MACH, BOLTZMANN AND ATOMISM

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This article examines the life, philosophy and scientific thoughts of Ernst Mach and his influence on the science of late nineteenth century, as an originator of 'Philosophy of Science'. In the same perspective, most innovative and the great ideas of Ludwig Boltzmann are examined that in spite of opposition to his theories because of anti-atomistic views of Mach, he continued his work which were not only found true but were greatly appreciated mainly during his final years on support of Planck and Einstein, and more so after his death when experimental studies of French scientist Jean Perrin verified his work. This is an interesting story to realize that how the thoughts and philosophy of one scientist could influence the scientific developments of the period and thus even affecting the thoughts and lives of many other scientists.

Ernst Mach (1838-1916)

Ernst Mach, an Austrian Philosopher and Physicist, born on Feb 18, 1838 in Moravia, Austrian Empire (now in Czech Republic), received his doctorate at the age of 22 in the year 1860 from the University of Vienna. He was appointed Professor of Experimental Physics in 1867 at Prague University, where he stayed for 28 years before returning to Vienna in 1895 to the chair of 'History and Philosophy of Science'. His major contributions to Physics relate to 'Doppler Effect', and the description of 'Spark-Shock Waves' and 'Ballistic Shock-Waves'. He said that when a bullet moves at a velocity higher than that of sound, it creates a compression of the air in front of it. He invented Interferometer. He also worked in the areas of 'Sensory Perception'. He contributed towards psychology and physiology, an inhibition influenced type of visual (optical) illusion (known as 'Mach Bands'), and especially he discovered non-acoustic function of the inner ear which is supposed to control human balance. Mach made a clear distinction between what he called as 'Physiological or Visual Space', and 'Geometrical Space'. He is more famous for 'Mach Number', which is the ratio of speed of the object to that of sound. His other grand idea is "Mach Principle', which concerns the physical origin of 'Inertia'.

But, most importantly other than these contributions, he evolved a 'Philosophy of Science'. He believed that only that phenomenon may be considered 'real', which recognizes 'sensations'. This view was absolutely incompatible with the concept of atoms and molecules. During 1897, after a lecture by Ludwig Boltzmann at 'Imperial Academy of Sciences' at Vienna, he declared, "I do not believe that Atoms exist", a very shocking statement to Boltzmann. Even Max Planck criticized Mach's views and his reluctance for not acknowledging the reality of atoms. Einstein however demonstrated in 1905 that statistical fluctuations of atoms did allow the measurement of their existence without any direct individuated sensory evidence. Mach even criticized Newton's ideas on space-time which did influence Einstein. But, later on when Einstein realized that Mach was only opposing the philosophy of Newton, he concluded that Mach's criticism is not on sound footing. Einstein then rejected Mach's views. Mach suffered cardiac arrest in 1898, retired from University of Vienna in 1901 and moved to his son's home near Munich in 1913. He died on Feb 19, 1916 at the age of 78.

Principally, Mach was a naturalist, a monist with anti-metaphysical attitude following empiricist tradition. He

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believed in verifiability theory of meaning and took an anti-realist stance in opposition to Atomism. He thought that the 'Nature' is 'Matter in Motion', believing in phenomenological physics. Mach had a great influence on the philosophy of science during later decades of nineteenth century and developed a 'phenomenological philosophy of science'. He considered scientific laws as summaries of experimental events, but later emphasized mathematical function also as a useful way to describe sensory appearances. This was more in line with the philosophy of Rene Descartes. He thought that the scientific laws may have more to do with describing sensations than with reality which may exist beyond sensations. Mach's physical theorization of his philosophy consists mainly of three principles; (i) Physics should be based on directly observable phenomenon, (ii) It should completely eschew absolute Space and Time in favour of relative motion, and (iii) Any phenomenon that would seem attributable to absolute Space and Time should instead be seen as emerged from large scale distribution of matter in Universe.[1]

Even Einstein considered the last principle as 'Mach's Principle', and cited this while discussing 'General Relativity'. Einstein, in 1938 said. "It is justified to consider Mach as the precursor of the General Theory of Relativity". Mach however had even rejected Einstein's theory before his death in 1916. Mach opposed Boltzmann and many others who proposed 'Atomic Theory'. Mach said that since one cannot observe things as small as Atoms directly, and since there is no consistent model of Atom (a fact at that time), atomic hypothesis is unwarranted, and perhaps not sufficiently 'economical'. These views of Mach greatly influenced the 'School of Logical Positivism', and the Vienna circle philosophers. Mach wrote a treatise on "*The Analysis of Sensations and the Relations of the Physical to the Psychical*" in 1890. It may be worthwhile quoting some interesting passages from his thoughts. On the 'Economy and Unity of Science', Mach said[2]:

> *"One and the same view underlies both my epistemological-physical writings and my present attempt to deal with the physiology of the senses — the view, namely, that all metaphysical elements are to be eliminated as superfluous and as destructive of the economy of science.* [Analysis of Sensations: xxxviii]"

He also had a view that it is not economical to have one theory for physics and another for psychology; the mind demands that the two be brought together. Attempts at such mutual adaptation had so far been failures and Mach hoped that his ideas could facilitate this [2]:

> *"To the physicist, qua physicist, the idea of "body" … [assists in] a real facilitation of view, and is not the cause of disturbance…. When, however, physics and psychology meet, the ideas held in the one domain prove to be untenable in the other. From the attempt at mutual adaptation arise the various atomic and monadistic theories — which, however, never attain their end. If we regard sensations, in the sense above defined (p.13), as the elements of the world, the problems referred to appear to be disposed of in all essentials, and the first and most important adaptation to be consequently effected. This fundamental view (without any pretension to being a philosophy for all eternity) can at present be adhered to in all fields of experience … [Analysis of Sensations: 32]*

Mach and Atomism

The best known legacy of Mach is anti-atomism. As discussed above, Mach was considered as anti-realist for unobservable entities, the origin of which lies probably not in his philosophical scepticism, but in his bio-psychological view of science. His views on this matter are as follows:

> *"… the biological-economical interpretation of the cognitive process can perfectly well co-exist on peaceable, and indeed on friendly, terms with that of present-day physics. The only real point of difference which has so far come to light concerns the belief in the reality of atoms. Here again, Planck can hardly find words degrading enough for such wrong headedness …. After exhorting the reader, with Christian charity, to respect his opponent, P. brands me, in the well-known biblical words, as a "false prophet." It appears that the physicists are on the way to founding a church; they are already using a church's traditional weapons. To this I answer simply: "If belief in the reality of atoms is so important to you, I cut myself off from the physicist's mode of thinking, I do not wish to be a true physicist, I renounce all scientific respect—in short: I decline with thanks the communion of the faithful. I prefer freedom of thought."* [The Guiding Principles of My Scientific Theory of Knowledge and Its Reception by My Contemporaries. 37-38]

Mach had a long-standing dispute with Boltzmann, who propounded the 'Kinetic Theory of Gases'. Boltzmann and Mach finally ended up agreeing in essence: if atomic theory was fruitful it should be used, but adopted what today might be considered an anti-metaphysical stance toward a theory that was still largely unsubstantiated. It was only in1905 with Einstein's study of Brownian motion that the kinetic theory of molecules was verified.

Planck, in 1909, wrote an essay "The Unity of the Physical World-Picture", which severely criticized Mach's philosophy. Mach had replied in 1910, with "The Guiding Principles of My Scientific Theory of Knowledge and Its Reception by My Contemporaries." Planck responded in 1910 with "On Mach's Theory of Physical Knowledge: A Reply."In essence, it was as follows:

"At issue were differences on how to make science free of human subjectivity, and how to achieve a unified science. Planck [1909] argues that while we once defined heat according to sensations, the study of heat has gone beyond this, now being under the purview of electrodynamics and kinetic theory; similarly, tones and colour are now understood as frequencies or wavelengths. Although physics had its beginnings in the analysis of sense impressions, its current success is due to removing these anthropomorphic elements. Planck formulates a vision of a human-independent science in reaction to Mach's claim that science is human-dependent.

Planck thought that physics can go beyond psychological dependency by basing itself on psychologically independent universal constants: "the constants appearing in the laws of heat radiation in free ether, like the constants of gravity, have a universal character and involve no reference to any special substance or any special body" [1909]. They are human-independent in a way that a unit like a centimetre is not. These constants can be used to "establish units of length, time, volume and temperature, which must of necessity retain their meaning for all time and for all cultures, even extra-terrestrial and extra-human ones" [1909].(from Stanford Encyclopaedia of Philosophy, 2011winter edition)".[3]

Mach's response is one of his last statements of position:

> *"I have no doubt that if somewhere in the universe a creature organized like ourselves could make observations … it would perceive a universe working similarly to that we ourselves describe …. As for the reality of atoms: I have no doubt that if atomic theory corresponds to the reality given by the senses, the conclusions drawn from it will also bear some relation to the facts — though what relation remains unclear. The distance from the glass of the first dark ring in reflected light corresponds to one-half of the period of Newton's 'fits', but to one quarter of Young and Fresnel's 'wavelength'. The findings of atomic theory, likewise, can undergo a variety of convenient reinterpretations, even if we are in no great hurry to take them for realities. [Mach 1910: 36-37]"*

Such views of Mach described above had immensely influenced the world of Science during late nineteenth century.

Let us now examine the life, philosophy and great scientific contributions of Ludwig Boltzmann whose ideas proved to be a turning point in the studies of physical and chemical sciences during twentieth century.

Ludwig Boltzmann (1844-1906)

Boltzmann, a great Austrian physicist and philosopher, born in Vienna on Feb 20, 1844, obtained his doctorate at the age of 22, in 1866 for his thesis on "Kinetic Theory of Gases". He was appointed to a chair of Theoretical Physics at Graz in 1869, moved to Vienna in 1873 accepting a chair of Mathematics, was back in Graz in 1876 in the chair of Experimental Physics. However, in 1894, he went back to Vienna to the chair of Theoretical Physics which became vacant on the death of his teacher Josef Stefan. In the following year, Mach was also appointed to a chair of 'History and Philosophy of Science' at Vienna. Boltzmann had lot many scientific opponents but Mach was rather a special opponent. We have discussed above the Mach's ideas and his opposition to Boltzmann's concepts to an extent. Let us now discuss the major scientific achievements of Boltzmann which revolutionized the world of science.

Boltzmann laid the foundations of 'Statistical Mechanics', which basically, using laws of probability explains and predicts the way the properties of atoms such as mass, charge and structure determine the physical properties of the matter such as thermal conductivity, viscosity and diffusion etc. Boltzmann's kinetic theory of gases including the Maxwell-Boltzmann distribution for molecular speeds in gases, Maxwell-Boltzmann Statistics and the Boltzmann distribution over energies remain the foundation of Classical Mechanics applicable to many phenomenon which do not require 'Quantum Statistics'. All these theories consider the reality of Atoms and Molecules. This was not acceptable to almost all German philosophers and even scientists like Ernst Mach and Wilhelm Ostwald. However Maxwell, Gibbs and many chemists agreed with the beliefs of Boltzmann. Boltzmann even had a dispute with the editor of an eminent physics journal, who refused him to refer to atoms and molecules or anything other than convenient theoretical constructs in his work.[4]

Boltzmann even made a compromise attempt and formulated a concept which may allow both atomists and anti-atomists to further their studies in physics. He said that using the theory of Hertz, let us use Atoms as 'Bilder', that is 'Models' or 'Pictures'. But, this too was not acceptable to either of the group. Ostwald even refuted the kinetic theory of gases and statistical mechanics basically because Boltzmann had assumed the presence of atoms and molecules. Not only that, the theoretical concepts of Boltzmann were further questioned by another philosophical objection in which the Hertz theory was interpreted to mean that electromagnetic behaviour is continuous, and there was no need to consider the presence of atoms and molecules, even thinking that all physical behaviour ultimately is electromagnetic. All these oppositions created a deep depression in the mind of Boltzmann because those could also mean the end of his kinetic theory and statistical interpretation of second law of thermodynamics.

Mach had resigned in 1901 because of his ill-health and Boltzmann returned to Vienna in 1902 from Leipzig where he had gone in 1900 on the invitation of Ostwald. Boltzmann himself decided to become a philosopher in order to refute the philosophical objections to his theories. He founded the 'Austrian Mathematical Society' in 1903. Now in Vienna, he taught Physics and Philosophy. Popularity of his lectures grew so much that he was even invited by Emperor for a reception at the Palace. He was however again discouraged when in 1904, he was not even invited to the 'Physical Section' of a conference in St. Louis, where most of the physicists of the day were rejecting his ideas of atoms and molecules. He was invited only to speak in "Applied Mathematics Section', where he attacked the philosophy, especially on 'Darwinian' grounds. Actually, his constant discouragement from the scientific world made him so depressed that he committed suicide on September 5, 1906 by hanging himself while he was on a vacation with his family near Trieste. And this brought the end of a bright scientific career of a great thinker at the age of 62. There is an engraving[4] on his grave, S=k ln W .

Boltzmann's Kinetic Theory of Gases

Boltzmann said that at any temperature above absolute zero, the atoms and molecules are in thermal motion. He theorized that the kinetic energy of the particles is proportional to the temperature T, governed by the equation, $(1/2)\ m\ v^2 = (3/2)\ kT$, where m is the mass and v, the velocity of the particle. The proportionality factor k is known as 'Boltzmann Constant', and relates the average kinetic energy to the temperature T (in degrees K). This Boltzmann constant k has the value of 1.3805×10^{-23} joules/kelvin.

The kinetic theory of gases also stipulates that the Entropy S=k ln W, where W is the probability of occurrence of macro state. Boltzmann is also considered as one of the founders of the concept of 'Quantum Mechanics', since he was the first to suggest in 1877, much before the concept of 'Quanta of Energy' was evolved by Planck in 1900, that the '*Energy levels of a physical system could be discrete*'.

Boltzmann and Second Law of Thermodynamics

Boltzmann gave the idea that the 'Second Law of Thermodynamics', which is 'Entropy Law' is the 'Law of Disorder', further stating that the dynamically ordered states are 'Infinitely Improbable'. He argued that this law is simply the result of the fact that in a world of mechanically colliding particles, disordered states are the most probable. He further said that a dynamically ordered state that is the state one with molecules moving at the same speed in the same direction is the most improbable state conceivable, an infinitely improbable configuration of energy. He also showed that this is only a statistical fact.

Conclusions

This article has examined the way Mach's philosophical thoughts influenced the scientific developments during later part of the nineteenth century. It has also summarized the influence of those thoughts and struggle which Boltzmann had to face for acceptance of his ideas by his contemporaries, his concepts of atoms and molecules, all of those were finally accepted in totality by the same world of science. Though Boltzmann was not the first to propound atomic theory; Dalton's laws of proportional weights involved in chemical compounds had definitely pointed towards an atomic picture - those laws could easily be explained by atomic hypothesis. What Boltzmann did in a highly successful and revolutionary way was to explain empirically observed 'Gas Laws' and many other properties of matter by way of statistical principles used in the 'Kinetic theory of Gases' - and further explain a whole lot of empirical thermodynamic principles. He put the whole field of thermodynamics including the 'Second Law of Thermodynamics' and the concept of 'Entropy' - in fact the most true branch of physics - (all other principles of physics can fail in nature but not the thermodynamic ones) - on a sound theoretical basis. If there was no Boltzmann, it is doubted if there would have been any 'Quantum Theory' - because there would have been no law derived governing 'Black Body Radiation' - and therefore, no crisis of matching something to observations, and hence no need for Planck to apply his mind! Boltzmann was a far greater Genius and a true Revolutionary.

This is also true that today, in understanding the physical world, the human race has moved far away from the Mach's worldview about atomicity. Mach's view is really no longer necessary today, and possibly in future as well. We are at the juncture where not only the atoms and molecules but the behaviour of subatomic particles is supposed to decide the physical properties of the matter. We are advancing further in stipulating that there is something even more fundamental than the behaviour of subatomic particles which actually decides not only the properties of the matter but the whole mechanism the way matter is woven in a matrix in this universe.

There is also an intrinsic message in above discussion which is that the scientific minds need to be a little more careful before rejecting any new proposition, especially one which sort of defies the presently known laws of science at any particular point of time. Who knows, that new concept may be a precursor to the newly evolving revolutionary thoughts, taking one to the domains unknown not yet explored! ❒

References

1. John T. Blackmore, Ernst Mach: His Work, Life and Influence, Berkeley University of California Press (1972)
2. Ernst Mach, The Analysis of Sensations and the Relations of the Physical to the Psychical, Translated by Williams C.M., La Salle, Open Court, (1984)
3. The Stanford Encyclopaedia of Philosophy, Winter Edition (2011)
4. John T. Blackmore, Ludwig Boltzmann - His later Life and Philosophy, 1900-1906, published (1995)