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**Area Detectors for Neutron
Protein Crystallography**

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ABSTRACT

The main problem in neutron protein crystallography is the low flux of present reactor based or pulsed neutron sources. This low flux is however well matched with presently available multiwire area detectors⁹. One way to increase the flux at the sample is to increase the wavelength bandwidth. The conventional technique uses a monochromator with a bandwidth of the order of 1%. This bandwidth can be increased by using a multilayer monochromator composed of different "d" spacings. This provides a large delta lambda increasing the flux manifold. In this case a reflection in diffraction condition is scanned by the wavelength bandwidth and not by rotation of the reciprocal lattice point through the Ewald sphere¹⁰. In order to collect most of the simultaneous diffraction a large cylindrical area detector covering an angular width of 120° with a height of approximately 20cm is needed. Such a detector should have a spacial resolution of 1.1mm, an efficiency of 80% at 2.0A and a counting rate of one million events per second. This detector will be subdivided into 4 sectors that will be decoded simultaneously into a Motorola based computer system. This data acquisition system allows time slicing and this detector is therefore useful for similar experiments using pulsed neutron sources.

2. THE BROOKHAVEN DETECTORS

Position sensitive area detectors have been in use at BNL since 1971. The early detectors¹ with an active area of 20 * 20 cm have been used for small angle scattering and membrane diffraction studies. These detectors used charge division with a resolution of about 3 mm, adequate for small angle scattering studies with sample sizes of at least several millimeters. With the development of the centroid finding filter², detectors with resolution of close to 1 mm became available. In addition to the better resolution, this readout technique provides stable, linear and calibrated spatial decoding ideal for protein crystallographic measurements. The characteristics of the present He detectors are listed in Table 1 and the basic electrode configurations are depicted in Fig. 1.

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Figure 1

Fig. 1) On the left is the electrode arrangement for the 20 * 20 cm detector used for protein crystallography and on the right the schematic for the larger 50 * 50 cm detector used for small angle scattering. The large detector has only a forward drift space while the smaller detectors utilize a drift space at the front and the back. The operation and design features of these detectors are described in references 1) through 7).

Table 1

Characteristics of ^3He neutron detectors

	H9B	H3A	H3B
Sensitive Area [cm]	50 X 50	20 X 20	18 X 18
Maximal sampling [pixel]	512 X 256	256 X 156	192 X 128
Resolution fwhm [mm]	2 X 2	1.30	1.3
Detection efficiency	75% at 5 Å	80% at 2 Å	80% at 4R
Maximal count rate [s^{-1}]	10^3	10^3	10^3
^3He (atm)	5.0	7.2	4.0
Propane (atm) quenching gas	0.9	2.0	1.45
<i>In use characteristics:</i>			
Application	small-angle	crystal	membrane
Typical wavelength [Å]	4-10	1.5-3	2.0-4.0
Typical count rate [s^{-1}]	10^4	10^3	10^3
Sampling [pixel]	128 X 128	256 X 128	192 X 128
Pixel size [mm]	3.875 X 3.915	0.814 X 1.61	.456 X 1.438

Due to the radial anode field and some inhomogeneities in the geometrical arrangement of the wire grids, small differences up to 7% in detection efficiencies are observed. A look up table is used to correct for these nonlinearities. Such look up tables are generated by using purely incoherent scatterers and the resultant intensities are normalized and the inverse is then used to correct the diffraction data. Fig 2 shows the scattering pattern from Vanadium corrected with a look up table generated by an incoherent D₂O/H₂O standard calibration sample. Fig 3 shows a typical diffraction pattern from a weakly scattering protein crystal.

Figure 2

3. DATA ACQUISITION READOUT SYSTEM

The development of these position sensitive detectors required the need for fast data acquisition systems to interface with modern fast computers. Our data acquisition system is described by Schoenborn et al.⁷ and maps the two dimensional information provided by the detector into a histogramming memory at a rate of 300 000 events per second. With the elimination of bus master arbitration and frame overlap testing the counting rate can be increased to 600 000 events per second. It has to be considered that these detectors are true event processing devices and the performance is linear and lies within the relevant counting statistics.

Figure 3

Figure 4

Fig.4 General layout of a typical Spectrometer system

For time dependent studies, such as inelastic neutron scattering, time slicing experiments or use of such detectors at spallation sources, the data must be processed and stored in time intervals as small as a few microseconds. Such a system has been developed by the instrumentation division at BNL and is fabricated largely by using commercial components. The specifically designed DMA interface and histogramming memory permits time slicing storage of two dimensional data with a switching time of a few nanoseconds. This memory interface provides accurately timed intervals of less than 1 microsecond extending to many hours. With 4.4 gigabytes of memory over 64 000 time slices can be stored. This time slicing interface uses a Motorola - VME bus with a secondary DMA to a VAX microcomputer. The general layout of a typical spectrometer system is given in Fig 4. Three such systems are now being used at the structural biology stations at the HFBR and one is now being implemented at a small angle station at Brookhaven's synchrotron (NSLS).

4. DETECTORS FOR PROTEIN CRYSTALLOGRAPHY

The major problem in neutron protein crystallography is the low flux of present neutron sources. The collection of a data set using conventional techniques with neutrons from a reactor takes many weeks. One way to increase speed is to increase flux at the sample and to provide larger detectors without losing resolution. The conventional technique uses monochromators like Cu or Be with a typical wavelength band width of 1% while the Laue technique uses a white spectra with a proportional increased flux. In the conventional technique the crystal is rotated to produce the diffraction conditions for the different reflections, while the wide band Laue technique offers diffraction condition for a very large number of reflections and seems at first hand to produce more data. The background is however proportional to the whole wavelength band width, but a particular reflection peak is proportional to only a small wavelength band of approximately 0.4Å. The white radiation used for Laue condition has typically a width of 5 to 10 Å increasing therefore the background manyfold. Since the background in neutron protein crystallography is already high due to the incoherent scattering of Hydrogen atoms any further increase in background is counterproductive. In order to take advantage of the flux increase given by an increased wavelength band, a bandwidth closely matching the diffraction width would be ideal. Multilayer monochromators are ideal for this since they can produce a given E/λ with matching the crystal characteristics, producing therefor a maximum peak to flux ratio with a best peak to background ratio.

To further reduce the data collection time, area detectors covering a large part of the accessible data space are required.

To achieve this we propose to fabricate a cylindrical detector (Fig. 5) with a 70 cm radius covering 120 degrees. The detector will have an active height of 17 cm. The anode and one cathode will consist of closely spaced wire grids, with a printed circuit board used for the 2nd cathode. The detector will again use the centroid finding filter read out method designed to yield a resolution of 1.3 mm and 2mm with a maximum parallax of 0.5mm. The detector will be He3 filled with propane as quenching gas.

In order to accommodate the higher counting rates encountered in this quasi Laue technique the detector will be subdivided into four separately segments, each with its own read out and histogramming data acquisition memory system.

Figure 5

4.1. Detectors for Spallation Sources

Spallation sources produce neutrons by bombardment of a heavy metal target like tungsten with pulses of high energy protons. A typical spallation neutron source has a repetition rate of 20 evenly spaced proton bursts. If these neutron burst are short in duration compared to the time interval between burst the wavelength dependent neutron velocity ($v = 3956/\lambda$; v in m/sec and λ in Å) can be used to form a spectra if the data is collected as a function of time. For a spectrometer with a 7 meter distance between the origin of the neutrons and the detector, neutrons between 1 and 5 Å will arrive at the detector between 1.8 msec and 8.8 msec. If it is now desirable to collect data with a wavelength band width of say 0.4 Å, data would have to be collected with an interval of 0.7 msec and the whole data collection would be over in 8.8 msec with the next neutron burst starting in 50 msec. Such spallation neutron sources seem to be ideal devices for protein crystallography using the quasi Laue technique but still using a large part of the whole wavelength band width available. In the illustration used above a 7 meter instrument was used as a compromise of spreading the wavelength component in time and neutron focusing optical consideration. A longer instrument would spread the data collection time but would pose more difficult neutron focusing problems. The short data collection time, assuming the same overall counting rate poses new problems for the data acquisition system - to prevent overlap the data has to be stored in less than one sixth of the time compared to the equivalent steady state case. One way to achieve this is to divide the data accumulation into two steps: 1) accumulate the address of every event sequentially and 2) perform the histogramming asynchronously.

Every event would have a single 32 bit composite address formed comprising the time and the 2 spatial coordinates (x and y) of the event and these addresses would be stored sequentially onto a fast disk with two ports - the second port is used to read out the data for histogramming into a 3D memory using a fast CPU. Two disks would be used in a ping pong fashion with each disk preceded by a derandomising buffer. In this scheme the data rate would be dependent primarily on the event processing time. Fig 6 shows a block diagram of such a proposed system with a data rate of 660 kHz.

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Figure 6

DATA ACQUISITION FLOW CHART

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