Scientific Program of SESAME Project

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Abstract. SESAME is a third generation light source with beam energy of 2.5 GeV, beam current of 400 mA, emittance 26 nm.rad and circumference of 133.2 m. It is under construction close to Amman – Jordan and will become operational end of 2012 or beginning of 2013. SESAME contains 16 straight sections out of which 13 straight sections are available for placing insertion devices such as undulator and wigglers. An extensive scientific programme has been established with the help of Scientific Advisory Committee (SAC) and the Beamline Advisory Committee (BAC). From the beginning 7 beamlines are planned for Phase – I covering diverse areas of scientific interest such as: SAXS/WAXS, PX, IR, Soft X-ray, Powder Diffraction, XRF/XAFS and Atomic, Molecular spectroscopy (AMO) beamline. SESAME once operational will be a very competitive machine in the category of third generation light sources.

1. Introduction

The synchrotron radiation was first discovered by Frank Elder, Anatole Gurewitsch, Robert Langmuir, and Herb Pollock at the General Electric synchrotron accelerator in 1946 [1]. Use of synchrotron radiation for fundamental science and applied technologies has experienced an explosive growth over the last twenty years. The growing importance of this new tool in such diverse fields as:

- Atomic and Molecular Science
- Surface and Material Science
- Environmental Science
- Archaeology
- Protein Crystallography
- Medical imaging
- Pharmaceutical R&D
- Micro fabrication

cannot be overlooked and is beginning to also have an economic impact. Around 60 synchrotron radiation sources are in operation worldwide and more are under construction.
Although synchrotron radiation sources became available in the meanwhile in several threshold countries including Brazil, China, India, Korea, Thailand and Taiwan, there are still many regions, including the Middle East, where such instruments are not available.

It is anticipated that a synchrotron light source would have a major impact on the development of science and technology in the Middle East region, with particular relevance to health and environmental issues, as well as benefits to industrial development, student training and the general economy of the region. As a cooperative venture by several countries in the Middle East region it also serves to promote understanding and peace in the region. The Synchrotron-Light for Experimental Science and Applications in the Middle East (SESAME) is a major international research centre now in construction in Jordan. It will enable world class research by scientists from across the Middle East and the Mediterranean region, in subjects

ranging from biology and medical sciences through materials science and physics to archaeology.
The centrepiece of SESAME is a third-generation 2.5 GeV synchrotron light source, originating from the decommissioned 0.8 GeV BESSY I facility, a gift from Germany. A synchrotron light source is an electron storage ring (an evacuated, donut-shaped tube, threading through magnets) in which a slender stream of high-energy electrons, bent by magnetic fields, orbits in a closed circular path. As their path is bent by ring magnets such as bending magnets or special magnets like undulators and wigglers electrons emit tangential beams of extremely intense, concentrated radiation over a broad span of wavelengths, ranging from the infra-red to ultra-violet to x-rays. These machines have had a revolutionary impact on many areas of basic and applied research by providing radiation that is more than one million times brighter, or more intense, than conventional sources, such as medical or industrial x-ray machines.

SESAME is governed by a Council which meets twice each year and presently has nine Members (Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestinian Authority, and Turkey). Negotiations are underway with Iraq and more are expected to join. Members have collective responsibility for the project and provide the annual operations budget (~$1.5M in 2009 and expected to grow to ~$5M when research operation starts in 2012). The President of the Council from 1999 to 2008 was Herwig Schopper, a former Director-General of CERN. In November 2008 Chris Llewellyn-Smith, also a former Director-General of CERN, took over as Council President. Observers of the Council include France, Germany, Greece, Italy, Japan (shortly to be confirmed) Kuwait, Portugal, Russia, Sweden, UK, and US.

2. SESAME Machine

In SESAME, an intense (400 mA) hair-like stream of high energy (2.5 GeV) electrons will circulate in a vacuum tube with a circumference of 133 meters. The facility is being constructed in a 75m x 75m building which was completed in 2008. The site in Allaan (about 30km North-West of Amman) and funds for the main and auxiliary buildings were provided by Jordan, which won out in a competition with 18 proposals from 7 countries. The starting point for the SESAME electron beam is the electron gun within microtron, which brings electron beam to energy of 22 MeV. At this energy beam is injected into the booster that further accelerates the beam to energy up to 800 MeV with the help of RF cavities. Finally the electron beam is injected from the booster ring into the main storage ring where after further acceleration the energy is increased to the final value of 2.5 GeV. Both microtron and the booster ring come from BESSY whereas the storage ring is designed from the scratch and under construction on SESAME site. A staff of 20 is now engaged in the installation of the BESSY I 0.8 GeV injection system.

The radiation is characterized in general by the following parameters: spectral range, photon flux, photon flux density, brilliance, and the polarization. The photon flux is the overall flux collected by an experiment and reaching the sample, the photon flux density is the flux per unit area at the sample and the brilliance is the flux per unit area and the opening angle. Fig. 1 to Fig. 3 [2] show the brilliance of photon beam off bending magnet, wiggler and undulator respectively versus the energy of emitted photons measured in keV. Today most of the calculations are using the results of the Schwinger theory [3]. The shape and intensity within the radiation cone according to the “Schwinger Theory” is given by:

$$\frac{d^2\phi}{d\theta d\Psi} = \frac{3\alpha}{4\pi^2}\gamma^2 \frac{\Delta\omega}{\omega}\frac{I}{e} y^2 (1+X^2)^2 \left[K_{2/3}^2(\xi) + \frac{X^2}{1+X^2} K_{1/3}^2(\xi) \right] \quad (2.1)$$

where:

- ϕ = photon flux (number of photons per second).
- Θ = observation angle in the horizontal plane.
- ψ = observation angle in the vertical plane.
- α = fine structure constant = (1/137).
- γ = electron energy/$m_e c^2$ (m_e = electron mass, c = speed of light).
- ω = angular frequency of photons (hω = photon energy = ε).
- I = beam current.
- e = electron charge = $1.6*10^{-19}$ coulomb.
- y = $\omega/\omega_c = \varepsilon/\varepsilon_c$.
- ε_c = critical photon energy ($=3\gamma^3 c/2\rho$)
- ε_c[keV]= $0.665*E^2$[GeV]B[T]
- ρ = radius of instantaneous curvature of electron trajectory in practical units,
- E = electron beam energy.
- B = magnetic field strength.
- X = $\gamma\psi$ (normalized angle in the vertical plane)
- ξ = $y(1+X^2)^{1.5}/2$

The subscripted K's in equation (2.1) are modified Bessel functions of the second kind. Equation (2.1) is the basic formula for the calculation of the characteristics of the synchrotron radiation. The polarization is given by the two terms within the square brackets.

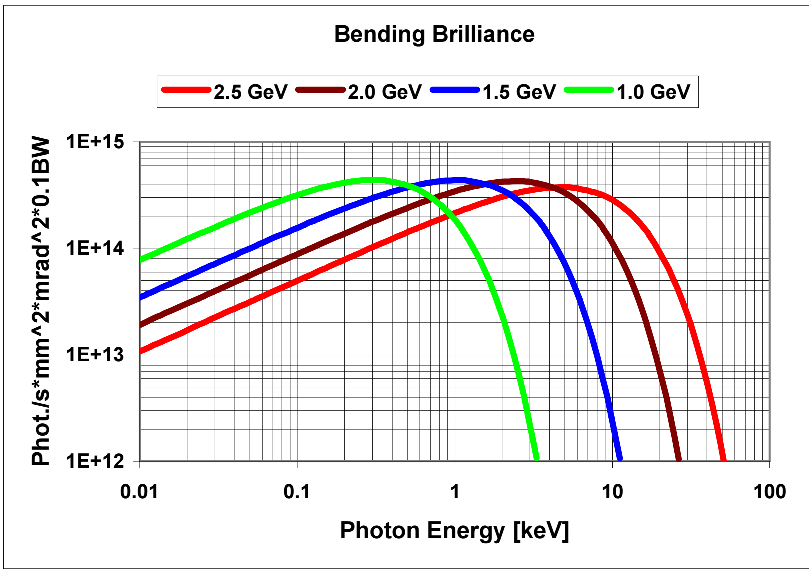

FIG. 1: The brilliance emitted within the bending magnet of SESAME from an electron beam with energies from 1.0 to 2.5 GeV.

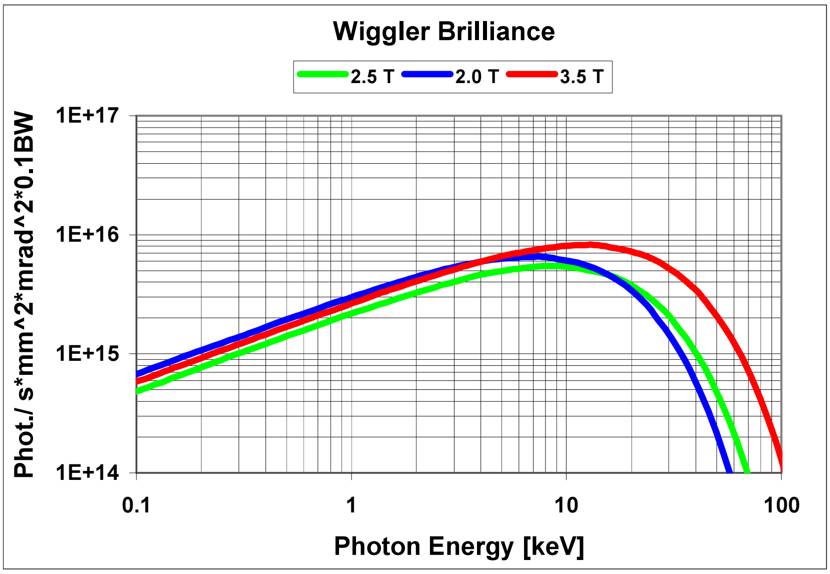

FIG. 2: The brilliance of the synchrotron radiation emitted from wigglers at SESAME.

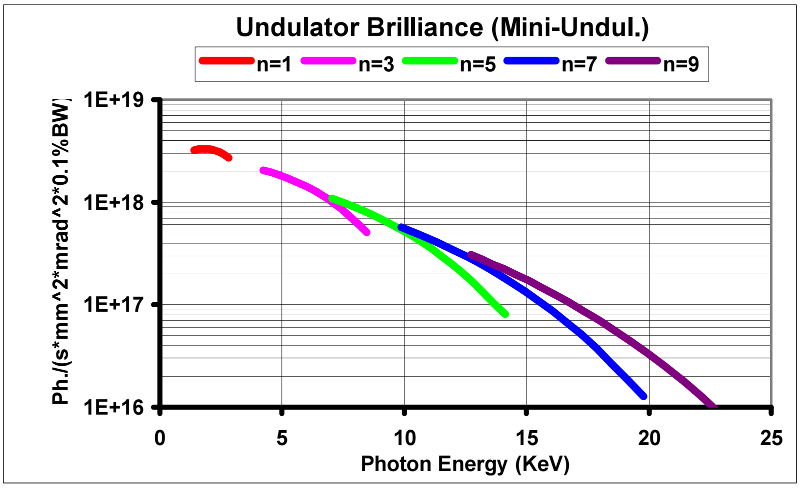

FIG. 3: The photon flux emitted from an undulator at SESAME. The parameters are: λ = 14 mm, gap = 5mm, k = 1.0 – 2.0, L = 1.4 m, E = 2.5 GeV, ε = 23.7 nm, coupl. = 2 %.

3. SESAME Beamlines

The facility will have the capacity to serve 30 or more experiments operating simultaneously on beamlines emerging tangentially from the ring. Twelve of these beamlines will originate from wiggler and undulator insertion devices, which provide even higher intensity than the sixteen possible beamlines originating from the ring bending magnets. An initial seven beamlines will be ready when operation starts in 2012. In a joint meeting of the “Beam Line- and Scientific Advisory Committee” at CCLRC Daresbury Laboratory, United Kingdom, in late December 2002, the decision was made about the “Potential First Phase Beam Lines” at SESAME.

The recommendation for these first beam lines was:

- MAD Protein Crystallography

- Small Angle X-ray Scattering
- Spectroscopy of Gases and Solids
- EXAFS
- Powder Diffraction
- Infra Red Spectroscopy

Following further discussions a set of beamlines was chosen see Table 1, based on the requirements of the user community in the SESAME region. It is expected that some of these beamlines will be operational on day one of operation of the SESAME storage ring.

TABLE 1: PLANNED PHASE – I BEAMLINES OF SESAME.

No.	Beamline	Energy Range	Source Type	Research Area
1.	Mad Protein Crystallography	4 – 14 keV	In-vacuum undulator	Structural Molecular Biology (SMB)
2.	Soft X-ray, Vacuum Ultra Violet (VUV)	0.05 – 2 keV	Elliptically Polarizing Undulator	Atomic, Molecular and Condensed Matter Physics
3.	Small and Wide Angle X-ray Scattering (SAXS/WAXS)	8 – 12 keV	Undulator	SMB, Material Science
4.	X-ray Fluorescence XRF/XAFS	3 – 30 keV	Multi-pole Wiggler	Material Science, Archaeology
5.	Powder Diffraction	3 – 25 keV	Multi-pole Wiggler	Material Science
6.	Infra-red Spectro-microscopy	0.01 – 1 eV	Bending Magnet	Environmental, Materials and Archaeological Science
7.	Atomic, Molecular & Optics	5 – 250 eV	Bending Magnet	Atomic and Molecular Physics

Decommissioned beamlines have been provided by the Daresbury SRS in the UK, LURE in France. Donation of a powder diffraction beamline for material science from the Swiss Light Source is under discussion. In addition insertion devices and beamline equipment have been donated by LBNL and SLAC in the US. Pakistan is building a soft x-ray beamline. Other Council Members are expected to do the same, as well as providing in-kind contributions, as is common for international projects. With the upgrading of donated equipment, the suite of beamlines needed at the start is essentially complete.

3.1. Techniques for using SR:

There are wide varieties of techniques available which can be employed when using the synchrotron radiation as a tool for research. The use of a particular depends upon the spectral range and the application. In the context of SESAME one can define the following broad spectral ranges:

1. Hard X-ray (λ = 0.01 nm – 1.0 nm)
2. Soft X-ray and Vacuum Ultra-violet (VUV) (λ = 1.0 nm – 10 nm)
3. Infrared (IR) (λ = 750 nm – 100 μm)

At SESAME several beamlines will operate in hard X-ray region employing various techniques. A non-exhaustive list is given below:

- X-ray microscopy
- X-ray fluorescence
- X-ray Absorption
- Powder Diffraction
- Protein crystallography

X-ray microscopy is a technique that can be applied all across the soft and hard X-ray spectrum. It is method which can be used for diffraction, imaging and spectroscopy at the same time. X-ray fluorescence is a technique which can be used in elemental analysis and one of the best methods available to determine the elemental composition of a given sample. X-ray absorption spectroscopy can be used to study solids, liquids and gases. In case of solids this technique can easily be used with amorphous or crystalline states. One of the very important applications using this method is the environmental science. The powder diffraction is commonly used in physics, chemistry, geology, and material science. The structural molecular biology (SMB) particularly gets great benefits from synchrotron radiation. The protein crystallography is used for studying macro-mloecules.

The soft X-ray and VUV beamlines are very useful and an important tool for the determination of electronic structure of matter. It is essential for the understanding of chemical, magnetic, electrical and physical properties of materials. Many techniques will be employed on these beamlines such as X-ray photoelectron spectroscopy (XPS), X-ray absorption near edge spectroscopy (XANES) and electron spectroscopy for chemistry analysis (ESCA).

The uses of synchrotron source in the infrared region have several interesting applications in wide variety of areas of research. With infrared one can use a powerful technique of spectromicroscopy which allows the mapping of interesting biological samples in a non-destructive manner. One example is the mapping of protein plaques which build up on the brain tissue of Alzheimer's disease patients. This technique allows studying protein samples of very small size without employing straining or extraction which is destructive techniques. The same technique can be used in studying archaeological samples.

Appendix 1: References

[1] Elder, F. R.; Gurewitsch, A. M.; Langmuir, R. V.; Pollock, H. C., "Radiation from Electrons in a Synchrotron" (1947) *Physical Review*, vol. 71, Issue 11, pp. 829-830.

[2] "Conceptual Design Report for the Upgrading of SESAME to 2.5 GeV", Yellow report available http://www.sesame.org.jo/publication/SesamePublications.aspx

[3] Schwinger Theory, Phys. Rev.75, 1912 (1949).