

CHAPTER TWO

A NEW THEORY OF MATTER

From 1863 to 1872 Mach was preparing a philosophical "new theory of matter," with some important parallels to his work in physics. He felt a new theory was needed after conducting a series of fault-finding arguments with spatial "billiard ball" type atoms. Mach advanced several types of arguments during this period, some physical, some philosophical, and some sense physiological observations.

Mach's first attacks on atomism occurred in two early papers on emission spectra and in his textbook *Compendium der Physik für Mediciner* (1863). At this time, Mach perceived difficulties with contemporaneous atomic views, but had not yet proposed an alternative. As he said, Mach used the *Compendium*, a text for his course of physics for medical students, as an organ to communicate his views on mechanical atomism:

In the year 1862 I drew up a compendium of physics for medical men in which because I strove after a certain philosophical satisfaction, I carried out rigorously the mechanical atomic theory. This work first made me conscious of the insufficiency of this theory and this was clearly expressed in the preface and at the end of the book, where I spoke of a total reformation of our views on the foundations of physics.¹

In the book, Mach approached atomism cautiously, laying out the indispensable features of discreteness, impenetrability, and obedience to the law of inertia.² His atoms exerted on one another a force of some nature falling off with the square of the distance. Atoms were also surrounded by cloud like *Aetheratome*, which repelled one another by forces of contact. Intra-atomic forces were not discussed. In fact, Mach wasn't even sure whether the atoms were chemically different among themselves or whether chemical differences emerged from varying combinations of identical atoms.³ Such was the very rough nature of atomism of the time.

Mach then gave several arguments as to why discrete particles were a more favorable view of matter than the competing theory of a material plenum. For example, the conduction and radiation of heat through matter in wave motions implied that bodies consisted of strata of discrete particulate matter capable of vibration. (As Swoboda has shown, Mach took over many of these pro-atomic arguments verbatim from G.T. Fechner's *Atomenlehre*, whose atomic conception was the model for Mach's *Compendium* treatment.)⁴ Such was Mach's skill in rehearsing the conventional arguments and explanations of the theory that Erwin Hiebert writes:

He had mastered the arguments of the atomic theory very well...although he later denounced the atomic theory vehemently and resolutely, he manifestly was not engaging in such polemics because of blindness or ignorance of the strengths and weaknesses of these conceptions.⁵

However, Mach went on to complain that the proposed reduction of all physical processes to the atomic level had not gone through. He then considered the possibility that atomism had outlived its usefulness, and that this hypothesis would give way to a deeper "metaphysical" theory of matter:

Here I have let the atomic theory step into the foreground everywhere, not indeed in the belief that it is the last and highest, and doesn't itself need further support, rather because it brings the appearances into a simple and visualizable association. The atomic theory, when one may express it thus, can be considered as a formula, which has already led to many results and will lead further to still more. In fact, whatever kind of metaphysical opinion may arise in the future, the results won according to the atomic theory will be translatable into them, as one may express formulas in polar coordinates or in parallel coordinates.⁶

He inclined toward such a new theory at the end of the book:

We have now become acquainted with a series of physical phenomena and laws, which we, so far as it was possible by elementary means, have embraced under the point of view of mechanics and the atomic theory. A complete and strict tracing back of physical laws to a few exact principles is no longer possible today. The gaps are still too great. For heat and light phenomena we have at least found the most general contour of a theory and at least this contour rests on fixed foundations. We have not yet won so much insight into the phenomena of electricity and magnetism. In these areas are rather empirical rules, to find one's way about in a large quantity of facts, than a real theory. However in this lies a stimulus to further research, and we hope that this will attain the goal, granted perhaps after a total reformulation of some of our fundamental physical views. At least the peculiarities of electrical and magnetic forces seem to point to the necessity of such a transformation.⁷

In the *Compendium* Mach's main objection to the mechanical view concerned Weber's law of electrical force between two moving, charged particles, which was also puzzling the world of physics at the time. The law said that, like gravity, the electrical force of attraction between two particles in motion was proportional to the charges and inversely proportional to the square of the distance. But, unlike gravity, it was *also* proportional to the velocity and the acceleration of the two charges. Presumably, if both gravity and electrical forces were mechanical phenomena at bottom, such asymmetries would not exist: "This dependence of forces on velocity is still a riddle at present; it never happens when two bodies exert gravitational forces on one another for example."⁸

Mach held the view that thermal or electrical phenomena might be more foundational sciences than mechanics and said in 1909 that "this thought seems to be becoming an actuality." But Mach's early objections came to focus on a different philosophical issue: the conception that atoms were extended in space. He said that his work on the spectra of elements convinced him that the underlying atomic processes were not three dimensional:

My attempts to explain mechanically the spectra of the chemical elements and the divergence of the theory with experience strengthened my view that we must not represent to ourselves the chemical elements in a space of three dimensions. I did not, however, speak of this candidly before orthodox physicists. My notices in Schlömilch's *Zeitschrift* of 1862 and 1864 contained only an indication of it.⁹

While still an upholder of the atomic theory, I sought to explain the line spectra of gases by the vibrations of the atomic constituents of a gas molecule with respect to each other. The difficulties which I encountered suggested to me (1863) the idea that non sensuous things did not necessarily have to be pictured in our sensuous space of three dimensions.¹⁰

In the earlier paper of the two, "Über die Spektra verschiedener Körper," Mach adopted the premise that when the atoms of a gas or heated substance were shaken, oscillations in the distances between the atoms suspended in a molecule produced the bright lines visible in their emission spectra. There was no explicit skepticism about the existence of atoms in this article; indeed, he seemed to need the atomic theory to preface his argument, but Mach limited himself in a tell tale way to the observable facts of spectral lines and the *distances*, without relying on the atoms as such. It was as if he proposed to consider distances without answering the question, "distances between what and what?" Perhaps for this reason, among others, Mach's article struck physicists as "zu naturphilosophisch."¹¹ In response to his critics, Mach followed up with an 1864 article, "Vorläufige Bemerkungen über das Licht glühender Gase" in which he said: "I must remind you that I by no means consider the atomic theory as something established in itself, but rather as a useful temporary empirical formula; as a kind of *regula falsi* to be used in drawing closer to the truth."¹²

He then reprised his argument from the *Compendium* that the results of the atomic theory could be "translated into a different 'metaphysical' view of matter which, henceforth, would prove to be more cogent." But now he explicitly declared his support for an alternative: "I personally am now already very much inclined toward such a translation. And I shortly hope to show that my remarks by no means hang together so necessarily with theories, but can be understood very readily as an expression of the facts."¹³

Like many physicists of his time, Mach had wanted to investigate the constitution of matter and saw the phenomena of light and heat radiation emanating from bodies as the key to uncovering it. For example, on September 26, 1860, Mach sent a letter to G.R. Kirchhoff describing a method for isolating the spectrum of a distant phosphorescing body from the spectrum of its reflected light by using a polarizing filter, which got a gruff answer and not the promise of financial support Mach anticipated.¹⁴ Unlike most physicists of his time, Mach came to see the wavelike transmissions of energy not merely as a sign of the constitution of matter, but as comprising a more fundamental level of description. In his notebook of 1874, for example, Mach wrote that he considered the passage of matter through space to be a wave, or a propagating "potential difference": "The movement of matter is a wave. A difference that progresses forward...Light as periodic potential."¹⁵

Ernst Mach's World Elements

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