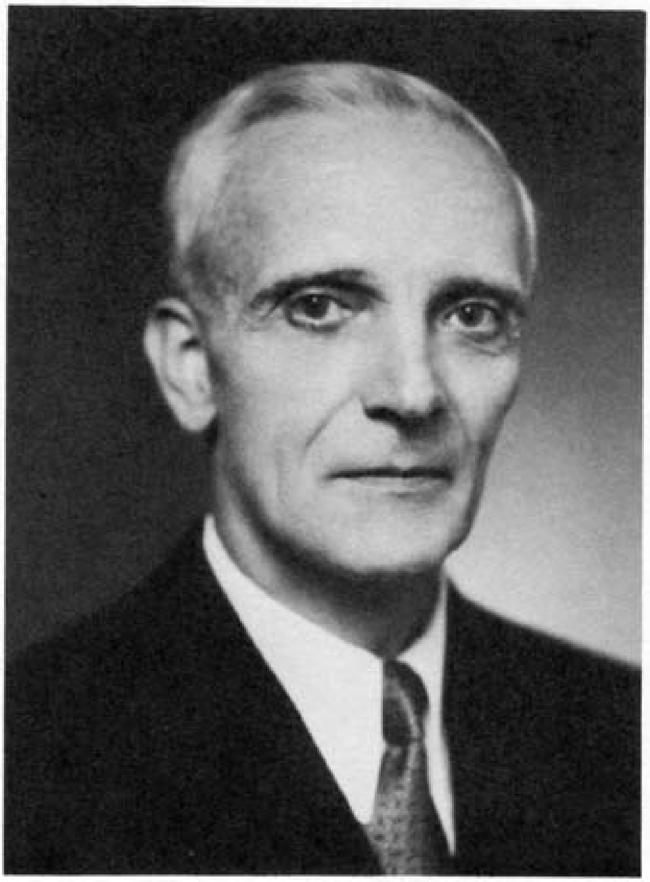
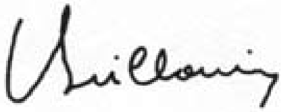
NATIONAL ACADEMY OF SCIENCES

LÉON NICOLAS BRILLOUIN

1889—1969

A Biographical Memoir by
L. HILLETH THOMAS





LÉON NICOLAS BRILLOUIN

August 7, 1889– October 4, 1969

BY L. HILLETH THOMAS

LÉON BRILLOUIN was born on August 7, 1889, at Sèvres, Seine-et-Oise, France. His father, Marcel Brillouin, was a professor of theoretical physics at the Collège de France, and many other members of the family had had academic careers as well. He first met physics in high school ("lycée"), and his interest was captured by a book of Blaise Pascal's letters, which he read at his father's suggestion. He completed his education in Paris at the Lycée Henri IV and the Lycée Louis le Grand. In 1908 he passed the examination for the Ecole Normale Supérieure (University of Paris).

During his undergraduate career he listened to lectures at the Sorbonne and at the Collège de France given by H. Poincaré, P. Langevin (anticipating Einstein's work on the special theory of relativity), H. A. Lorentz, and A. Einstein himself. He worked in 1911 in Perrin's laboratory for a Diplôme d'Etudes on Brownian movement, published as his first scientific paper in 1912. He spent the academic year 1912–1913 studying with Sommerfeld in Munich. Back in Paris, he published notes on the scattering and dispersion of light and on the thermal conductivity and viscosity of monatomic liquids and an important theoretical paper on light diffraction problems discussed by the method of steepest descents (1916).

He was in the middle of his Ph.D. research when the First World War broke out in 1914. He spent the war years, first as a private and then as a lieutenant in the French Signal Corps, in the laboratory of General Ferrié, where he invented the first resistance amplifier and designed and built all sorts of equipment for electrical measurement for radio reception and for control by radio signals. This work was to continue at the French Arsenal at Toulon until 1922, and brought him the French Légion d'Honneur from the navy. The results of his investigations gave rise to numerous papers, published from 1919 on. During this time he also started important theoretical work on the radiation resistance of transmitters, treated by retarded potentials (published in 1922).

After the First World War, Brillouin returned to his Ph.D. work, and in 1928 published his thesis, in which he discussed in detail the interaction of radiation quanta and solids. For this purpose he developed a consistent interpretation of the thermal properties of solids, including their dilatation, and thermal conduction, starting with the specific heat theory of P. Debye and M. Born. He also gave a complete rediscussion of radiation stresses, written in tensor notation. The whole theory, for nonlinear conditions, applied to all kinds of elastic and electric waves. The theory included properties that could be described as Bragg reflections of the EM wave on the wave planes of the elastic wave, with a frequency shift depending on the angle of incidence.

Brillouin lectured on radio at the Ecole Supérieure d'Electricité from 1921 to 1931. He published many papers extending the theory of the interaction of radiative quanta and matter during this time, including scattering at sum and difference frequencies, the Brillouin doublet, which anticipates the Raman effect.

Other papers included a new definition of group velocity, a general discussion of statistical thermodynamics, the extension of the Brillouin doublet theory to the Bragg-Laue spots, relativity and quanta for philosophers, and an attempt to explain viscosity and surface tension in the general theory of his thesis; later came papers on the invention of electronic equipment producing square pulses of known intensity with durations from 10^{-6} to 1 second.

During this period he won international recognition. He was selected as member and secretary of the second, third, fourth, and fifth Solvay Congresses (1921, 1924, 1927, 1930) and attended many international conferences from 1924 on. He became a full professor of theoretical physics at the University of Paris (Institut Henri Poincaré) in 1928, and was a visiting professor at Madison, Wisconsin, in 1928 and at a summer session in 1929 at Ann Arbor, Michigan.

Brillouin entered the field of the new quantum mechanics in 1926 with successive approximations starting from Hamilton-Jacobi theory to build up wave mechanics. The mathematics had first been proposed by H. Jeffries, and Brillouin was followed by Wentzel and Kramers. This JBWK method is of great importance in all applications from quantum chemistry to magnetism, where Brillouin functions extend Langevin's work. He published papers showing how to extend the Bose-Einstein and Fermi-Dirac formulas for statistical equilibrium to nonequilibrium cases. On the same lines he published a book that included the extension of the method of separation of variables from classical to quantum mechanics.

Extending Sommerfeld's application of quantum mechanics to the electron theory of metals, Brillouin published papers that led to the idea of the Brillouin zones. In the next year (1932), he took the chair in the Collège de France, where his father had been teaching for thirty-two years. The very important idea of Brillouin zones, starting with one-dimensional problems soluble with Mathieu-Hill functions, leads in three dimensions to a classification of the quantum states in terms of a three-dimensional set of zones. This applies to any kind of waves of light, EM waves, elastic vibrations, electrons, waves representing any elementary particles, in any three dimensionally periodic structures. This was the germ of the theory extended and described by many authors, including Mott, Jones, and Shockley, over many years.

In the period from 1930 to 1939 he continued much of his earlier work, extending the theory of ideal solids, giving a new discussion of group velocity, discussing perturbation methods for wave mechanics (including the Brillouin-Wigner formula), going on to self-consistent fields under various conditions, and developing the Brillouin theorem for the best possible approximation by the Hartree-Fock method. This avoids much that can be criticized in plasma theory. He wrote many papers explaining and applying the theory of metals in an elementary way and summarizing the work of his doctor's thesis on the Brillouin doublet. He was in charge of the "Agrégation" examinations in 1932, 1933, and 1934 and published discussions of the problems given in them. In 1935 he published papers discussing quantized waves and second quantization.

From 1936 through 1940, he published many papers in applied mathematics, acoustics, and problems of wave propagation and the propagation of any of these through a periodically stratified medium. He founded, with his brother Jacques, *Revue d' Acoustique,* and used it as the vehicle for the publication of a number of his own papers. He considered the diagrams of thermodynamics as a simple example of affine geometry and published a textbook on the subject of tensors. He distinguished surface tension of films from that of liquids and generalized radiation stress theory. He discussed in many papers the guiding of waves, the perturbation of proper vibrations by a changing shape of the boundary, extending the work first presented at the Solvay Conference 1921. He received an honorary fellowship of the Indian Academy of Sciences in 1938.

In the spring of 1939, Brillouin spent two months on a lecture tour of the United States, during which he noted the poor reception of the French foreign broadcasts and commented on this when he returned to France. An important paper in which the idea of the magnetron originated was published in 1940. He accepted the position of general director of the French National Broadcasting System and supervised its operation during 1939 and 1940, and oversaw the destruction of broadcasting stations throughout northern France during the German invasion. He escaped to Portugal in January 1941 and landed in New York in May as a visitor to the United States.

Brillouin taught at the University of Wisconsin in 1941 and 1942, at Brown University in Rhode Island in 1942 and 1943. He joined with some French refugees on occasional visits to New York to organize a free French University (The Ecole Libre des Hautes Etudes). He restarted important theoretical work on magnetrons, concluding correctly that the whole space charge would rotate as a fluid mass in a magnetic field, a solution now called the Brillouin flow, an extension of Larmor's method, and later played an important part in plasma theory. When his visitor's visa was changed to an immigration visa in 1943, he joined the Panel of Applied Mathematics at Columbia University, and during the next four years he published some dozen papers on the magnetron. At the same time he returned to war work on antennas, reducing the simplest formulation to an integral equation, and other problems published in three papers. He also published a technical paper on how to build a coil yielding a single dipole moment for an instrument of high precision.

In an important theoretical paper he reconsidered the scattering of electromagnetic waves, which had been discussed in 1905 by Mie and in 1918 by Watson. For a sphere of large radius (α) compared to the wave length (λ), the computed cross section is twice the geometric cross section that would be predicted by geometrical optics. He carefully considered the asymptotic formulas needed, showing that the light scattered at large angles and the light scattered at very small angles each give, at very large distances, a cross section equal to the geometrical cross section, but that to observe this the distance must be at least ($3\alpha^2/\lambda$), so that observation is in general impracticable. This is a typical instance of the lack of convergence of wave mechanics or optics to geometrical mechanics or optics.

After the Second World War, during the summer of 1945, he went to Mexico for a series of lectures and in January 1946 to Harvard, first as a research professor at the Cruft Laboratory and then as Gordon McKay Professor of Applied Mathematics, a position he held until 1946. During these years he was impressed by the first large electromechanical computer (the Aiken-IBM Mark I) and published three papers and an engineering paper showing the impracticability of a heat engine based on a cyclic, heat-generated magnetic circuit.

He published next a whole series of papers on unrelated applications of Mathieu-Hill equations, all more generally using a moving rather than a static field, by successive approximations based on the BWK method and using Floquet's theorem to extend a solution from one period to the next. He then discussed wave guides for slow waves in connection with traveling wave tubes, where the wave velocity is decreased to match the electron velocity.

The mechanism of interaction between waves and electrons traveling together was discussed in several papers pointing out the connection between the traveling wave amplifier, in which an intense electron beam transfers energy to the wave, and the linear accelerator, in which the wave is energetic and energy is transferred from it to a weak beam. In the first case, bunching the large space charge results in a nonlinear problem, in the second the weak bunches are trapped by the waves and progressively accelerated. While at Harvard he started thinking about some important fundamental problems, in particular the meaning of determinism and the applicability of the second law of thermodynamics to living organisms.

He became an American citizen in 1949 and returned to New York as IBM director of electronic education, at first at Poughkeepsie, but moved to the Scientific Computing Laboratory at Columbia University in 1952. He was elected to the National Academy of Sciences in 1953. During this time he seized on C. Shannon's idea that information is related to entropy and developed this into the Neg-entropy Principle of Information. This at once eliminates the paradoxes of Maxwell's and La Place's demons, and the idea was developed in many papers and books. It supplements the Heisenberg uncertainty principle in quantum mechanics and leads to the impossibility of measuring exceedingly small distances of 10^{-13} to 10^{-15} centimeters, at which distances continuous space is found to be physically unacceptable.

He was elected in 1961 to the Académie Internationale de Philosophie des Sciences. He took up the position of adjunct professor at Columbia University in 1954 and held this until his death in 1969. During this time he worked on many problems on the interaction of waves and electrons, leading to a theory of super-conductivity similar to Bardeen's but avoiding some difficulties. He ventured into biophysics, supposing first protein chains could behave like one-dimensional semiconductors. He extended Poincaré's consideration of the nonanalytic nature in practice of the dependence on parameters of systems of many particles. For instance, a displacement of one centimeter of a mass of one gram at the distance of Sirius gives rise to a fractional variation of the earth's field of gravitation of less than 10^{-100}, which is, however, sufficient to prevent us computing the motion of the molecules of a gas for longer than a 10^{-6} second. Such problems are discussed in detail in a paper in 1962, with many simple examples of small changes in an initial parameter leading to large changes.

From then on—in addition to a summary for the Acoustical Society of his results on the birth and growth of Brillouin scattering—he published seven rather mathematical and philosophical papers concerning the connection of special relativity theory with gravitation, the mass of potential energy, and a last paper on the experimental checks of general relativity. He was also working on special problems for the Navy until his death on 4 October 1969.

I knew Professor Brillouin personally from 1949 on and can attest to the kindness and modesty that accompanied his brilliance and intuition. He seems to me one of the greatest applied mathematicians and theoretical physicists of his generation, that of Dirac and Schrödinger. He knew well how to apply his theory to practical engineering problems and was a wonderful teacher. His name is attached to much theory—often many years earlier than its application—including the Brillouin doublet in 1920, the Brillouin-Wentzel-Kramers method in 1926, the Brillouin zones in crystals in 1930, the Brillouin-Wigner formula in 1932, the Brillouin theorem on self-consistent fields in 1933, the Brillouin flow of particles in magnetic fields in 1940, and, last but not least, the connection between neg-entropy and information in 1950.

I AM GLAD TO ACKNOWLEDGE my debt to the 1962 review of his scientific career made by Brillouin himself for the American Institute of Physics project on the History of Recent Physics, of which this memoir is largely a precis, with some small additions.

BIBLIOGRAPHY

Articles Published

1912

Diffusion de granules animés d'un mouvement brownien. Diplôme d'études.

1914

Diffusion de la lumière par un corps transparent homogène. C. R. Séances Acad. Sci., 158:1331–34.

Uber die Fortpflanzung des Lichtes in dispergierenden Medien. Ann. Phys. Ser. 4, 44(10):203–40.

Conductibilité calorifique et viscosité des liquides monatomiques. C. R. Séances Acad. Sci., 159:27–30.

1916

Sur une méthode de calcul approchée de certaines intégrales, dite méthode de col. Ann. Sci. Ecole Norm. Sup. 33(1):17–69.

1919

Mesures électriques en haute fréquence. Soc. Electric.

1920

Le spectre continu des rayons X. C. R. Séances Acad. Sci., 170(5):274–76.

La théorie des solides et les quanta (Thèse de Doctorat). Ann. Sci. Ecole Norm. Sup., 37(12):357–459.

1921

Sur la propagation de la lumière dans un milieu dispersif. C. R. Séances Acad. Sci., 173(23):1167–70.

Thermodynamique et probabilité: révision des hypothèses fondamentales. J. Phys. Radium Ser. 6, 2(3):65–84.

L'agitation moléculaire et les lois du rayonnement thermique. J. Phys. Radium Ser. 6, 2(5):142–55.

1922

Les amplificateurs à résistance. L'Onde Electr., 1:7–17; 101–23.

Diffusion de la lumière et des rayons X par un corps transparent

homogène: Influence de l'agitation thermique. Ann. Phys., 17:88–122.

Sur l'origine de la résistance de rayonnement. Radio Electr., 3(4):147–52.

Les théories d'Einstein et leur vérification expérimentale. Sci. Vie., 63:19–29.

La viscosité des liquides et son interprétation théorique. J. Phys. Radium Ser. 6, 3(9):326–40.

Influence de l'agitation thermique sur la viscosité des liquides: Propagation d'ondes élastiques dans un milieu en mouvement. J. Phys. Radium Ser. 6, 3(10):362–83.

1923

Communications au 3. Conseil de Physique Solvay de 1921. Paris: Gauthier Villars.

With M. G. Beauvais. Les amplificateurs à résistance et les ondes courtes. L'Onde Electr. 2:267–74.

A propos des divers achémas d'amplificateurs. Radio Electr., 4(3):109–13.

1924

With M. Fromy. L'influence du brouillage sur les récepteurs à réaction. L'Onde Electr., 3:181–89; 268–78; 299–313.

Les problèmes de la télémécanique. Rev. Marit., 173.

Réflexion et réfraction des quanta de lumière. C. R. Séances Acad. Sci., 178(21):1696–98.

Amplificateur à résistances pour très courtes longueurs d'onde. Radio Electr., 5(63):256–58.

Les amplificateurs à résistances pour basses fréquences. Radio Electr., 5(64):179–180.

1925

With M. Fromy. Les circuits poly-ondes. L'Onde Electr., 4:371–86; 419–23.

Les tensions superficielles:Interprétation de la relation d'Eotvos. C. R. Séances Acad. Sci., 180(17):1248–51.

Les lois de l'élasticité sous forme tensorielle valable pour des coordinées quelconques. Ann. Phys., 3:251–98.

Les tensions de radiation:leur interprétation en mécanique classique et en relativité. J. Phys. Radium Ser. 6, 6(11):337–53.
Sur les tensions de radiation. Ann. Phys., 4:528–86.

1926

Les spectres de rotation dans la nouvelle mécanique des quanta, avec le calcul des matrices. C. R. Séances Acad. Sci., 182(6):374–76.
La nouvelle mécanique atomique. J. Phys. Radium Ser. 6, 7(5):135–60.
La mécanique ondulatoire de Schrödinger:une méthode générale de résolution par approximations successives. C. R. Séances Acad. Sci., 183(1):24–26.
Sur un type général de problèmes, permettant la séparation des variables dans la mécanique ondulatoire de Schrödinger. C. R. Séances Acad. Sci., 183(4):270–71.
Remarques sur la mécanique ondulatoire. J. Phys. Radium Ser. 6, 7(12):353–68.

1927

Les moments de rotation et le magnétisme, dans la mécanique ondulatoire. J. Phys. Radium Ser. 6, 8:74–84.
With M. Fromy. Les circuits à deux ondes et leurs applications. L'Onde Electr. 6:561–79.
Peut-on déceler directement le moment magnétique de l'électron? C. R. Séances Acad. Sci., 184(2):82–84.
La statistique des quanta de lumière. C. R. Séances Acad. Sci., 184(10):589–91.
Comparaison des différentes statistiques appliquées aux problèmes de quanta. Ann. Phys., 7:315–31.

1928

Les lois de l'élasticité en coordonnées quelconques. In: *Congrès International de Mathématiques à Toronto,* vol. 2, pp. 73–97. Canada: University of Toronto Press.
Les circuits à deux ondes. L'Onde Electr., 7(73):33–39.
A direct experiment to test the hypothesis of the spinning electron. Proc. Natl. Acad. Sci. USA, 14(10):755–63.

1929

Les statistiques quantiques et leur application aux réactions photochemiques. In: *Réunion Internationale de Chimie-Physique. Rapports et Discussions*, pp. 281–297. Paris: Les Presses Universitaires de France.

La théorie électronique des métaux d'après Sommerfeld, et le libre parcours moyen des électrons. C. R. Séances Acad. Sci., 188(3):242–44.

Appareil débitant un courant constant pendant un temps connu, très court. Application à l'électrodiagnostic. Bull. Acad. Sci. USSR, Classe Sci. Physico-Mathémat. Ser. 7, 3:275–96.

1930

Chronaximètre Brillouin-Zimmern. Bull. Off. Soc. Electrothér. Radiol.

With A. Zimmern. Un chronaximètre entièrement électrique. Rev. Cie Gén. Radiol., 8:3.

Un chronaximètre entièrement électrique. Bull. Soc. Phys., 296:120.

Les électrons dans les métaux et le rôle des conditions de réflexion sélective de Bragg. C. R. Seánces Acad. Sci., 191(4):198–200.

Les électrons dans les métaux et le classement des ondes de De Broglie correspondantes. C. R. Séances Acad. Sci., 191(6):292–94.

Les électrons libres dans le métaux et le rôle des réflexions de Bragg. J. Phys. Radium Ser. 7, 1(11):377–400.

1931

Titres et Travaux Scientifiques. Niert: Imprimerie Poitevine. 56 pp.

Elasticité agitation thermique et fusion des corps solides. C. R. Séances Acad. Sci., 192(11):668–69.

1932

Propagation des ondes électromagnétiques dans les milieux matériels. In: *Proceedings of the International Electrical Congress, Paris, 1932*, vol. 2, pp. 739–88. Paris: Gauthier Villars.

Statistique et magnétisme des électrons libres. C. R. Séances Acad. Sci., 194(3):255–58.

La théorie quantique des corps solides. Scientia, 51:206–15.

With M. Lévy. Sur un montage à réaction indépendante de la fréquence. C. R. Séances Acad. Sci., 194(14):1151–53.

Les problèmes de perturbation et les champs self-consistents. J. Phys. Radium, Series 7, Vol. 3, No. 9, pp. 373–89.

Les électrons libres dans un réseau cristallin. Equation ondulatoire et propriétés magnétiques. J. Phys. Radium Ser. 7, 3(12):565–81.

1933

Le problème d'agrégation de 1932 et sa solution. Bull. Union Physiciens, 27:171–86.

Champs self-consistents et électrons métalliques III. J. Phys. Radium Ser. 7, 4(1):1–9.

Comment interpréter la supraconductibilité. C. R. Séances Acad. Sci., 196(15):1088–90.

Le champ self-consistent pour les électrons liés; la supraconductibilité. J. Phys. Radium Ser. 7, 4(7):333–61.

Les propriétés électriques des métaux et la mécanique ondulatoire. Rev. Gén. Electr., 34(6):163–75; 202–8.

Sur la stabilité du courant dans un supraconducteur. J. Phys. Radium Ser. 7, 4(12):677–90.

Le problème d'agrégation de 1933 et sa solution. Bull. Union Physiciens, 28:169–85.

1934

Les prix Nobel de physique (1932 et 1933). Rev. Gén. Electr., 35(1):3–16.

Le modèle d'atome de Fock-Dirac et l'existence des potentiels d'ionisation. J. Phys. Radium Ser. 7, 5(5):185–92.

Le champ self-consistent de Fock pour les électrons des métaux. J. Phys. Radium Ser. 7, 5(8):413–18.

Les bases de la théorie électronique des métaux et la méthode du champ self-consistent. Helv. Phys. Acta, 7, Suppl. 2:33–46.

Fluctuations de courant dans un conducteur. Helv. Phys. Acta, 7, Suppl. 2:45–67.

Le problème d'agrégation de 1934 et sa solution. Bull. Union Physiciens, 29:168.

Réflexions sur l'infiniment petit:de Pascal à Heisenberg. Rev. Gén. Electr., 36:683.

Les conférences d'Acoustique au Collège de France en mai 1934. Rev. Acoust., 3(1):161.

1935

Propagation des ondes en mécanique ondulatoire:exemple des ondes élastiques. J. Phys., 6:185.
Les ondes physiques transversales en mécanique ondulatoire et l'oscillateur harmonique à quatre dimensions. C. R. Séances Acad. Sci., 200:1725.
Thermodynamique et géométrie affine. J. Phys., 6:359.
Comment les physiciens envisagent aujourd'hui la constitution de l'atome. Sci. Vie: 293.
Le rôle des surfaces absorbantes dans la propagation du son. Rev. Acoust., 4(4):113–29.
Les conférences d'Acoustique au Collège de France en 1935. Rev. Acoust., 4(4):178.
Les théorie des électrons dans les métaux:la supraconductibilité. Rev. Gén. Electr., 38(15):491–501.
Supraconductivity and the difficulties of its interpretation. Proc. R. Soc. A, 152(875):19–21.

1936

Jubile de M. Marcel Brillouin. Rev. Gén. Electr., 39:307.
La chaleur spécifique des liquides et leur constitution. J. Phys. Radium Ser. 7, 7(4):153–57.
La radiophonie permise par les découvertes de l'Electronique, conférence à Radio-Paris. Cahiers Radio-Paris, 7:139.
Diffusion de la lumière par les liquides. Bull. Soc. Fr. Phys., 382:15.
Les filtres électriques et la théorie des matrices. Rev. Gén. Electr., 39(1):3–16.
Les filtres électriques et la théorie des matrices. Bull. Soc. Fr. Electr. Ser. 5, 6(63):348–50.
Les pressions et tensions de radiation. Rev. Acoust., 5(3 & 4):99–111.
Propagation des ondes électromagnétiques dans un tuyau. Rev. Gén. Electr., 40(8):227–39.
La théorie des matrices et la propagation des ondes. J. Phys. Radium Ser. 7, 7(11):401–10.

1937

On thermal agitation in liquids. Trans. Faraday Soc., 38, Part 1:54–57.

Sur les càbles téléphoniques (discussion with M. L. Simon). Bull. Soc. Fr. Electr. Ser. 5, 7(75):329–30.

Perturbation d'um problème de valeurs proprce. C. R. Séances Acad. Sci., 204(25):1863–65.

Vatskornas byggnad är höljd:dunkel. In: *Olösta gator aktuilla Problem*, p. 49. Stockhölm: Wahlström.

Nouveaux dispositifs de charge des lignes téléphoniques à bandes passantes multiples. Rev. Gén. Electr., 42(25):771–78. (Also in Rev. Gén. Electr., 42(26):803–16.

1938

Le rôle des irrégularités sur les cables. Ann. Post. Télégr. Téléph., 27:296–321.

Les irrégularités des câbles coaxiaux téléphoniques et pour télévision. Rev. Commun. Electr., 17:162.

Etude théorique des câbles diélectriques. Rev. Commun. Electr., 16:170.

Theoretical study of dielectric cables. Electr. Commun., 16(4):350–72.

Irregularities in telephone and television coaxial cables. Electr. Commun., 17(2):164–87.

Propagation des ondes sur les câbles diélectriques (discussion du rapport). Bull. Soc. Fr. Electr. Ser. 5, 7(4):899–932.

Nécessité de distinguer deux définitions différentes de la tension superficielle. J. Phys. Radium Ser. 7, 9(11):462–4.

On thermal dependence of elasticity in solids. Proc. Indian Acad. Sci., 8(5A):251–4.

On thermal dependence of elasticity in solids. Phys. Rev., 54(11):916–17.

1939

Récents développements relatifs à la propagation des ondes electromagnétique: guidées. Union Int. Cont. Cancer Acta: 135.

Individuality of elementary particles. Quantum statistics. Pauli's principle. New theories in physics. In: *International Institute of Intellectual Cooperation Warsaw Congress. 1938*, pp. 119–71. IIIC: Paris.

L'Acoustique d'une salle. Cahiers Radio-Paris, 10:422.
Propagation des ondes sur les cables diélectriques (discussion du rapport). Bull. Soc. Fr. Electr. Ser. 5, 9(98):207–10.
Le tuyau acoustique comme filtre passehaut. Rev. Acoust., 8:1.
Quelques questions de physique moderne et leur application à la technique industrielle. Tech. Mod., 31:1.
On thermal dependence of elasticity in solids. Phys. Rev., 55(11):1139 (A).
Acoustical wave propagation in pipes. J. Acoust. Soc. Am., 11(1):10.

1940

Influence de la température sur l'élasticité d'un solide. In: *Mémorial des Sciences Mathématiques*. Fascicule 99. Paris: Gauthier Villars, 65 pp.
Hyperfrequency waves and their practical use. J. Franklin Inst., 229(6):709–36.
La théorie du magnétron. J. Phys. Radium Ser. 8, 1(7):233–41.

1941

Theory of the magnetron. Electr. Commun., 20(2):112–21.
Theory of the magnetron. Phys. Rev., 60(5):385–96.
Hyperfrequency waves and their practical use. Electr. Commun., 19(4):118–30.

1942

Theory of the magnetron. Phys. Rev., 61(1–2):103(A).
Theory of the magnetron. Oscillations in a split-anode magnetron. Phys. Rev., 62(3–4):166–77.

1943

Theory of the magnetron. Phys. Rev., 63(3–4):127–36.
The antenna problem. Q. Appl. Math., 1(3):201–14.

1944

Practical results from theoretical studies of magnetrons. Proc. IRE, 32(4):216–230.
Transit time and space change in a plane diode. Electr. Commun., 22(2):110–23.

Antennae for ultra-high frequencies—Wide band antennae. Electr. Commun., 21(4): 257–81.

Antennae for ultra-high frequencies—Wide band antennae. Electr. Commun. 22(1):11–39.

A theorem of larmor and its importance for electrons in magnetic fields. Proc. Natl. Electron. Conf., 1:489–99.

1945

Electron trajectories in a plane diode—A general result. Electr. Commun., 22(3):212–16.

Madame Curie. Répub. Fr., 2:6.

Science Française et science Américaine. Répub. Fr., 2:25.

A theorem of larmor and its importance for electrons in magnetic fields. Phys. Rev., 67(7–8):260–66.

1946

Influence of space charge on the bunching of electron beams. Phys. Rev., 70(3–4):187–96.

Electron trajectories in a plane single-anode magnetron—A general result. Electr. Commun., 23(4):460–63.

1947

Les grandes machines mathématiques américaines. Ann. Télécommun. 2:329.

Les grandes machines mathématiques américaines. Atomas, 21:400–04.

1948

Electromagnetic delay lines. In: *Proceedings of a Symposium on Large Scale Digital Calculating Machinery, Cambridge,* Annals of the Computation Laboratory of Harvard University, vol. 16, pp. 110–24. Cambridge: Harvard University Press.

A practical method for solving Hill's equations. Q. Appl. Math., 6(2):167–78.

Waves and electrons traveling together. A comparison between traveling wave tubes and linear accelerators. Phys. Rev., 74(1):90–92.

With H. Iskenderian. Thermomagnetic generator. Electr. Commun., 25(3):300–11.

Wave guides for slow waves. J. Appl. Phys., 19(11):1023–41.

1949

Einstein fête ses 70 ans. France-Amérique.
Life, thermodynamics and cybernetics. Am. Sci., 37:554–68. (Reprinted in trans.: Kagaku, 20:216; Die Amer. Rund., 6:38.)
Interaction between waves and electrons traveling together. Am. Phys. Soc. NY, 13:59.
The scattering cross section of spheres for electromagnetic waves. J. Appl. Phys., 20(11):1110–24.
The traveling-wave tube (discussion of waves for large amplitudes). J. Appl. Phys., 20(12):1196–206.

1950

Thermodynamics and information theory. Am. Sci., 38:594.
The B.W.K. Approximation and Hill's Equation, II. Q. Appl. Math., 7(4):363–80.
Le cerveau et la machine. Nouv. Litt., 5.
Can the rectifier become a thermodynamical demon? (letter). Phys. Rev., 78(5):627–28.

1951

Electronic theory of the plane magnetron. In: *Advances in electronics,* vol. 3, pp. 85–144. New York: Academic Press.
With F. Bloch. Electronic theory of the cylindrical magnetron. In: *Advances in Electronics,* vol. 3, pp. 145–81. New York: Academic Press.
Maxwell's demon cannot operate: Information and entropy. I. J. Appl. Phys., 22(3):334–37.
Physical entropy and information. II. J. Appl. Phys., 22(3):338–43.
Information theory and most efficient codings for communication or memory devices. J. Appl. Phys., 22(9):1108–11.

1952

La vie, la pensée et la physico-chimic. Cah. Pléiade, 13:147–78.

1953

Principe de Néguentropie pour l'information. In: *Louis de Broglie, Physicien et Penseur,* pp. 359–68. Paris: Editions Albin Michel.
The negentropy principle of information. J. Appl. Phys., 24(9):1152.

On the Theory of the Magnetron—Symposium on Electron Physics. Washington, D.C. National Bureau of Standards, Circular 527.

1954

Negentropy and information in telecommunications, writing and reading. J. Appl. Phys., 25:595.

Information theory and uncertainty principle. J. Appl. Phys., 25:887.

1955

Interaction between waves and electrons. Proc. Natl. Acad. Sci. USA, 41:401.

Science et information. Nouv. Rev. Fr., July: 12 pp.

Entropy and growth of an organism. Ann. NY Acad. Sci., 63(4):454.

Peut-on déceler l'action des ultrasons sur les électrons. Congr. Intl. Ultrasons, 9.

1956

Les pressions de radiation et leur aspect tensoriel. J. Phys., 17:379.

The problem of computing. Conv. Automat. (Milan): group 1.D.

Solitaire ou embrigadé. Nouv. Rev. Fr.: 866.

1957

Poésie mathématique et théories physiques. Nouv. Rev. Fr.: 316.

Interaction d'ondes et électrons, la supra-conductivité. J. Phys., 18:331.

1958

Mirages de supraconductivité. J. Phys., 19:112.

Encore la supraconductivité. J. Phys., 19:184.

Inevitable experimental errors, determinism and information theory. Inf. Control, 2:45.

Information theory and the divergent sums in physics. Ann. Phys., 5:243.

Physics and information theory. Dsch. Phys. Tag., Essen (Oct.): 140–51.

Mathematics, physics and information. Inf. Control, 1:1.

1959

Information theory and its applications to fundamental problems in physics. Nature, 183:501.

1960

Poincaré and the shortcomings of the Hamilton-Jacobi method for classical or quantized mechanics. Arch. Ration. Mech. Anal., 5:76–94.

1961

Science et imagination. Nouv. Rev. Fr. (May).

Thermodynamics, statistics and information. Am. J. Phys., 29:318–78.

Discussion du rôle effectif des discontinuités de Poincaré. Séminaire Janet (Mécanique), Institut H. Poincaré, Paris, No. 1:1-01–1-06.

Molécules géantes et semi-conducteurs (Mécanique ondulatoire et biologie moléculaire). Cah. Phys. Rev. Opt., 157–69.

1962

Empirical laws and physical theories; the respective roles of information and imagination. In: *Conference on Self-Organizing Systems (COSOS), May 1962.*

Giant molecules and semi-conductors. In: *Horizons in Biochemistry.* New York: Academic Press.

Poincaré's theorem and uncertainty principle in classical mechanics. Inf. Control.

1964

The enigma $E = mc^2$: Potential energy and renormalization of mass. J. Phys. (France), 25(10):883–86.

Potential energy and its mass. C. R. Acad. Sci. (France), 259(15):2361–62.

1965

The actual mass of potential energy, a correction to classical relativity. Proc. Natl. Acad. Sci. USA, 53(3):475–82.

The actual mass of potential energy II. Proc. Natl. Acad. Sci. USA, 53(6):1280–84.

1966

Does a gravity-spectral effect exist? C. R. Acad. Sci. B (France), 263(13):755–56.

1967

Cosmic red shift and interstellar thermal radiation. C. R. Acad. Sci. B (France), 263(12):669–71.

General relativity theory of gravitation and experiments. Proc. Natl. Acad. Sci. USA, 57(6):1529–35.

BOOKS PUBLISHED

1923

La Théorie des Quanta et l'Atome de Bohr. Paris: Presses Universitaires. 181 pp.

1928

With L. de Broglie. *Selected Papers on Wave Mechanics.* London: Blackie & Son. 150 pp.

1930

Les Statistiques Quantiques et leurs Applications aux Electrons. Actualities scientifiques et industrielles, No. 15. Paris: Hermann. 44 pp.

La Théorie des Quanta, 2d ed., II. *Les Statistiques Quantiques et leurs Applications.* Paris: Presses Universitaires. 404 pp.

1931

Quantenstatistik, vol. 13, Struktur der Materie. Berlin: Springer. 530 pp.

La Théorie des Quanta, 2d ed., I. *L'Atome de Bohr; la Mecanique Analytique et la Quanta; les Spectres de Multiplets.* Paris: Presses Universitaires. 364 pp.

1932

Notions de mécanique ondulatoire, les méthodes d'approximation. Actualities scientifiques et industrielles, No. 39. 35 pp.

1933

La Diffraction de la Lumière par les Ultrasons. Actualities scientifiques et industrielles, No. 59. 32 pp.

La Méthode du Champ Self-consistent. Actualities scientifiques et industrielles, No. 7. Paris: Hermann. 47 pp.

1934

With H. Armagnat. *Les Mesures en Haute Frequence.* (Rev. ed.: Cours de l'Ecole Superieure d'Electricite, 1934.) Paris: Chiron. 200 pp.

Les Electrons dans les Metaux, du Point de Vue Ondulatoire. Actualities scientifiques et industrielles, No. 88. Paris: Hermann. 35 pp.

Conductibilite Electrique et Thermique des Métaux. Actualities scientifiques et industrielles, No. 89. Paris: Hermann. 75 pp.

Les Champs Self-consistents de Hartrée et de Fock. Actualities scientifiques et industrielles, No. 159. Paris: Hermann. 37 pp.

L'Atome de Thomas-Fermi et la Méthode du Champ Self-consistent. Actualities scientifiques et industrielles, No. 160. Paris: Hermann. 46 pp.

1935

Jubile de M. M. Brillouin pour son 80'ième Anniversaire. Paris: Gauthier-Villars. 440 pp.

Notions Elémentaires de Mathématiques pour les Sciences Expérimentales (2d ed., 1938; 3d ed., 1947). Paris: Masson A. Cie. 284 pp.

Jubilé Scientifique de M. M. Brillouin. Paris: Gauthier-Villars. 40 pp.

1937

Cours de Physique Théorique: Les Tenseurs en Mécanique et en Elasticité (2d ed., 1949). Paris: Masson A. Cie. 370 pp.

La Structure des Corps Solides dans la Physique Moderne. Actualities scientifiques et industrielles, No. 549. Paris: Hermann. 53 pp.

1938

La Théorie de la Diffraction de la Lumière par les Ultrasons. Actualities scientifiques et industrielles, No, 718. Paris: Hermann. 67 pp.

1940

Mémorial des Sciences Mathématiques No. 99. Influence de la Température sur l'Elasticité d'un Solide. Paris: Gauthier-Villars. 65 pp.

1946

Wave Propagation in Periodic Structures. New York: McGraw-Hill. 247 pp.

1953

Wave Propagation in Periodic Structures, 2d ed. New York: Dover. 255 pp.

1956

Science and Information Theory. New York: Academic Press. 320 pp. (2d ed., 1961)

With M. Parodi. *Propagation des Ondes dans les Milieux Périodiques.* Paris: Masson A. Cie. 347 pp.

1959

La Science et la Théorie de l'Information. Paris: Masson A. Cie. 302 pp.

Vie, Matière et Observation. Paris: Albin. 246 pp.

1960

With A. Sommerfeld. *Wave Propagation and Group Velocity.* New York: Academic Press. 154 pp.

1963

Tensors in Mechanics and Elasticity, trans. R. Brennan. New York: Academic Press.

1970

Relativity Re-examined. London: Academic Press. 111 pp.