Léon Brillouin Laboratory





Condensed matter physics,
Material physics,
Metallurgy,
Nano-objects,
Polymers,
Bio-sciences,
Earth sciences
Archeology,
....

Léon Brillouin Laboratory Saclay

Neutron Scattering National Laboratory

Serving Science & Industry

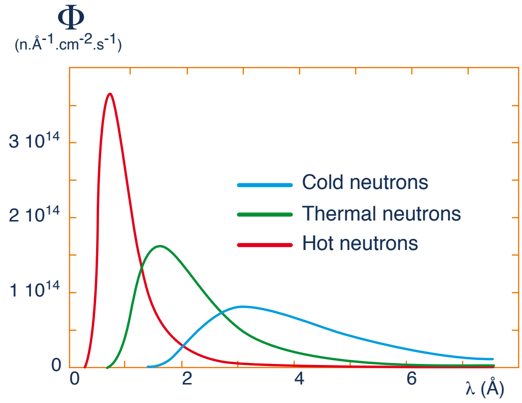
http://www-llb.cea.fr

Laboratoire Léon Brillouin

The Orphée Reactor

is a fission reactor of 14 MW of power. Its very compact core is immersed in a tank of heavy water.

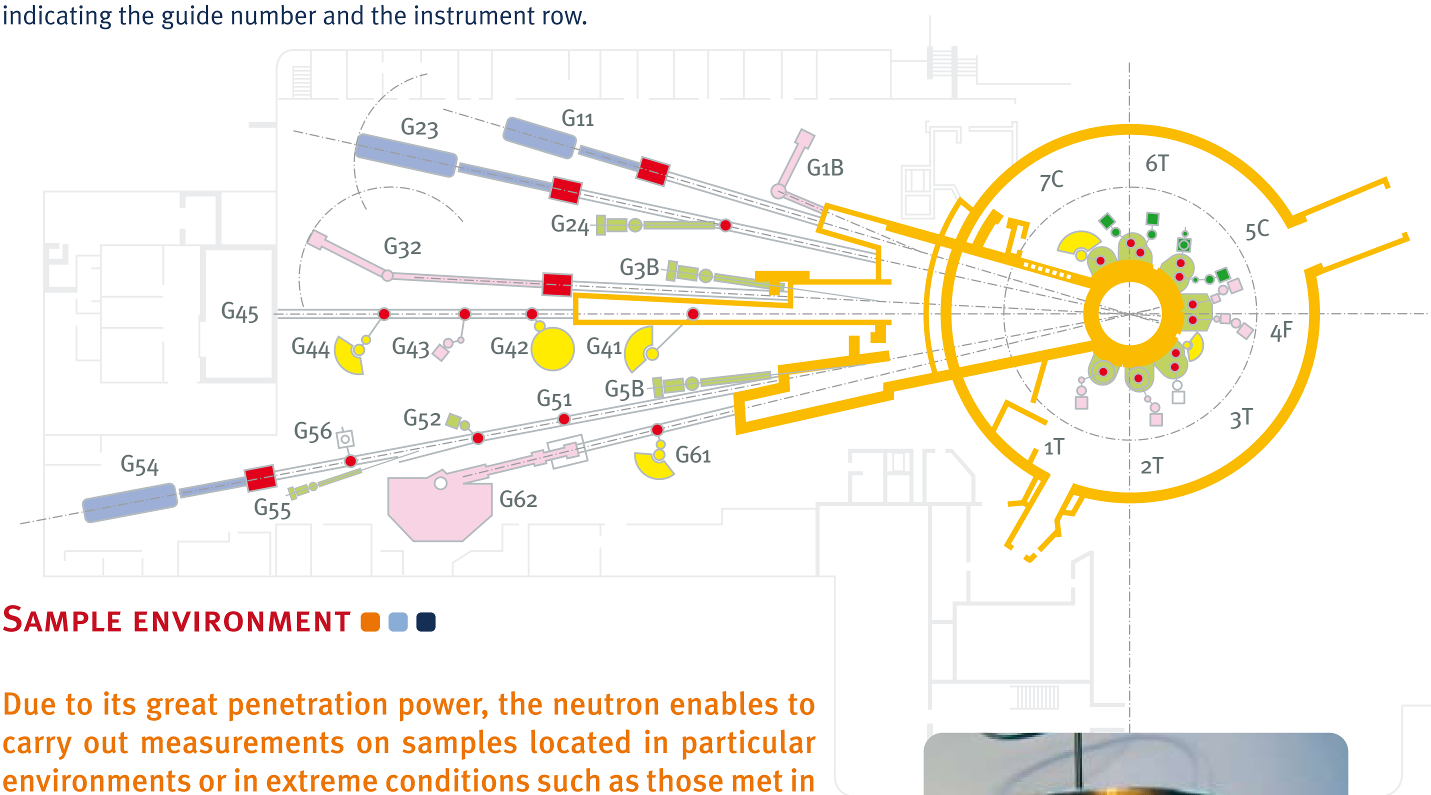
Thanks to its moderators of 20.300 and 1400 K, it provides beams whose energy follows the Maxwellian distribution around 100 meV (λ~0.08 nm), 25 meV (0.18 nm), and 5 meV (0.35 nm).



25 instruments at the disposal of scientists

Choosing the most adapted instrument for the experiment required:

In the reactor hall, each instrument is referenced by the letter T (Thermique), F(Froid) or C (Chaud) to indicate if it receives thermal, cold or hot neutron beams, preceded by a figure which localizes it. The instruments placed in the guide hall are referenced by the G letter, followed by two figures indicating the guide number and the instrument row.



Sample environment

Due to its great penetration power, the neutron enables to carry out measurements on samples located in particular environments or in extreme conditions such as those met in the earth centre or on far distance planets. These measures show us new properties which are quite unexpected most of the time.

- Low and high temperatures : 50 mK to 2000 K.
- Intense magnetic fields : up to 10 testas.
- Very high pressures : up to 50 GP (500 000 atm).
- Magnetic field.
- Laser beam (photo-inducted phenomena).
- Mechanical constraints applications (solids).
- Flow with shears (fluids).
- ....

Cell for measurement under very high pressure

The Léon Brillouin Laboratory (LLB)

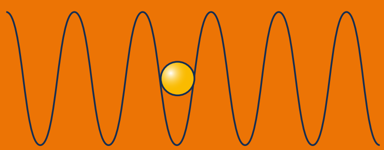
is a National Laboratory supported jointly by the "Centre National de la Recherche Scientifique" (CNRS) and the "Commissariat à l'Energie Atomique" (CEA). Classified as a "Large Installation". LLB is part of a European network and receives grants from the European Union.

Its missions ▸ to promote the use of diffraction and neutron spectroscopy ▸ to welcome and assist experimentators ▸ to do some research on its own scientific programmes.

The Neutron

A particle well adapted to the exploration of the matter

Waves and particles are two representations of a same reality



Velocity (v), energy (E), wavelength (λ) and wave vector ($\vec{k}$) are linked by the relationships:

$$E = \frac{1}{2} mv^2 \; ; \; \lambda = \frac{h}{mv} \; ; \; \vec{k} = \frac{2\pi m}{h} \vec{v}$$

(m = neutron mass, h = Planck constant)

$\lambda = 0.18\ \text{nm} \leftrightarrow E = 25\ \text{meV} \leftrightarrow v = 2200\ \text{m/s}$

- The energy of neutrons, whose wavelength is close to typical distance between two atoms, is similar to atomic and magnetic excitation energies within the matter.

▸ **Definition of atomic structure**

▸ **Atomic and magnetic moments dynamic measurement**

- Neutrons interact with the atom nucleus; they are sensitive to isotope.

▸ **Good light atom visibility**

▸ **Labelling by isotopic substitution**

- The neutrons are strongly scattered by the magnetic moments.

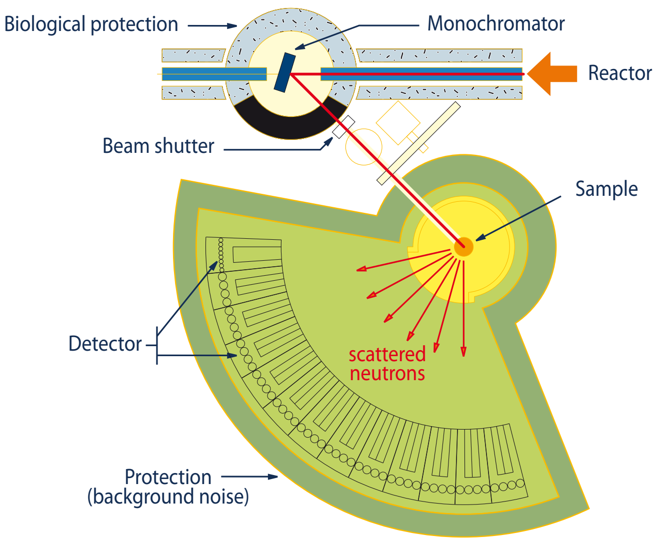
▸ **Most efficient tool to determine magnetic structures**

- Neutrons are little absorbed by matter.

▸ **Bulk exploration of the matter**

Principle of an experiment

After some "preparation", the neutrons coming out of ORPHEE reactor are directed to the sample. From interaction with the atoms they are deflected and exchange energy and/or spin components with them. After scattering, thanks to the modification of these parameters, some important information can be deduced about the atomic and magnetic structure as well as the atomic dynamical behaviour of the atoms in the sample. According to the measurements to be made and the sample nature, one must choose the most appropriate spectrometer.



Total Scattering

"Powder" Diffractometers

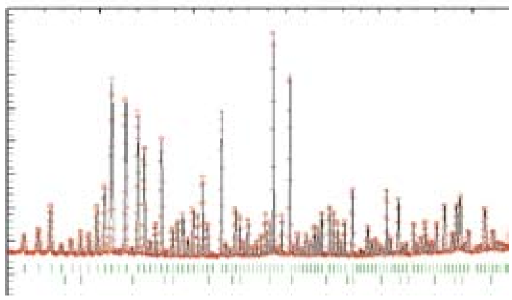
It's the most simple spectrometer. A beam, made monochromatic thanks to Bragg reflection on a crystal, is directed to a sample. The diffracted neutrons are counted by multi-detectors or detector benches which allow a rapid acquisition of diagrams. These instruments are well adapted to take measurements on powders, poly-crystals, liquids and amorphous materials. Diagrams are analysed by very powerful refinement programmes. These experiments enable to determine:

- In crystals, the symmetry of the cell and the average position and space occupied by each atom.
- In disordered systems, pair correlation functions.

Atomic structure

A crystallized material diffractogram shows peaks (Bragg peaks) whose position and intensity are linked to the structure of the elementary cell. The samples can be inorganic, molecular or biological crystals. The structure is correlated to the physical, chemical, pharmaceutical, environmental, ... properties of the material.

Thanks to their specific properties, the neutrons can "see" light atoms easily, hydrogen in particular. The choice of the instrument is determined by the general size of the crystal cell parameter and the required resolution



Comparison between the experiment (dots) and the adjustment to a structure hypothesis (continuous line)

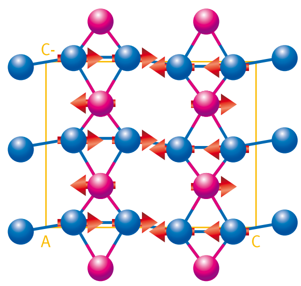
Magnetic structure

Magnetism in solids is due to the presence of microscopic magnetic moments (small magnets) carried by atoms (due to the presence of unpaired electrons). According to the material, in an ordered magnetic phase, these small moments can be:

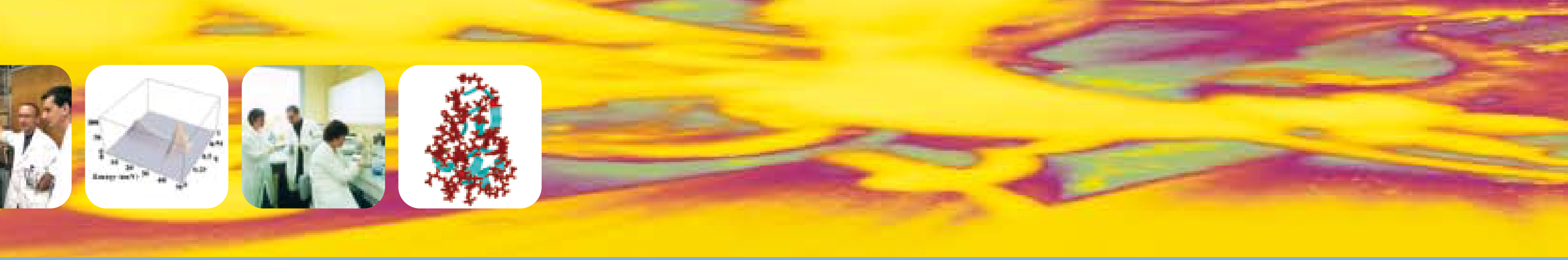
- Either all parallel (ferromagnetism).
- Or anti-parallel (anti-ferromagnetism) and sometimes ordered in a more complicated way (ferrimagnetism, helicoidal structure, ...

Neutron diffraction enables to determine these structures very accurately and to monitor their changes at different temperatures and under magnetic field.

Permanent magnet (ferromagnetic)

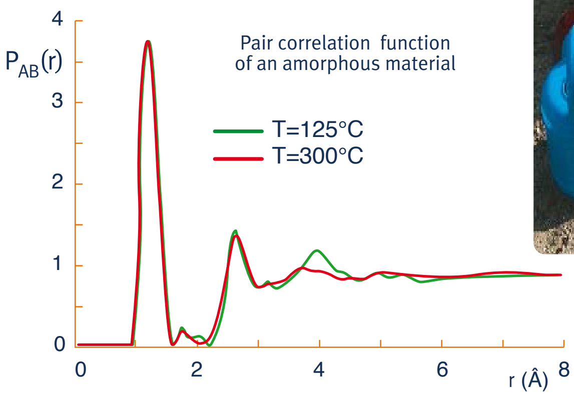


$Co_3(OD)_2(SO_4)_2$ (Canted antiferromagnet)



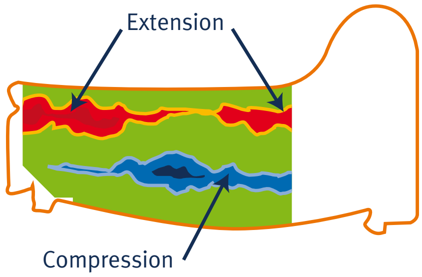
DISORDERED SYSTEMS

In liquids and amorphous materials, it is no longer possible to determine the exact position of the atoms, but only the average neighbourhood of each atom (short distance order). This order is characterized by the pair correlation function $P_{AB}(r)$, which gives the probability to find a type B atom at a "r" distance from a type A atom. Neutron scattering measures the Fourier transform of this function.



CONSTRAINTS AND TEXTURES

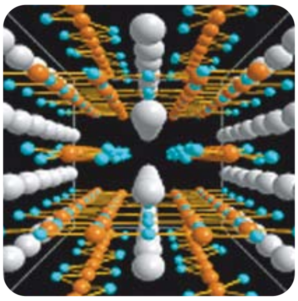
If we measure the space variation of the crystal cell parameter, it is possible to make up a 3D mapping of the constraints in a mechanical industrial piece with a resolution of I mm³. Neutrons penetration power enables to set up this mapping for industrial pieces such as engine sumps or plane spars.



Constraint analysis in a wagon wheel
after 1 400 000 km of run

"SINGLE CRYSTAL" DIFFRACTOMETERS (or 4 circles)

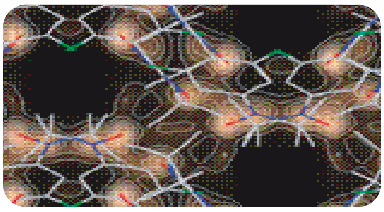
Diffraction spectra obtained on single crystals provide very rich structural and magnetic information. The data acquisition procedure and sample preparation are more complex in this case, but they allow to detect very fine details in magnetic structures.



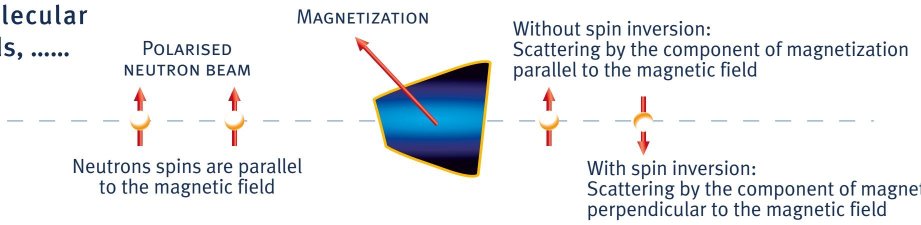
Travelling in the heart of crystal

"POLARIZED NEUTRONS" DIFFRACTOMETERS

Some spectrometers can measure the change of direction of the neutron spin after scattering. This technique enables to determine more accurately the magnetic structures. More generally, it enables to determine the spin density distribution in the core of magnetic crystals, even if the magnetism is quite weak: molecular magnets, new magnetic compounds, ...

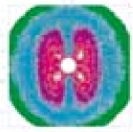


Spin density in molecular magnet

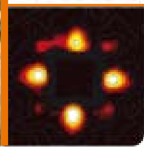


Small angle scattering

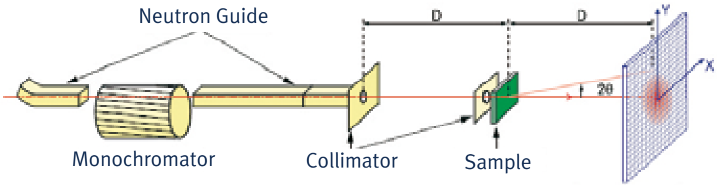
Produced by nano-objects (polymers, micelles, vesicles, proteins, precipitates, critical fluctuations, vortex ....) small angle neutron scattering (SANS) enables to measure the size of the scattering objects (between ~0.1 et ~100 nm).



SANS spectra produced by the the relative shift between hard particles in a polymer matrix under stretching



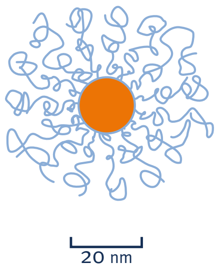
Scattering by a vortex lattice (vortex = lines of normal phase in a type II superconductor under magnetic field)



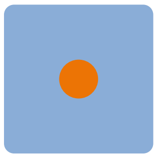
Contrast variation technique

To study the soft matter, the big difference in scattering amplitude between H and D isotopes allows:

- To emphasize one labelled element among the others,
- In a composite object, to cancel the contrast between the solvent and one component and consequently to make it invisible.



The H/D proportion makes the solvent “orange”; only the “hairs” scatter.



The H/D solving mixture is“blue”: neutrons only see the core.

Polymer “hairs” attached to a silica ball
(different colours show different “scattering densities”).

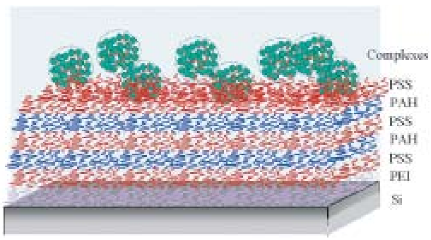
Reflectrometry: structure and magnetism of surface and interface

The study of layers from 1 to 100 nm of thickness, in the vicinity of an interface between two materials, is possible by neutrons reflectrometry. One can measure:

- **A composition profile.**
- **A surface roughness.**
- **The apparition of stratification of layers.**
- **.......**

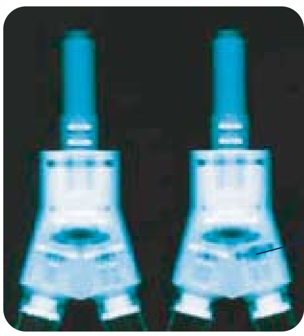
The use of a polarized incident beam provides access to the magnetism within the thin layers: surface magnetism, magnetic coupling between thin layers, interface magnetism, without forgetting the nano-objects from spintronics.

Biochips elaboration:
Adsorption of complex protein- polyelectrolyte on silicon.



Neutronography

Similar in its principle to a test by X-ray, the neutron radiography provides specific information: for example, to visualise elements containing hydrogen in metallic structures.

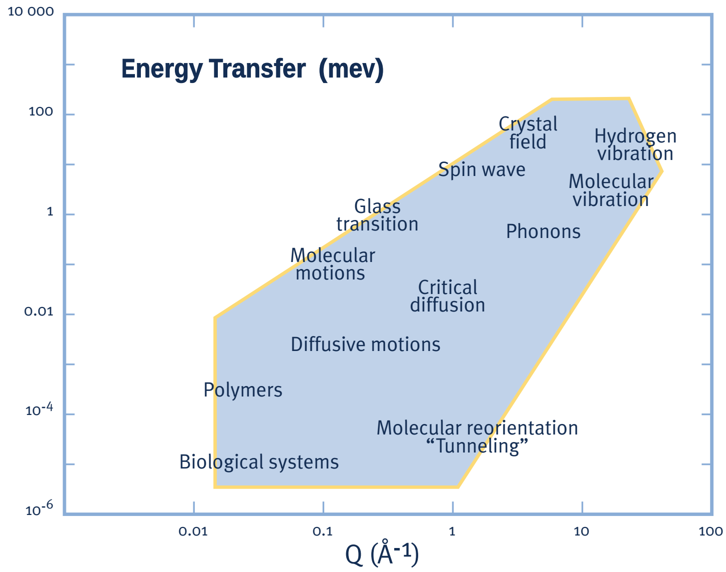


Neutron radiography of Ariane pyrotechnics jack;
a rubber joint is missing

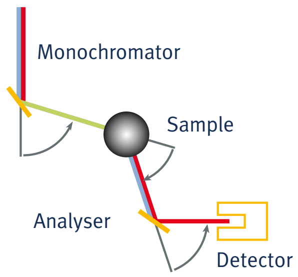
Inelastic Diffraction

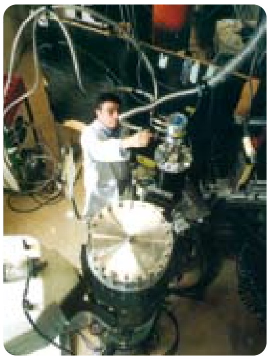
analysis of neutron energy change during the scattering process gives information about the atomic and magnetic excitations in the sample. Determining an excitation is to define its nature and the relationship between its energy and its momentum (dispersion relation).

Opposite: energy plane, wavevector (notice the double logarithmic scale) for the different excitations met in the condensed matter and measured by neutron scattering.



"Three axes" spectrometers

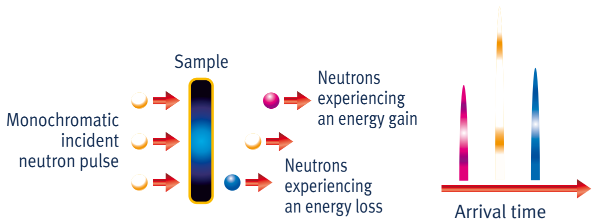




The monocromator can select a wavelength thanks to the Bragg reflexion. Due to the inelastic scattering process, the beam that emerges from the sample will become polychromatic.Through sideways sweeping, the analyzing crystal reflects successively each wavelength towards the counter. The term "three axes" refers to the monochromator, sample, and analyser rotation axes.

This technique is, for example, well adapted to drawing lines of collective excitation scattering : phonons, magnons, etc ...

"Time of flight" spectrometer



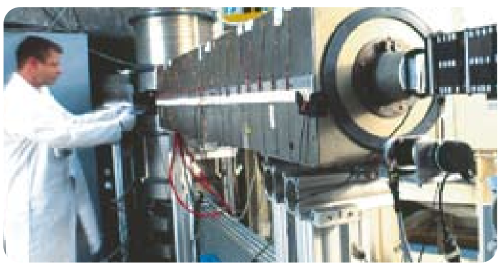
A "pulse" of monochromatic neutrons is sent to the sample. Due to inelastic scattering in the sample, the neutrons which gain or lose energy see their velocity increased or reduced respectively. By measuring the arrival time of each neutron in a detector located at a known distance, we can deduce its velocity change, and consequently its energy exchange with the atoms of the sample.

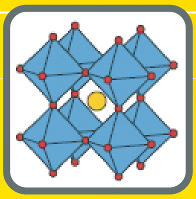
This technique is well adapted to the characterization of individual movements, vibrations, rotations or translations, of elements having a high incoherent scattering like hydrogen: molecular crystals, polymers, biological molecules ...

"Spin echo" spectrometer

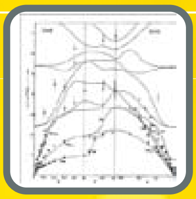
The neutron spin precession in a magnetic field (Larmor precession) provides us with a very accurate chronometer. This effect will enable to measure the change in velocity, (i.e. of the neutron energy) while scattering.

This very accurate technique enables to measure energy changes of only a few nano-eV such as the ones encountered in some phase dynamic transitions, in polymeric, or biological system.

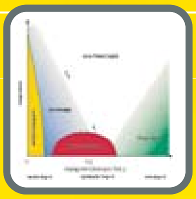




Crystal Structure

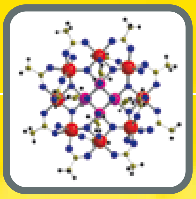


Collective excitations
Scattering relationship

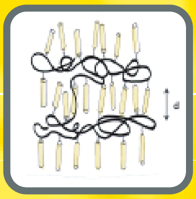


Superconductivity

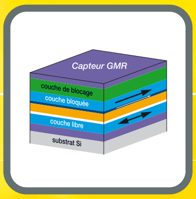
Magnetic interaction



Molecular agregate



Liquid crystals



Magnetic multilayer

Biophysics

Pharmaceutical
products

Mechanical constraints

Metallurgy:
Micro-structure

Composite materials

On Saclay Plateau,

In an exceptional Scientific environment

(SYNCHROTRON, SOLEIL, CNRS Laboratories, CEA, ORSAY University)

The LLB welcomes you

Occasional experiments:
Submission dates: April 1^{st} and October 1^{st}

Post-doctoral training

Sabbatical Year

Thesis preparation
- *Magnetism and superconductivity*
- *Structure and phase transition*
- *Material sciences and industrial applications*
- *Physico-chemistry: soft matter, polyelectrolytes,*
- *Grafted molecules, ...*
- *Biology.*
- ....

Short Training:
- *FAN of LLB, Seminars and courses in laboratories*
And teaching modules with the collaboration of SFN (French Society of Neutronics).

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