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3.6
Neutron Scattering facilities at China Institute of Atomic Energy

---Present and future situations

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Abstract

The 15 MW Heavy Water Research Reactor (HWRR) at CIAE in Beijing is the only neutron source available for neutron scattering experiments in China at present. A 60 MW new research reactor, China Advanced Research Reactor (CARR), now is being built at CIAE to meet the increasing demand of neutron scattering research in China. A brief description of HWRR, the presently existing neutron scattering equipments at HWRR, CARR, and the facilities to be installed at CARR are presented.

1. Introduction

Neutron scattering facilities at CIAE are centered on the 15 MW HWRR, which is the only reactor available for neutron scattering experiments at present in China. In 1987, the installation of a cold source in one of its beam tubes was completed. So far totally 5 neutron scattering spectrometers are installed at 4 beam tubes. A 60 Mw new research reactor—CARR, equipped with both cold and hot sources now is being built at CIAE to meet the increasing demands of future neutron scattering research in China. A brief description of HWRR and its neutron scattering facilities, as well as CARR and the neutron scattering facilities to be built will be presented below.

2. HWRR and its cold source

The HWRR was designed and constructed under the aid of the former Soviet Union. It was put into operation in September 1958 with a power of 7MW (maximum power 10 MW, corresponding to a maximum thermal neutron flux of 1.2×10^{14} n/cm^2 s). Uranium metal with 2% enrichment of U-235 was used as fuel. Heavy water was chosen as moderator and coolant while graphite was used as reflector. The reactor was upgraded during 1979-1980, and went critical again in June 1980. The upgraded new core was designed as neutron trap type, and has a compact lattice, together with the change of the fuel enrichment from 2% to 3%, resulting an increase of maximum power from 10 to 15 MW and enhancement of the maximum unperturbed thermal neutron flux to 2.8×10^{14}n/cm^2 s in the core.

The reactor provides six radial horizontal beam tubes and a thermal column for neutron beam experiments. The maximum thermal neutron flux at the inner end of beam tubes is 3.2×10^{9}n/cm^2 s per kW and 3.16×10^{5}n/cm^2 s per kW at the exit. 4 horizontal beam tubes are used for neutron scattering experiments.

In 1987, a LH_2 cold source[1,2] of ϕ 110 mm$\times$50 mm volume, was inserted into No. 4 beam tube to a depth of 3.5m, located at the inner end of the beam tube next to the reactor core to get more cold neutrons. The LH_2 container is made of A1-Mg alloy A_9C_3. A thermal siphon connected to a helium compressor system is used to keep the moderator temperature at about 21K. Evaporated hydrogen from the moderator cell is re-condensed in the condenser through heat exchange with cold helium gas from the compressor. The thermal load on the moderator cell due to nuclear heating is estimated to be below 30 W at 10 MW reactor power.

A 32 m guide tube (27 m bent plus 5 m straight guide) installed at the exit of the cold beam tube, transporting cold neutron beam to an experiment hall next to HWRR building. The transported neutron beam of 22 mm$\times$52 mm area is divided into two sections of each 22 mm $\times$22 mm area at the guide exit. At present only one of them is used for SANS.

The neutron spectra at the guide tube exit measured by time-of-flight method [3] for both LH_2 moderator on and off are shown in Fig. 1, indicating that the average multiplication for neutrons with wavelength greater than 4 Å is ~12.

3. NEUTRON SPECTROMETERS AT HWRR

At present, five neutron scattering facilities are installed at the beam tubes:

(a) Powder neutron diffractometer

The powder diffractometer installed at beam tube 3 is a conventional 2-axis spectrometer with 2θ range of ~130° . Neutrons of 1.18 Å/1.16 Å wavelength reflected by a PG(002) / Cu(220) crystal are selected as incident beam. With first collimator of 20', $\Delta\lambda/\lambda=0.016$ for 1.16 Å neutrons and the incident neutron flux at sample position is < 10^6 n/cm^2 s.

(b) Four-circle neutron diffractometer

The four-circle neutron diffractometer at beam tube 5 shares the beam with a triple-axis spectrometer. Germanium or copper single crystal is used as monochromator. With 15° fixed take-off angle, the corresponding incident neutron wavelength is 1.69A for Ge(111) or 0.66 Å for Cu(220). For $\lambda=1.69$ Å, $\Delta\lambda/\lambda=0.045$ and the neutron flux at sample position is $\leqslant 10^6$n/cm^2 s.

(c) Triple-axis spectrometer

Although the triple-axis spectrometer at beam tube 5 originally was built for lattice dynamic study, it also used occasionally as a diffractometer for structure study. Ge (111) and PG (002) crystal is used as the monochromator and the analyzer respectively. The sample table and analyzer table are moved by air-pad system. Cryogens and small oven as well as magnetic field system can be added on sample table to control sample environment during experiment. Neutron flux at sample position is about 10^6 n/ cm^2 s (λ = 1.8 Å) with maximum beam size of 40 mm × 90 mm. The incident wavelength can be selected between 1.3 Å and 3.3 Å.

A beryllium filter wide-angle detector system was designed and built to match the triple-axis spectrometer, constituting an inverse geometry spectrometer for high frequency phonon density of state measurements.

(d) Double-chopper time-of-flight spectrometer

The time-of flight spectrometer at beam tube 1 was designed with the purpose of lattice dynamics study. The key components of the spectrometer contain two choppers, rotating synchronously at a speed up to 13000 rpm. The neutron beam from the reactor is pulsed roughly by the first chopper and then is reflected by a PG monochromator to get monochromatic incident neutrons in the energy region of 5-200 meV with $\Delta E/E \approx (3\text{-}8)\%$. The second chopper improves the rough-pulsed monochromatic neutrons to a fine pulse of about 30 μs. Neutron flux at sample position is ~ 10^3n/cm^2 s with signal to noise ratio better than 20. The scattered beam is detected by 54 ^{3}He detectors simultaneously at 9 different scattering angles covering an angular region of 90°, located at 2 meters from the sample. The data are stored by a time-of-flight coding unit and analyzed by a PC.

(e) Small angle neutron scattering spectrometer

A small angle neutron scattering spectrometer with a 64 × 64 element (each 1cm^2 area) BF_3 area detector was installed at the end of the guide tube. The incident neutron beam from the mechanical selector covers the wavelength region from 3 to 10 Å with $\Delta\lambda/\lambda \approx 0.15$. The Q value ranges from 0.001 Å^{-1} to 0.1 Å^{-1}.

4. CARR and the equipment to be built around its beam tubes

According to the design, CARR [4] is a tank-in-pool inverse neutron trap type research reactor with nuclear power of 60 MW. The fuel element is made from silicide uranium with 20% enrichment of U-235. The core is 70 cm high and 45.5 cm in diameter. Slightly pressurized water is used as the primary cooling water as well as moderator. The core is surrounded by a Φ2.5 m × 2.5 m heavy water tank, in which the under-moderated neutrons leaking out through the core surface would further be moderated to form a flux peak with maximum unperturbed thermal neutron flux of 8×10^{14} n/cm^2 s. 9 tangent beam tubes (some of them have two beams outlets) are arranged. Among them 7 are allocated to neutron scattering experiments,

The reactor body is immersed in a pool of 16 m diameter, and the core is located 12m below the pool water surface.

CARR is due the year of 2005 to come critical.

5. Equipments to be installed at CARR

A liquid hydrogen cold source at 20 K and a 2000 K graphite hot source will be installed in the reflector. Cold and hot neutron beams are each extracted from one beam tube. Four guide tubes with beam cross section of 30 mm × 150 mm will be put into the cold beam tube for transportation the cold neutron beams to a 36 m×60 m experimental hall. Two of the guides, one nature Ni coated and one Ni-58 coated (or supermirror), are planned to come in use soon after CARR becomes critical. The others will be installed in the future.

All of the spectrometers installed at HWRR will be upgraded and moved to CARR for continue using. The triple-axis spectrometer, four circle spectrometer, time of flight spectrometer, and the powder neutron diffractometer will be installed in the reactor hall, using thermal neutron beams from the tubes. The SANS will be installed in the guide hall at the exit of the nature Ni guide.

A high resolution powder diffractometer ($\triangle d/d = 2\times10^{-3}$, neutron flux at sample position $> 10^6$ n/cm^2 s), and a multi-purpose hot neutron beam spectrometer, which can be operated as a diffractometer, a beryllium filter detector spectrometer or a triple axis spectrometer according to different combinations of its components, will be built and installed at the reactor hall; A horizontal scattering geometry polarize neutron reflectometer will be constructed and accommodated at guide hall using cold neutrons from the Ni-58 (or supermirror) guide tube.

Fig. 2 is the layout of the facilites at CARR.

6. Research activities

Since 1980's cooperation research on the crystal and magnetic structures of rare earth-intermetallic compounds [5,6] have been made between CIAE, Physics Department of Peking University, and Institute of physics of Chinese Academy. Single crystal structure analysis of non-linear optical materials and the effect of neutron diffraction intensity enhancement under applied DC voltage are studied. Crystal structures and phonon property researches on high temperature superconducting materials [7,8] with the aim of learning the mechanism have been another area in CIAE's neutron scattering programmer. Phonon density of states of amorphous Invar materials [9], shape memory alloys and metal hydrides [10] have also been made. Topics of interest to petroleum industry, materials sciences and biology [11] have been studied by SANS.

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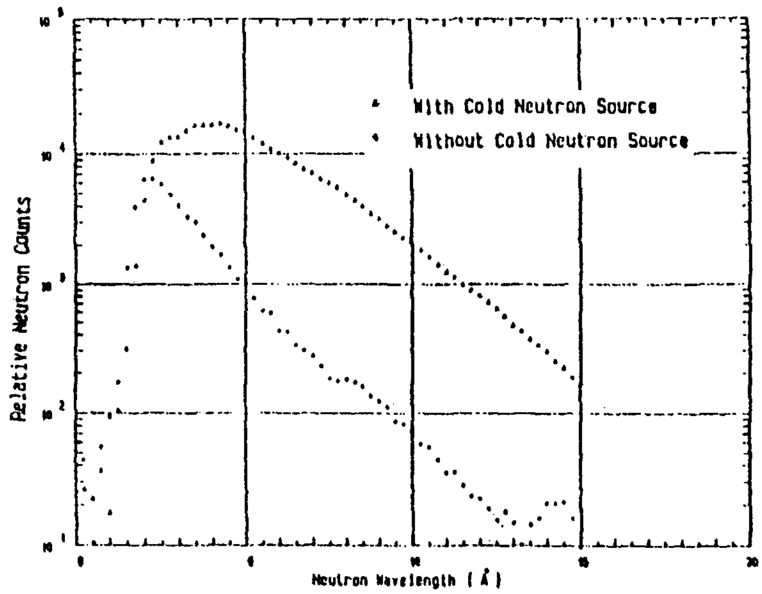

Fig.1 Neutron Spectra Measured at the Guide Exit

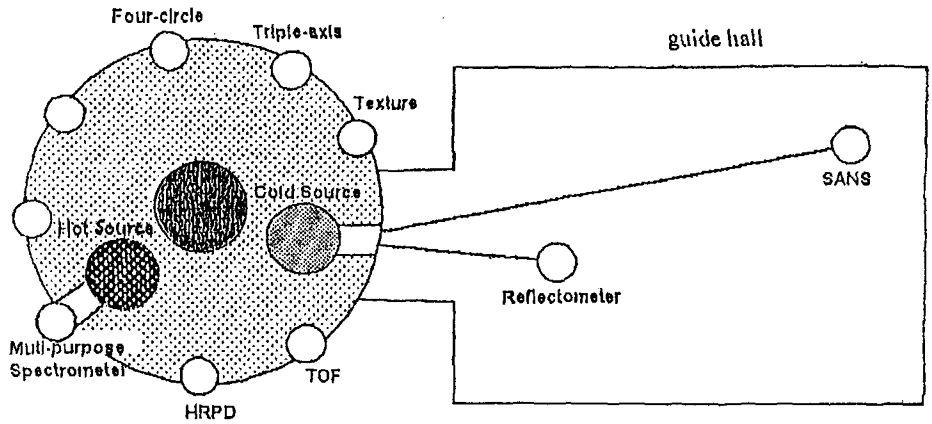

Fig. 2 layout of neutron scattering facilities at CARR