# Scientific session of the Division of General Physics and Astronomy of the Academy of Sciences of the USSR (24 April, 1991)

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A scientific session of the Division of General Physics and Astronomy of the Academy of Sciences of the USSR was held on 24 April 1991 in the P. L. Kapitsa Institute for Physics Problems. The following reports were presented at the session:

*1. L. S. Levitov.* Fibonacci numbers in botany and physics (phyllotaxis).

*2. V. L. Aksenov.* Research on high-temperature superconductors using the IBR-2 high-flux pulsed reactor.

A brief summary of one report is given below.

**V. L. Aksenov.** *Research on high-temperature superconductors using the IBR-2 high-flux pulsed reactor.* The fast pulsed IBR-2 reactor is a periodic pulsed reactor. It was put into service in the Laboratory of Neutron Physics at the Joint Institute for Nuclear Research in Dubna in 1984 and is the only completed high-power pulsed reactor in the world from designs produced in the 1960s and 1970s.[1]

In contrast to the usual type of nuclear reactor in which fission occurs continuously, in the IBR reactor the power is released in short periodic pulses with large time intervals between them. The pulses are created by mechanically varying the neutron multiplication factor. In the IBR-2 reactor the reactivity is modulated using a movable reflector consisting of two parts: the main and auxiliary elements. The two elements rotate with different velocities near the active core. A pulse is generated when the two elements are both simultaneously opposite the core.

The thermal characteristics and kinetics of pulsed and steady-state reactors differ only slightly. However, because of the low average power (three orders of magntiude lower than the pulse power), a pulse reactor is simpler to operate and is much less expensive because of the low activation of the equipment and the slow burn-up rate of the active core. Assuming the IBR-2 reactor is operated 2500 hours per year, the operating life of the core (92 kg of $PuO_2$) is 20 years, while the operating life of the moving reflector is 5 years.

The IBR-2 reactor is currently the highest-flux pulsed source of neutrons in the world: at the average power of 2 MW the flux of thermal neutrons from the surface of the moderator is $10^{16}$ N/cm$^2$·sec. The high flux is a result of the high peak power of 1500 MW. Table I shows a comparison between the basic parameters of the IBR-2 and the best neutron sources: ISIS (Rutherford–Appleton Laboratory, Great Britian), LANSCE (Los Alamos National Laboratory, USA), and KENS (National Laboratory of High-Energy Physics, Japan).

In comparison with other neutron sources the IBR-2 is somewhat limited by the large pulse width for thermal neutrons. But for cold neutrons at high intensity the pulse width is practically the same as for other pulsed sources. Hence for cold neutrons the IBR-2 reactor has significant advantages over the other neutron sources. Work was begun in 1987 on a cold solid-methane moderator. This work is currently in its final stages. The new moderator is schedules to be installed on the reactor in 1992.

A new movable reflector will be installed in 1993 to decrease the pulse width. It will differ from the current reflector in that the main and auxiliary elements will move toward one another. In this case one expects that the pulse duration for thermal neutrons will decrease by a factor of two.

Table I also shows the expected parameters of a planned modernized reactor, which will be called the IBR-3. Modernization is needed because by 1996–1997 the main components of the IBR-2 reactor will have completed their specified radiation operating life and will require replacement. This replacement will offer the possibility of improving the basic characteristics of the reactor.

Presently there are 11 spectrometers for physics research on the IBR-2. Four are designated for research on

TABLE I. Comparison of pulsed neutron sources for condensed matter physics ($T$ = thermal neutrons ($E_{\alpha} = 5\cdot 10^{-3}$ to $5\cdot 10^{-1}$ eV), $X$ = cold neutrons ($E_{\alpha} = 10^{-4}$ to $5\cdot 10^{-3}$ eV)).

| | | ISIS, RAL, GB 1990 | LANSCE, LANL, USA 1990 | KENS-1, KEK, JAPAN 1990 | IBR-2 JINR 1990/1992 | IBR-2 JINR MR-2PM 1993 | IBR-3 JINR (planned) 2000 |
|---|---|---|---|---|---|---|---|
| $\bar{I}_n\cdot 10^{-15}$, n/sec | $T$ | 0,05 | 0,03 | 0,02 | 5 | 5 | 7 |
| | $X$ | 0,03 | 0,02 | 0,017 | $\frac{0,05}{0,6}$ | 0,6 | 3 |
| $\Delta t$, μsec | $T$ | 20 | 20 | 100 | 300 | 150 | 100 |
| | $X$ | 200 | 200 | 150 | $\frac{300}{240}$ | 160 | 130 |
| $Q\cdot 10^{-10} = \frac{I_n}{(\Delta t)^2}$ | $T$ | 12,5 | 7,5 | 0,2 | 5,6 | 22,2 | 70 |
| | $X$ | 0,08 | 0,05 | 0,08 | $\frac{0,06}{1,04}$ | 2,3 | 17,8 |

The basic characteristics chosen here are $\bar{I}_n$, the integrated yield of neutrons from the surface of the moderator per second, $\Delta t$, the neutron pulse duration, and $Q$, the quality factor of the source.

  

atomic and magnetic structure and four are reserved for the study of atomic, molecular, and magnetic dynamics. Spectrometers using polarized and ultracold neutrons and a precision diffractometer for the neutron optics form a separate group. The characteristics of the spectrometers on the IBR-2 reactor and their use in physics research has been discussed in Refs. 2 and 3. A high-resolution Fourier diffractometer[4] will be put into operation in 1992 and will have a spatial resolution of $\Delta d/d = 5\cdot 10^{-4}$.

The IBR-2 reactor can be used to obtain extensive information about the structure, dynamics, and the magnetic properties of high-temperature superconductors. We mention a few of the most interesting results. Recently the DN-2 diffractometer was used to study the replacement of copper in yttrium ceramics by iron isotopes.[5] This study determined the distribution of iron (in chains or in planes) as a funciton of its concentration. In addition, the study led to a new question on the nature of the magnetic phase for iron concentrations greater than 0.5. Interesting results on the synthesis of high-temperature superconducting ceramics were obtained on the DN-2.

Data on the structure of bismuth 2-3-2 compounds obtained on the DN-2 diffractometer have been published in Ref. 6. Ceramics and a single crystal size ($1.5\times 1.0\times 0.03$ mm) prepared in the Physics Institute of the Academy of Sciences of the Czechoslovak Federated Republic and in the Polytechnic Institute in Prague were used in the study. The atomic structure of these compounds contains excess oxygen (over and above the formal valency), which leads to local distortions and hence to a modulation of the crystal lattice as a result of elastic forces. Since superconductivity in high-temperature superconductors is extremely sensitive to the oxygen content, there may be a correlation between the appearance of superconductivity and of superstructure. Such a correlation was not observed in these studies, which were done in the temperature region 8–920° K.

The phonon spectra of high-temperature superconducting ceramics has been studied intensively using the KDSOG spectrometer.[7] The most interesting result is the observation of temperature anomalies in the low-frequency region: at 6 meV for lanthanum compounds and between 20 and 40 meV for yttrium and bismuth ceramics. Recently an experimental study was done of the spectra with isotopic substitution of copper. THe partial contributions of the vibrations of copper and the other elements of the lattice were separated.

Extremely interesting data were obtained in the experiments with polarized neutrons using the SPN spectrometer. By studying reflections from the surfaces of high-temperature superconducting films,[8] discrepancies in the penetration depth of the magnetic field measured by different methods were eliminated and a value close to 1000Å was established. A method of studying depolarization of the neutrons after passing through the sample was proposed in Ref. 9. A new possibility appears for studying the magnetic field distribution inside high-temperature superconductors and the relaxation of the magnetic characteristics.

A study of the parameters of the crystal line electric field enables one to determine the value of the energy gap $\Delta_0$ and to estimate the constant $\rho$ of the interaction between localized electrons and conduction electrons. Measurements of this kind have been carried out using the KDSOG spectrometer and the ISIS source (RAL, Great Britain) on different kinds of high-temperature superconductor doped with thulium.[10] The observed decrease in the widths of the transition lines between crystal electric field levels is correlated with the onset of superconductivity. Estimates give $\Delta_0 \geqslant 14.2$ meV, $\rho = 0.025 \pm 0.005$.

A more detailed discussion of these and other results can be found in the book of Ref. 11.


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