in the model results in different final velocities, in contrast to a realistic accelerator where the focus is on achieving the highest possible final velocity, rather than the shortest possible travel time. However, the principle of timed pulses to accelerate the charges is well demonstrated.

This experiment brings competition and collaboration to the display. It takes a few runs for the visitors to work out when to press and when to release to obtain the best result. The linear accelerator is the most popular experiment and is often used when we arrange pentathlon games for group visitors.

Spallation

For the ESS laboratory, protons are accelerated to a high velocity and directed to hit the nuclei of atoms, causing a large number of neutrons to be released.

To model this behavior, a steel ball is shot into the nucleus where golf balls are neutrons and steel balls are protons (figure 5). Visitors get scores if a neutron (golf ball) enters one of the beam line slots located around the edge of the table, representing the path for a beam line. For spallation, a large number of neutrons are needed since only a few will actually travel to the desired destination. Neutrons, since they have no charge, are difficult to direct but they can also probe a material without being disturbed by other charged particles or magnetic fields. This is a simple but very illustrative interactive display.

Figure 6. Wii-con.

Virtual journey through MAX IV

Computer game designers at Virtual Historical Models in Malmö, Sweden produced five different Wii-controlled simulations. Two large 50″ screens display the journey (figure 6). Here, the visitor can learn more about the electron gun, the linear accelerator, the storage ring and the beam line. They can also choose to meet three different scientists specializing in research about proteins, electronic materials and archeology. This constitutes an interactive informational station that complements the exhibit displays.

Figure 7. Storage ring model.

The storage ring

At Max IV, the electrons leave the linear accelerator and are guided by electromagnets in the magnet lattice to travel repeatedly around the storage ring. The light produced by the relativistic electrons can be enhanced by vibrating the electrons even more by using a series of strong alternating-pole magnets called wigglers or undulators. The light that is produced is sent into a beam line for final conditioning before it interacts with the experimental target. In the model, a steel ball representing an electron is circulated in a ring shaped clear pipe by an air mattress pump (figure 7). A set of permanent magnets representing a wiggler can be drawn towards the pipe (also connecting a switch to an LED), and if the ball's speed is high enough, it will be wiggling after it passes through the magnets. As a result, a flash of light from the LED travels down a narrow clear pipe (the beam line). The LED is actually triggered when the ball passes through a photo sensor just beyond the magnets. If the speed is too low, the ball will be captured by the magnetic field, fail to reach the photo sensor and no light will be produced. It is hard work to get the ball to the proper speed, but the reward for speed and timing is the flash of light.

Monochromator

Each experiment, depending on the method and material involved, requires a specific wavelength of light. The light created by the undulator or wiggler has a broad spectrum of wavelengths. This light can be broken into component wavelengths by utilizing a diffraction grating or crystals for diffraction of shorter wavelength light. Once broken down, the desired wavelength can be selected and guided to the experiment with a series of slits and mirrors. The selection apparatus is the monochromator and it is located within the experimental beam lines at the laboratory.

In the science museum display, light from a halogen bulb is directed onto a photo sensor and a spectrum analysis is performed (figure 8(a)). The resulting spectrum is shown by an intensity versus wavelength plot displayed in real time on a screen just above the monochromator model (figure 8(b)). There are three possible ways to observe the light. One way is to move a mirror into the light path which guides the light directly to the light sensor; this will display the entire spectrum of light on the display screen. The other two possibilities are to direct the light through either a diffraction grating or a prism to disperse it into its spectral colors. The interacting visitor can then move the photo sensor to select specific colors of the spectrum and determine the wavelength of the peak intensity on the display screen for that selected color.

Light interacting with matter; the DNA painting

Synchrotron radiation uses light to probe matter. From the analyzed output, researchers can find details about the molecular structure, energy composition and other characteristics of the observed matter, down to the nanoscale. The scale and energy used to make a measurement depend upon the wavelength of the light incident on the material. Changing the wavelength changes what it is possible to observe. The analogy of probing with synchrotron light is incorporated in a

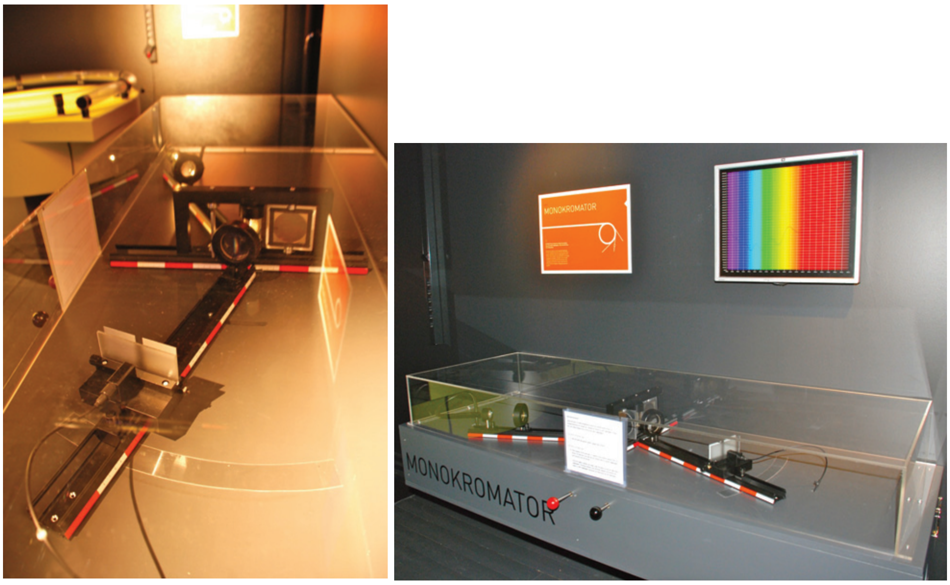

Figure 8. (a) Monochromator interactive model and (b) spectrum display screen.

special painting inspired by a top-down view of a DNA molecule helix (figure 9). This 1.4 m^2 painting has observable details that depend on the color (wavelength) of the light that illuminates it. Utilizing color subtraction phenomena, where an object's perceived color is relative to the color that is illuminating the object, the visitor can choose the levels of red, green and blue light and notice how the observed colors of the painting change with these different wavelengths (figure 9). To add a unique dimension, special ultraviolet sensitive paints were used, so when the painting is illuminated with UV light, finer details and new fields of color within the painting are observed. The shorter UV wavelength shows minute details, modeling results obtained at this smaller wavelength measurement scale. Simultaneously, the higher energy light stimulates other colors, modeling new observed energy configurations. Another benefit is the integration of art into the science display, adding an aesthetic to the science centre and intriguing a larger audience.

Microscopy: observations with the video microscope

At this display, the visitor uses a handheld USB microscope to investigate over 40 different objects, such as insects, plants, sand, sugar, salt, sponge, rope, hair, electronic components and micro-machined materials, that are located in a glass case. The microscope can be placed directly over the object and the magnified image is shown on a screen (figure 10). This accomplishes two investigations of interest. The first one is being able to see everyday objects easily magnified. The second is experiencing the limits of the microscope, thereby leading the visitors' interest to the 'Beyond the microscope' station that is directly across from the video microscope station.

Beyond the microscope experimental station

Here, the visitor can further investigate objects on the molecular scale, this time using either x-rays from the synchrotron or neutrons from the spallation source. Ten plastic blocks with photographs of different objects can be inserted into the experimental station (figure 11). Each plastic block has a picture of the object being investigated on the top side. Quick response (QR) codes are on the bottom of the block, and a web camera inside the experimental station picks up the code. A program chooses the correct image to display on the screen when the visitor decides whether the object will be investigated using synchrotron light (as in MAX IV) or neutrons (as in ESS). The images displayed were made at real synchrotron or neutron sources, and it is easy to see that the results differ depending upon the

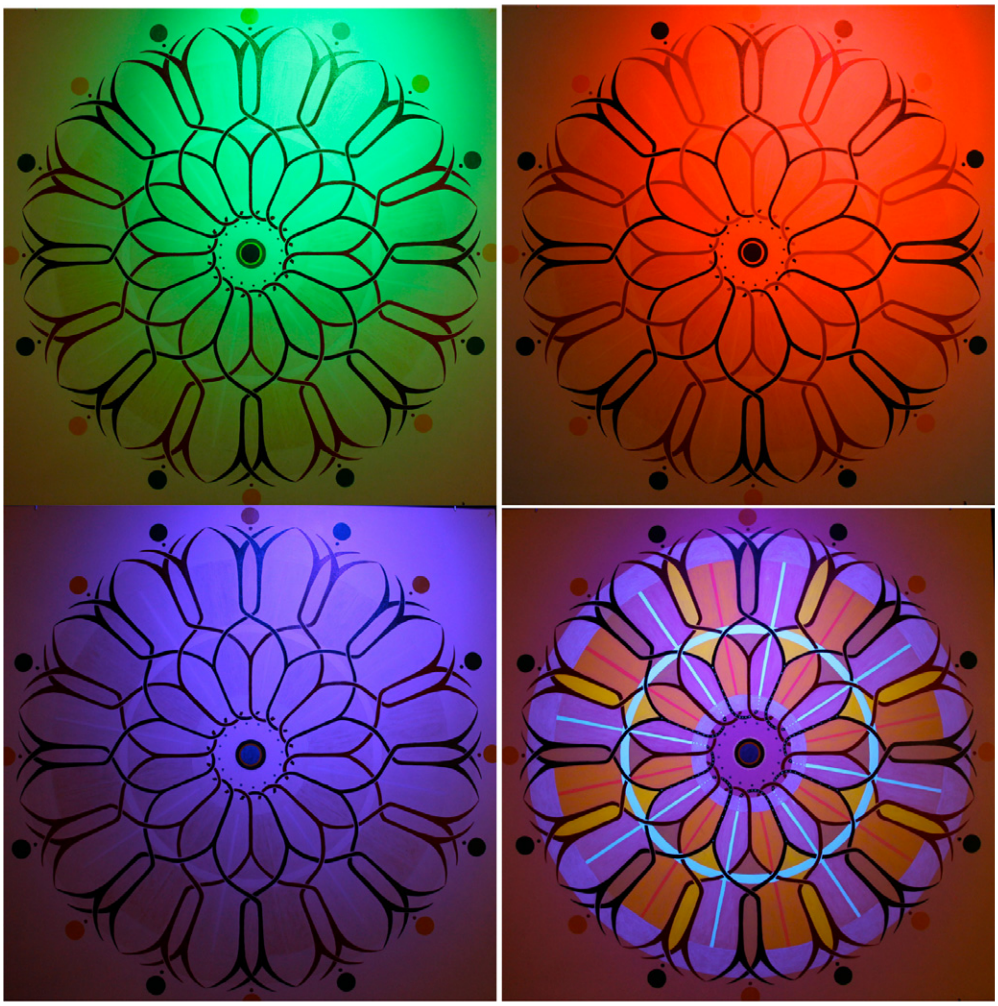

Figure 9. DNA painting with colored lights; lower right illuminated with UV light. Painting created by Diane Sandall.

investigation technique chosen. The images used at the science centre were provided by the Paul Scherrer Institute.

The objects that can be viewed include a radio, a hard disc, a rifle bullet, magnetic material, protein crystals, and more. These images provide a basic understanding of the differences between neutrons and x-rays for imaging, and how these two methods are complementary.

Physics show

Another well-known method to display science to the public in an active outreach forum is the demonstration show. Integrating performance with the physics presentation results in more audience

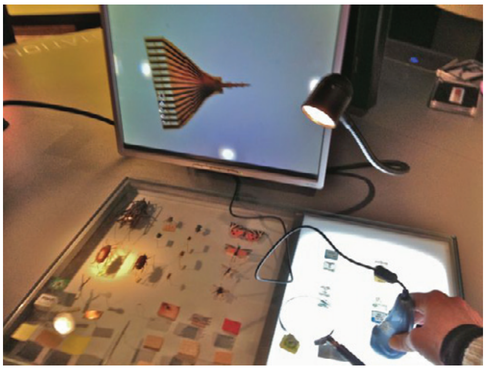

Figure 10. USB handheld microscope.

Figure 11. Beyond the microscope experimental station.

engagement and excites them about the whole experience. A key aspect of the show is information delivery accessible to a variety of age groups; the younger members of the audience love the physics demonstrations while the older members of the audience not only enjoy the demonstration, but also learn the laws and principles being discussed. Everyone present is exposed to the basic science behind the research and learns something about the direction of current research. For the shows involving MAX IV, the audience is taken on a journey to understand waves, light and energy. In addition, the concept of a spectrum is introduced and illustrated, and the application of all these principles to research methods is explained (figure 12). The show promotes both the understanding of the applied physics used at MAX IV and also the importance of implementing scientific research tools on new materials. The scripted show is designed to be versatile; it can be performed either as a complete show to an audience, or in sections presented at guided information tables in the science centre or school visits. The total script, including photographs and an equipment list, is available at a website[4].

More details can be obtained by contacting the author Stanley Micklavzina, who has designed outreach shows for other events such as the 2005 World Year of Physics [3] and other national and international events [4].

Conclusion

The involvement of university students in all these outreach activities, be it assisting with a show, training to present demonstration shows or simply being involved in showing science to visitors, has a high impact on their education. Some students become teachers, and some become ambassadors of science to the public due to their experience with building and presenting demonstrations and interacting with the public. Some students become directly interested in the research and even change their focus of study after becoming a part of the outreach activities!

Having a theme in a science centre, art centre, school visit or public presentation, which directly relates to current research being carried out, builds a bridge addressing the isolation between scientific research and the community at large. This is an important step for the continuation of research and education now and for the future. Institutions of research and learning should expand their involvement with community performance art and science centres to also help to broaden and invigorate the community experience. The centres gain by bringing the latest innovations and investigations

[4] www.sljus.lu.se/staff/stacey/quantumland/JourneytoQuantumland.pdf.

Figure 12. Light, waves and matter presentation show. The left photograph shows a light spectrum from different sources (lamps) observed through diffraction glasses. The right photograph shows the set-up for the demonstration show without the diffraction.

to schools, as well as the general public. The response at Vattenhallen has been very positive. The exhibit opened in December 2012 and statistics for 2013 show we have doubled the number of secondary school students (gymnasieelever) and the main reason for this increase in older students is this exhibit. It is beneficial for all involved, and the expanded communication benefits the future of science research and education. Funding sources for this project include the Science and Engineering Faculties at Lund University, the MAX IV Laboratory, the European Spallation Source, the Öresund Materials Innovation Community and Region Skåne. More background and information about synchrotron light and research may be found at the MAX IV website [1].

A partial list of synchrotron facilities offering educational resources and outreach is given below. Light is an incredible research tool, so bringing its attention to the public and classroom becomes even more relevant as we venture further into materials and the nanoscale world.

- Australian Synchrotron, (AS) Melbourne, Australia: hands-on visits and experiments[5].
- Canadian Light Source (CLS), Saskatchewan, Canada: outreach and hands-on material[6].
- Diamond Light Source (DIAMOND), South Oxfordshire, UK: a few applets and some material for teachers are available[7].
- Jefferson Lab, Virginia, USA: lots of different things which are very diverse but certainly inspired, and much of it is directly relevant[8].
- Brookhaven National Laboratory, USA: well organized page with information and events aimed at different target groups; relevant and extensive[9].
- Paul Scherrer Institute, Swiss Light Source (SLS) [5], Switzerland: a hands-on centre where there are full-time employees who work with students. Most information in their links for outreach is in German, but the onsite laboratory is a very interesting concept to consider[10].
- SOLEIL, France: materials and information for outreach[11].
- The European X-ray Laser Project (XFEL), Germany: lots of fun things that are brought out for their Night of Science exhibition. Engaging the community of both scientists and the public[12].

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[6] www.lightsource.ca/education/
[7] www.diamond.ac.uk/Home/Teachers.html
[8] http://education.jlab.org/indexpages/teachers.html
[9] www.bnl.gov/education/
[10] www.psi.ch/pa/school-lab/
[11] www.synchrotron-soleil.fr/portal/page/portal/RessourcesPedagogiques
[12] www.xfel.eu/news/2013/european_xfel_night_of_science_exhibition_attracts_thousands/

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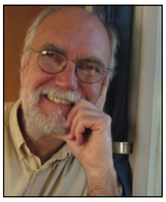
[5] www.psi.ch/sls/swiss-light-source



Stanley Micklavzina is a physics instructor at the University of Oregon, USA. His expertise is in physics demonstrations and producing physics shows where performance is a key element integrated within the science being shown. He has taken two sabbaticals within ten years, working as an outreach coordinator for MAX IV, Sweden's national synchrotron radiation laboratory.

Monica Almqvist is an associate professor at Electrical Measurement, Lund University, Sweden. Her main research interest is in ultrasound beam characterization and dolphin echolocation. She is the initiator and director of Vattenhallen Science Center LTH, which brings 35 000 school students and visitors to Lund University each year.

Stacey L Sörensen has a PhD in Physics from the University of Oregon. She has used synchrotron radiation in her research on atoms, molecules, surfaces and clusters during most of her career at Lund University. Presently her research focuses on spectroscopic imaging of molecules and nanosystems.