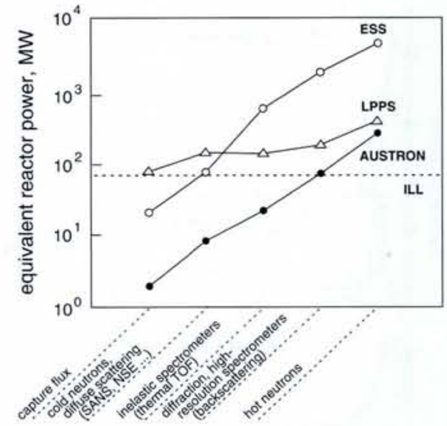
LONG PULSE SPALLATION SOURCES

A Cost-Effective Option for New Sources

Roger Pynn from the Los Alamos National Laboratory discusses the proposal that a new type of simply designed, long-pulse neutron spallation source (based on a single proton linac) combined with adapted instrumentation can outperform reactor sources of equal cost.



A comparison of the luminosity, at representative data collection rates, for various types of instrument applications at a number of existing and proposed neutron sources — proposed European Spallation Source (ESS); ISIS and the proposed Austron spallation source; Institut Laue-Langevin (ILL); proposed long-pulse spallation source (LPSS) based on a 5 MW pulsed proton linac. LPSS has a definite advantage for many applications (becoming more pronounced as the wavelength resolution requirement decreases). From: F. Mezei, 1993 Int. Conf. on the Applications of Neutron Scattering (Abingdon, UK).

Neutrons for research are often expensive! Nowhere is this better understood than in the United States where the Advanced Neutron Source — a nuclear reactor that was to have been the flagship for American neutron scattering in the coming decades — was recently cancelled because of its 3000 M$ price tag. But this road-block may perhaps be side-stepped if ideas recently suggested by Ferenc Mezei of the Hahn-Meitner Institute, Berlin, can be implemented.

Same Average Flux with Less Heating

Mezei's argument starts by noting that there are two equivalent ways of determining the wavelength of neutrons used for scattering experiments. In the first, most widely exploited method, a monochromatic (single wavelength) beam of neutrons prepared by Bragg reflection from a single crystal is directed at the sample under investigation. The stream of neutrons impinging on the sample in such experiments is continuous.

The alternative experimental method uses a shutter — like that of a camera — in front of the neutron source to pulse the beam incident on the sample at an appropriate frequency. If the time at which a pulse of neutrons passes the shutter is known, a measurement of a neutron's arrival time at a detector further down the beam-line allows the velocity (and hence the wavelength) of each neutron to be determined.

If we ignore subtleties such as the variation of spectral brightness with neutron wavelength, the time-averaged neutron flux incident on the sample is the same for both types of experiment described above. In the crystal-monochromator case, the neutrons striking the sample all have the same wavelength whereas, for the time-of-flight method, the wavelength varies with time during the interval between successive neutron pulses. If the two methods are designed to have the same resolution — that is, the same precision in the determination of the neutron wavelength — they are equivalent, provided each neutron wavelength in the time-of-flight measurement provides useful data.

As long as we are not too greedy and do not try to make measurements with TOO many wavelengths at once, each wavelength in the time-of-flight method will give useful data. The definition of "too greedy" depends on the type of experiment. For powder diffraction, for example, we may be able to use 10000 distinguishable wavelengths while for triple-axis spectroscopy, 10 may be ample.

A second thread of Mezei's argument is based on the limitations of current neutron production technology. The first of these limitations is the cooling of neutron generators, which places a fairly hard technological limit on the maximum, time-averaged flux of neutrons that can be produced. In this context, the spallation process is somewhat more efficient than nuclear fission because it only deposits about 25 MeV per useful neutron generated versus about 180 MeV for fission.

With the problem stripped to its bare bones in this way, the solution is obvious — we should use the time-of-flight method for scattering experiments and turn off the neutron source when the time-of-flight shutter is closed to avoid generating heat when we don't need to. Furthermore, we should use the spallation process to produce neutrons because it does so with less heating.

Existing Sources Give Short Pulses

But surely we already have such neutron sources — the pulsed spallation sources at ISIS in England, LANSCE and IPNS in the United States, and KENS in Japan? Not quite! These sources are designed to combine the functions of neutron production and the time-of-flight shutter: they produce pulses of neutrons that are short enough to be used directly for time-of-flight measurements without using shutters. In addition to removing flexibility (the pulse length cannot be varied easily and is the same for all spectrometers that view a neutron moderator), this strategy is more costly and technologically complex than necessary in many cases. All short-pulse spallation sources need some sort of particle storage ring — a rapid cycling synchrotron or an accumulator — to shorten the proton pulses produced by a linear accelerator so that short neutron pulses are produced when the proton pulses impinge on a heavy metal target. This ring is just one more technological bottleneck and expense that Mezei's proposal avoids.

This is not to say that one should abandon short-pulse spallation sources. Shutter technology is also a bottleneck and for experiments that need very short neutron pulses or high-energy neutrons, shutters that open and close quickly enough have not yet been built. For these applications, which include powder diffraction and high-energy spectroscopy, short-pulse sources are still the best option. But, in many other areas — such as reflectometry, low- and medium-energy spectroscopy, diffuse scattering, and neutron spin echo — one can use the long (≈ 1 msec) proton pulses directly from a linear accelerator to build a long-pulse spallation source (LPSS) that makes the most of Mezei's arguments.

US Takes Up LPSS

The US neutron scattering community has just begun thinking about an LPSS. At a recent workshop held at the Lawrence Berkeley Laboratory, members of the community confirmed that a 1 MW LPSS with a 6% duty factor could be expected to perform 3 to 4 times better than the Institut Laue-Langevin (ILL) reactor in Grenoble for selected experiments. This ideal performance increase is fairly easy to understand. A 1 MW spallation source can generate a cold neutron flux that is about a quarter of that provided by the ILL. Since the LPSS is only turned on for 6% of the time, its peak flux is about 16 times higher than its average flux, or about 4 times higher than the ILL cold flux. Because the time-of-flight shutter is synchronised with the source, it will transmit the peak flux, providing the gain indicated. This gain factor cannot be realized for all experiments and some real work is needed to establish what performance can be expected with current neutron technology for all types of neutron scattering spectrometers. The Berkeley workshop started this process.

Perhaps the most important conclusion of the Berkeley workshop was that a 1 MW LPSS would provide a capability "in the same ball-park" as the ILL for a broad range of neutron scattering experiments. And because such a source would exploit a technology based on time-of-flight measurements rather than crystal monochromators, it would

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US NEUTRON SOURCES

A 1993 report by a sub-panel of the US Department of Energy (DoE) Basic Energy Sciences Advisory Committee (BESAC) recommended priority be given to the Advanced Neutron (reactor) Source (ANS) and to a new spallation source. In view of the cancellation by the US Administration of the ANS last February and the need to develop a coherent programme for neutron scattering within DoE, Martha Krebs, the Director of DOE's Office of Energy, asked BESAC in July (with an unspecified deadline):

- To evaluate possible upgrades to existing reactor sources at:
  • ORNL (Oak Ridge National Laboratory)
  • BNL (Brookhaven National Laboratory).
- For advice on the type of accelerator-based spallation source that could be built at ONRL for about one-third of the cost of the 3000 M$ ANS which was proposed by ONRL. ORNL has been identified by DoE as the preferred site for a spallation source and is due to receive 16 M$ for a two-year conceptual design study of a 1 MW/1000 M$ facility (a similar study is currently underway for a proposed 5 MW European Spallation Source).

Meanwhile, several upgraded or new facilities have been proposed in the US, namely:

• ANL (Argonne National Laboratory), site of the nearly complete 800 M$ Advanced Photon Source, has a detailed design for upgrading its Intense Pulse Neutron Source.

• BNL, site of the new Relativistic Heavy Ion Collider, has designed a spallation source.

• LANL (Los Alamos National Laboratory) is considering a 95 M$ upgrade of its proton linac (LANSCE) to give a 1 MW long-pulse spallation source. LANL will lead a first phase, 300 M$ technical study of a spallation-based tritium production facility that includes the construction of a prototype, although plans for a final facility based elsewhere are meeting opposition.

P.G. Boswell

provide an independent avenue for future progress in neutron scattering.

It is far too early to say whether a long-pulse source will be built in the US. However, the availability at the Los Alamos National Laboratory of a proton linear accelerator which has produced a megawatt of beam power for the past two decades would make the construction of such a source remarkably cost-effective, a feature which is especially attractive in these times of tight budgets for scientific projects.

ECAMP-5

Spanning a Broad Field

H. Hotop reports that the highlights of the 5th European Conference on Atomic and Molecular Physics (ECAMP-5) demonstrate the breadth and depth of a field which spans topics ranging from basic reasearch to applications.

Precision Spectroscopy

The combination of intense, pulsed UV laser radiation with fast, position-sensitive photon detection methods allows detailed diagnostic studies of turbulent combustion processes (cover illustration). P. Andresen (Bielefeld) demonstrated that the simultaneous measurement of gas composition, temperature, pressure, and flow velocity leads to a better understanding of fundamental processes in turbulent reaction flow fields, thereby allowing the design of efficient, clean motors, jet engines and furnaces. G. Meijer (Nijmegen) presented cavity ring-down (CRD) spectroscopy, a novel method for trace-gas detection based on measuring the rate of absorption rather than the magnitude of absorption of a (laser-) light pulse confined in a high-Q optical cavity. Noise-equivalent absorption coefficients in the 10^{-10} cm^{-1} range have been demonstrated in the visible and near-UV range.

Impressive advances have been recently made at four facilities in Europe — TSR (Heidleberg); ESR (Darmstadt); ASTRID (Aarhus); CRYRING (Stockholm) — which operate ion-storage cooler rings. D. Habs (Heidelberg) gave an overview of the fascinating atomic and molecular physics programme that is being carried out. Electron cooling of atomic ions leads to brilliant monochromatic beams of highly-charged ions which can be used for new kinds of precision experiments, both in spectroscopy and collisions. Many beautiful results have been obtained in the last three years in X-ray spectroscopy (*e.g.*, of hydrogen-like U^{91+} ions) and in radiative, laser-stimulated and dielectronic recombination of ions in collisions with electrons. Advanced electron cooling schemes with a magnetically expanded electron beam now allow studies at energy resolutions of 10 meV and below. Molecular ions have also been successfully studied, taking advantage of the vibrational and rotational cooling associated with storage times of several seconds. M. Larsson (Stockholm) highlighted the progress in dissociative recombination experiments with storage rings and J. Tenyson (London) surveyed recent advances in the theoretical descriptions of processes.

Electron-Ion & Ion-Surface Interactions

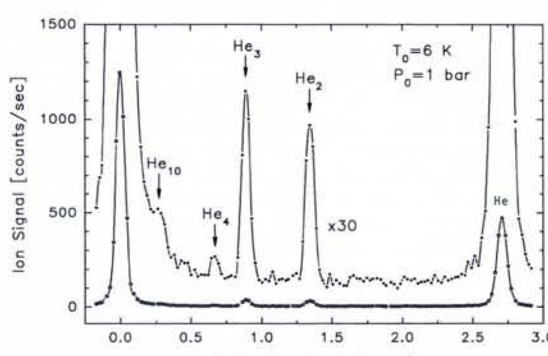
Regarding electron collisions with atoms, molecules and surfaces, the dynamics of ionization processes has been studied in great detail using (e, 2e)- and (e, 3e)-coincidence experiments. They reveal electron correlation effects in bound and continuum states, including post-collision interactions affecting near-threshold inner-shell ionization processes (G. Stefani, Rome). Future studies will consider atoms in both excited states and external fields as well as surfaces. Recent progress includes electron-photon (e, eγ) and electron-electron (e, 2e) coincidence studies involving spin-polarized electrons. The results will shed light on exchange effects and spin-orbit interaction, both in bound and continuum states. Some problems, especially for chiral molecules, remain to be clarified. D. Teillet-Billy (Orsay) discussed the physics of the dynamics of energy transfer in electron collisions with molecules absorbed at surfaces. Specific properties of resonant electron-molecules scattering can be explored for adsorbate analysis and exploited to induce reactions on surfaces. Progress in positron and positronium scattering studies were surveyed by G. Laricchia (London). Experimental investigations of positron collisions with simple atomic and molecular systems have advanced to near-threshold and differential measurements of selected scattering channels. Controlled diffusion experiments involving positronium projectiles have recently begun.

New Techniques - New Insights

New techniques are leading to new insights. This is illustrated by the following:

• Recent advances made in investigations of heavy-particle collisions which include the development of ion-recoil spectroscopy allowing, for instance, detailed studies of state-selective, electron capture of highly-charged ions with a high-energy resolution and sensitivity (J. Ullrich, Darmstadt). Ion-recoil spectroscopy also allows the kinematically complete measurement of electron-impact induced single ionization and of photon-induced double ionization.

• The interaction of slow, highly charged ions with metal and insulator surfaces leading to



Diffraction of helium clusters. *This diffraction pattern was taken with a He_2 cluster beam produced by expanding pure ^4He through a 5 µm nozzle (6 K source temperature; 1 bar source pressure). The forward undiffracted peak is at 0 mrad and the first-order diffraction peaks corresponding to the monomer, dimer, trimer, and tetramer are all clearly resolved. It should be noted that the relative intensities depend on the source pressure, with He_2 as the dominant cluster contribution at low pressures, followed by trimers at intermediate pressures. Since the diffraction mechanism is totally non-destructive, this type of experiment provides the first unequivocal evidence not only for the dimer, but also for the existence of the trimer and tetramer. There is great interest in the trimer since it is the best candidate for showing long-range Efimov states. See W. Schöllkopf & J.P. Tonnies,* Science ***266*** *(1994) 1345.*