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Ludwig Boltzmann, Man, Physicist, Biologist, Philosopher.

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On September 5th, 1906, one of the greatest thinkers of all times ended his life at Duino, near Trieste. Ludwig Boltzmann is well known all over the world as one of the founders of classical physics. He is less well known as a passionate contributor to biology and as an interesting philosopher. However, all these aspects were treated in the International Boltzmann Symposium held at Vienna University in September, 1981, in honour of the great man, 75 years after his death.

The immense influence of Boltzmann on physics is reflected in the international standard terms: Maxwell-Boltzmann distribution law, Boltzmann factor, Boltzmann statistics, Boltzmann constant, Stefan-Boltzmann radiation law. Boltzmann's greatest achievement has been christened "Boltzmann principle" by his follower, Albert Einstein. Indeed, Einstein has been called by one of his foremost students in his Berlin period, the Hungarian Cornelius Lanczos, the "natural successor" of Boltzmann. Another great physicist whose greatest successes derived from Boltzmann was Max Planck in Berlin. He established his quantum hypothesis, which revolutionized physics, on the basis of Boltzmann's ideas and equations. This is all the more surprising and remarkable as Planck had been a determined

opponent of Boltzmann for many years. It speaks for the human greatness of Planck that after his conversion to Boltzmann, in 1900, he never tired of singing Boltzmann's praise.

The Man

The life of Ludwig Boltzmann lacked dramatic events. He was born at Vienna in 1844 as the son of an Imperial tax official, and went to schools mainly in Upper Austria. At Linz, Anton Bruckner was his private music teacher; Boltzmann remained deeply devoted to music all his life, and he always saw to it that he could take an active part in chamber music. He returned to Vienna to study at the University under the excellent Josef Stefan, who was an early champion both of physical atomistics and of Maxwell's new, revolutionary, ideas on the electromagnetic field and on light. Through his great gifts, Stefan, the son of illiterate Carinthian peasants of Slovene mother tongue, had worked his way up to a chair at Vienna University and also to the position of Vice president at the Imperial Academy of Sciences. He is held in high esteem now not only in Austria, but also in Slovenia. Stefan supported work on atomistics although in his time many famous physicists still discounted the idea of the atom.

Boltzmann's genius was recognized early, and after periods as professor of mathematics at Graz and Vienna he was in 1876 appointed to the chair of experimental physics at Graz, where he stayed for 14 years.

He was an excellent experimentalist and carried out fine work in electricity and optics. Yet his love belonged to theory. Apparently Boltzmann is the true original author of the statement that nothing more practical exists but a good theory.

At Graz Boltzmann also married and founded a big family. He bought a country house in a fine situation on a hill overlooking the beautiful country around the provincial capital of Styria. By now his reputation was so great that promising young men from far away countries joined him for work, including the later Nobel Prize Winners, the German Walther Nernst and the Swede Svante Arrhenius. In Boltzmann's hospitable home some of the greatest ideas in physics were hatched in friendly discussions, interrupted by walks over the hills with their luxuriant flora. Food and drink were also abundant.

A most honourable invitation to Berlin University as successor to Kirchhoff in 1888 was rejected after Boltzmann during a dinner with the colleagues, including the mighty Helmholtz, had come to the conclusion that the Prussian spirit was not for him. The formidable Helmholtz had been nicknamed the Reich Chancellor of German Physics. But in 1890 he did accept a call to Munich. Now, for the first time, the chair was one of theoretical physics. After Stefan's death Boltzmann returned to Vienna in 1894 where he remained to the end, except for two years at Leipzig. It was on the invitation of Wilhelm Ostwald, the founder of physical chemistry, that Boltzmann moved there. But Ostwald was, though he was on excellent personal terms with Boltzmann, an antiatomist. This was one of the reasons why the move was not exactly a success.

During his last period at Vienna Boltzmann was not only the (only) professor of theoretical physics, but he also taught natural philosophy. In this respect he was the successor to Ernst Mach, who had come to Vienna from Prague in 1895 as a professor of philosophy but who had to retire from active teaching in 1901 because of a stroke. The replacement of Mach by Boltzmann was a curious fact as the two men were hard adversaries both in physics and in philosophy, though personally they esteemed each other. In physics, Mach was, along with Ostwald, the leading antiatomist in Central Europe. In philosophy he was the founder of the neopositivist doctrine, to which Boltzmann was bitterly opposed. Boltzmann's lectures on natural philosophy were great events. Hundreds of listeners attended, many of them unconnected with the University.

Boltzmann was a clear and at the same time fiery lecturer, much loved and admired by his audiences. Both in experiental and in theoretical fields the lectures were prepared most carefully. Nevertheless, in his actual talks Boltzmann loved asides, anecdotes and jokes. He had a most attractive sense of humour. For instance, after a pedantic German professor in his textbook on mechanics had written that among deformable bodies there is one that can deform itself consciously, namely man, Boltzmann wrote on the margin: "Also the pig can deform its body consciously, but truly such nonsense can be written only by man."

In his lectures and writings, Boltzmann loved to refer to the great composers and poets. In his Foreword to his "Popular Writings" (1905) he paid glowing tribute to the poets, Shakespeare and Goethe. But he added that without Schiller there might have been a person

with the same kind of nose and beard, but no personality as he. Not only Schiller's poetic sense, but also his moral power had deeply influenced Boltzmann. Among the musicians, Mozart and Schubert were named admiringly, but Beethoven was the one who most deeply impressed Boltzmann. Interestingly, for Einstein the order was rather Mozart-Schubert-Beethoven; Beethoven's heavy emotions did not suit him so well.

Likewise, the beauties of Nature also moved Boltzmann. He did not mind confessing that the colour of the ocean had made him break in to tears - how can, he asked, a colour make you cry ? Also it was not only practical utility and convenience that made Boltzmann welcome the magnificent achievements of technolgy. With enthusiastic admiration he spoke of the Eiffel Tower, of Brooklyn Bridge and of the work of the great "electricians". Surely he viewed the works of the engineers as beautiful expressions of the human mind, itself the greatest product of Nature.

The Scientist

In physics it was Boltzmann more than anybody else who led atomism to victory after it had not only been rejected by many of the leading thinkers through millenia, including Plato, but also been persecuted. Thus in France as late as 1624 the teaching of atomistics had been made a crime punishable by death. It is very likely that the rise of atomistics in the middle of the 19th century was helped by the need for a consistent interpretation of the phenomena observed in the interconversion of heat and work. At a

period when heat engines became common, metallurgy began to need enormous amounts of heat and power, and chemical industry developed rapidly, an understanding of these phenomena became essential for economy.

The science of the interconversion of heat and work, thermodynamics, had produced two main laws: the First Law, also known as the law of the conservation of energy, and the Second Law, the law of the increase of entropy. Entropy was a concept and term consciously created by Rudolf Clausius in 1865. Through the increase of entropy in every natural process the obvious, but puzzling, onesidedness of events is described in a most useful way. For instance, in the mixing of cold and hot water in a bathtub, a process easily enough observed, entropy increases. However, lukewarm water will not, by itself, separate into cold and hot water. Further investigation shows that similar rules apply to the mixing of different substances. Coffee and milk mix, but milk coffee will not return to its components.

Some leaders in physics like Mach and young Planck wanted to restrict thermodynamics to the unambiguous description and mathematical formulation of the phenomena observed with large (visible and weighable) objects: conservation of energy and increase of entropy. This was the phenomenological approach, as it was called. Further explanation was not be sought. Others, like Clausius, Maxwell, Stefan and Boltzmann, wanted to explain thermodynamics on the basis of the existence of atoms. Admittedly for this purpose one had to ge beyond experience. At that stage in science nobody could "see" atoms. Therefore, the atomistic explanation was hypothetical, and errors could not be excluded. On the other hand, there was hope for new insights and for improved prediction of the outcome

of experiments. The information content of atomism is higher than that of phenomenology, but the information was, at least initially, not quite secure !

Boltzmann reached his peak when he devoted himself to the explanation of the mysterious Second Law, the law of the increase of entropy. After having made more and more progress during many years through hard work and application of a lot of mathematics, he finally arrived, in 1877, at his world-shaking equation ("Boltzmann's principle") which later was rewritten by Planck in the form

$$S = k.\log W.$$

This has been called one of the most beautiful equations of all physics by Boltzmann's student and successor at Vienna, the fine physicist Fritz Hasenöhrl. Quoting words from Goethe's Faust that had been applied by Boltzmann himself to Maxwell's equations in electromagnetism, one of the physicists present at the inauguration of the Boltzmann monument in Vienna's Central Cemetery asked: "Was it a God who wrote these signs ?" This beautiful monument was created by the sculptor Gustinus Ambrosi Pilgrims from all the world visit it.

Now what do these signs mean ? Apart from k, which is a constant ("Boltzmann's constant", according to Planck), the equation indicates that a magnitude "S" increases in step with another magnitude "logarithm of W", and therefore also with W itself. Now S is nothing else than the entropy of Clausius, and W ("Wahrscheinlichkeit") is the probability of a particular arrangement, in a wide sense, of the atoms. Thus it is claimed that the increase in entropy reflects the spontaneous, but

inexorable trend towards more probable arrangements of the atoms present. Necessity has been reduced to statistics. Thus physicists show quite easily that the disorderly arrangement of atoms in milk coffee is far more probable than orderly separation into milk and coffee.

Reduction of natural law to probability was considered as heresy by some. It was objected that from time to time improbable events must also occur. Boltzmann did not live to know of such events, "fluctuations". Yet only a short time after his death, Jean Perrin in Paris demonstrated that "Brownian movement", the irregular and disorderly movement of tiny particles suspended in water, observable under the microscope, is nothing else but a case of fluctuations. The equations tested by Perrin had been supplied by Einstein and, independently, by Boltzmann's student, the Pole Marian von Smoluchowski.

Boltzmann's inclination towards statistics also led him to enthusiastic acceptance of Darwin's theory. Survival of the fittest is a statistical phenomen. Darwin opened the way to rational understanding of development and evolution in biology, and in this way for the inclusion of biology into modern science. Boltzmann called his century "Darwin's century". Passionately, indeed violently, he argued against the "obscurantists" who had turned against Darwin, and he expected the "salvation" of philosophy.from Darwin's theory. Boltzmann explained that the products of the mind, the laws of thinking, as well as the senses for morality and for beauty can be derived on the basis of their utility in the evolution of mankind's ancestors and of mankind itself. Recalling that Pythagoras in gratitude had sacrificed to the gods hundreds of oxen. Boltzmann compared the foes of Darwin to oxen fearing new truths.

Boltzmann also applied Darwinian ideas to the origin of life. Anticipating concepts that are common in our time, he suggested that in the primordial waters on Earth "complexes" arose through modification by chance and through struggle for survival that maintained itself and later produced similar offspring. This is what now is known as chemical evolution. Further, Boltzmann explained that photosynthesis evolved among plants in response to the need for a source of useful energy.

The Philosopher

Mach was not only opposed to atoms, he also rejected entirely the notion of an external, independent, world. According to him, this is metaphysics. Science should be limited to the economical ordering of sensations, of elements of experience. By the way, Mach was aware of the similarity of such views to those of bishop Berkeley in the 18th century. In his lectures on natural philosophy Boltzmann argued not only against Mach's subjective idealism, now often called positivism, but also against the various schools of objective idealism, notably against Hegel and Schopenhauer, whom he called "a mindless, ignorant philosophaster who degenerates the heads by hollow verbiage basically and for ever." These words had originally been used by Schopenhauer himself against Hegel. Boltzmann spoke out in favour of realism, and in his lecture against Schopenhauer he even called his own views "materialist". His main argument was concordance, i.e. the fact that the experiences of our different senses at different times and also the results obtained with the most varied physical instruments again and again lead back to an external world with consistent properties.

Boltzmann had a wide circle of students, admirers and friends. His kindness, helpfulness and humour were most attractive. His achievements in physics were recognized all over the world, and he was a member of many Academies. Yet he was not a happy man. Increasingly he suffered from ill-health. He complained about "neurasthenny". Moreover, he feared that atomistics was to be eclipsed, at least temporarily. His views in biology and philosophy also led to opposition. Even in politics his ideas were not universally popular. While he was never active in public affairs, he expressed himself as a democrat and republican. In younger years Boltzmann, a great debater, would have enjoyed the resulting battles. But the combined action of increasing opposition and of ill-health apparently were too much for him.

In the international world of science Boltzmann is now given greater attention than ever before, and more and more work is devoted to the analysis of his work. As an illustration, may we point to the important book by René Dugas, Paris, with the striking title "La theorie de physique au sens de Boltzmann". "Statistical mechanics", the work of Maxwell, Boltzmann and the American, J.W.Gibbs, is an enormously active branch. Information theory is also derived from Boltzmann statistics. Einstein and Planck based their quantum theories upon Boltzmann. In his native country it is now widely realized that Ludwig Boltzmann was not only a first-class expert in physics, but a genius of universal importance. Several institutions and prizes have been named after Boltzmann, and his complete works are being issued in compact and annotated form.