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(*b*. Langford Grove, near Maldon, Essex, England, 12 November 1842; *d*. Terling Place, Witham, Essex, England, 30 June 1919),

experimental and theoretical physics.

Lord Rayleigh (as he is universally known in scientific circles) was one of the greatest ornaments of British science in the last half of the nineteenth century and the first two decades of the twentieth. A peer by inheritance, he took the unusual course of devoting himself to a scientific career and maintained his research activity continuously from the time of his graduation from Cambridge University in 1865 until almost literally the day of his death. Rayleigh’s investigations, reported in 430 scientific papers and his monumental two-volume treatise *The Theory of Sound* (1877–1878), covered every field of what in the twentieth century is commonly referred to as “classical” physics; at the same time he kept abreast of, and made incisive critical comments on, the latest developments of quantum and relativistic physics. Not in any sense a pure mathematician, Rayleigh applied mathematics with great skill and accuracy to a host of problems in theoretical physics. In addition he was an ingenious and resourceful experimentalist, with the uncanny ability to extract the most from the simplest arrangements of apparatus. The discovery and isolation of argon, usually considered by the lay public as his greatest scientific achievement, was a triumph of both careful logical reasoning and patient and painstaking experimentation.

At Cambridge, Strutt became a pupil of the mathematician E. J. Routh and profited greatly from his thorough coaching. This and the inspiration gained from the lectures of Sir George Stokes, at that time Lucasian professor of mathematics, paved the way in part at least for Strutt’s emergence as senior wrangler in the mathematical tripos as well as Smith’s Prizeman. He became a fellow of Trinity College, Cambridge, in 1866; and from that time on, there was no doubt that he was headed for a distinguished scientific career.

Strutt varied the usual custom of a tour of the Continent after graduation with a visit to the United States, then recovering from the Civil War. On his return to England in 1868 he purchased a set of experimental equipment and proceeded to carry out some investigations at the family seat in Terling Place. This was the genesis of the famous laboratory in which most of his later scientific work was done. Strutt early formed the habit of getting along with very simple scientific apparatus and made much of it himself. It is clear that he was considered somewhat of a freak by members of his family and friends for his determination not to be contented with the life of a country gentleman. It is equally clear that Strutt did not feel he was violating any strongly entrenched custom. He simply wanted to be a scientist; and with typical British stubbornness he pursued this course, feeling that there was nothing unusual or blameworthy in his action.

In 1871 Strutt married Evelyn Balfour, sister of Arthur James Balfour, who became a celebrated scholar, philosopher, and statesman. A serious attack of rheumatic fever occurred shortly after the marriage, and as a recuperative measure Strutt undertook a trip up the Nile. It was on this journey that the *Theory of Sound* had its genesis, although the first volume was not completed and published until 1877. Shortly after returning to England in 1873, Strutt succeeded to the title and took up residence at Terling. He then began serious experimental work in the laboratory attached to the manor house. He had already developed considerable theoretical interest in radiation phenomena and had published papers on acoustics and optics in the late 1860’s and early 1870’s. One of these, on the theory of resonance, extended in important fashion the work of Helmholtz and established Rayleigh as a leading authority on sound. Another paper from this early period resolved a long-staning puzzle in optics, the blue color of the sky. In this research, published in 1871, Rayleigh derived the well-known law expressing the scattering of light by small particles as a function of the inverse fourth power of the wavelength of the incident light. It is of interest to note that in this work he used the elastic-solid theory of light and not the recently introduced electromagnetic theory of Maxwell.

In his laboratory at Terling, Rayleigh embarked on a series of experimental studies of optical instruments that apparently originated in his attempts to manufacture cheap diffraction gratings by photographic means. Although not very successful, these early experiments led him to the very important study of the resolving power of gratings, a matter that was then poorly understood by optical experts. It seems clear that Rayleigh was the first to publish formally a clear defintion of resolving power of gratings, a matter that was the poorly understood by optical experts. It seems clear that Raylegihg was the first to publish formally a clear definition of resolving power of an optical device. He proved that the resolving power of a plane transparent grating is equal to the product of the order of the spectrum and the total number of lines in the grating. This work was continued with a series of fundamental researches on the optical properties of the spectroscope, an instrument that in the late 1870's was becoming increasingly important in the study of the solar spectrum as well as of the spectra of the chemical elements. In his study of optical diffraction and interference, Rayleigh anticipated the French physicist Charles Soret in the invention of the optical zone plate, with its interesting light-focusing property.

During the late 1870's Rayleigh's laboratory in his home at Terling became well established as the seat of his researches, and it appeared likely that he would spend the rest of his career there without serious interruption. The fates decreed otherwise, however, for in 1879 James Clerk Maxwell, the first Cavendish professor of experimental physics at Cambridge, died. Sir William Thomson (later Lord Kelvin), at that time professor of natural philosophy at the University of Glasgow, refused to be considered for the post in succession to Maxwell. Rayleigh, the next obvious choice, accepted the appointment in December 1879–not without some reluctance, since his natural preference was to continue the Terling routine. The professorial salary was not unwelcome, however, in the face of falling revenues from his estate due to the severe agricultural depression then prevailing in Britain.

Rayleigh remained as professor at Cambridge until 1884. Although admittedly not a brilliant lecturer, he was an effective instructor and, moreover, succeeded in putting laboratory instruction in elementary physics on a firm basis. This was a revolutionary accomplishment in England, and the influence of Rayleigh's pioneer efforts was ultimately felt in higher educational institutions throughout the country. A rather elaborate research program was also set up with the help of his assistants Glazebrook and Shaw, both of whom later became scientists of note. This program involved the redetermination of three electrical standards: the ohm, the ampere, and the volt. Work of this sort had already been started by Maxwell for the British Association for the Advancement of Science. Rayleigh's continuation and development demanded the construction of more precise equipment than Maxwell's, as well as meticulous care and patience in its use. When the investigation was completed in 1884, the results stood the test of time remarkably well. The realization of the importance of standards in physical measurements that this work implied undoubtedly influenced Rayleigh favorably toward the establishment of a government standards laboratory in Britain, which eventually (1900) took the form of the National Physical Laboratory at Teddingtown, Middlesex.

In 1884 Rayleigh served as president of the British Association for the Advancement of Science, which held its annual meeting that year in Montreal, the first outside the United Kingdom. It provided the occasion for a second trip to the North American continent, and Rayleigh took advantage of it to increase his acquaintance with prominent physicists in the United States and Canada. Immediately after his return to Britain he resigned his professorship at Cambridge and retired to his laboratory at Terling, which remained his scientific headquarters for the rest of his life. Rayleigh did accept a professorship at the Royal Institution of Great Britain in London, and served from 1887 to 1905. This post, however, involved residence in London for only a short time each year and the presentation of a certain number of lectures on topics of his research interest. It did not seriously disturb the continuity of his research program at Terling.

The late 1880's saw the establishment of a more or less definite pattern of research activity. Preferring to have several irons in the fire at the same time, Rayleigh divided his time rather evenly between experimental work in the laboratory and theoretical investigations in his study. An avidereader of the technical literature, he found the origin of many of his researches in questions suggested to him by his reading. He had an uncanny knack of putting his finger on a weak or difficult point in another man's research results and of building an important contribution of his own on it. Rayleigh's grasp of such widely diverse fields as optics and hydrodynamics, acoustics and electromagnetic theory, was phenomenal; and only Maxwell, Kelvin, and Helmholtz came near him this aspect of his genius.

During the middle and late 1880's Rayleigh's increasing tendency to extend his research net became apparent. His published papers from this period report results of experimental and theoretical work on radiation both optical and acoustical, eletromagnetism, general mechanical theorems, vibrations of elastic media, capillarity, and thermodynamics. To this period belongs his pioneer work on the filtration (selective transmission) of waves in periodic structures, as well as his first precise measurements of the density of gases, which led to the discovery of argon. It was also the period in which Rayleigh apparently first became interested in the problem of the complete radiation law, which governs the distribution of energy in the spectrum of blackbody radiation. His work here was tentative, but he fully recognized the physical significance of this puzzling problem to which Planck, Wien, and others were devoting considerable attention. What is now known as the Rayleigh-Jeans law was first enunicated by Raylkeigh in 1900.

The discovery and isolation of argon was undoubtedly Rayleigh's most dramatic and famous accomplishment. It emerged as the solution to a scientific puzzle, and Rayleigh was usually at his best when faced by a puzzle. The difficulty was encountered in high-precision measurements of the density of nitrogen, undertaken in the first instance with the aim of obtaining better values of the atomic weight of that element. It was found that the density of nitrogen prepared from ammonia was about one part in two hundred less than the density about one part in two hundred less than the density of nitrogen obtained from air. Repeated reweighings only confirmed the difference and led to Rayleigh's publishing in *Nature* (1892) a short note citing the apparent dilemma and asking for suggestions for its resolution. In a certain sense this was unfortunate, in the light of the priority problem involved in the subsequent discovery. It does, however, illustrate Rayleigh's single-minded devotion to science as a social profession and what may appropriately be called his scientific unselfishness.

The ultimate solution to the peculiar problem of the density of nitrogen was suggested by the reading of a paper published by Henry Cavendish in 1795. He had oxidized the nitrogen in a given volume of air by sparking the air with a primitive static machine. Cavendish found that no matter how long he conducted the sparking, there was always a small residue of gas that apparently could not be further oxidized. He abandoned the research at that point. Had he continued, he presumably would have been the discoverer of argon. Rayleigh decided to push Cavendish's experiment to a conclusion, acting finally on the conviction that there really was another constituent of atmospheric air in addition to the commonly accepted ones.

Rayleigh used an induction coil to provide the electrical discharge for the oxidation of nitrogen, but the process of accumulating enough of the new gas to test its properties was a slow one. In the meantime Sir William Ramsay, having noted Rayleigh's nitrogen-density problem, proceeded to attempt the isolation of the unknown gas by much faster chemical means. Ramsay kept Rayleigh thoroughly informed of his activities, but some confusion and uncertainty still exist over whether Rayleigh actually gave Ramsay his scientific blessing. In the end both shared in the recognition for the discovery of argon and presented their results in a joint paper. There was the usual skepticism over the validity of the result, especially on the part of chemists, who found it hard to believe that a genuinely new element could have remained undetected for so long. The relative chemical inertness of argon was, of course, the explanation. Sooner or later spectroscopic analysis would in any case have revealed its existence. Rayleigh and Ramsay were led to take the hard way in its recognition.

It was largely because of this discovery that Rayleigh was awarded the Nobel Prize in physics in 1904, while Ramsay received the Nobel Prize in chemistry the same year. It is rather ironic that Rayleigh received the prize for work as relevant for chemistry as for physics, when he never felt he had much competence as a chemist. And indeed there seems little question that his other contributions to physics were vastly more significant than the discovery of argon. The latter caught both the scientific and the popular fancy, however. Although Rayleigh took the discovery very seriously–as he did all his research–and worked very hard at it, it seems clear that once the existence of the new gas and the demonstration of its properties were irrefutably established, Rayleigh was disinclined to go on with this kind of research. Even during the three years of the argon research (1892–1895) he found time to contribute to the scientific literature some twelve papers dealing with the interference and scattering of light, the telephone and its technical problems, and the measurement of the minimum audible intensity of sound.

An illustration of Rayleigh's uncanny ability to forecast developments in physics is provided by his 1899 paper "On the Cooling of Air by Radiation and Conduction and on the Propagation of Sound." In this he faced the problem of the anomalously high sound attenuation observed in air (much greater than that predicted by the transport properties of viscosity and heat conduction). He predicted that the solution to the difficulty might well be found in a relaxation mechanism involving reciprocal transfer of energy between translational and internal energy states of the molecules of the gas through which the sound passes. This suggestion was adopted by various later investigators and has led to the establishment of the vigorous field of molecular acoustics, which by the second half of the twentieth century has thrown new and important light not only on ultrasonic propagation but also on the structure and interaction of molecules.

Any appraisal of Rayleigh's scientific achievements must include mention of his relation to modern physics and, in particular, to the formulation and development of quantum and relativity theories. This poses an interesting but somewhat puzzling problem. In his reading and his association with other scientists, Rayleigh kept fully abreast of all the important activity in physics. He keenly realized the difficulties that classical physics (electromagnetic theory, thermodynamics, and statistical mechanics) was encountering near the end of the nineteenth century in the attempt to explain the experimental phenomena of radiation spectra. But he refused to give up hope that adequate solutions would be forthcoming within the framework of traditional physical theories. Revolutionary ideas evidently were distasteful to him. He could never develop much enthusiasm for Planck's quantum theory and its subsequent development. He never attacked the theory with any vehemence but simply felt it was not to his taste.

His derivation of what came later to be called the Rayleigh-Jeans radiation law (published in 1900, a few months before Planck's famous paper on the distribution law) reflects Rayleigh's general attitude very well. The statistical principle of equipartition of energy among resonators worked very well for long wavelengths. One has the impression that Rayleigh felt a secret longing that with some ingenious maneuvering it might be made to work for the short wavelenghts as well. Of course it never has! But he certainly cannot be accused of allowing any nostalgia for traditionalism in physics to keep him from seriously considering the problem and its importance.

Somewhat similar remarks apply to the problem of the unraveling of the intricacies of atomic spectra. Rayleigh fully realized the ultimate significance of this in connection with atomic constitution and tried his hands at numerous calculations of vibratory systems that might possess frequencies in accord, for example, with the Balmer formula for the emission spectrum of hydrogen. He admitted freely that the failures of these attempts indicated the need for new approaches. At the same time Bohr's theory was too radical and revolutionary for his liking.

Rayleigh also was much concerned with the physical problems that ultimately led to the theory of relativity. As far back as 1887 he was interested in astronomical aberration and its bearing on the theory of a luminiferous ether. At that time he indicated a preference for Fresnel's assumption of a stationary ether, despite the presumably null results of Michelson's famous 1881 experiment. Rayleigh was skeptical of the validity of Michelson's early work. Here again it seems clear that he was much disturbed by the possibility that the ether would have to be abandoned as an unworkable hypothesis. His loyalty to the classical wave theory of light was very great. Rayleigh saw the necessity for further experiments, however, and in 1901 undertook to detect possible double refraction in a material medium due to motion through a presumptive stationary ether. The negative results added to the mounting evidence that no physical phenomenon can enable one to distinguish between the motion of two inertial systems so as to say that one is at rest while the other is moving in an absolute sense. Rayleigh contributed nothing to the Einstein theory of relativity as such, although it is evident that he followed its developments with interest. Here again his rather conservative nature asserted itself.

The pace of Rayleigh's research activity did not slacken as he approached his later years. In the last fifteen years of his life he produced ninety papers, of which some reported notable work. For example, to this period belongs a paper on sound waves of finite amplitude, in which the earlier investigations of W. J. M. Rankine and Hugoniot on what came to be called shock waves were much extended. This laid the groundwork for much future development. Other important contributions to acoustics after 1905 were concerned with the binaural effect in human hearing, in which Rayleigh's pioneer investigations paved the way for the relatively enormous amount of interest in this problem in the later twentieth century, and with the filtration and scattering of sound.

The Theory of Sound was kept up-to-date with appropriate revisions and is still a vade mecum in every acoustical research laboratory. The scattering of light from a corrugated surface also provided new insight into a difficult problem.

Along with this intense research activity, Rayleigh devoted considerable attention to professional scientific societies and governmental applied science. The details of the life of a research scientist working at his desk or in his laboratory often seem to offer little of dramatic character. But Rayleigh became an important public figure in his lifetime and devoted much energy to the promotion of science as a whole and physical science in particular. He early became interested in the affairs of the British Association for the Advancement of Science. His first research results were presented at a meeting of the Association at Norwich in 1868, and he served as president of Section A (Mathematics and Physics) at the Southampton meeting in 1882. His presidency of the entire Association for the Montreal meeting in 1884 has already been mentioned.

Elected to the Royal Society in 1873, Rayleigh served as secretary (succeeding to Sir George Stokes) from 1885 to 1896. He took his duties very seriously and made some interesting discoveries in the archives of the Society, including the neglected paper by the Scottish engineer J. J. Waterston, pioneer in the molecular theory of gases. In 1905 Rayleigh was elected president of the Royal Society and served until 1908. Because he never treated any organizational post as a sinecure, he was much in demand when advice and active work on difficult problems were sought.

In 1896 Rayleigh accepted appointment as scientific adviser to Trinity House, a post Michael Faraday had held some sixty years previously. This organization, dating to the time of Henry VIII, has as its function the erection and maintenance of such coastal installations as lighthouses and buoys. Rayleigh served this organization for fifteen years. Much of his later work in optics and acoustics was suggested by problems arising in connection with tests of fog signals and lights. This work for Trinity House is an illustration of his willingness to give freely of time and energy to scientific committees of government and professional organizations in the interests of applied science. A leader in the movement culminating in the establishment of the National Physical Laboratory at Teddington (the British counterpart of the United States National Bureau of Standards), he presided over its executive committee until shortly before his death. Other examples of Rayleigh's public service are his chairmanships of the Explosives Committee of the War Office and his long tour of duty as chief gas examiner of the London gas supply.

Despite the relative shortness of his own career as a university teacher, Rayleigh took a great interest in educational problems and served on the governing boards of several educational institutions. From 1908 to his death in 1919 he served as chancellor of Cambridge University.

The bulk of Rayleigh's experimental notebooks, calculations, and the original **MSS** of his published papers have been acquired by the United States Air Force Cambridge Research Laboratories in Bedford, Massachusetts, and are now housed there as the Rayleigh Archives. Photostat copies have been distributed to other libraries, particularly the Niels Bohr Library of the American Institute of Physics in New York, and are available for scholarly study.

Public recognition of his scientific achievements came to Rayleigh in full measure. After receiving the Nobel Prize in 1904, he donated its cash award, amounting to about $38,500, to Cambridge University to improve the Cavendish Laboratory and the University Library. Rayleigh was one of the first members of the new Order of Merit when it was established in 1902. He also became a privy councillor in 1905. He was the recipient of thirteen honorary degrees and held honorary memberships in, or received special awards from over fifty learned societies.

Rayleigh may justly be considered the last great polymath of physical science. He outlived his closest rivals Helmholtz, Gibbs, Kelvin, and Poincaré by a measurable span of years and remained professionally active to the end of his life. At the time of his death he left three completed professional papers unpublished. The amount of work he accomplished in the roughly fifty-five years of his professional career can only be regarded as prodigious. By nature he was not a profoundly or boldly imaginative scientist who would initiate a wholly new idea like the electromagnetic theory of radiation, the quantum theory, or relativity. In this respect he differed from Maxwell, Planck, Bohr, and Einstein. But he did advance enormously the power and scope of applicability of practically every branch of classical physics. He was admired and respected for his sound scientific judgment and his ability to penetrate to the heart of any scientific problem he encountered. Above all, Rayleigh was a modest man. Typical of this was the remark he made in his speech accepting the Order of Merit: "The only merit of which I personally am conscious is that of having pleased myself by my studies, and any results that may have been due to my researches are owing to the fact that it has been a pleasure to me to become a physicist."

BIBLIOGRAPHY

I. Original Works. Lord Rayleigh's complete bibliography includes one book and 430 articles. All the articles have been published in his *Scientific Papers*, 6 vols. (Cambridge, 1899–1920), repr., 3 vols. (New York, 1964). The scope of Rayleigh's research activity is indicated by the following. His book is *The Theory of Sound*, 2 vols. (London, 1877–1878). His articles include "On Some Electromagnetic Phenomena Considered in Connexion With the Dynamical Theory," in *Philosophical Magazine*, **38** (1869), 1–14; "On the Theory of Resonance," in *Philosophical Transactions of the Royal Society*, **161** (1870), 77–118; "On the Light From the Sky, Its Polarization and Colour Appendix," in *Philosophical Magazine*, **41** (1871), 107–120, 274–279; "On the Scattering of Light by Small Particles," *ibid*., 447–454; "Investigation of the Disturbance Produced by a Spherical Obstacle on the Waves of Sound," in *Proceedings of the London Mathematical Society*, **4** (1872), 253–283; "On the Application of Photography to Copy Diffraction-Gratings," in *British Association Report* (1872), **39** ; "On the Diffraction of Object-Glasses," in *Astronomical Society Monthly Notes*, **33** (1872), 59–63; "Some General Theorems Relating to Vibrations," in *Proceedings of the London Mathematical Society*, **4** (1873), 357–368; "On the Manufacture and Theory of Diffraction-Gratings," in *Philosophical Magazine*, **47** (1874), 81–93, 193–205; "General Theorems Relatilng to Equilibrium and Initial and Steady Motions," *ibid*., **49** (1875), 218–224; "On the Dissipation of Energy," in *Nature*, **40** (1875), 454–455; "On Waves," in *Philosophical Magazine*, **1** (1876), 257–259; "Our Perception of the Direction of a Source of Sound," in *Nature*, **41** (1876), 32–33; "On the Application of the Principle of Reciprocity to Acoustics," in *Proceedings of the Royal Society*, **25** (1876), 118–122: "Acoustical Observations. I," in *Philosophical Magazine*, n.s. **3** (1877), 456–464; "Absolute Pitch," in *Nature*, **17** (1877), 12–14: "On the Relation Between the Functions of Laplace and Bessel," in *Proceedings of the London Mathematical Society*, **9** (1878), 61–64; "On the Capillary Phenomena of Jets," in *Proceedings of the Royal Society*, **29** (1879), 71–97; and "Acoustical Observations. II," in *Philosophical Magazine*, **7** (1879); 149–162.

Later articles are "On Reflection of Vibrations at the Confines of Two Media Between Which the Transition is Gradual," in *Proceedings of the London Mathematical Society*, **9** (1880), 51–56; "On the Resolving-Power of Telescopes," in *Philosophical Magazine*, **10** (1880), 116–119; "On the Electromagnetic Theory of Light," *ibid*., **12** (1881), 81–101; "On the Determination of the Ohm [B.A. Unit] in Absolute Measure," in *Proceedings of the Royal Society*, **32** (1881), 104–141, written with Arthur Schuster; "Experiments to Determine the Value of the British Association Unit of Resistance in Absolute Measure," in *Philosophical Transactions of the Royal Society*, **173** (1882), 661–697; "On the Specific Resistance of Mercury," *ibid*., **174** (1882), 173–185, written with Mrs. H. Sidgwick; "Address to the Mathematical and Physical Science Section of the British Association," in *British Association Report* (1882), 437–441; "On an Instrument Capable of Measuring the Intensity of Aerial Vibrations," in *Philosophical Magazine*, **14** (1882), 186–187; "On the Maintained Vibrations," *ibid*., **15** (1883), 229–235; "Distribution of Energy in the Spectrum," in *Nature*, **27** (1883), 559–560; "On the Crispations of Fluid Resting Upon a Vibrating Support," in *Philosophical Magazine,***16** (1883), 50–58; "On Laplace's Theory of Capillarity," *ibid*., 309–315; "On the Circulation of Air Observed in Kundt's Tubes and on Some Allied Acoustical Problems," in *Philosophical Transactions*, **175** (1883), 1–21; "The Form of Standing Waves on the Surface of Running Water," in *Proceedings of the London Mathematical Society*, **15** (1883), 69–78; "On the Constant of Magnetic Rotation of Light in Bisulphide of Carbon," in *Philosophical Transactions of the Royal Society*, **76** (1884), 343–366; "On Waves Propagated Along the Plane Surface of an Elastic Solid," in *Proceedings of the London Mathematical Society*, **17** (1885), 4–11: "On the Maintenance of Vibrations by Forces of Double Frequency and on the Propagation of Waves Through a Medium Endowed With a Periodic Structure," in *Philosophical Magazine*, **24** (1887), 145–159; "On the Relative Densities of Hydrogen and Oxygen (Preliminary Notice)," in *Proceedings of the Royal Society*, **43** (1887), 356–363; "On the Free Vibrations of an Infinite Plate of Homogeneous Isotropic Elastic Matter," in *Proceedings of the London Mathematical Society*, **20** (1889), 225–234; "On the Character of the Complete Radiation at a Given Temperature," in *Philosophical Magazine*, **27** (1889), 460–469; "Foam," in *Proceedings of the Royal Institution*, **13** (1890), 85–97; "On the Tension of Water Surfaces, Clean and Contaminated, Investigated by the Method of Ripples," in *Philosophical Magazine*, **30** (1890), 386–400; "On The Theory of Surface Forces," in *Philosophical Magazine*, **30** (1890), 285–298, 456–475; "On the Virial of a System of Hard Colliding Bodies," in *Nature*, **45** (1891), 80–82; "On the Relative Densitites of Hydrogen and Oxygen. II," in *Proceedings of the Royal Society*, **50** (1892), 448–463; and "On the Physics of Media That are Composed of Free and Perfectly Elastic Molecules in a State of Motion," in *Philosophical Transactions of the Royal Society*, **183A** (1892), 1–5.

See also "Density of Nitrogen," in *Nature*, **46** (1892), 512–513; "On the Reflection of Sound or Light From a Corrugated Surface," in *British Association Report* (1893), 690–691; "On an Anomaly Encountered in Determinations of the Density of Nitrogen Gas," in *Proceedings of the Royal Society*, **55** (1894), 340–344; "An Attempt at a Quantitative Theory of the Telephone," in *Philosophical Magazine*, **38** (1894), 295–301; "On the Amplitude of Aerial Waves Which Are But Just Audible," *ibid*., 365–370; "Argon, a New Constituent of the Atmosphere," in *Philosophical Transactions of the Royal Society*, **186A** (1895), 187–241, written with William Ramsay; "Argon," in *Proceedings of the Royal Institution*, **14** (1895), 524–538; "On the Propagation of Waves Upon the Plane Surface Separating Two Portions of Fluid of Different Vorticities," in *Proceedings of the London Mathematical Society*, **27** (1895), 13–18; "On Some Physical Properties of Argon and Helium," in *Proceedings of the Royal Society*, **59** (1896), 198–208; "On the Propagation of Waves Along Connected Systems of Similar Bodies," in *Philosophical Magazine*, **44** (1897), 356–362; "Note on the Pressure of Radiation, Showing an Apparent Failure of the Usual Electromagnetic Equations," *ibid*., **45** (1898), 522–525; "On the Cooling of Air by Radiation and Conduction and on the Propagation of Sound," *ibid*., **47** (1899), 308–314; "On the Transmission of Light Through an Atmosphere Containing Small Particles on Suspension, and On the Origin of the Blue of the Sky," *ibid*., 375–384; "On the Calculation of the Frequency of Vibration of a System in Its Gravest Mode, With an Example from Hydrodynamics," *ibid*., 566–572; "The Law of Partition of Kinetic Energy," *ibid*., **49** (1900), 98–118; "Remarks Upon the Law of Complete Radiation," *ibid*., 539–540; "On the Magnetic Rotation of Light and the Second Law of Thermodynamics," in *Nature*, **64** (1901), 577–578; "On the

Pressure of Vibrations," in *Philosophical Magazine*, **3** (1902), 338–346; "Is Rotatory Polarization Influenced by the Earth's Motion?" *ibid*., **4** (1902), 215–220; "Does Motion Through the Aether Cause Double Refraction?" *ibid*., 678–683; "On the Bending of Waves Round a Spherical Obstacle," in *Proceedings of the Royal Society*, **72** (1903), 401–441; "On the Acoustic Shadow of a Sphere," in *Philosophical Transactions of the Royal Society*, **203A** (1904), 87–110; "The Dynamical Theory of Gases and of Radiation," in *Nature*, **71** (1905), 559; **72** (1905), 54–55, 243–244; "On Electrical Vibrations and the Constitution of the Atom," in *Philosophical Magazine*, **11** (1906), 117–123; "On the Experimental Determination of the Ratio of the Electrical Units," *ibid*., **12** (1906), 97–108; "On Our Perception of Sound Direction," *ibid*., **13** (1907), 214–232; "Note As to the Application of the Principle of Dynamical Similarity," in *Report of the Advisory Committee for Aeronautics* (1909–1910), 38; "Aerial Plane Waves of Finite Amplitude," in *Proceedings of the Royal Society*, **84A** (1910), 247–284; "On the Propagation of Waves Through a Stratified Medium, with Special Reference to the Question of Reflection," in *Proceedings of the Royal Society*, **86A** (1912), 207–266; "On the Motion of a Viscous Fluid," in *Philosophical Magazine*, **26** (1913), 776–786; "The Pressure of Radiation and Carnot's Principle," in *Nature*, **92** (1914), 527–528; "Some Problems Concerning the Mutual Influence of Resonators Exposed to Primary Plane Waves," in *Philosophical Magazine*, **29** (1915), 209–222; "The Principle of Similitude," in *Nature*, **95** (1915), 66–68, 644; "The Theory of the Helmholtz Resonator," in *Proceedings of the Royal Society*, **92A** (1915), 265–275; "The Le Chatelier-Braun Principle," in *Transactions of the Chemical Society*, **91** (1917), 250–252; "The Theory of Anomalous Dispersion," in *Philosophical Magazine*, **33** (1917), 496–499; "On the Pressure Developed in a Liquid During the Collapse of a Spherical Cavity," *ibid*., **34** (1917), 94–98; "On the Scattering of Light by a Cloud of Similar Small Particles of Any Shape and Oriented at Random," *ibid*., **35** (1918), 373–381; "Propagation of Sound and Light in an Irregular Atmosphere," in *Nature*, **101** (1918), 284; "On the Problem of Random Vibrations, and of Random Flights in One, Two, or Three Dimensions," in *Philosophical Magazine*, **37** (1919), 321–347; "Presidential Address," in *Proceedings of the Society for Psychical Research*, **30** (1919), 275–290; and "On Resonant Reflexion of Sound From a Perforated Wall," in *Philosophical Magazine*, **39** (1920), 225–233.

II. Secondary Literature. See the obituary notice by Sir Arthur Schuster, in *Proceedings of the Royal Society*, **98A** (1921), 1; Robert John Strutt, *Life of John William Strutt, Third Baron Rayleigh O.M., F.R.S.* (London, 1924); 2nd augmented ed. with annotations by the author and foreword by John N. Howard (Madison, Wis., 1968); and R. Bruce Lindsay, *Lord Rayleigh, the Man and His Works* (Oxford–London, 1970).

R. B. Lindsay