Siam Photon

SYNCHROTRON
LIGHT RESEARCH INSTITUTE
(PUBLIC ORGANIZATION)

SLRI
DATA BOOKLET
2011

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SECTION 1

THE SIAM PHOTON SOURCE

The Siam Photon Source

The Siam Photon Source (SPS) is a 1.2 GeV synchrotron light source. The injector system of the SPS comprises a 40 MeV linac (LINAC) and a 1 GeV booster synchrotron (SYN). The electron beam energy is ramped to 1.2 GeV in the storage ring (STR).

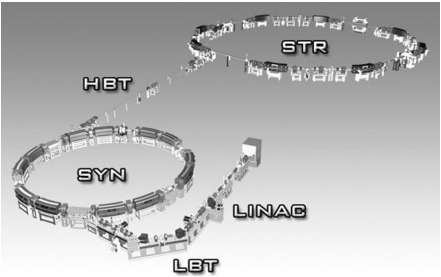


Figure 1.1. Layout of the Siam Photon Source.

The storage ring

The SPS storage ring comprises 4 superperiods of a Double Bend Acromat (DBA) lattice. The components of on period are shown in Figure 1.2.

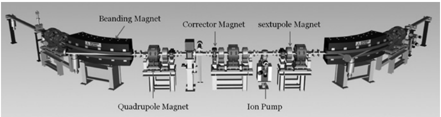


Figure 1.2. Lay out of DBA-lattice of a period

Table 1.1 The SPS storage ring parameters

Energy	1.20 GeV
Circumference	81.3 m
Revolution time	271.2 ns
Bending Radius	2.78 m
Betatron tune Horizontal	4.75
Vertical	2.86
Energy loss per turn	66 keV
Natural emittance	41 nm-rad
RF frequency	118 MHz
Harmonic number	32
Bunch length	52.3 mm

Synchrotron light spectra

Currently, synchrotron light is generated from the SPS by bending magnets and the U60 (60 mm period length permanent magnet undulator).

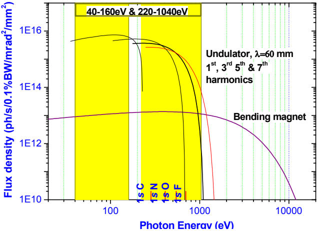


Figure 1.3. The photon flux density of SPS.

SECTION 2

BEAMLINE SPECIFICATIONS

BL1: Time-resolved XAS (Bonn-SUT-SLRI)

Unlike conventional x-ray absorption spectroscopy (XAS) which relies on a point by point mechanical scanning for collection procedure, the energy dispersive XAS employs a bent crystal to disperse and focus a range of X-ray energies. The attractiveness of energy dispersive scheme also consists of the fact that the sample is located in the polychromatic focus area which permits to study small amount of sample. The transmitted x-ray is detected simultaneously with the position sensitive detector (PSD). The PSD used at BL4 is the NMOS linear image sensor which consist of 1024 element photodiode. The combination of EDM and PSD allows the simultaneous detection of the absorption spectra within a short period of time. Thus this beamline is capable of obtaining the information of electronic and structural changes under applied factors such as temperature, pressure, electromagnetic field, and irradiation (in-situ measurement).

The energy bandwidth (ΔE) of the polychromatic x-ray can be calculated via;

$$\frac{2}{R} = \frac{\sin\theta}{p} + \frac{\sin\theta}{q}$$

$$\Delta E = E\cot\theta\left[\frac{l}{R} - \frac{l\sin\theta}{p}\right]$$

where *R, p, q, θ, E* and *l* are crystal radius, source-to-crystal length, crystal-to-focus length, Bragg angle, photon energy and crystal length, respectively.

Beamline specification

Radiation source	Bending magnet
Photon Energy	3-8 keV
Wavelength	4.13-1.55 Å
Energy Resolution ($\Delta E/E$)	10^{-1}
Spot size (H×V)	2 mm × 2 mm
Detectors	NMOS (S3904-1024, Hamamatsu)
Sample type	Powder / solid / liquid
Applications/ Research Field	Investigation of electronic and structural changes, In-situ XAS

BL2.2: Small Angle X-ray Scattering (SAXS)

BL2.2 is a Small Angle X-ray Scattering (SAXS) beamline dedicated for nano-scale structural investigation of materials such as nano-particle, polymer, fiber and colloid. In order to optimize the photon flux, the beamline adopts a Double Multilayer Monochromator (DMM) for monochromatizing synchrotron x-ray from the bending magnet number 2 of the Siam Photon Source.

Beamline specification

Radiation source	Bending magnet
Photon Energy	6-9 keV
Wavelength	1.4-2.1 Å
Energy Resolution ($\Delta E/E$)	10^{-2}
Spot size (H×V)	1 mm × 0.2 mm
Detectors	CCD (Mar165) / image plate
Sample type	Powder / solid / liquid / fiber
Applications/ Research Field	Nano structural investigation of materials, nano particle size analyses

For 9 keV x-ray and Mar SX165 CCD detector, the relations between a chosen sample-detector distance L, range of the amplitude of the scattering vector

$$q=(4\pi/\lambda)\sin\theta,$$

where the scattering angle is 2θ, and range of measurable characteristic length of the structure

$$d=2\pi/q$$

are given in the following table.

Table 2.1. q-range and measurable characteristic length

L (m)	q-range (nm^{-1})	d (nm)
0.5	0.46-7.45	0.84-13.78
1.0	0.23-3.75	1.67-27.56
1.5	0.15-2.51	2.51-41.33
2.0	0.11-1.88	3.34-55.11
2.5	0.09-1.50	4.18-68.89
3.0	0.08-1.25	5.01-82.67
3.5	0.07-1.07	5.85-96.44
4.0	0.06-0.94	6.68-110.22

Some useful formulae

Rod-like particles

$$I(q) = \frac{\pi L}{q} I_c(q), \qquad I_c(q) = \rho_0^2 A^2 \left(2\frac{J_1(qR)}{qR} \right)^2$$

Flat particles

$$I(q) = \frac{2\pi A}{q^2} I_t(q), \quad I_c(q) = \rho_0^2 T^2 \left(\frac{\sin(qT/2)}{qT/2} \right)^2$$

Guinier Law

Radius of gyration for the whole particle R$_g$

$$I(q) = \rho_0^2 V^2 \exp(-\frac{1}{3} q^2 R_g^2)$$

Radius of gyration of the cross-section R$_c$

$$I(q) = \rho_0^2 A^2 \exp(-\frac{1}{2} q^2 R_c^2)$$

Radius of gyration of the thickness R$_t$

$$I(q) = \rho_0^2 T^2 \exp(-q^2 R_t^2)$$

Pair Distribution Function

Globular particles

$$p(r) = \frac{1}{2\pi^2} \int_0^\infty I(q) \cdot (qr) \cdot \sin(qr)\, dq$$

Rod-like particles

$$p_c(r) = \frac{1}{2\pi} \int_0^\infty I_c(q)(qr) J_0(qr) dq$$

Flat particles

$$p_t(r) = \frac{1}{\pi} \int_0^\infty I_t(q) \cos(qr) dq$$

Table 2.2. Relation between radius of gyration and geometrical parameters

Shape	R_g^2	Shape	R_g^2
Sphere	$\frac{3R}{5}$	Hollow sphere	$\frac{3}{5}\frac{R_2^5 - R_1^5}{R_2^3 - R_1^3}$
Rod	$\frac{L^2}{12}+\frac{R^2}{12}$	Hollow cylinder	$\frac{R_1^2 + R_2^2}{2}+\frac{h^2}{12}$
Ellipsoid	$\frac{a^2+b^2+c^2}{5}$	Thin rod	$\frac{L}{12}$
Prism	$\frac{a^2+b^2+c^2}{12}$	Thin disk	$\frac{R}{2}$
Elliptic cylinder	$\frac{a^2+b^2}{4}+\frac{h^2}{12}$	Guassian chain	$\frac{Nl^2}{6}$

BL3.2a: Photoelectron Emission Spectroscopy (PES)

An Undulator (U60) provides a highly collimated light with high photon flux in the region of VUV and Soft X-rays (photon energy from 40 to 1040 eV) for BL3.2. The beamline is divided into 2 branch-lines, BL3.2a Photoelecron Emission Spectroscopy (PES) and BL3.2b Photoemission Electron Microscopy (PEEM). By using PES technique, the energy of electrons emitted from sample's surface by photoelectric effect are measured to calculate the binding energies of elemental compositions in the sample. Such information obtained is very useful, particularly for studies of variety of material surface and interface. The end-station of BL3.2a is equipped with electron energy analyzers, LEED optics, electron and ion guns, the molecular beam epitaxy (MBE) system with reflected high-energy electron diffraction (RHEED) optics and the surface magneto-optical Kerr effect (SMOKE) system.

Beamline specification

Radiation source	Undulator (U60) with λ_U= 60 mm
Photon Energy	40-160 eV 220-1040 eV
Wavelength	309.96-77.49 Å 56.36-11.92 Å
Energy Resolution (ΔE/E)	10^{-4}
Spot size (HxV)	4.7 mm x 1.2 mm @ VSXAS#1, 3.7 mm x 0.8 mm @ VSXPS, 1.2 mm x 0.3 mm @ VSXAS#2 and 0.3 mm x 0.1 mm @ ARPES
Detectors	Electron energy analyzers from Thermo VG Scientific: Angle-resolved (ARUPS10), Angle-integral (Alpha110 and CLAM2)
Sample type	Solid, flat and smooth, UHV compatible and conductive. Powder form can be used in case of XPS
Applications/ Research Field	Surface, interface and thin-film researches, Material Science

BL3.2b: Photoemission Electron Microscopy (PEEM)

At BL3.2b (PEEM), a sample is irradiated with monochromatic light from varied line-spacing plane-grating monochromator. Electrons created by photoemission and photoabsorption processes are projected by a set of magnetic lenses onto a micro-channel plate intensifier and a phosphor screen where the final image is formed. By scanning incident photon energy and capturing PEEM image at each energy step, a series of images which contains photoabsorption spectra from selective areas of the sample can be obtained. Alternatively, photon energy is fixed and an electron energy analyzer is used to determine the photoemission spectra of photoelectrons emitted from certain areas of the sample.

PEEM is, therefore, an effective tool to study surface and interface phenomena. Examples of researches that benefit from PEEM's capability include thin-film depositions, structural analyses of composite materials, study on novel electronic substrate, applied physics involving surface phenomena and the study of biological systems.

Beamline specification

Radiation source	Undulator (U60) with λ_U= 60 mm
Photon Energy	40-160 eV 220-1040 eV
Wavelength	309.96-77.49 Å 56.36-11.92 Å
Energy Resolution (ΔE/E)	10^{-4}
Spot size (HxV)	FWHM 0.22102 x 0.04229 mm @ 40 eV (from calculation)
Detectors	Micro-channel plate Sensicam QE CCD camera Electron energy analyzer
Sample type	Solid , flat and smooth, UHV compatible and conductive
Applications/ Research Field	Surface, interface and thin-film researches, Material Science , Biological Imaging with μ–XAS technique.

Electron Binding Energies

Electron binding energies (electron volts, ev) of the elements in their natural form) are listed in Table 2.3 Values in the table are taken from X-ray Data Booklet (LNBL/PUB-490 Rev.2).

Table 2.3 Electron binding energies (electron volts) for the elements in their natural forms.

Element	K 1s	L_1 2s	L_2 $2p_{1/2}$	L_3 $2p_{3/2}$	M_1 3s	M_2 $3p_{1/2}$	M_3 $3p_{3/2}$	M_4 $3d_{3/2}$	M_5 $3d_{5/2}$	N_1 4s	N_2 $4p_{1/2}$	N_3 $4p_{3/2}$
1 H	13.6											
2 He	24.6											
3 Li	54.7											
4 Be	111.5											
5 B	188											
6 C	284.2											
7 N	409.9	37.3										
8 O	543.1	41.6										
9 F	696.7											
10 Ne	870.2	48.5	21.7	21.6								
11 Na	1070.8	63.5	30.65	30.81								
12 Mg	1303.0	88.7	49.78	49.50								
13 Al	1559.6	117.8	72.95	72.55								
14 Si	1839	149.7	99.82	99.42								
15 P	2145.5	189	136	135								
16 S	2472	230.9	163.6	162.5								
17 Cl	2822.4	270	202	200								
18 Ar	3205.9	326.3	250.6	248.4	29.3	15.9	15.7					
19 K	3608.4	378.6	297.3	294.6	34.8	18.3	18.3					
20 Ca	4038.5	438.4	349.7	346.2	44.3	25.4	25.4					
21 Sc	4492	498.0	403.6	398.7	51.1	28.3	28.3					
22 Ti	4966	560.9	460.2	453.8	58.7	32.6	32.6					
23 V	5465	626.7	519.8	512.1	66.3	37.2	37.2					

Table 2.3 Electron binding energies (eV) (continued).

Element	K 1s	L_1 2s	L_2 $2p_{1/2}$	L_3 $2p_{3/2}$	M_1 3s	M_2 $3p_{1/2}$	M_3 $3p_{3/2}$	M_4 $3d_{3/2}$	M_5 $3d_{5/2}$	N_1 4s	N_2 $4p_{1/2}$	N_3 $4p_{3/2}$
24 Cr	5989	696.0	583.8	574.1	74.1	42.2	42.2					
25 Mn	6539	769.1	649.9	638.7	82.3	47.2	47.2					
26 Fe	7112	844.6	719.9	706.8	91.3	52.7	52.7					
27 Co	7709	925.1	793.2	778.1	101.0	58.9	59.9					
28 Ni	8333	1008.6	870.0	852.7	110.8	68.0	66.2					
29 Cu	8979	1096.7	952.3	932.7	122.5	77.3	75.1					
30 Zn	9659	1196.2	1044.9	1021.8	139.8	91.4	88.6	10.2	10.1			
31 Ga	10367	1299.0	1143.2	1116.4	159.5	103.5	100.0	18.7	18.7			
32 Ge	11103	1414.6	1248.1	1217.0	180.1	124.9	120.8	29.8	29.2			
33 As	11867	1527.0	1359.1	1323.6	204.7	146.2	141.2	41.7	41.7			
34 Se	12658	1652.0	1474.3	1433.9	229.6	166.5	160.7	55.5	54.6			
35 Br	13474	1782	1596	1550	257	189	182	70	69			
36 Kr	14326	1921	1730.9	1678.4	292.8	222.2	214.4	95.0	93.8	27.5	14.1	14.1
37 Rb	15200	2065	1864	1804	326.7	248.7	239.1	113.0	112	30.5	16.3	15.3
38 Sr	16105	2216	2007	1940	358.7	280.3	270.0	136.0	134.2	38.9	21.3	20.1
39 Y	17038	2373	2156	2080	392.0	310.6	298.8	157.7	155.8	43.8	24.4	23.1
40 Zr	17998	2532	2307	2223	430.3	343.5	329.8	181.1	178.8	50.6	28.5	27.1
41 Nb	18986	2698	2465	2371	466.6	376.1	360.6	205.0	202.3	56.4	32.6	30.8
42 Mo	20000	2866	2625	2520	506.3	411.6	394.0	231.1	227.9	63.2	37.6	35.5
43 Tc	21044	3043	2793	2677	544	447.6	417.7	257.6	253.9	69.5	42.3	39.9
44 Ru	22117	3224	2967	2838	586.1	483.5	461.4	284.2	280.0	75.0	46.3	43.2
45 Rh	23220	3412	3146	3004	628.1	521.3	496.5	311.9	307.2	81.4	50.5	47.3
46 Pd	24350	3604	3330	3173	671.6	559.9	532.3	340.5	335.2	87.1	55.7	50.9
47 Ag	25514	3806	3524	3351	719.0	603.8	573.0	374.0	368.3	97.0	63.7	58.3

Table 2.3 Electron binding energies (eV) (continued).

Element	K 1s	L_1 2s	L_2 $2p_{1/2}$	L_3 $2p_{3/2}$	M_1 3s	M_2 $3p_{1/2}$	M_3 $3p_{3/2}$	M_4 $3d_{3/2}$	M_5 $3d_{5/2}$	N_1 4s	N_2 $4p_{1/2}$	N_3 $4p_{3/2}$
48 Cd	26711	4018	3727	3538	772.0	652.6	618.4	411.9	405.2	109.8	63.9	63.9
49 In	27940	4238	3938	3730	827.2	703.2	665.3	451.4	443.9	122.9	73.5	73.5
50 Sn	29200	4465	4156	3929	884.7	756.5	714.6	493.2	484.9	137.1	83.6	83.6
51 Sb	30491	4698	4380	4132	946	812.7	766.4	537.5	528.2	153.2	95.6	95.6
52 Te	31814	4939	4612	4341	1006	870.8	820.0	583.4	573.0	169.4	103.3	103.3
53 I	33169	5188	4852	4557	1072	931	875	630.8	619.3	186	123	123
54 Xe	34561	5453	5107	4786	1148.7	1002.1	940.6	689.0	676.4	213.2	146.7	145.5
55 Cs	35985	5714	5359	5012	1211	1071	1003	740.5	726.6	232.3	172.4	161.3
56 Ba	37441	5989	5624	5247	1293	1137	1063	795.7	780.5	253.5	192	178.6
57 La	38925	6266	5891	5483	1362	1209	1128	853	836	274.7	205.8	196.0
58 Ce	40443	6549	6164	5723	1436	1274	1187	902.4	883.8	291.0	223.2	206.5
59 Pr	41991	6835	6440	5964	1511	1337	1242	948.3	928.8	304.5	236.3	217.6
60 Nd	43569	7126	6722	6208	1575	1403	1297	1003.3	980.4	319.2	243.3	224.6
61 Pm	45184	7428	7013	6459	—	1471	1357	1052	1027	—	242	242
62 Sm	46834	7737	7312	6716	1723	1541	1420	1110.9	1083.4	347.2	265.6	247.4
63 Eu	48519	8052	7617	6977	1800	1614	1481	1158.6	1127.5	360	284	257
64 Gd	50239	8376	7930	7243	1881	1688	1544	1221.9	1189.6	378.6	286	271
65 Tb	51996	8708	8252	7514	1968	1768	1611	1276.9	1241.1	396.0	322.4	284.1
66 Dy	53789	9046	8581	7790	2047	1842	1676	1333	1292.6	414.2	333.5	293.2
67 Ho	55618	9394	8918	8071	2128	1923	1741	1392	1351	432.4	343.5	308.2
68 Er	57486	9751	9264	8358	2207	2006	1812	1453	1409	449.8	366.2	320.2
69 Tm	59390	10116	9617	8648	2307	2090	1885	1515	1468	470.9	385.9	332.6
70 Yb	61332	10486	9978	8944	2398	2173	1950	1576	1528	480.5	388.7	339.7

Table 2.3 Electron binding energies (eV) (continued).

Element	N_4 4d$_{3/2}$	N_5 4d$_{5/2}$	N_6 4f$_{5/2}$	N_7 4f$_{7/2}$	O_1 5s	O_2 5p$_{1/2}$	O_3 5p$_{3/2}$	O_4 5d$_{3/2}$	O_5 5d$_{5/2}$	P_1 6s	P_2 6p$_{1/2}$	P_3 6p$_{3/2}$
48 Cd	11.7	l0.7										
49 In	17.7	16.9										
50 Sn	24.9	23.9										
51 Sb	33.3	32.1										
52 Te	41.9	40.4										
53 I	50.6	48.9										
54 Xe	69.5	67.5	—	—	23.3	13.4	12.1					
55 Cs	79.8	77.5	—	—	22.7	14.2	12.1					
56 Ba	92.6	89.9	—	—	30.3	17.0	14.8					
57 La	105.3	102.5	—	—	34.3	19.3	16.8					
58 Ce	109	—	0.1	0.1	37.8	19.8	17.0					
59 Pr	115.1	115.1	2.0	2.0	37.4	22.3	22.3					
60 Nd	120.5	120.5	1.5	1.5	37.5	21.1	21.1					
61 Pm	120	120	—	—	—	—	—					
62 Sm	129	129	5.2	5.2	37.4	21.3	21.3					
63 Eu	133	127.7	0	0	32	22	22					
64 Gd	—	142.6	8.6	8.6	36	28	21					
65 Tb	150.5	150.5	7.7	2.4	45.6	28.7	22.6					
66 Dy	153.6	153.6	8.0	4.3	49.9	26.3	26.3					
67 Ho	160	160	8.6	5.2	49.3	30.8	24.1					
68 Er	167.6	167.6	—	4.7	50.6	31.4	24.7					
69 Tm	175.5	175.5	—	4.6	54.7	31.8	25.0					
70 Yb	191.2	182.4	2.5	1.3	52.0	30.3	24.1					

Table 2.3 Electron binding energies (eV) (continued).

Element	K 1s	L_1 2s	L_2 2$p_{1/2}$	L_3 2$p_{3/2}$	M_1 3s	M_2 3$p_{1/2}$	M_3 3$p_{3/2}$	M_4 3$d_{3/2}$	M_5 3$d_{5/2}$	N_1 4s	N_2 4$p_{1/2}$	N_3 4$p_{3/2}$
71 Lu	63314	10870	10349	9244	2491	2264	2024	1639	1589	506.8	412.4	359.2
72 Hf	65351	11271	10739	9561	2601	2365	2108	1716	1662	538	438.2	380.7
73 Ta	67416	11682	11136	9881	2708	2469	2194	1793	1735	563.4	463.4	400.9
74 W	69525	12100	11544	10207	2820	2575	2281	1872	1809	594.1	490.4	423.6
75 Re	71676	12527	11959	10535	2932	2682	2367	1949	1883	625.4	518.7	446.8
76 Os	73871	12968	12385	10871	3049	2792	2457	2031	1960	658.2	549.1	470.7
77 Ir	76111	13419	12824	11215	3174	2909	2551	2116	2040	691.1	577.8	495.8
78 Pt	78395	13880	13273	11564	3296	3027	2645	2202	2122	725.4	609.1	519.4
79 Au	80725	14353	13734	11919	3425	3148	2743	2291	2206	762.1	642.7	546.3
80 Hg	83102	14839	14209	12284	3562	3279	2847	2385	2295	802.2	680.2	576.6
81 Tl	85530	15347	14698	12658	3704	3416	2957	2485	2389	846.2	720.5	609.5
82 Pb	88005	15861	15200	13035	3851	3554	3066	2586	2484	891.8	761.9	643.5
83 Bi	90524	16388	15711	13419	3999	3696	3177	2688	2580	939	805.2	678.8
84 Po	93105	16939	16244	13814	4149	3854	3302	2798	2683	995	851	705
85 At	95730	17493	16785	14214	4317	4008	3426	2909	2787	1042	886	740
86 Rn	98404	18049	17337	14619	4482	4159	3538	3022	2892	1097	929	768
87 Fr	101137	18639	17907	15031	4652	4327	3663	3136	3000	1153	980	810
88 Ra	103922	19237	18484	15444	4822	4490	3792	3248	3105	1208	1058	879
89 Ac	106755	19840	19083	15871	5002	4656	3909	3370	3219	1269	1080	890
90 Th	109651	20472	19693	16300	5182	4830	4046	3491	3332	1330	1168	966.4
91 Pa	112601	21105	20314	16733	5367	5001	4174	3611	3442	1387	1224	1007
92 U	115606	21757	20948	17166	5548	5182	4303	3728	3552	1439	1271	1043

Table 2.3 Electron binding energies (eV) (continued).

Element	N_4 4$d_{3/2}$	N_5 4$d_{5/2}$	N_6 4$f_{5/2}$	N_7 4$f_{7/2}$	O_1 5s	O_2 5$p_{1/2}$	O_3 5$p_{3/2}$	O_4 5$d_{3/2}$	O_5 5$d_{5/2}$	P_1 6s	P_2 6$p_{1/2}$	P_3 6$p_{3/2}$
71 Lu	206.1	196.3	8.9	7.5	57.3	33.6	26.7					
72 Hf	220.0	211.5	15.9	14.2	64.2	38	29.9					
73 Ta	237.9	226.4	23.5	21.6	69.7	42.2	32.7					
74 W	255.9	243.5	33.6	31.4	75.6	45.3	36.8					
75 Re	273.9	260.5	42.9	40.5	83	45.6	34.6					
76 Os	293.1	278.5	53.4	50.7	84	58	44.5					
77 Ir	311.9	296.3	63.8	60.8	95.2	63.0	48.0					
78 Pt	331.6	314.6	74.5	71.2	101.7	65.3	51.7					
79 Au	353.2	335.1	87.6	84.0	107.2	74.2	57.2					
80 Hg	378.2	358.8	104.0	99.9	127	83.1	64.5	9.6	7.8			
81 Tl	405.7	385.0	122.2	117.8	136.0	94.6	73.5	14.7	12.5			
82 Pb	434.3	412.2	141.7	136.9	147	106.4	83.3	20.7	18.1			
83 Bi	464.0	440.1	162.3	157.0	159.3	119.0	92.6	26.9	23.8			
84 Po	500	473	184	184	177	132	104	31	31			
85 At	533	507	210	210	195	148	115	40	40			
86 Rn	567	541	238	238	214	164	127	48	48	26		
87 Fr	603	577	268	268	234	182	140	58	58	34	15	15
88 Ra	636	603	299	299	254	200	153	68	68	44	19	19
89 Ac	675	639	319	319	272	215	167	80	80	—	—	—
90 Th	712.1	675.2	342.4	333.1	290	229	182	92.5	85.4	41.4	24.5	16.6
91 Pa	743	708	371	360	310	232	232	94	94	—	—	—
92 U	778.3	736.2	388.2	377.4	321	257	192	102.8	94.2	43.9	26.8	16.8

BL 4.1: IR Spectroscopy and Imaging

Infrared microspectroscopy is a very useful technique for the identification of chemical compounds. Because of high brightness of synchrotron radiation, synchrotron based Infrared microspectroscopy provides high spatial resolution, better signal to noise ratio and shorter data acquisition time than conventional technique. BL 4.1: IR Spectroscopy and Imaging is designed to extract the far- to mid-infrared light (spectral range between 4000-100 cm-1) from the 1.2 GeV Siam Photon Source. This beamline is divided into 2 branch-lines in order to provide 2 end-stations working simultaneously. An infrared beam of high brilliance in the 1-100 microns wavelength range, with a spectral region optimized between 2.5-100 microns is delivered to an FTIR spectrometer, attached to an infrared microscope. FTIR Microspectroscopy has been used to identify and spatially resolved the chemical makeup of many samples such as biological materials, various plant and animal tissues, minerals, polymers films and laminates, semiconductors, forensics materials, pharmaceutical materials, etc.

Beamline specification

Radiation source	Edge and Bending Magnet
Photon Energy	0.3-0.025 eV
Wavelength	1.5-50 μm
Spot size (H×V)	10 × 10 μm
Detectors	MCT (Mercury Cadmium Telluride)
Sample type	Powder / solid / liquid / fiber/ solid coated on IR slide
Applications/ Research Field	Soft Matter Biomedical and biological science Archeology Enviromental science Polymer science

Table 2.4 Principle absorption of main IR frequencies

Wavenumber (cm^{-1})	Functional Group	Type of vibration
3300 – 3600	Alcohol	O-H (Strong and broad)
3000-2800& 1500-1440	Alkanes	H-C-H Asymmetric & Symmetric Stretch & H-C-H Bend
3100-3000& 1675-1600	Alkenes	C=C-H Asymmetric Stretch & C-C=C Symmetric Stretch
3300-3200	Alkynes	
1600-1500& 1400-1300	Nitro Groups	N=O Stretch & N=O Bend
3500-3100& 1640-1560	Amines-Primary	N-H Stretch & N-H Bend
3500-3100& 1550-1450	Amines-Secondary	N-H Stretch & N-H Bend
3500-3100& 1670-1600& 1640-1550	Amides	N-H Stretch (similar to amines) & C=O Stretch & N-H Bend
3400-2400& 1730-1650	Carboxylic Acids	Hydrogen-bonded O-H Stretch & C=O Stretch
1750-1625	ketones	C=O Stretch
1750-1625	aldehyde	C=O Stretch
1755-1650& 1300-1000	Esters	C=O Stretch & C-O Stretch

BL6a: Deep X-ray Lithography (DXL)

BL6a is a white light beamline for Deep X-ray Lithography used for LIGA process. X-ray LIGA is a technique using synchrotron radiation for micromachining and MEMS fabrication, with specific needs such as mass production, smooth side wall, various lateral shapes, precise metal parts and high aspect ratio microstructures. Design and fabrication of high aspect ratio microstructures using X-ray lithography can provide high precision micromolding for micro-component in industrial fabrication process. DXL can also be applied in MEMS technology which is use to fabricate sensors and actuators such as humidity sensor, accelerator sensor, pressure sensor, microswitch, microheater, and microvalve. LIGA process is shown in Figure 2.1.

Since it is a white light beamline BL6a can also be used for irradiation of specimens. Experiments such as a study on effects of radiation on biological samples can be performed by irradiating sample with synchrotron light at BL6a.

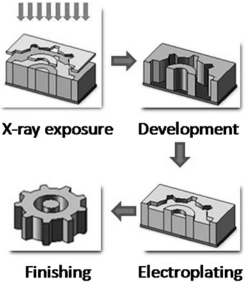


Figure 2.1. X-ray LIGA process

Beamline specification

Radiation source	Bending magnet
Photon Energy	White beam
Spot size (HxV)	87.2 mm × 7.4 mm
Photoresist	SU-8, PMMA, Dry film
Applications/ Research Field	Design and fabrication of high-aspect-ratio microstructure, micromolding, micropart sensor, actuator and etc.

BL6b: Micro–X–ray Fluorescence (μ-XRF)

BL6b, a beamline for synchrotron μ-X-ray fluorescence spectroscopy and imaging technique, utilizes continuous X-rays from a bending magnet. The synchrotron light with energy below 1 keV is filtered out by a beryllium window with 100 μm thickness. The horizontal and vertical divergences of the beam are 5.3 mrad and 1.1 mrad, respectively. The Polycapillary X-ray half-lens is then used in order to focus the white beam onto sample with spots size below 100 μm. This endstation is specifically for the elemental analysis of a wide variety of materials in Energy-Dispersive mode.

This technique provides good-qualitative and quantitative XRF analyses, with advantages for samples with low mass density and small analysis areas. Moreover, the distribution mapping of specific elements in particular area can be achieved. This is a user-friendly and non-destructive technique, in which various research fields can be studied e.g. biology, chemistry, material science, life science, environment science, soil science, cultural heritage, etc.

Beamline specification

Radiation source	Bending magnet
Photon Energy	White beam
Spot size (HxV)	95 × 95 µm
Detectors	Si(PIN) detector (energy resolution: 150 eV)
Sample type	Solid/powder/living samples (eg., plant)
Applications/ Research Field	Element analysis, element distribution analysis /biology, chemistry, materials, life sciences, environment science, soil science, cultural heritage and etc.

X-Ray Emission Energies

In table 2.5, characteristic K, L, and M x-ray emission lines are given for elements with 11 = Z = 92. Only the strongest lines are included: $\mathbf{K}\mathrm{a}_1$, $\mathbf{K}\mathrm{a}_2$, $\mathbf{K}\beta_1$, $\mathbf{L}\mathrm{a}_1$, $\mathbf{L}\mathrm{a}_2$, $\mathbf{L}\beta_1$, $\mathbf{L}\beta_2$, $\mathbf{L}\gamma_1$, $\mathbf{M}\mathrm{a}_1$. Values in the table are taken from X-ray Data Booklet (LNBL/PUB-490 Rev.2).

Table 2.5 Photon energies, in electron volts, of principal K-, L-, and M-shell emission lines.

Element	Kα_1	Kα_2	Kβ_1	Lα_1	Lα_2	Lβ_1	Lβ_2	Lγ_1	Mα_1
11 Na	1,040.98	1,040.98	1,071.1						
12 Mg	1,253.60	1,253.60	1,302.2						
13 Al	1,486.70	1,486.27	1,557.45						
14 Si	1,739.98	1,739.38	1,835.94						
15 P	2,013.7	2,012.7	2,139.1						
16 S	2,307.84	2,306.64	2,464.04						
17 Cl	2,622.39	2,620.78	2,815.6						
18 Ar	2,957.70	2,955.63	3,190.5						
19 K	3,313.8	3,311.1	3,589.6						
20 Ca	3,691.68	3,688.09	4,012.7	341.3	341.3	344.9			
21 Sc	4,090.6	4,086.1	4,460.5	395.4	395.4	399.6			
22 Ti	4,510.84	4,504.86	4,931.81	452.2	452.2	458.4			
23 V	4,952.20	4,944.64	5,427.29	511.3	511.3	519.2			
24 Cr	5,414.72	5,405.509	5,946.71	572.8	572.8	582.8			
25 Mn	5,898.75	5,887.65	6,490.45	637.4	637.4	648.8			
26 Fe	6,403.84	6,390.84	7,057.98	705.0	705.0	718.5			

Table 2.5 Energies of x-ray emission lines (continued).

Element	Kα_1	Kα_2	Kβ_1	Lα_1	Lα_2	Lβ_1	Lβ_2	Lγ_1	Mα_1
27 Co	6,930.32	6,915.30	7,649.43	776.2	776.2	791.4			
28 Ni	7,478.15	7,460.89	8,264.66	851.5	851.5	868.8			
29 Cu	8,047.78	8,027.83	8,905.29	929.7	929.7	949.8			
30 Zn	8,638.86	8,615.78	9,572.0	1,011.7	1,011.7	1,034.7			
31 Ga	9,251.74	9,224.82	10,264.2	1,097.92	1,097.92	1,124.8			
32 Ge	9,886.42	9,855.32	10,982.1	1,188.00	1,188.00	1,218.5			
33 As	10,543.72	10,507.99	11,726.2	1,282.0	1,282.0	1,317.0			
34 Se	11,222.4	11,181.4	12,495.9	1,379.10	1,379.10	1,419.23			
35 Br	11,924.2	11,877.6	13,291.4	1,480.43	1,480.43	1,525.90			
36 Kr	12,649	12,598	14,112	1,586.0	1,586.0	1,636.6			
37 Rb	13,395.3	13,335.8	14,961.3	1,694.13	1,692.56	1,752.17			
38 Sr	14,165	14,097.9	15,835.7	1,806.56	1,804.74	1,871.72			
39 Y	14,958.4	14,882.9	16,737.8	1,922.56	1,920.47	1,995.84			
40 Zr	15,775.1	15,690.9	17,667.8	2,042.36	2,039.9	2,124.4	2,219.4	2,302.7	
41 Nb	16,615.1	16,521.0	18,622.5	2,165.89	2,163.0	2,257.4	2,367.0	2,461.8	
42 Mo	17,479.34	17,374.3	19,608.3	2,293.16	2,289.85	2,394.81	2,518.3	2,623.5	
43 Tc	18,367.1	18,250.8	20,619	2,424	2,420	2,538	2,674	2,792	

Table 2.5 Energies of x-ray emission lines (continued).

Element	**K**α_1	**K**α_2	**K**β_1	**L**α_1	**L**α_2	**L**β_1	**L**β_2	**L**γ_1	**M**α_1
44 Ru	19,279.2	19,150.4	21,656.8	2,558.55	2,554.31	2,683.23	2,836.0	2,964.5	
45 Rh	20,216.1	20,073.7	22,723.6	2,696.74	2,692.05	2,834.41	3,001.3	3,143.8	
46 Pd	21,177.1	21,020.1	23,818.7	2,838.61	2,833.29	2,990.22	3,171.79	3,328.7	
47 Ag	22,162.92	21,990.3	24,942.4	2,984.31	2,978.21	3,150.94	3,347.81	3,519.59	
48 Cd	23,173.6	22,984.1	26,095.5	3,133.73	3,126.91	3,316.57	3,528.12	3,716.86	
49 In	24,209.7	24,002.0	27,275.9	3,286.94	3,279.29	3,487.21	3,713.81	3,920.81	
50 Sn	25,271.3	25,044.0	28,486.0	3,443.98	3,435.42	3,662.80	3,904.86	4,131.12	
51 Sb	26,359.1	26,110.8	29,725.6	3,604.72	3,595.32	3,843.57	4,100.78	4,347.79	
52 Te	27,472.3	27,201.7	30,995.7	3,769.33	3,758.8	4,029.58	4,301.7	4,570.9	
53 I	28,612.0	28,317.2	32,294.7	3,937.65	3,926.04	4,220.72	4,507.5	4,800.9	
54 Xe	29,779	29,458	33,624	4,109.9	—	—	—	—	
55 Cs	30,972.8	30,625.1	34,986.9	4,286.5	4,272.2	4,619.8	4,935.9	5,280.4	
56 Ba	32,193.6	31,817.1	36,378.2	4,466.26	4,450.90	4,827.53	5,156.5	5,531.1	
57 La	33,441.8	33,034.1	37,801.0	4,650.97	4,634.23	5,042.1	5,383.5	5,788.5	833
58 Ce	34,719.7	34,278.9	39,257.3	4,840.2	4,823.0	5,262.2	5,613.4	6,052	883
59 Pr	36,026.3	35,550.2	40,748.2	5,033.7	5,013.5	5,488.9	5,850	6,322.1	929
60 Nd	37,361.0	36,847.4	42,271.3	5,230.4	5,207.7	5,721.6	6,089.4	6,602.1	978

Table 2.5 Energies of x-ray emission lines (continued).

Element	**Kα_1**	**Kα_2**	**Kβ_1**	**Lα_1**	**Lα_2**	**Lβ_1**	**Lβ_2**	**Lγ_1**	**Mα_1**
61 Pm	38,724.7	38,171.2	43,826	5,432.5	5,407.8	5,961	6,339	6,892	—
62 Sm	40,118.1	39,522.4	45,413	5,636.1	5,609.0	6,205.1	6,586	7,178	1,081
63 Eu	41,542.2	40,901.9	47,037.9	5,845.7	5,816.6	6,456.4	6,843.2	7,480.3	1,131
64 Gd	42,996.2	42,308.9	48,697	6,057.2	6,025.0	6,713.2	7,102.8	7,785.8	1,185
65 Tb	44,481.6	43,744.1	50,382	6,272.8	6,238.0	6,978	7,366.7	8,102	1,240
66 Dy	45,998.4	45,207.8	52,119	6,495.2	6,457.7	7,247.7	7,635.7	8,418.8	1,293
67 Ho	47,546.7	46,699.7	53,877	6,719.8	6,679.5	7,525.3	7,911	8,747	1,348
68 Er	49,127.7	48,221.1	55,681	6,948.7	6,905.0	7,810.9	8,189.0	9,089	1,406
69 Tm	50,741.6	49,772.6	57,517	7,179.9	7,133.1	8,101	8,468	9,426	1,462
70 Yb	52,388.9	51,354.0	59,370	7,415.6	7,367.3	8,401.8	8,758.8	9,780.1	1,521.4
71 Lu	54,069.8	52,965.0	61,283	7,655.5	7,604.9	8,709.0	9,048.9	10,143.4	1,581.3
72 Hf	55,790.2	54,611.4	63,234	7,899.0	7,844.6	9,022.7	9,347.3	10,515.8	1,644.6
73 Ta	57,532	56,277	65,223	8,146.1	8,087.9	9,343.1	9,651.8	10,895.2	1,710
74 W	59,318.24	57,981.7	67,244.3	8,397.6	8,335.2	9,672.35	9,961.5	11,285.9	1,775.4
75 Re	61,140.3	59,717.9	69,310	8,652.5	8,586.2	10,010.0	10,275.2	11,685.4	1,842.5
76 Os	63,000.5	61,486.7	71,413	8,911.7	8,841.0	10,355.3	10,598.5	12,095.3	1,910.2
77 Ir	64,895.6	63,286.7	73,560.8	9,175.1	9,099.5	10,708.3	10,920.3	12,512.6	1,979.9

Table 2.5 Energies of x-ray emission lines (continued).

Element	**Kα_1**	**Kα_2**	**Kβ_1**	**Lα_1**	**Lα_2**	**Lβ_1**	**Lβ_2**	**Lγ_1**	**Mα_1**
78 Pt	66,832	65,112	75,74	9,442.	9,361.	11,07	11,25	12,942	2,050.
79 Au	68,803.	66,989	77,98	9,713.	9,628.	11,44	11,58	13,381	2,122.
80 Hg	70,819	68,895	80,25	9,988.	9,897.	11,82	11,92	13,830	2,195.
81 Tl	72,871.	70,831	82,57	10,26	10,17	12,21	12,27	14,291	2,270.
82 Pb	74,969.	72,804	84,93	10,55	10,44	12,61	12,62	14,764	2,345.
83 Bi	77,107.	74,814	87,34	10,83	10,73	13,02	12,97	15,247	2,422.
84 Po	79,290	76,862	89,80	11,13	11,01	13,44	13,34	15,744	—
85 At	81,520	78,950	92,30	11,42	11,30	13,87	—	16,251	—
86 Rn	83,780	81,070	94,87	11,72	11,59	14,31	—	16,770	—
87 Fr	86,100	83,230	97,47	12,03	11,89	14,77	14,45	17,303	—
88 Ra	88,470	85,430	100,1	12,33	12,19	15,23	14,84	17,849	—
89 Ac	90,884	87,670	102,8	12,65	12,50	15,71	—	18,408	—
90 Th	93,350	89,953	105,6	12,96	12,80	16,20	15,62	18,982	2,996.
91 Pa	95,868	92,287	108,4	13,29	13,12	16,70	16,02	19,568	3,082.
92 U	98,439	94,665	111,3	13,61	13,43	17,22	16,42	20,167	3,170.

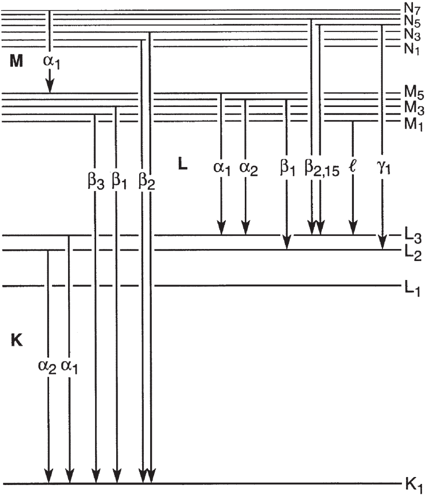


Figure 2.2. Transitions that give rise to the emission lines in Table 2.5.

BL6b: X-ray powder diffraction

X-ray powder diffraction technique (P-XRD) at BL6b is used in a time-sharing mode, as a complementary technique, with μ-XRF. The system consists of a single-axis goniometer and a proportional counter detector with receiving and scattering soller slits. The diffractometer is donated by the King Mongkut's University of Technology (KMUTT). A Si (111) crystal is used to reflect the beam into the P-XRD branch. With the angle of approximately 14°, 8 keV X-rays can be selected for P-XRD end station. When the crystal is removed, white beam of X-rays can go to micro-XRF end station.

Powder diffraction is a powerful analytical technique for investigation of crystalline materials. Each crystal structure produces a distinctive diffraction pattern. The positions of the diffraction peaks give information on the lattice d-spacing of the crystal, and the relative intensity of the peaks indicates particular phase and type of material providing a fingerprint for material identification. Samples with mixed phases show superposed patterns containing information on relative concentration of the mixtures.

Beamline specification

Radiation source	Bending magnet
Photon Energy	8 keV
Wavelength	1.55 Å
Energy Resolution ΔE/E)	10^{-4}
Spot size (HxV)	10 × 3 mm
Detectors	Proportional counter
Sample type	Powder
Applications/ Research Field	crystalline material structure, atomic arrangement, /Chemistry, Material science

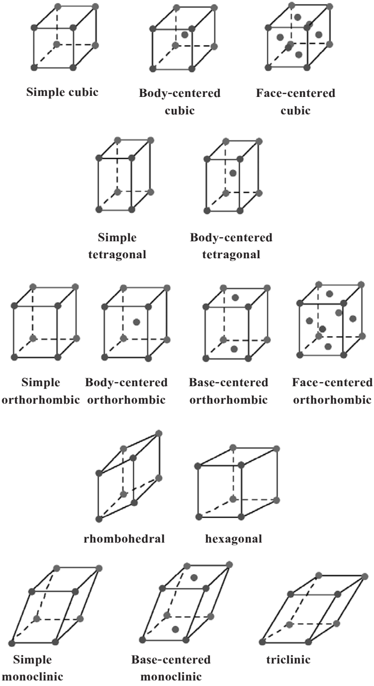


Figure 2.3. The 14 Bravais Lattices of 3-dimensional Space.

Table 2.6 Equation of d-spacing for all seven crystal systems

Crystal System	**Equation**
Cubic	$\frac{1}{d_{hkl}^2} = \frac{k^2 + k^2 + l^2}{a^2}$
Tetragonal	$\frac{1}{d_{hkl}^2} = \frac{k^2 + k^2}{a^2} + \frac{+l^2}{c^2}$
Hexagonal	$\frac{1}{d_{hkl}^2} = \frac{4}{3}\left(\frac{k^2 + hk + k^2}{a^2}\right) + \frac{+l^2}{c^2}$
Rhombohedral	$\frac{1}{d_{hkl}^2} = \frac{\left(k^2 + k^2 + l^2\right)\sin^2\alpha + 2(hk + kl + hl)(\cos^2\alpha - \cos\alpha)}{a^2(1 - 3\cos^2\alpha + 2\cos^3\alpha)}$
Orthorhombic	$\frac{1}{d_{hkl}^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}$
Monoclinic	$\frac{1}{d_{hkl}^2} = \frac{1}{\sin^2\beta}\left(\frac{h^2}{a^2} + \frac{k^2\sin^2\beta}{b^2} + \frac{l^2}{c^2} - \frac{2hl\cos\beta}{ac}\right)$
Triclinic	$\frac{1}{d_{hkl}^2} = \left(1 - \cos^2\alpha - \cos^2\beta - \cos^2\gamma + 2\cos\alpha\cos\beta\cos\gamma\right)^{-1}$ $\times\left(\frac{h^2}{a^2}\sin^2\alpha + \frac{k^2}{b^2}\sin^2\beta + \frac{l^2}{c^2}\sin^2\gamma + \frac{2kl}{bc}(\cos\beta\cos\gamma - \cos\alpha)\right.$ $\left.+\frac{2lh}{ca}(\cos\gamma\cos\alpha - \cos\beta) + \frac{2hk}{ab}(\cos\alpha\cos\beta - \cos\gamma)\right)$

BL7.2: Macromolecule Crystallography beamline and end station (MX)

The end station for Macromolecule Crystallography (MX) beamline has been installed at Siam Photon Laboratory (SPL) to promote the MX research and serve an increasing number of MX users in Thailand. While waiting for the installation of the wavelength shifter into the SPL storage ring and the construction of the BL 7.2 to complete, an x-ray diffractometer has been utilized for data collection, using rotating anode as an x-ray source. Diffraction data obtained can be analyzed to give three-dimensional structure of the macromolecule. The procedure for structure determination consists of crystallization, data collection, data processing, structure refinement/validation and model building. The information allows us to understand biological processes at the most basic level: which molecules interact, how they interact and how enzymes catalyze reactions. Since the three-dimensional structures of proteins and nucleic acids are essential for the understanding of reaction mechanisms, there are many applications of MX technique. For example, it is a powerful tool to determine how a pharmaceutical drug interacts with its protein target and what changes might improve it.

Beamline specification

Radiation source	Wavelength shifter
Photon Energy	5-20 keV
Wavelength	2.48-0.62 Å
Energy Resolution ΔE/E)	10^{-4}
Spot size (HxV)	940 × 130 μm
Detectors	CCD (Mar SX165)
Sample type	Macromolecule crystal (proteins and nucleic acids)
Applications/ Research Field	Three-dimensional structural analysis used for agricultural, pharmaceutical and industrial applications

Table 2.7 Bravais Lattice, Laue class and Space Group Determination.

Crystal system	Unit Cell Dimensions	Laue class (after Integration)	Screw axis	14 Bravais Lacttices (from autoindex)				
				Primitive	C-centered	Face-centered	Body-centered	Rhombo-hedral
Triclinic	a≠b≠c ; α≠β≠γ	-1		**P1 (1)**				
Monoclinic	a≠b≠c ;	2/m		**P2 (3)**	**C2 (5)**			
	α=γ=90˚		k	**P2$_1$ (4)**				
	β≠90˚							
Orthorhombic	a≠b≠c ;	m m m		**P222 (16)**	**C222 (21)**	**F222 (22)**	**I222 (23)**	
	α=β=γ=90˚	(2/m 2/m 2/m)	l	**P222$_1$ (17)**	**C222$_1$ (20)**		**I2$_1$2$_1$2$_1$ (24)**	
			h, k	**P2$_1$2$_1$2 (18)**				
			h, k, l	**P2$_1$2$_1$2$_1$ (19)**				
Tetragonal	a=b≠c ;	4/m		**P4 (75)**			**I4 (79)**	
	α=β=γ=90˚		l	**P4$_1$ P4$_2$ P4$_3$ (76-78)**			**I4$_1$ (80)**	
		4/m m m		**P422 (89)**			**I422 (97)**	
		(4/m 2/m 2/m)	k	**P42$_1$2 (90)**			**I4$_1$22 (98)**	
			l	**P4$_1$22 (91) P4$_2$22 (93)**				
			l, k	**P4$_3$22 (95)**				
				P4$_1$2$_1$2 (92) P4$_2$2$_1$2 (94) P4$_3$2$_1$2 (96)				

Table 2.7 Bravais Lattice, Laue class and Space Group Determination (continued).

Cubic	a=b=c ; α=β=γ=90˚	m-3 (2/m -3)	1	**P23 (195)** **$P2_13$ (198)**		**F23 (196)**	**I23 (197)** **$I2_13$ (199)**	
		m3m (4/m -3 2/m)	1	**P432 (207)** **$P4_132$ (213) $P4_232$ (208) $P4_332$ (212)**		**F432 (209)** **$F4_132$ (210)**	**I432 (211)** **$I4_132$ (214)**	
Hexagonal	a=b≠c ; α=β=90˚ γ≠120˚	-3	1	**P3 (143)** **$P3_1$ $P3_2$ (144-145)**				**R3 (146)**
		-3m1	1	**P321 (150)** **$P3_121$ (152) $P3_221$ (154)**				**R32 (155)**
		-31m	1	**P312 (149)** **$P3_112$ (151) $P3_212$ (153)**				
		6/m	1	**P6 (168)** **$P6_1$ (169) $P6_2$ (171)** **$P6_3$ (173)** **$P6_4$ (172) $P6_5$ (170)**				
		6/m m m	1	**P622 (177)** **$P6_122$ (178) $P6_222$ (180) $P6_322$ (182)** **$P6_422$ (181) $P6_522$ (179)**				

BL8: X-ray Absorption Spectroscopy (XAS)

BL8 is dedicated to X-ray Absorption Spectroscopy (XAS). XAS is a powerful technique for determining chemical speciation and local structure (type of neighboring atoms, coordination number, inter-atomic distance) around the absorbing atom. Moreover XAS is a non-destructive tool which can be employed to study samples in different scientific areas, such as material science, biology, environmental science, archeology and geology. The technique can be applied to crystalline and amorphous samples in all physical forms.

BL8 is a bending magnet beamline, tunable by a fixed-exit double crystal monochromator (DCM), equipped with several types of crystal for covering photon energy from 1250 eV to 10000 eV. K-edge absorption of Magnesium up to Zinc can be studied. Other heavier atomic species can be investigated via L or M edges.

XAS can be carried out in either transmission mode (TM-XAS) in which transmitted intensity of x-rays after the sample is detected or fluorescent mode (FL-XAS) in which intensity of fluorescent x-rays from the sample is detected.

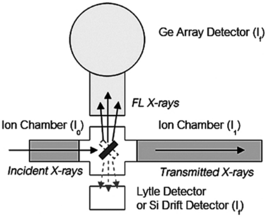


Figure 2.4 Experimental setup for TM-XAS and FL-XAS

Beamline specification

Radiation source	Bending magnet
Photon Energy	1.25 keV-10 keV
Wavelength	1.24-9.94 Å
Energy Resolution ΔE/E)	1e-4 to 3e-4
Spot size (HxV)	13 mm × 1 mm
Detectors	10-cm and 40-cm long ion chamber (TM mode) 13-element Ge detector (FL mode) Lytle detector (FL mode) Silicon drift detector (FL mode)
Sample type	Powder / solid / liquid / gas
Applications/ Research Field	Chemical and structural investigation of an absorbing element; providing oxidation state, local coordination number, interatomic distance and type of neighboring atoms

Table 2.8 DCM crystal and energy range

Crystal type	**2d spacing (Å)**	**Photon energy range (eV)**
KTP(011)	10.955	1250-4780
InSb(111)	7.481	1830-3700
Si(111)	6.271	2180-8350
Ge(220)	4.001	3440-10000
Si(220)	3.840	3570-10000

Table 2.9 Electron binding energies, in electron volts, for the elements in their natural forms (1-10 keV).

Element	K 1s	L1 2s	L2 2p1/2	L3 2p3/2	M1 3s	M2 3p1/2	M3 3p3/2	M4 3d3/2	M5 3d5/2
11 Na	1070.8								
12 Mg	1303.0								
13 Al	1559.6								
14 Si	1839								
15 P	2145.5								
16 S	2472								
17 Cl	2822.4								
18 Ar	3205.9								
19 K	3608.4								
20 Ca	4038.5								
21 Sc	4492								
22 Ti	4966								
23 V	5465								
24 Cr	5989								
25 Mn	6539								
26 Fe	7112								

Table 2.9 Electron binding energies (continued).

Element	K 1s	L1 2s	L2 2p1/2	L3 2p3/2	M1 3s	M2 3p1/2	M3 3p3/2	M4 3d3/2	M5 3d5/2
27 Co	7709								
28 Ni	8333	1008.6							
29 Cu	8979	1096.7							
30 Zn	9659	1196.2	1044.9	1021.8					
31 Ga	10367	1299.0	1143.2	1116.4					
32 Ge		1414.6	1248.1	1217.0					
33 As		1527.0	1359.1	1323.6					
34 Se		1652	1474.3	1433.9					
35 Br		1782	1596	1550					
36 Kr		1921	1730.9	1678.4					
37 Rb		2065	1864	1804					
38 Sr		2216	2007	1940					
39 Y		2373	2156	2080					
40 Zr		2532	2307	2223					
41 Nb		2698	2465	2371					
42 Mo		2866	2625	2520					

Table 2.9 Electron binding energies (continued).

Element	K 1s	L1 2s	L2 2p1/2	L3 2p3/2	M1 3s	M2 3p1/2	M3 3p3/2	M4 3d3/2	M5 3d5/2
43 Tc		3043	2793	2677					
44 Ru		3224	2967	2838					
45 Rh		3412	3146	3004					
46 Pd		3604	3330	3173					
47 Ag		3806	3524	3351					
48 Cd		4018	3727	3538					
49 In		4238	3938	3730					
50 Sn		4465	4156	3929					
51 Sb		4698	4380	4132					
52 Te		4939	4612	4341	1006				
53 I		5188	4852	4557	1072				
54 Xe		5453	5107	4786	1148.	1002.1			
55 Cs		5714	5359	5012	1211	1071	1003		
56 Ba		5989	5624	5247	1293	1137	1063		
57 La		6266	5891	5483	1362	1209	1128		
58 Ce		6549	6164	5723	1436	1274	1187		

Table 2.9 Electron binding energies (continued).

Element	K 1s	L1 2s	L2 2p1/2	L3 2p3/2	M1 3s	M2 3p1/2	M3 3p3/2	M4 3d3/2	M5 3d5/2
59 Pr		6835	6440	5964	1511	1337	1242		
60 Nd		7126	6722	6208	1575	1403	1297	1003.3	
61 Pm		7428	7013	6459	-	1471	1357	1052	1027
62 Sm		7737	7312	6716	1723	1541	1420	1110.9	1083.4
63 Eu		8052	7617	6977	1800	1614	1481	1158.6	1127.5
64 Gd		8376	7930	7243	1881	1688	1544	1221.9	1189.6
65 Tb		8708	8252	7514	1968	1768	1611	1276.9	1241.1
66 Dy		9046	8581	7790	2047	1842	1676	1333	1292.6
67 Ho		9394	8918	8071	2128	1923	1741	1392	1351
68 Er		9751	9264	8358	2207	2006	1812	1453	1409
69 Tm		10116	9617	8648	2307	2090	1885	1515	1468
70 Yb		10486	9978	8944	2398	2173	1950	1576	1528
71 Lu			10349	9244	2491	2264	2024	1639	1589
72 Hf				9561	2601	2365	2108	1716	1662
73 Ta				9881	2708	2469	2194	1793	1735
74 W					2820	2575	2281	1872	1809

Table 2.9 Electron binding energies (continued).

Element	K 1s	L1 2s	L2 2p1/2	L3 2p3/2	M1 3s	M2 3p1/2	M3 3p3/2	M4 3d3/2	M5 3d5/2
75 Re					2932	2682	2367	1949	1883
76 Os					3049	2792	2457	2031	1960
78 Ir					3174	2090	2551	2116	2040
78 Pt					3296	3027	2645	2202	2122
79 Au					3425	3148	2743	2291	2206
80 Hg					3562	3279	2847	2385	2295
81 Tl					3704	3416	2957	2485	2389
82 Pb					3851	3554	3066	2586	2484
83 Bi					3999	3696	3177	2688	2580
84 Po					4149	3854	3302	2798	2683
85 At					4317	4008	3426	2909	2787
86 Rn					4482	4159	3538	3022	2892
87 Fr					4652	4327	3663	3136	3000
88 Ra					4822	4490	3792	3248	3105
89 Ac					5002	4656	3909	3370	3219
90 Th					5182	4830	4046	3491	3332

Table 2.9 Electron binding energies (continued).

Element	K 1s	L1 2s	L2 2p1/2	L3 2p3/2	M1 3s	M2 3p1/2	M3 3p3/2	M4 3d3/2	M5 3d5/2
91 Pa					5367	5001	4174	3611	3442
92 U					5548	5182	4303	3728	3552

SECTION 3

MISCELLANEOUS

Physical constants and unit conversion Table was taken from "The NIST Reference on Constants, Units, and Uncertainty" (http://physics.nist.gov/cuu/Constants/index.html.)

Physical Constants

Quantity	**Symbol equation**	**Value**
speed of light	c	$2.997\ 924\ 58\times10^{8}$ ms^{-1} $(10^{10}$ $\mathrm{cm\ s}^{-1})$
Planck constant	h	$6.626\ 068\ 76(52)\times10^{-34}$ J s$(10^{-27}$erg s)
conversion constant	$\mathrm{h}c$	197.326 960 1(78) MeV fm (=eV nm)
electronic charge	e	$1.602\ 176\ 487(40)\times10^{-19}$ C = $4.803\ 204\ 27(12)\times10^{-10}$ esu
electronic mass	m_e	0.510 998 902(21) MeV/C^2 =$9.109\ 998\ 902(21)\times10^{-31}$ kg
permittivity of free space	$\varepsilon_0 = 1/(\mu_0 c^2)$	$8.854\ 187\ 817\ \ldots\times10^{-12}$ F m^{-1}
permeability of free space	μ_0	$4\pi\times10^{-7}$ N A^{-2} = $12.566\ 370\ 614\ldots\times10^{-7}$ N A^{-2}
fine-structure constant	$\alpha = e^2 / 4\pi\varepsilon_0 \mathrm{h} c$	1/137.035 999 76(50)
classical electron radius	$r_e = e^2 / 4\pi\varepsilon_0 m_e c^2$	$2.817\ 940\ 285(31)\times10^{-15}$ m
Avogadro constant	N_A	$6.022\ 141\ 99(47)\times10^{23}$ mol^{-1}
Boltzman constant	k	$1.380\ 650\ 3(24)\times10^{-23}$ J K^{-1}=$8.617\ 342(15)\times10^{-5}$ eV K^{-1}
pi number	π	3.141 592 653 589 793 238
natural number	e	2.718 281 828 459 045 235

Unit conversion

1 in. = 2.54 cm

1 Å = 10^{-8} cm

1 fm = 10^{-13} cm

1 barn = 10^{-24} cm2

1 newton = 10^{5} dyne

1 joule = 10^{7} erg

1 cal = 4.184 joule

1eV = $1.602\,176\,5\text{x}10^{-12}$ erg

1 eV/c^{2} = $1.782\,662\text{x}10^{-33}$ g

hc(1 eV) = 1.239 842 μm

1eV/h = $2.417\,989\text{x}10^{14}$ Hz

1eV/k = 11 604.5 K

1 coulumb = $2.997\,924\,58\text{x}10^{9}$ esu

1 tesla = 10^{4} gauss

1 atm = $1.013\,25\text{x}10^{6}$ dyne/cm^{2}

0^{o} C = 273.15 K

Useful Equations

Relation ship between wavelength and photon energy

$$E[\mathrm{eV}] = 1239.842 / \lambda[\mathrm{nm}]$$

Bragg's law

$$n\lambda = 2d \sin\theta$$

Bragg's law with refraction correction for multilayer

$$n\lambda = 2d \sin\theta \left(1 - \frac{4\bar{\delta}d^2}{n\lambda^2}\right)$$

where $\bar{\delta}$ is the period-averaged real part of refractive index

Synchrotron

Critical photon energy

$$\varepsilon_c[\mathrm{keV}] = 0.665B[\mathrm{T}]E^2[\mathrm{GeV}]$$

Energy loss/turn

$$U_0[\mathrm{keV}] = 88.54E^4[\mathrm{GeV}] / \rho[\mathrm{m}]$$

Relativistic factor

$$\gamma = \frac{E}{m_e c^2} = E[\mathrm{MeV}] / 0.511$$

Undulator strength

$$K = 0.934B[\mathrm{T}]\lambda_U[\mathrm{cm}]$$

Fundamental wavelength of undulator

$$\lambda_n = \frac{\lambda_U}{2\gamma^2 n}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right)$$

SECTION 4

USER INFORMATION

How to apply for beamtime at SLRI

To apply for the beamtime please follow the following steps

1. Go to SLRI webpage (http://www.slri.or.th/en/), select 'Login' tab and login to your account. If you do not have the username and password, please register your account.
2. Select 'Beamtime application' (which will appear after logging in).
3. Fill in the beamtime application form.
4. The technical proposal for the project is required to be attached with the application form. The proposal form can be downloaded from the beamtime application page.
5. Click 'submit' to send your beamtime application form online.

Technical data and specification of beamlines and end-stations are provided for your information on the web pages (under the 'Beamline' tab). You may need to take a look at these pages to make sure that the technique is applicable for your project proposal. For further information please contact the User Office or the beamline manager.

Contact SLRI

Web Site: www.slri.or.th
E-mail: useroffice@slri.or.th
Tel: 66 4421 7040 Fax: 66 44 217047
Post Address: PO. Box 93 Nakhon Ratchasima 30000
THAILAND
Location: 111 University Avenue, Muang,
Nakhon Ratchasima, 30000

Bangkok Office

Address: 75/47 Ministry of Science and Technology,
Rama VI Rd., Tungpayathai, Ratchathewi, Bangkok
10400 THAILAND
Tel: 66 2354 3954 Fax: 66 2354 3955

SLRI extension phone numbers

User Office	**1605, 1606**
Safety Office	**1515, 1516, 1517**
Emergengy	**1555**

Contact beamlines

Beamline	BL manager	E-mail	Tel.(ext.)
BL1	Dr. Yingyot Puarporn	yingyot@slri.or.th	1487
BL2.2	Dr. Supagorn Rugmai	supagorn@slri.or.th	1491
BL3.2a	Dr. Hideki Nakajima	hideki@slri.or.th	1483
BL3.2b	Dr. Chanan Euraksakun	chanan@slri.or.th	1477
BL4.1	Dr. Wanwisa Pattanasiriwisava	wanwisa@slri.or.th	1480
BL6a	Dr. Rungrueng Pattanakun	rungrueang@slri.or.th	1407
BL6b	Dr. Somchai Tancharakorn	somchai@slri.or.th	1476
BL7.2	Dr. Chompunuch Songsiririthikul	chompunuch@slri.or.th	1485
BL8	Dr. Wantana Klysubun	wantana@slri.r.th	1490

How to get to SLRI

SLRI is located inside the campus of Suranaree University of Technology (SUT) which is approximately 20 km from the city of Nakhon Ratchasima (or normally called Korat). Korat is 250 km north-east of Bangkok.

Flying to Thailand

The main airport of Thailand is the Suvannabhumi International Airport. There are frequent Airport Link trains from the airport to the center of Bangkok, which take approximately 15 - 30 minutes.

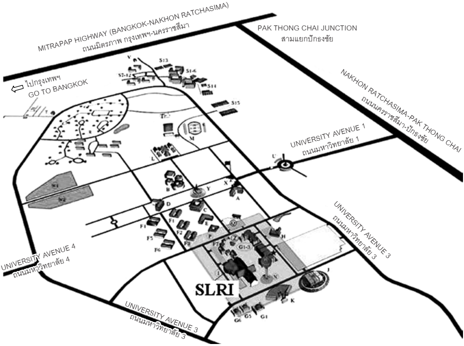


Figure 4.1. SLRI map.

From Bangkok to SLRI

By Car

From Suvannabhumi Airport

Get to the Bangkok-Chonburi Motorway (No. 7). From the Motorway turn right into the Eastern Ring Road (Kanchanapisek Rd.) going north to Bang Pa In. At the end of the Eastern Ring Road get into the Highway Number 1 (Phahon Yothin Road) going to Sara Buri.

Just before reaching Sara Buri, turn right into the Highway Number 2 (Mittraphap Road) going to Nakhon Ratchasima. Just before reaching the city of Nakhon Ratchasima there is an intersection, left turn to Khon Khan, right turn to Pakthongchai and straight ahead to Nakhon Ratchasima. Turn right at the intersection into Pakthongchai Road (No. 304) going to Pakthongchai. Approximately 7 km from the intersection make a right turn into University Avenue. Approximately 5 km down the road is the main entrance of Suranaree University of Technology.

From the north of Bangkok

Get into Vipavadee-Rangsit Road and then into Highway Number 1 (Phahon Yothin Road) going to Sara Buri. Then follow the same direction as from the airport.

From the south of Bangkok

The first option is to get into the Eastern Ring Road (Kanchanapisek Rd.) going north to Bang Pa In and then follow the direction as from the airport. The second choice is to get into Suvintawong Road (Number 304) going to Chacherngsao - Kabin Buri - Wang Namkiew - Pakthongchai - Nakhon Ratchasima (practically just stay on 304). You will reach the left turn into University Avenue, approximately 20 km after Pakthongchai.

The trip from Bangkok will take approximately 3 hours.

By Bus

The buses leave from the North-Northeast Bus Terminal (generally called Mor Chit Mai). The best way to get to the bus terminal is by a taxi (from the airport or from the center of Bangkok). At the terminal there are direct buses to Nakhon Ratchasima. Three companies run the direct buses, Air Korat Pattana, Ratchasima Tour and Suranaree Air. Their ticket booths are on the second floor of the terminal. You should get the ticket to New Korat Bus Terminal (or Bor Kor Sor Mai, in Thai). The ticket costs 198 Baht. A direct bus will take 3 hours. There are also non-direct buses which stop many places along the way. A non-direct bus will take around 5 hours.

From Korat Bus Terminal there are buses to Suranaree University of Technology (the bus costs around 20 baht). There are also taxis available at the bus terminal (the taxi costs around 200 Baht).

By Taxi

It is possible to take a taxi directly from Bangkok to Nakhon Ratchasima. The taxi cost around 3000 Baht.

By Train

There are a few trains leaving from the Hua Lampong train station in Bangkok to Nakhon Ratchasima. The train takes approximately 5 hours. From the Nakhon Ratchasima train station there are tri-cycle taxis (Tuk Tuk) to anywhere in Korat.

By Air

There are planes flying from Bangkok and some other cities (such as Chiang Mai and Phuket) to Nakhon Ratchasima. The details should be checked with the airlines.

Useful phone numbers in Nakhon Ratchasima

Post Office	044 - 242031
Poklang Police Station	044 - 211191, 044 - 211879, 044 - 211403
Muang Nakhonratchasima Police station	044 - 242485, 044 - 255563
Taxi service center	044 - 342255, 044 - 371777
Tourist Police	044 - 341777
Train station	044 - 242044
Bus station (old)	044 - 242899
Bus station (new)	044 - 256006-9
Happy Air travellers company	044 - 252992, 044 - 252997

Hospital

Maharaj Hospital	044 - 254990-1
Khai Suranari Military Camp Hospital	044 - 273370-5
Bangkok Ratchasima hospital	044 - 429-999
St.Mary Hospital	044 - 242385
Korat Memorial	044 - 242662
Por Pat Hospital	044 - 230530 - 3

Hotel

Dusit Princess Khorat	044 - 256629-35
K.S. Pavilion	044 - 261944-5, 044 - 263039
Orchid Hotel	044 - 278323
Pang Rujee Resort	044 - 933591-2
Ratchapruk Grand Hotel	044 - 262325-9
Rayagrand Hotel	044 - 354354
Sima Thani	044 - 213100
surasammanakarn	044 - 224880

Synchrotron Worldwide .

Synchrotron	Location & Country	Energy (GeV)	Circumference (m)	Commissioned	Web
APS	Argonne National Laboratory, USA	7	1104	1995	http://www.aps.anl.gov
ALBA	Cerdanyola del Vallès near Barcelona, Spain	3	270	2010	http://www.cells.es/
Australian Synchrotron	Melbourne, Australia	3	216	2006	http://www.synchrotron.org.au/
ANKA	Karlsruhe Institute of Technology, Germany	2.5	110.4	2000	http://ankaweb.fzk.de/
LNLS	Campinas, Brazil	1.37	93.2	1997	http://www.lnls.br/site/home.aspx
SESAME	Allaan, Jordan	2.5	125	Under Construction	http://www.sesame.org.jo/

Synchrotron Worldwide (continued).

Synchrotron	Location	Energy (GeV)	Circumference (m)	Commissioned	Web
ALS	Lawrence Berkeley Laboratory, USA	1.9	196.8	1993	http://www-als.lbl.gov/
NSLS	Brookhaven National Laboratory, USA	2.8	170	1982	http://www.nsls.bnl.gov/
SSRL	SLAC, USA	3	234	1973	http://www-ssrl.slac.stanford.edu/
SRC	Madison, USA	1	121	1968	http://www.src.wisc.edu
CHESS	Cornell University, USA	5.5	768	1979	http://www.chess.cornell.edu/
Soleil	Paris, France	3	354	2006	http://www.synchrotron-soleil.fr/
SSRF	Shanghai, China	3.5	432	2007	http://ssrf.sinap.ac.cn/english/

Synchrotron Worldwide (continued).

Synchrotron	Location & Country	Energy (GeV)	Circumference (m)	Commissioned	Web
SSRF	Shanghai, China	3.5	432	2007	http://ssrf.sinap.ac.cn/english/
SLS	Paul Scherrer Institute, Switzerland	2.8	288	2001	http://sls.web.psi.ch
BESSY II	Helmholtz-Zentrum Berlin in Berlin, Germany	1.7	240	1998	http://www.helmholtz-berlin.de/
ESRF	Grenoble, France	6	844	1992	http://www.esrf.eu/
MAX-II	MAX-lab, Sweden	1.5	90	1997	http://www.maxlab.lu.se/
MAX-III	MAX-lab, Sweden	0.7	36	2008	http://www.maxlab.lu.se/
ELETTRA	Trieste, Italy	2-2.4	260	1993	http://www.elettra.trieste.it/
ASTRID	Aarhus University, Denmark	0.58	40	1991	http://www.isa.au.dk/facilities/facilities.asp

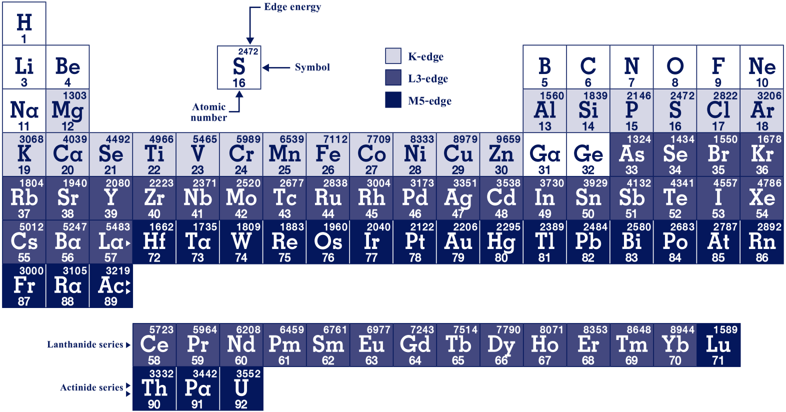
Synchrotron Worldwide (continued).

Synchrotron	Location & Country	Energy (GeV)	Circumference (m)	Commissioned	Web
Diamond Light Source	Oxfordshire, UK	3	561.6	2006	http://www.diamond.ac.uk/
DORIS III	DESY, Germany	4.5	289	1980	http://hasylab.desy.de/facilities/doris_iii
PETRA III	DESY, Germany	6.5	2304	2009	http://hasylab.desy.de/facilities/petra_iii/index_eng.html
CLS	University of Saskatchewan, Canada	2.9	171	2002	http://www.lightsource.ca
SPring-8	Harima, Japan	8	1436	1997	http://www.spring8.or.jp/
PF	KEK,Tsukuba, Japan	2.5	187	1997	http://www.kek.jp/intra-e/
TLS	Hsinchu Science Park, Taiwan	3.3	518.4	2008	http://www.nsrrc.org.tw/
SPS	Nakhon Ratchasima, Thailand	1.2	81.4	2004	http://www.slri.or.th/

Synchrotron Worldwide (continued).

Synchrotron	Location & Country	Energy (GeV)	Circumference (m)	Commissioned	Web
Indus 1	Raja Ramanna Centre for Advanced Technology, Indore, India	0.45	18.96	1999	http://www.cat.gov.in/technology/accel/indus/
Indus 2	Raja Ramanna Centre for Advanced Technology, Indore, India	2.5	36	2005	www.cat.gov.in/technology/accel/atdhome.html
CAMD	LSU, Louisiana, US	1.5	-	-	http://www.camd.lsu.edu/
PLS	PAL, Pohang, Korea	2.5	280.56	1994	http://paleng.postech.ac.kr/

X-ray Absorption Edges accessible at BL-8



H 1																	
Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10
Na 11	1303 Mg 12											1560 Al 13	1839 Si 14	2146 P 15	2472 S 16	2822 Cl 17	3206 Ar 18
3068 K 19	4039 Ca 20	4492 Se 21	4966 Ti 22	5465 V 23	5989 Cr 24	6539 Mn 25	7112 Fe 26	7709 Co 27	8333 Ni 28	8979 Cu 29	9659 Zn 30	Ga 31	Ge 32	1324 As 33	1434 Se 34	1550 Br 35	1678 Kr 36
1804 Rb 37	1940 Sr 38	2080 Y 39	2223 Zr 40	2371 Nb 41	2520 Mo 42	2677 Tc 43	2838 Ru 44	3004 Rh 45	3173 Pd 46	3351 Ag 47	3538 Cd 48	3730 In 49	3929 Sn 50	4132 Sb 51	4341 Te 52	4557 I 53	4786 Xe 54
5012 Cs 55	5247 Ba 56	5483 La ▸ 57	1662 Hf 72	1735 Ta 73	1809 W 74	1883 Re 75	1960 Os 76	2040 Ir 77	2122 Pt 78	2206 Au 79	2295 Hg 80	2389 Tl 81	2484 Pb 82	2580 Bi 83	2683 Po 84	2787 At 85	2892 Rn 86
3000 Fr 87	3105 Ra 88	3219 Ac ▸ 89															

Lanthanide series ▸	5723 Ce 58	5964 Pr 59	6208 Nd 60	6459 Pm 61	6761 Sm 62	6977 Eu 63	7243 Gd 64	7514 Tb 65	7790 Dy 66	8071 Ho 67	8353 Er 68	8648 Tm 69	8944 Yb 70	1589 Lu 71
Actinide series ▸	3332 Th 90	3442 Pa 91	3552 U 92											