Laboratoire Léon Brillouin

Orphée à la Lyre, 1957

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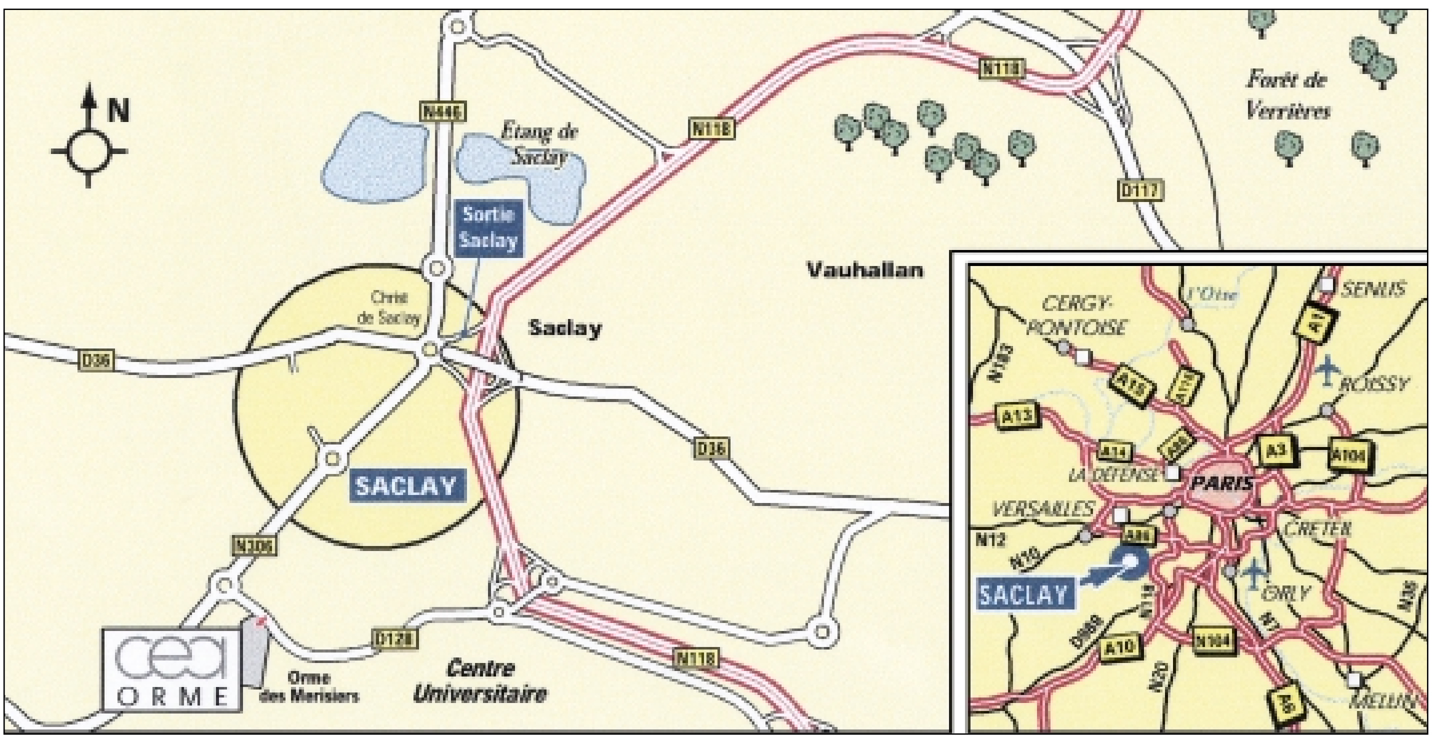


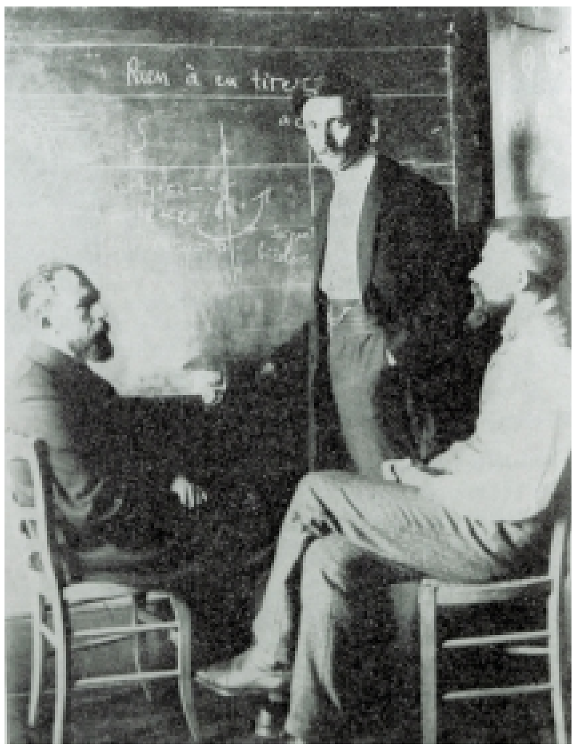
The Laboratoire Léon Brillouin

Neutron spectroscopy first appeared in the United States at the end of World War II, making use of the reactors built in conjunction with the Manhattan project.

The technique quickly proved to be a powerful means of investigating condensed matter and, in spite of its high cost, gradually saw expanded use throughout the world; in France, with the EL3 reactor at Saclay (1957) and with the Mélusine and Siloé reactors in Grenoble (1959).

In 1972, the start up of the High Flux Reactor at the Laue Langevin Institute (originally a Franco-German effort, later to be joined by the British) gave a powerful impetus to the development of this technique.

In order to preserve and develop the vitality of France in this field, the CEA and the CNRS decided in 1974 to create a joint laboratory charged with the construction and operation of several neutron spectrometers. The vocation of this laboratory was to make these tools available to the French scientific community as well as to develop its own research programs.



Léon Brillouin (standing) at the Ecole Normale Supérieure, with Beauvais and Perrot (1910).

The decision to construct a specialised reactor, optimised for the production of neutron beams, was made in 1976.

The reactor «Orphée» went critical in December 1980. Since that time, the «Laboratoire Léon Brillouin» has evenly balanced its two missions: to design and to ensure the evolution of high performance spectrometers; to develop contacts with a significant number of French laboratories, either in the form of scientific collaborations, or by welcoming and helping visiting teams of researchers to perform experiments. Moreover, for the last ten years, the Laboratory has actively promoted the participation of other European countries.

In 1997, the LLB welcomed around 750 visitors, and nearly 400 experiments were completed on its 25 operating spectrometers. Approximately 20% of the proposals for experiments originated from non-French laboratories within the European Union.

The neutron

The hypothesis of the existence of a neutral particle similar in mass to the proton, was formulated in 1920 by Rutherford as the result of four important earlier discoveries: the periodic table of elements (Mendeleev, 1869); the theory of natural radioactivity (Becquerel, 1896; P. and M. Curie, 1898); the discovery of the atomic nucleus and the planetary model (Bohr, 1913); the theory of artificial transmutation (Rutherford, 1919). This hypothesis explains why, when the atomic number is increased by one, the mass of the corresponding atom changes by about two times the mass of the proton. In 1930, Bothe and Becker observed that, if a beam of alpha particles bombards beryllium, the resulting radiation is more penetrating than any previously known radiation and can still be detected even after crossing 10 cm of lead. J. Chadwick, a student of Rutherford, showed in 1932 that this radiation consists of heavy particles, with no electrical charge: the neutron.

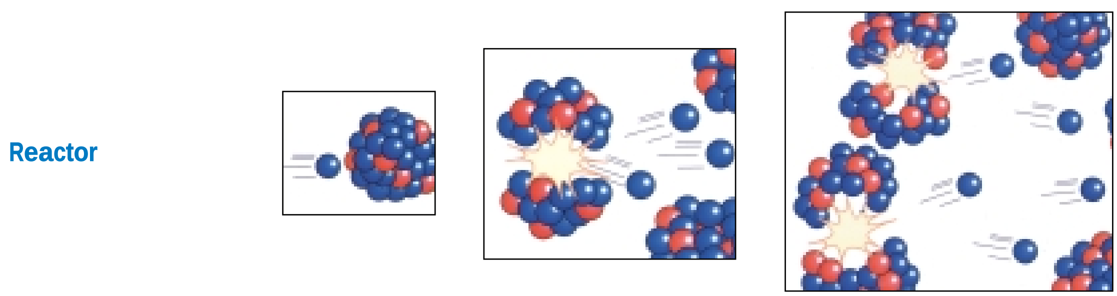
Nuclear reactors

The fission of the uranium atom, that is to say its breaking up into two fragments after having absorbed a neutron, was demonstrated in 1938 (I. Joliot-Curie, O. Hahn). The emission of excess neutrons during this process was subsequently observed and, as a consequence, the fission of other uranium nuclei...and the possibility of a «chain reaction» (F. Joliot, Halban, Kowalski, 1939).

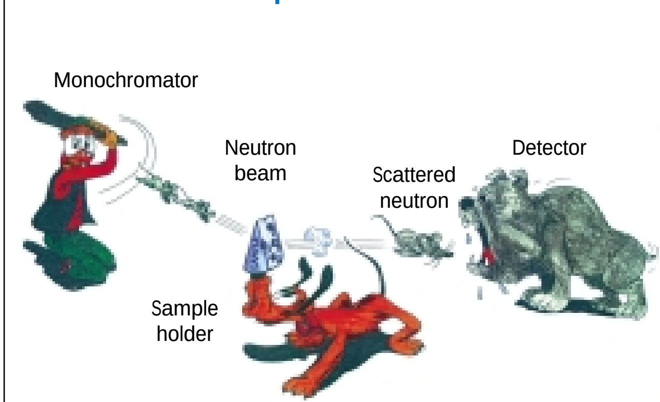
As sources for neutrons, non-military reactors may be categorised as follows:

- those intended to produce electricity. The goal is to maximise the amount of heat produced, in other words the total number of atoms that split per second. The core is not very concentrated (natural or slightly enriched uranium) but does occupy a substantial volume.
- those intended to produce a high flux of neutrons, either of high energy for the irradiation of materials (used in technological research), or «thermal» for outgoing beams (used in neutron scattering for basic or applied research). It is the specific power, in other words the number of atoms per cm^3 that split per second, which is to be maximised. The core is normally very compact and highly enriched with fissile uranium (^{235}U).

An other method exists for producing intense neutron beams : by knocking heavy atoms (Pb, Hg, ...) with high energy protons, the excitation state of the nucleus is such that they relax with emission of neutrons. It is the principle of the spallation sources.



Fission and a chain reaction



Scattering configuration in real space

Neutron scattering: direction for use

Neutron spectroscopy is typically done at large scale facilities where, as is the case of the « Laboratoire Léon Brillouin », scientists, engineers and technicians work jointly to perform experiments with thermal neutron scattering in a variety of fields.

In this laboratory, our sponsoring agencies (the CNRS and the CEA) have chosen to maintain basic and technological research activities as well as to provide a service to external users. Each year, numerous Ph.D. are defended at the LLB and countless results are obtained by visiting researchers, who come here from both French and foreign laboratories.

This document has been designed for the young (and not so young) scientist, so that he or she may discover the mysteries of thermal neutron scattering.

This brochure obviously cannot cover all aspects of neutron scattering. Subjects not included are, for example: the calculation of the scattering function and its links with the correlation functions of the position of the scatterers; the powerful tool represented by the analysis of polarisation ; ....

Books on the scattering of thermal neutrons include:

S.W. Lovesey-*Theory of neutron scattering from condensed matter*-Clarendon Press, Oxford (1984).

M. Bée-*Quasi-elastic neutron scattering*-Adam Hilger, Bristol and Philadelphia (1988).

P.A. Krupchitski-*Fundamental research with polarized slow neutrons*-(translated by V.I. Kisin)-Springer-Verlag, Berlin (1987).

V.F. Sears-*Neutron Optics*-Oxford University Press, New York (1989).

«Hercules» - *Neutron and Synchrotron radiation for condensed matter studies*-Springer-Verlag, les éditions de physique (1993).

Working at the LLB

Our goal

One important mission of the LLB is to encourage the use of neutron spectrometry in the various areas of fundamental and applied research. For this purpose, it is important to keep a high quality research program within the laboratory itself; this in turn requires the ability to receive numerous doctoral and post-doctoral students. Laboratory visits, either for individuals or for groups, are organised on request. Such visits allow one to discover the installation itself, and to develop contacts with the different research teams working on various fields.
The LLB gives, to external teams of scientists, access to its experimental facilities on the basis of a written proposal and scientific selection, in the following cases :
- scientists of french laboratories,
- scientists of european union or associated states, in the frame of E.C. funded access contracts,
- scientists of foreign laboratories preferably having a contractual agreement.

Access for industrials can be directly negociated with the Direction of LLB.

Submission of a proposal

Please contact the Scientific Secretariat of the LLB the first time you would like to submit a proposal; they will send you the appropriate application forms. Submission through the web is also possible. Each year (usually, at the end of november) we plan 4 thematics “Round Table” discussions where external users can meet and discuss with all LLB’s members. Their announcement is made during summer.

A brochure giving the title and dates of each Round Table, and including a participation bulletin, can be sent on simple request to the scientific secretary.

A selection committee is associated with each Round Table; it is composed of scientist representatives from the French and European communities, as well as members of the LLB. The selection is made twice a year (deadline for proposal submission: 1st of april, 1st of october); each proposal is rated:

- A The experiment has been accepted on the basis of its scientific merits and will be scheduled.
- B The experiment has been accepted but may be completed only if sufficient beam time is available.
- C The experiment has not been accepted.

For additional information, please contact:

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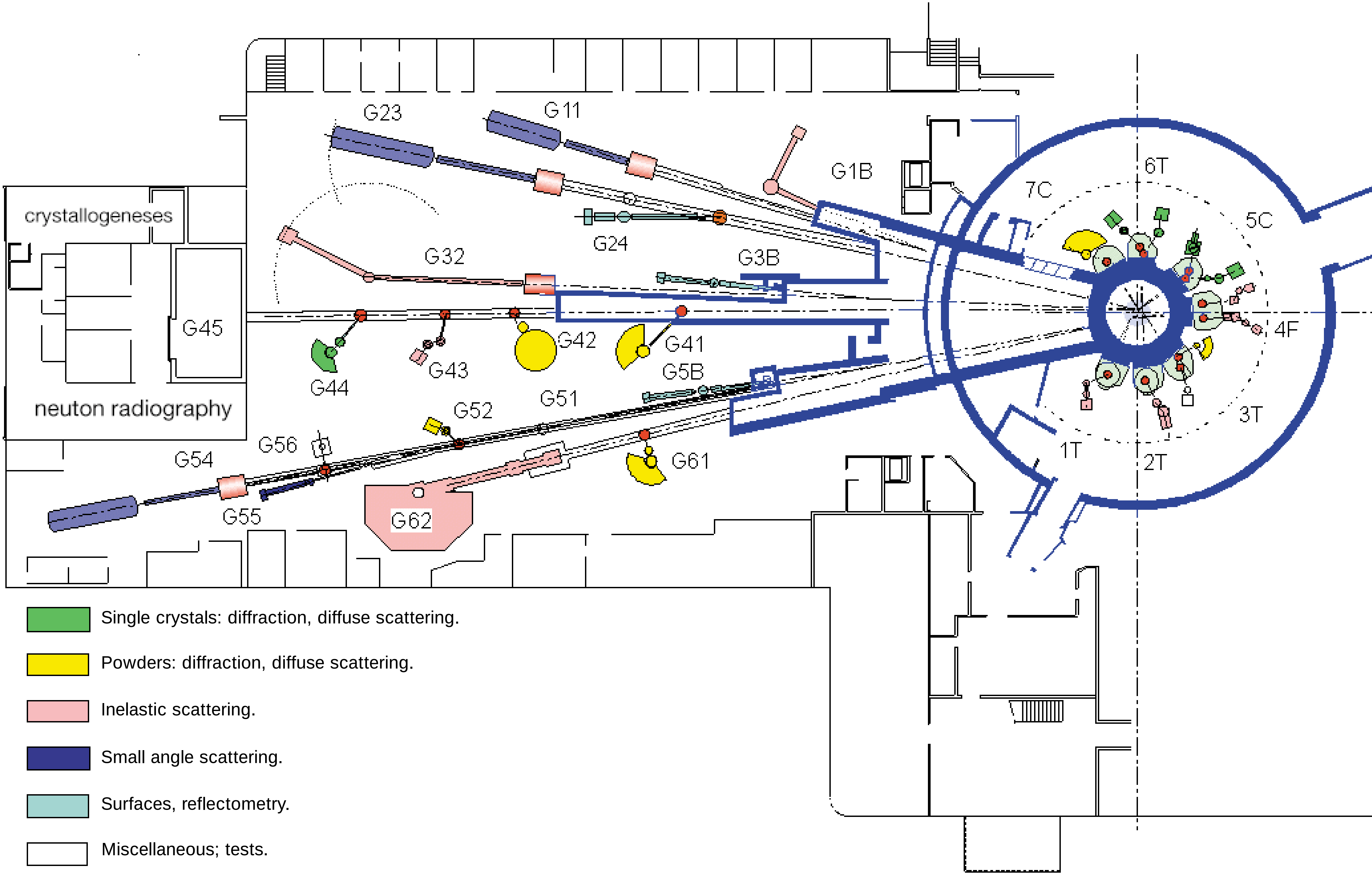
GENERAL LAYOUT OF SPECTROMETERS



Single crystals: diffraction, diffuse scattering.

Powders: diffraction, diffuse scattering.

Inelastic scattering.

Small angle scattering.

Surfaces, reflectometry.

Miscellaneous; tests.

Photo Credits

Front cover	Orphée à la Lyre; 1957 – by Jean Cocteau	©Adagp, Paris 1998
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Page 12	Neutron and X-rays radiography of a pocket calculator	CEA
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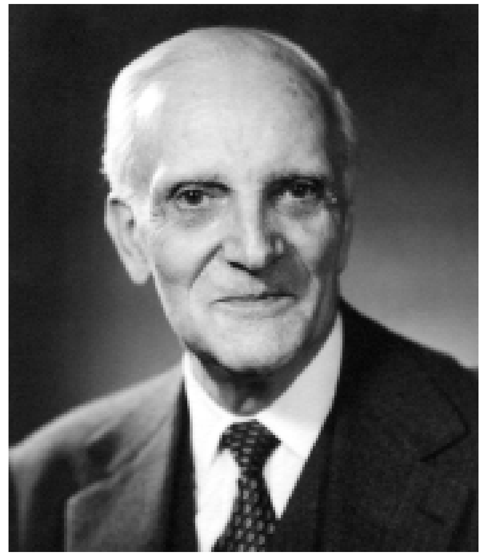
Léon Brillouin
1889-1969



Léon Brillouin, born in Sèvres in 1889, was admitted to the Ecole Normale Supérieure in 1908. In contrast with most young French physicists of the time, Brillouin continued his education (1912) at the Institute of Theoretical Physics in Munich, which was under the direction of A. Sommerfeld. The Von Laue experiment on «the diffraction of Roentgen rays» (X-rays) by a crystal took place there, several months before his arrival. On his return to France (1913), he began a thesis on the theory of solids; he proposed an equation of state based on the atomic vibrations (phonons) that propagate through a solid. He also studied the propagation of monochromatic light waves and their interaction with acoustic waves; he showed that the scattered wave is made up of the sum of three components (Brillouin effect): one at the frequency of the incident wave (ω_0), the two others at frequencies located relative to it ($\omega_0 \pm \Delta\omega$) (Brillouin doublet); their separation is dependent on the scattering angle. It wasn't until ten years later that this theoretical prediction was observed experimentally. His work came to a halt during the First World War (1914-1918); in 1920 Brillouin defended his thesis (Jury: Marie Curie, Paul Langevin, Jean Perrin!).

Thus began for Léon Brillouin a period of great scientific production with major contributions in the «quantum revolution» in several areas of physics:

- he proposed an approximate resolution method of Schrödinger's equation (B.K.W. method: **B**rillouin, **K**ramers, **W**entzel), applied to electrons;
- he modified the theory of paramagnetism (Langevin had provided a «classical» model twenty years earlier) by introducing the quantification of the orbital moment (the Brillouin function, 1927);.
- during the course of his work on the propagation of electron waves in a crystal lattice, he decided to introduce a concept that would be found particularly useful in the theory of crystalline solids: the Brillouin zones (1930);
- he published a series of articles in which he discussed methods for the study of systems with several electrons (Brillouin-Wigner formula).

Along with his research activities, Brillouin also taught. His first position was at the Sorbonne where he was offered the Theoretical Physics Chair in 1928; he then taught at the College de France to which he was elected in 1932.

In August 1939, a month before the declaration of war against Germany, Léon Brillouin, as a specialist of wave propagation, was named director of the French National Radio-diffusion. In May 1940 came the collapse of France; the government and the high administration of which he was a member, retired to Vichy. He remained there for six months before resigning and leaving for the United States where he joined the « France libre » organization. There he participated in the war effort by working in the field of radar at Columbia University in New York. At the end of the war, he decided to stay in the United States where he taught at Harvard and at Columbia; Brillouin was elected to the U.S National Academy of Sciences in 1953. Far from abandoning research, he became involved in a new field: «The Theory of Information». He invented the concept of «Neguentropy» (negative entropy) to demonstrate the similarity between entropy and information, and accordingly, that «Maxwell's Demon» does not violate Carnot's principle. He died in New York in 1969.

Bibliographie :

Les Tenseurs en Mécanique et en Elasticité, Paris 1937, 1949.
Quantenstatistik, Berlin 1931.
Propagation des Ondes dans les Milieux Périodiques, Paris 1956.
La Science et la Théorie de l'Information, Paris 1959.
More information: « Léon Brillouin, A la Croisée des Ondes », R. Mosseri, Belin (1999).