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(*b*. Budapest, Hungary, 27 July 1848; *d*. Budapest, 8 April 1919)

physics.

Most of the world literature lists Eötvös (pronounced ut' vush) in the fashion given in the heading, which is the German version of the Hungarian name. The reason for this is that he published most of his major papers in both Hungarian and German. Roland is a translation of the Hungarian name Loránd, and his full name in Hungarian is Vásárosnaményi Báro Eötvös Loránd. The correct full name in English translation is Roland, Baron Eötvös of Vásárosnamény.

Eötvös was the scion of an aristocratic and intellectual family. His father, Joseph, Baron Eötvös of Vásárosnamény, at the time of Roland's birth held the portfolio of public instruction and religious affairs in the first, short-lived, responsible Hungarian cabinet; his mother was the former Agnes Rosty. The family had a long background of public service (the barony was conferred on his great-grandfather in the eighteenth century), but its intellectual tendencies came to full bloom only in his father, who became Hungary's foremost writer and political philosopher of the nineteenth century. Young Roland thus grew up in an environment leading more or less toward a study of law and government (his family, by hereditary right, belonged to the upper house of parliament). He entered the University of Budapest in 1865 as a law student but, already interested in the mathematical and physical sciences, took private lessons in mathematics from Otto Petzval.

At his father's request Joseph Krenner, the future professor of mineralogy at the university, introduced Eötvös to the study of physical sciences; at the same time he worked in the chemistry laboratory of Charles Than.

In 1867 Eötvös definitely abandoned the study of law and entered the University of Heidelberg. His studies included mathematics, physics, and chemistry, taught there by such outstanding teachers as Kirchhoff, Helmholtz, and Bunsen. After three semesters he went to the University of Königsberg but found the lectures of the theoretical physicist Franz Neumann and of the mathematician Friedrich Richelot less to his taste. For a while Eötvös toyed with the idea of joining the arctic expedition headed by August Petermann; but he finally decided, on his father's advice, to return to Heidelberg, where he obtained his doctorate *summa cum laude* in the summer of 1870. Apparently the subject of his doctoral thesis was identical with the subjects of three papers published by him in 1871, 1874, and 1875; they dealt with a problem formulated by Fizeau. The question was raised whether the relative motion of a light source, with respect to an immobile ether, can be detected by measuring the light intensities in both the same and the opposite directions of the motion. Eötvös generalized the calculations for both the emitter and the detector being in motion and extended it to astronomical observations. This purely theoretical work became, decades later, the object of many important papers, leading ultimately to the theory of relativity.

His professors profoundly influenced Eötvös's working habits. Kirchhoff taught him the importance of accuracy in measurements. Helmholtz liked to spend as much time as possible with his students and showed Eötvös the value of individual discussion. His knowledge of theoretical physics, and in particular of potential theory, came from Franz Neumann.

At the end of his studies in 1870, Eötvös returned to Hungary and in 1871 became *Privatdozent* at the University of Budapest. In 1872 he was promoted to full professor at the same university. At first he taught theoretical physics; in 1874 he added experimental physics to his duties; and in 1878, at the retirement of Ányos Jedlik, professor of experimental physics, he took over that chair.

In 1876 Eötvös married Gizella Horvath, the daughter of the minister of justice, Boldizsar Horvath. They had two daughters, Ilona and Rolanda.

A few years earlier, while he was still a student at the University of Konigsberg, Eötvös designed a simple optical method for determining the constant of capillarity (surface tension). He presented the subject at a physics colloquium, and Franz Neumann found the idea quite praiseworthy. Capillarity thus became the first research subject he attacked and led him to his first important discovery. He showed that the temperature coefficient of the molecular surface energy of a liquid—expressible as , where *M* is the molecular weight, *v* is the specific volume of the liquid, and γ is the capillarity constant or surface tension—is independent of the nature of simple unassociated liquids. The integral form of the law of Eötvös is usually written as, $\gamma v^{2/3} = k(T_0 - T)$, where *k* is a constant for all simple liquids (k≈2.12) and T_0 is (approximately) the critical temperature.

His investigations on capillarity were published in a few papers between 1876 and 1886. After 1886 there were no further communications by Eötvös on this subject, although the law of Eötvös attracted wide attention and during the next few decades a considerable number of papers appeared, examining and extending the concepts introduced by him.

After 1886 practically all of Eötvös's scientific papers concentrated on his lifework: gravitation. He was interested in this subject on and off before then, and there is some evidence of a gradually awakening interest in earlier papers and speeches. The exact year when his interest swung from phenomena involving van der Waals forces to the weakest known forces in the universe cannot be ascertained. A partial motivation

may have been a request by the Természettudományi Tarsulat (Hungarian Society for Natural Sciences) in 1881 for the determination of the gravitational acceleration in different parts of Hungary.

Eötvös's first short Hungarian-language publication on gravitational phenomena appeared in 1888. In January 1889 he presented a short paper to the Hungarian Academy of Sciences concerning his search for a difference in gravitational attraction exerted by the earth on different substances. This short paper, published in 1890, reported that within the accuracy achieved with his torsion balance, all substances investigated experienced the same force of attraction per unit of mass.

From the beginning of his gravitational researches Eötvös concentrated on the use of the instrument he called in a later paper the Coulomb balance, in recognition of the invention and use of torsion balance by Charles Coulomb. Actually, the torsion balance had been invented earlier (and independently) by Rev. John Michell, who had applied the principle upon which it is based as early as 1768 and, shortly before his death, completed construction of the particular torsion balance that in the hands of Henry Cavendish became an outstanding instrument for the determination of the attraction between two masses. The original Michell-Cavendish instrument places two masses at the ends of a horizontal bar suspended to allow a horizontal displacement of the masses around the torsion axis (see Figure 1). If the gravitational potential U is a function of the Cartesian coordinates x, y, z, it is possible to determine with that instrument the curvature of the gravitational field in a horizontal plane, i.e.,

For this reason Eötvös called this instrument the curvature variometer, to distinguish it from his horizontal variometer. The latter (see Figure 2) still supports two masses on a horizontally suspended bar, but the masses are offset both horizontally and vertically. By using the new geometry, and can be measured in addition to the two components measured by the earlier instrument. An added refinement was measurement of the oscillation period of the torsion pendulum, instead of the static deviation of the suspended bar, thus gaining an added sensitivity for the instrument.

The achievements of Eötvös in the use of his instrument are threefold. By developing the complete theory of the Eötvös balance, he was able to push its sensitivity to such a point that it took decades to devise methods for exceeding his precision. It is only proper to mention that the high degree of precision he achieved was not due solely to the design of the instrument but depended also on the unparalleled skill he displayed in using it.

The other two accomplishments encompassed the clear recognition of the very important applications of the balance: geophysical exploration and the equivalence of gravitational and inertial mass. In both cases the recognition was followed by intense work proving his insight.

Prospecting by gravitational methods is the technique of measuring the gravitational field at the earth's surface and predicting, from the data obtained, the structure beneath the surface. In principle this information can be derived from direct measurements of gravity by means of a gravimeter, or from gradient measurements by means of the Eötvös balance. While the gravimeter can give faster results (the time required for a single observation is a small fraction of that required by the torsion balance) the signal-to-noise ratio was originally more favorable for the gradient measurement. As a consequence the Eötvös balance was, until good gravimeters were developed, the leading instrument for geophysical prospecting.

Between 1888 and 1922 Eötvös, together with his collaborators, published a number of papers on his investigations. These included the theory and design

of the instrument and the results of its widespread application in Hungary and abroad.

The second extremely important application of the Eötvös balance involved a predetermination of the rate of gravitational acceleration for different bodies. It had been known from earlier work that all bodies fall with the same acceleration (in a vacuum), but the best previous determinations yielded only a limited accuracy. In response to a prize announcement by the University of Gottingen, Eötvös and his collaborators followed up his early measurements on this subject. The new measurements provided not merely a more accurate proof of a principle believed right until then, but much more: his results, proving that gravitational mass and inertial mass are equivalent, the possible deviation being about five parts in 10^9, became one of the building stones of the theory of general relativity. The experiment proves the "weak" form of the principle of equivalence, which states that the trajectory of a test particle, under the influence of gravitational fields only, depends only on its initial position and velocity, not on its mass and nature. Later confirmation of his results (during the last fifty years) reduced the possible deviation from perfect equivalence by a factor of 1,000.

Late in life Eötvös became interested in the variation of the gravitational acceleration caused by the relative motion of a body with respect to the earth. The experimental proof of this effect was the subject of two posthumous papers.

Parallel to the geophysical application of the torsion balance, he pursued an investigation of the magnetic anomalies accompanying the gravitational effects. His interest in magnetism led him to paleomagnetic work on bricks and other ceramic objects that covered a period of about 2,000 years. Another side issue attracting his interest was the shape of the earth.

Eötvös's intensive research efforts did not prevent him from pursuing other interests. Shortly after his appointment as professor of physics, he became aware of the shortcomings of both high school and university instruction in Hungary, and from then on he devoted considerable effort to improving both. In 1881 the minister of instruction requested him to make a trip to Paris for the purpose of studying the French system of higher education. These efforts led to a short appointment (June 1894–January 1895) as minister of public instruction and religious affairs (the cabinet post held twice by his father). One of the highlights of this period was the founding of the Eötvös Collegium, patterned after the French Ecole Normale Superieure and named for his father. Its stated purpose was to improve the training of high school teachers. The effort was quite successful; the surprising increase in the number of outstanding Hungarian scientists during the twentieth century may be indirect proof of the effectiveness of the new school.

Eötvös served one year as rector of the University of Budapest. As professor of physics he devoted much care and time to the preparation of his lectures; he also invented many good demonstration experiments and insisted that his students understand the basic principles underlying them. He became a corresponding member of the Hungarian Academy of Sciences in 1873 and a full member ten years later; in 1889 he was elected its president. Although the usual term for the presidency was three years, he was reelected until his resignation in 1905. Many honors were bestowed upon him, including election to a number of foreign academies, as well as prizes and decorations.

In 1885 Eötvös and four friends founded the (Hungarian) Society for Mathematics. A little later physicists were attracted to the new society. In 1891 the Mathematical and Physical Society was founded, and Eötvös was elected its first president, a post he held until his death.

His main relaxation was mountain climbing. For quite a long time he was well-known as one of Europe's foremost climbers: a peak in the Dolomites is named for him, and the mountaineering handbooks record a number of "first climbs" he made either alone or with his daughters, who became his steady climbing companions.

BIBLIOGRAPHY

I. Original Works. Eötvös's most important papers include "Über den Zusammenhang der Oberflächenspannung der Flussigkeiten mit ihrem Molekularvolumen," in *Annalen der Physik und Chemie*, 27 (1886), 448–459; "Untersuchungen über Gravitation and Erdmagnetismus," *ibid*, 59 (1896), 354–400; "Étude sur les surfaces de niveau et la variation de la pesanteur et de la force magnétique," in C.-E. Guillaume and L. Poincaré, eds., *Rapports présentés au Congrès international de physique réuni à Paris en 1900*, III (Paris, 1900), 371–393; "Programme des recherches gravimétriques dans les régions vésuviennes," in *Comptes rendus des seances de la premiére réunion de la commission permanente de l'Association internationale de sismologie réunie à Rome* (1906), pp. 177–179; "Bericht über Arbeiten mit der Drehwage ausgeführt im Auftrage der koniglich ungarischen Regierung in den Jahren 1909–1911," in *Verhandlungen der XVII allgemeinen Konferenz der internal. Erdmessung in Hamburg*, I (1912), 427–438; and "Beiträge zum Gesetze der Proportionalität von Trägheit und Gravität," in *Annalen derPhysik*, 68 (1922), 11–66, written with D. Pekár and J. Fekete.

Most of these, together with a few other papers, were republished by the Hungarian Academy of Sciences under the title *Roland Eötvös Gesammelte Arbeiten*, P. Selenyi, ed. (Budapest, 1953). A complete bibliography, except for posthumous papers, is given (in Hungarian) in the special Eötvös issue of *Matematikai és physikai lapok*, **27** (1918), 284–290. A reproduction of the same bibliography, with the posthumous papers included, is to be found in Elek Környei, *Eötvös Loránd, A tudós és müvelödéspolitikus irasaiból* (Budapest, 1964).

II. Secondary Literature. The book by Környei listed above and the special issue of *Matematikai és physikai lapok* contain discussions (in Hungarian) of his life and theories. His contributions to physics are the subject of an excellent paper by R. H. Dicke, "The Eötvös Experiment," in *Scientific American*, **205** (Dec. 1961), 84–94, as well as R. H. Dicke, "Some Remarks on Equivalence Principles," in *Annales Universitatis scientiarum budapestinensis de Rolando Eötvös Nominatae*, Geological Section, 7 (1964). See also R. H. Dicke, "Remarks on the Observational Basis of General Relativity," in H. Y. Chiu and W. F. Hoffmann, eds., *Gravitation and Relativity* (New York, 1964), pp. 1–16; and P. G. Roll, R. Krotkov, and R. H. Dicke, "The Equivalence of Inertial and Passive Gravitational Mass," in *Annals of Physics*, **26** (1964), 442–517. The latter paper emphasizes also the importance of the Eötvös experiment for the theory of general relativity. An appreciation of the geophysical aspects is given by A. H. Miller, in "The Theory and Operation of the Eötvös Torsion Balance," in *Journal of the Royal Astronomical Society of Canada*, **28** (1934), 1–31, with the most important relevant papers by Eötvös and his collaborators listed in the bibliography (unfortunately with many misprints). Another useful source of information on the geophysical importance of the torsion balance can be found in Donald C. Barton, "Gravity Measurements With the Eötvös Torsion Balance, Physics of the Earth II., The Figure of the Earth," in *Bulletin of the National Research Council. Washington*, 78 (1931), **167–190.**