# One hundred years since Albert Einstein's annus mirabilis

## Part 2

**Peter Symonds**
**12 July 2005**

*This is the second part of a four-part series on Einstein's scientific contributions.* Part one *was published on July 11. Parts* three *and* four *will be published on July 13 and 14 respectively.*

Newton's synthesis—vastly elaborated and extended to statics and dynamics, to liquids and gases as well as to solids—remained the basis of physics for the next 200 years. The mechanical view of the world—that everything could be reduced to forces acting on masses—was, however, increasingly challenged in the nineteenth century. Newton's conception of light as a stream of particles gave way to the wave theory of light, which alone was able to explain optical phenomena such as interference and diffraction.

Research into the apparently unrelated field of electricity and magnetism produced a startling confirmation of the wave theory of light. In 1820, Hans Oersted demonstrated that an electrical current flowing through a wire produces a magnetic force. In 1831, Michael Faraday showed that a moving magnet could induce an electric current in a wire—the basis of an electric generator. Electricity and magnetism were clearly interrelated. But Faraday went further to speculate that light might also be related.

Newton envisaged forces like gravity as acting instantaneously at a distance. Faraday, however, introduced the notion of a field—an invisible web of lines of force radiating from an electric charge or a magnet. The classic demonstration of a magnetic field is the pattern formed by iron filings when scattered around a magnet. In a lecture in 1844, Faraday proposed that disturbances could trigger vibrations in such fields that would take time to travel across space. He even suggested that light may be just such a wave—an idea that was dismissed as preposterous at the time.

A comprehensive field theory of electromagnetism was finally elaborated by James Clerk Maxwell in the 1860s and summed up in a series of four mathematical equations, now known as Maxwell's equations. Not only did his theory explain and quantify all previously discovered electrical and magnetic effects, but it calculated the speed of propagation of electromagnetic waves and found it to be the speed of light. He wrote: "We can scarcely avoid the inference that *light consists of transverse undulations of the same medium which is the cause of electric and magnetic phenomena*." (Maxwell's italics) [7]

Maxwell's demonstration that light was an electromagnetic wave was one of the crowning achievements of nineteenth century science. As one historian of science put it: "All of this is why Maxwell is placed alongside Newton in the pantheon of great scientists. Between them, Newton's laws and his theory of gravity, and Maxwell's equations, explained everything known to physics at the end of the 1860s. Without doubt, Maxwell's achievement was the greatest piece of physics since the *Principia* [of Newton]." [8]

In parallel, the application of steam engines in the industrial revolution spurred on the development of thermodynamics—the study of heat and motion—and led to the discovery of the law of conservation of energy—that energy may change form, but total energy remains a constant. In the field of chemistry, atomic theory—that matter is composed of indivisible particles of different types—provided the theoretical basis for bringing order to the rapid developments being made. Combining Newtonian mechanics and statistics, Maxwell and Ludwig Boltzmann developed the kinetic theory of matter—the derivation of the general properties of matter, including the laws of thermodynamics, from a mathematical treatment of the average behaviour of its component atoms or molecules.

By the end of the nineteenth century, huge advances had been made in every area of physics. Each of the major theories provided an accurate explanation of the phenomena within its arena of focus: Maxwell's laws comprehensively dealt with electricity, magnetism and electromagnetic waves; Newtonian mechanics could be applied to force and motion; and its extension to statistical mechanics explained heat and the properties of matter as the product of the movement of atoms and molecules.

One reaction to these achievements was to conclude that nothing much remained to be done. In 1894, the experimental physicist Albert Michelson, who later won the Nobel Prize for physics, declared in a speech to dedicate a new laboratory at the University of Chicago: "The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote... Our future discoveries must be looked for in the sixth place of decimals."

William Thomson, also known as Lord Kelvin, who had made a major contribution to the development of thermodynamics, expressed similar sentiments in a lecture to the Royal Institute in 1900. "There is nothing new to be discovered in physics now. All that remains is more and more precise measurement," he declared, famously adding that there were "two small clouds on the horizon"—the unusual characteristics of a phenomenon known as blackbody radiation and the unexpected results of an experiment conducted by Michelson and his associate Edward Morley in 1887.

### An accumulation of contradictions

The appearance that nothing much remained to be done in the field of physics at the dawn of the twentieth century was extremely deceptive. The very advance of the science threw up new theoretical challenges that were far from resolved. Thompson's "two small clouds" provided the impetus for developments that were about to burst forth. The first "cloud" led to

Einstein's postulate that light behaved as a particle and to quantum mechanics. The second highlighted the incompatibility of Newtonian mechanics and Maxwell's laws, which was only resolved by relativity theory.

The Michelson-Morley experiment was an attempt to measure the properties of the ether. Physicists had concluded from Maxwell's explanation of light as an electromagnetic wave that there had to be something that "waved". Water waves obviously travelled through water and sound waves, less obviously, required air or another medium. So light needed a medium—the ether. The postulation of an ether, however, greatly complicated the application of Maxwell's equations to moving charges or magnets.

By assuming that the ether was static, Henrik Lorentz was able to offer an interpretation of Maxwell's equations that appeared to provide a solution. As Einstein explained in a tribute to Lorentz: "Upon this simplified foundation Lorentz based a complete theory of all electromagnetic phenomena known at the time, including those of the electrodynamics of moving bodies. It is a work of such consistency, lucidity and beauty as has only rarely been attained in an empirical science. The only phenomenon that could not be entirely explained on this basis, i.e., without additional assumptions, was the famous Michelson-Morley experiment." [9]

Physicists reasoned that if the ether were static, then it should be possible to measure the motion of the Earth through it. Prior to the Michelson-Morley experiment, all efforts to do so had failed. Lorentz had been able to explain the negative results by demonstrating that the methods were not accurate enough. Michelson and Morley, however, devised an ingenious optical apparatus for meeting Lorentz's required order of accuracy.

Essentially the experiment involved racing two beams of light—one along the path of the earth through the ether, and the other at right angles to it. The speeds of the two beams, the two scientists reasoned, would be different. To use an analogy, if one measures the speed of a train from a car travelling on a parallel road, it will vary depending on the speed of the car. The faster the car travels, according to Newton's laws, the slower the measured speed of the train. Likewise, if the earth is travelling into the ether, one should be "catching up" to the beam of light and its measured speed should be slower—unlike the beam of light travelling at right angles to the earth's motion.

The result defied all expectations: no difference in speed was detected. In a letter in 1892, an exasperated Lorentz wrote: "I am utterly at a loss to clear away this contradiction [between the ether theory and the result of the Michelson-Morley experiment], and yet I believe if we were to abandon Fresnel theory [the idea that the ether was at rest] we should have no adequate theory at all... Can there be some point in the theory of Mr Michelson's experiment which has yet been overlooked?" [10]

Unwilling to abandon the ether, Lorentz, and independently George Fitzgerald, found that the only way to account for the Michelson-Morley result was to assume that moving objects actually shrank in the direction of motion through the ether. If the experimental apparatus physically contracted along this one dimension, it would account for the failure to detect predicted motion. Such shrinkages would be infinitesimal and thus unobservable in everyday circumstances, but that did not make the idea any less bizarre, even offensive, to physicists.

Lorentz's solution also required another strange modification. He found that objects moving at constant velocity with respect to the ether had differing "local times". The mathematician Henri Poincaré offered a physical explanation: the variation in times could be accounted for by imagining that each object had its own clock and that the clocks were synchronised using light signals. As light moves at a finite velocity, the times would vary.

**The crisis of physics**

These strange and disturbing conclusions were not the only difficulties confronting physicists in the last decade of the nineteenth century. Experimental developments were opening up new vistas and also new problems. In the late 1880s, Heinrich Hertz confirmed the existence of low frequency electromagnetic waves—radio waves. He showed that these waves travelled at the speed of light and, like light, could be reflected and refracted. In 1895, Wilhelm Rontgen discovered X-rays—later shown to be a very high frequency electromagnetic wave.

The first clues that atoms were not small, immutable, indivisible objects also emerged. By 1899, J.J. Thomson confirmed the existence of the first subatomic particle—the electron. He succeeded in demonstrating that this negatively charged particle had a mass only about one two thousandth of a hydrogen atom—the simplest and smallest atom.

The study of radioactive substances in the 1890s by Henri Becquerel, and Pierre and Marie Curie produced perplexing results. What we now know involves the disintegration of unstable atomic nuclei, was found to produce a variety of rays—later identified as alpha, beta and gamma—and the transformation of one chemical element into another, something that was previously thought to be impossible. The ability of radioactive substances such as radium to radiate energy, apparently spontaneously and continuously, appeared to contradict the law of the conservation of energy.

While some scientists were concluding that virtually everything had been achieved in physics, others were declaring a major crisis. In his popular book *The Value of Science* published in 1905, Poincaré wrote: "Are we now about to enter upon a third period? Are we on the eve of a second crisis? These principles on which we have built all, are they about to crumble away in their turn? This has been for some time a pertinent question... It is not only the conservation of energy that is in question; all other principles are equally in danger, as we shall see in passing them successively in review." [11]

This turmoil in science—in physics in particular—had philosophical ramifications. In his efforts to place science on a new foundation, physicist Ernst Mach threw the proverbial baby out with the bathwater. He set out to rid science of all "metaphysical conceptions" and to establish it strictly on the basis of observable qualities and measurable quantities. The very existence of matter as the source of our sensations he ridiculed as an unnecessary metaphysical superstition. "To us investigators, the concept 'soul' is irrelevant and a matter for laughter, but matter is an abstraction of exactly the same kind, just as good and just as bad as it is. We know as much about the soul as we do of matter," Mach wrote. [12]

For Mach, objects were simply "complexes of sensations". The task of scientists was to study observable effects, to measure variables and to mathematically correlate them to produce scientific laws. Atoms and molecules were dismissed as metaphysical constructs. For all his irreverence, Mach, whether consciously or not, was reviving the philosophical idealist conceptions of Bishop George Berkeley who, in his eighteenth century polemics against atheism, likewise denied the existence of an external material world.

Mach was not alone in his philosophical improvisations, but he was influential and at the centre of controversies with physicists such as Planck and Boltzmann who, like most scientists, intuitively recognised that their investigations were of an external world, existing independently of thought. Mach's positions were symptomatic of the ferment in physics and influenced a generation of physicists, including Einstein. As one historian of science commented: "To many of the younger physicists of the time, attacking the problems of physics with conceptions inherited from classical nineteenth century physics did not seem to lead anywhere. And here Mach's iconoclasm and incisive critical courage, if not the details of his philosophy, made a strong impression on his readers." [13]

Einstein's relation to Mach has been the subject of lengthy essays. Suffice it to say, that while he appreciated Mach's critical outlook and his analysis of Newtonian mechanics, Einstein never fully accepted Mach's philosophical stance. Unlike Mach, Einstein acknowledged the existence of atoms and molecules. Two of his five 1905 papers involved the application of Boltzmann's statistical mechanics to determining the size of molecules and explaining their behaviour. These two papers are less well known, although both played an important role in putting an end to scepticism about the atom. In his later writings, Einstein explicitly rejected Mach's philosophical idealism. He began a lecture in 1931, for instance, with the blunt declaration: "The belief in an external world independent of the perceiving subject is the basis of all natural science."

*To be continued*

**Notes:**

7. Quoted in *Science: A History*, John Gribbin, Penguin, 2003, p.431
8. Ibid, p.432
9. "H.A. Lorentz, Creator and Personality" in *Opinions and Ideas*, Albert Einstein, Crown Publishers, 1982, p.75
10. Op cit, Rigden, p. 82
11. *The Value of Science*, Henri Poincaré, English translation, Dover, 1958, p. 96
12. Quoted in *Ernst Mach: His Work, Life and Influence*, John T. Blackmore, University of California
13. *Thematic Origins of Scientific Thought*, Gerald Holton, Harvard University Press, revised edition 1988, p.241