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MATTHEW R. EDWARDS, editor, *Pushing Gravity: New Perspectives on Le Sage's Theory of Gravitation*. Montreal: Apeiron, C. Roy Keys Inc., 2002. iv + 316 pp. US$25.00. ISBN

Isaac Newton's theory of universal gravitation was based on a mathematical description of the motion of bodies according to an inverse square force law. Although Newton sometimes reflected on possible physical causes of gravity, he declined in his *Principia Mathematica* to speculate publicly on the subject. In his own famous words, he would 'frame no hypothesis' to account for how gravity could act across empty space and penetrate to the interstices of every body in the universe.

A physical theory of gravity in agreement with Newtonian mathematical laws was advanced by the Genevan physicist Georges-Louis Le Sage (1724–1803). Le Sage posited that the universe is filled with a fluid or gas of otherworldly ('ultramundane') corpuscles, tiny particles moving in all directions with very high velocities. Although most of these corpuscles pass through ponderable bodies, some are intercepted as they collide with the atoms of ordinary matter. An isolated body will be in equilibrium with respect to the colliding ultramundane corpuscles since it is bombarded equally on all sides. However, in a system consisting of two bodies each body blocks some of the corpuscles from reaching the other, resulting in a net pushing force that draws the bodies together. Using the fact that the solid angle subtended by a body decreases as the square of the distance, one is led directly to Newton's inverse square relation. To explain why the gravitational pushing force is independent of the shape and size of bodies, Le Sage supposed that the atoms of ordinary matter consist largely of empty space. The corpuscles penetrate through all bodies: as they do so a very few collide with the minute parts of ordinary atoms. The corpuscles themselves rarely interact with each other and exert no sensible mutual influence. (In later physics this last fact would be expressed by positing a very large mean free path for the ultramundane gravitational gas.)

Le Sage's theory was in general sympathy with contemporary thinking in the foundations of mechanics. Jean d'Alembert's *Treatise on Dynamics* (1743) was based on an impulse model for force, in which changes in motion occurred as the result of small discrete impulses. In the corollary to Problem 9 of his book d'Alembert set forth an explicit collision mechanism to explain the action of a continuous force such as gravity on a body M. He supposed that this action results from the collision with M of a small body of infinitesimal mass m moving with a velocity u that is effectively infinite. The collision is regarded as perfectly inelastic, and results in the imparting of the small impulse μ of momentum to M.

The motion of a body down a curved inclined plane was seen by d'Alembert as consisting of a succession of infinitesimal inelastic collisions between the body and the plane. Gravity imparted impulses of velocity to the body which were then modified as a result of the inelastic collision. The physical analysis corresponded to a mathematical treatment in which the cross-sections of bodies as well as their trajectories through space were regarded as polygons with infinitely many sides, each side consisting of an infinitesimal spatial element.

In the later eighteenth century there was a movement away from the mechanical–geometrical style of theorizing evident in the writings of Le Sage and d'Alembert. In mathematics, geometrical conceptions gave way to analytical methods, a development that reached its highest point in the formalism of Joseph Lagrange. In physics, the microscopic models of the older generation (essentially an expression of mechanical and Cartesian world views) yielded to more positivist notions of quantitative description. Le Sage's theory did not find favourable grounds for development and lay dormant for close to a century. In the late nineteenth century, with the advent of the kinetic theory of gases, it was revived and investigated closely by William Thomson, James Clerk Maxwell, S. Tolver Preston, and others. At the beginning of the twentieth century Hendrik Lorentz formulated an electromagnetic version of the theory, and the entire subject was discussed (largely in unfavourable terms) by Henri Poincaré in his *Science and Method* (1918). Around 1920 the Italian experimental physicist Quirino Majorana devised a new model of gravity in which gravitational force is caused by an energy flux emitted by matter. Majorana carried out very detailed experiments in which he found evidence for gravitational shielding, a phenomenon that should in principle occur in both his theory and traditional Le Sage theories. Since the 1920s the theories of Le Sage and Majorana have become intertwined from the viewpoint of experimental verification.

The collection assembled here under the editorship of Matthew R. Edwards contains several essays chronicling the history of mechanical theories of gravity from 1700 to the present. There are papers on Fatio De Duillier (Frans van Lunteren), Newton (Eric Aiton), Le Sage (James Evans), Thomson and Maxwell (Edwards), Bernhard Riemann (H.-J. Treder), and Majorana (Roberto de Andrade Martins). The book includes as well a range of papers by modern-day authors who are concerned to explore the ramifications of a mechanical theory of gravity for a number of questions in contemporary cosmology, geology, and experimental physics. These scientific essays are occasionally rather speculative and sometimes at odds with currently accepted physical theory. The alternative proposals include ones that favour static cosmological models (over cosmological expansion) and the expanding earth hypothesis (over plate tectonics). Although there is no unity of viewpoint, there is a broad sense that the currently accepted paradigm to explain gravitation—Einstein's general theory of relativity—must be either supplemented or replaced by a theory rooted in mechanical principles.

While the scientific papers present a good overview of current thinking, the historical part provides an informative and interesting survey of mechanical theories of gravity from 1700 to the present. James Evans suggests that Le Sage's theory lost favour with the generation of scientists who came of age after 1750. Indeed, the corpuscular theory had certain technical difficulties. As was already made clear by d'Alembert, the velocity of the gravitational corpuscles would need to be very large relative to the velocities of ponderable masses. (Otherwise the force of gravity between two bodies would depend on their velocities, an effect which is not observed.) This conclusion was strengthened by other considerations. By means of reasoning of the kind used in the kinetic theory of gases it is not difficult to show that the pressure exerted by the ultramundane corpuscular gas on ponderable bodies is proportional to the square v^2 of the average speed v of the corpuscles. The resistance experienced by a planet moving with speed u through the corpuscular fluid will be proportional to uv. The ratio of the resistance to the gravitational force is therefore proportional to u/v. Because astronomical observation indicates that planets experience no resistance as they move through space, it must be the case that u/v is extremely small. It follows that the velocity v of the ultramundane corpuscles is very large—Le Sage estimated this speed to be 10^{13} times the speed of light. Furthermore, if a Le Sage-type mechanism is valid, the collisions of the corpuscles with bodies must be at least partially inelastic. (If the collisions were perfectly elastic, rebounding corpuscles on the shaded sides of the bodies would compensate for the differential in the corpuscular fluid or gas pressure and equilibrium would subsist.) With the development of thermodynamics and energy physics in the nineteenth century, it was recognized that this situation would lead to untenable physical consequences. Using thermodynamic considerations and arguments from the kinetic theory of gases Maxwell calculated that the very high velocity of the corpuscular fluid would result in the virtually instantaneous incineration of all matter in the universe. Although other researchers challenged this conclusion and suggested ways in which Maxwell's deduction could be refuted, kinetic theories of gravity have continued to be vulnerable to objections from thermodynamics.

Later developments of Le Sage's theory included the replacement of his original corpuscular fluid by an electromagnetic medium (this results in a physical theory consistent with general relativity), and by persistent attempts to amend the original mechanical theory in response to thermodynamic criticisms. Modern-day Le Sagians and neo-Le Sagians are quite diverse in their attempts to explain the mystery of gravity. The continued viability of Le Sage as a scientific doctrine will depend on the outcome of experimental tests (gravitational shielding, gravitational anomalies during eclipses) and on the success of integrating the theory into a mathematical framework comparable or consistent with general relativity. It is remarkable that Le Sage's theory, conceived before the discovery of atoms, electromagnetism, and relativity, is still generating new offshoots and experiments in the twenty-first century.

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