Paul Langevin

Paul Langevin was the first person to write the 'Newton's equation' for a Brownian particle. This equation is now called the Langevin equation and is often the starting equation required for understanding systems where microscopic fluctuations play an important role.

Brownian motion is the observed random motion of a small particle immersed in a fluid. For example if a very dilute mixture of milk in water is seen under the microscope one would see the micron-sized fat droplets executing a random motion. In 1905 Albert Einstein presented the first detailed mathematical analysis of Brownian motion. Einstein's derivation basically involved looking at the diffusion of a large number of Brownian particles in the presence of a density gradient. Using arguments from statistical mechanics and thermodynamics he related the diffusion constant D to: (I) the mean square displacement Δ^2, in time t, of individual particles by the formula $\Delta^2 = 2\,Dt$ and (II) the macroscopic properties of the fluid such as its viscosity h and absolute temperature T by the famous Einstein relation $6\,ph\,a\,D = R\;T/N$, where N is the avogadro number, R is the gas constant and a is the radius of the particle. Einstein's achievement was in proposing a definite quantitative measurement on the motion of a Brownian particle that could provide a direct proof of the atomistic nature of matter. Indeed this led to one of the first accurate experimental measurements of the Avogadro number. An important aspect of Einstein's analysis of the problem involved looking at a *collection* of Brownian particles.

In his 1908 paper Langevin took a completely different approach when he wrote an equation of motion for the *individual* Brownian particle. Langevin argued that the viscous force that a Brownian particle experiences from the fluid is only an average force. In addition it is important to take into account the fluctuations of the force about this mean value which come about from the random kicks that the Brownian particle gets from the fluid molecules. Langevin thus added an additional *random force* to the equation of motion. He solved the equation of motion and using the equipartition theorem rederived Einstein's relation for the mean square displacement of a Brownian particle. In a sense Langevin's treatment is a more microscopic treatment of Brownian motion since here one can directly see the random motion as coming from the random force. The Langevin equation is now often the starting fundamental equation used in the description of a huge variety of phenomena involving randomness and fluctuations not only in physics but also in various other fields such as chemistry, biology and even economics. Langevin's 1908 paper is also important in that it inspired not only new physics but also new mathematics. His equation eventually led to the development of the entirely new field of stochastic differential equations.

The other major contributions of Langevin were his theories of paramagnetism and diamagnetism. Paramagnets and diamagnets are substances which get magnetized in the presence of external magnetic fields. Unlike ferromagnets they lose their magnetization when the field is removed. Paramagnetic substances get magnetized along the direction of the field and are attracted by magnets while diamagnetic substances get magnetized opposite to the field direction and are repelled by magnets.

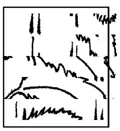
Langevin showed that paramagnetism could be explained by associating a permanent magnetic moment to every atom. In the absence of a magnetic field, because of thermal effects the atomic moments point randomly and the system has no net magnetization. However in the presence of a field the moments align along the field direction. Langevin used statistical mechanics to obtain the net magnetization of a paramagnetic sample and showed how one could get the Curie law for temperature dependence of the paramagnetic susceptibility. This theory is one of the earliest examples of the description of large-scale properties of a substance in terms of the properties of electrons and atoms. Langevin's theory was subsequently expanded by Pierre Ernst Weiss, who postulated the existence of an internal, molecular magnetic field in materials such as iron. This concept, when combined with Langevin's theory, served to explain the properties of strongly magnetic materials such as iron. Langevin also extended his description of magnetism in terms of electron theory to account for diamagnetism, and showed how a magnetic field would affect the motion of electrons in the molecules to produce a moment that is opposite to the applied field. This theory explained the temperature independence of the diamagnetic effect and also allowed estimates of the size of electron orbits. Langevin's work on the atomic theory of magnetism was remarkable for it came at a time when the structure of the atom was still not clearly understood.

Paul Langevin was born in Paris on January 23, 1872. He studied at Ecole de Physique et Chimie (1888-1892) then at Ecole Normale Superieure (1893-1896) and lastly at the Cavendish Laboratory in Cambridge. He obtained his PhD under Pierre Curie and also worked with Jean Perrin and J J Thomson during his student days.

Among his other contributions were his work on molecular structure of gases and the analysis of secondary emission of X-rays from metals exposed to radiation. Langevin also made the important contribution of developing a practical application of the piezoelectric effect, discovered in 1880 by Pierre Curie and his brother Jacques Curie. In the piezoelectric effect a crystal, on being subjected to pressure on its faces, develops an electrical potential difference across its faces. The converse effect whereby a voltage difference causes a crystal to get stressed was first theoretically predicted and later also verified in experiments by the Curies. The piezoelectric effect is the principle on which the quartz crystal used in watches works. In 1917, almost forty years after its discovery, Langevin developed the first application of the piezoelectric effect when he constructed an underwater ultrasonic detector. Using a piezoelectric quartz element sandwiched between two steel plates he made a transducer which could emit high frequency waves and also detect the reflected echo. This device could be used for submarine detection and was the precursor to the first sonar.

Langevin was one of the early supporters of the theory of relativity and played an important role in popularizing it in France. Einstein later wrote that Langevin had all the required tools for the development of the special theory of relativity and would have developed the theory had Einstein himself not done it. Langevin loved teaching and was a great teacher. During the second world war Langevin became a vocal anti-fascist and peace activist and later joined the French communist party. In 1940 he was arrested by the Nazis after their invasion of France. He escaped to Switzerland in 1944 and returned later to France after the end of the war. Langevin died in 1946.

Abhishek Dhar
Raman Research Institute, Bangalore 560 080, India.
Email:dabhi@rri.res.in



We are most likely to learn the best methods of discovering truths, by examining how truths, now universally recognized, have really been discovered.

William Whewell