The Michelson-Morley Experiment(s)

Early Experimentation:

By the 1870s, the luminiferous ether was an accepted feature of contemporary physics. Double slit experiments early in the 1800s had demonstrated that light is wave-like, suggesting that it must propagate through some medium. Physicists disagreed on the exact nature of the ether: some thought of it as a fluid, while others thought it behaved like an elastic solid, for example. The consensus was that the ether was necessary to explain the propagation of light and would provide a rest frame for the universe. Newton himself had argued that a single correct coordinate system for space and time existed, and the idea was taken for granted by many physicists. The most significant disagreement among physicists was whether the ether was entirely stationary (the ether drift hypothesis) or was dragged along with the Earth, either partially or completely (the ether drag hypothesis). By the 1880s, the ether drift model was more widely accepted.

Michelson's original experiment of 1881 was designed to measure the velocity of the Earth against the stationary ether's rest frame. Testing the existence of the ether did not make much sense in his context, as there was little reason to doubt its existence. All earlier tests had found no relationship to first order in v/c. A relationship corresponding to v^2/c^2 was possible, but this required incredibly precise measurement. Michelson accomplished this with his new invention, the interferometer, which was probably his largest source of fame during his lifetime. The 1881 experiment found no change in light's velocity, which Michelson attributed to ether drag.

Few other physicists paid attention to this first experiment. Those who did focused on the ingenuity of the interferometer rather than the actual results. One person who did pay attention was Hendrik Lorentz, who pointed out that Michelson had miscalculated one of the light beams' paths. This, along with a desire for still greater precision, convinced Michelson to repeat his experiment. Around this time he began collaborating with Edward Morley, whose chemistry lab provided him with high quality equipment. In 1886, the two repeated the famous Fizeau Experiment, comparing the velocity of light passing through water running in opposite directions. They found that light moves at the same velocity regardless of the water's motion, suggesting that the ether is not affected by moving matter. This contradicted the ether drag hypothesis and Michelson's 1881 results, which provided another reason to redo the experiment.

The Famous Experiment:

The Michelson-Morley Experiment of 1887 was specifically intended to resolve the ether drag question. The pair intended to perform several tests at different points in the year, to incorporate the effects of the Earth's revolution, but they never completed these later trials. This may have been due to their disappointment at early negative results or Michelson's excitement to move on to other projects to test his interferometer. The same year, Heinrich Hertz demonstrated the existence of electromagnetic waves, confirming Maxwell's electromagnetic theory and seeming to confirm the need for a medium for the waves. Michelson was concerned with interferometry's applications, while the broader community was more impressed with Hertz's results than with Michelson's; as a result, the Michelson-Morley Experiment did not immediately lead to the death or even the questioning of the ether model.

Once again, Lorentz was one of the few who noticed the experiment. He first identified the negative results as one of the major unsolved problems of contemporary physics and derived the length contraction formula and Lorentz transformation in order to explain it. Lord Kelvin also directly referred to the experiment in a speech in 1900 (the source of his famous "two dark clouds" quote), further spreading awareness. By this point, experiments had contradicted both the ether drift and ether drift theories. Michelson, Morley, and a new collaborator, Dayton C. Miller, continued experimenting in different situations and with greater and greater precision, while theorists formulated alternate ideas. Lorentz contraction was one example of this; unlike Einstein, he attributed contraction to changes in molecular-scale forces due to motion through a stationary ether and continued to believe in absolute measurements of time and space (the Lorentz transformation of t being only a mathematical formality). Conversely, Henri Poincaré argued against absolute space and time, questioned the necessity of the ether, and theorized the equivalence of all inertial reference frames (even referring to this as "the Principle of Relativity"). Poincaré came very close to Einsteinian relativity, but did not develop it fully.

From Ether to Relativity:

Despite these early contributions from Lorentz and Poincaré, Albert Einstein is correctly identified as the founder of special relativity. His 1905 paper was not immediately noticed, as he was only 26 years old and had no prior reputation. Two early supporters were Max Planck, who developed relativistic dynamics, and Hermann Minkowski, who formulated relativity in terms of four-dimensional spacetime and thus made Einstein's theory more comprehensible (Einstein was initially hostile to this mathematical modeling, but later accepted it as essential to general relativity). Although Einstein did not draw a direct connection to the Michelson-Morley Experiment in 1905, others soon did, and relativity's supporters quickly realized its importance in explaining the ether's contradictions. Not everyone was enthusiastic about relativity: William F. Magie was indignant that relativity had succeeded in explaining a single result while the ether could explain everything except that one result. Others mixed different components of the ether and relativity models, leading to confusion over which interpretation meant what.

Among the opponents of relativity were Michelson, Morley, and Miller, who continued interferometry experiments up through the 1920s. They applied various conditions to test the velocity of light, such as magnetic fields, high-altitude trials (guessing that ether drag may be weaker higher up), and vertical beams of light (designed to test the Earth's rotational rather than translational motion). All tests returned negative results. The most significant tipping point in favor of relativity came in 1919, when a solar eclipse provided strong evidence of general relativity. Rather than accepting Einstein's ideas, these results encouraged Michelson and Miller to continue experimentation at even higher altitudes. That said, they were not blindly dogmatic or reactionary: they were honest about their many negative results and their work was taken seriously by contemporaries. The final blow to the ether probably came in 1930, when an automated interferometer capable of incredible precision found no effect of ether wind. Michelson died the next year, having still not fully embraced relativity.

Key Ideas:

- The shift from the ether to special relativity did not simply happen as a result of the passage of time. Throughout the narrative above, specific individuals consciously made efforts to spread awareness of what they considered important to their colleagues. The advance of science was pushed along by the likes of Lorentz, Kelvin, and Minkowski. This is not to suggest that changes in scientific thought are simply the result of elites telling their peers what to think. It simply demonstrates that individuals have an active role in forging a scientific consensus.

- Almost 20 years passed between the famous 1887 experiment and the publication of special relativity, and it was even longer before that theory was widely accepted. The Michelson-Morley Experiment is sometimes characterized as beginning a "crisis" in physics, but this does not capture how long it took for its results to be resolved. The physicists who knew about the experiment recognized it as a problem, but its results did not immediately plunge physics into chaos. The ether theory was able to continue basically unchallenged for many years afterward.
- 19th century physics was characterized by the consolidation of different fields: electricity and magnetism were combined, then electromagnetism and optics; the kinetic theory of gases and modern thermodynamics connected different phenomena to classical mechanics. Eventually it was hoped that all of physics would be subsumed into a single field, based either in mechanics or electromagnetism. The ether seemed to be the final step in this realization, and therefore its formulation was a crowning feature of 19th century physics. Abandoning the ether, for many, intuitively seemed like a step backward away from the resolution of the field. It is easy to call physicists who refused to shift to relativity "stubborn" or even "stupid," but it is important to understand how important the ether was to their worldview.
- In 1907, Michelson became the first American to win the Nobel Prize in physics. The prize was awarded for the spectrometer's advances in precision measurement rather than his actual experiment. In the 19th century, America was mostly peripheral to the physics world, which was concentrated in Western Europe. In the 1920s, America's influence began to grow, to the point where the country dominated physics in the 1950s and 1960s. Michelson's Nobel Prize can be considered an early step in this decades-long process.
- Historians have debated whether Einstein knew about or was influenced by the Michelson-Morley Experiment, closely analyzing his writings and searching out new or obscure sources. This may seem like a minor detail to obsess over, but it carries heavy implications about the relationship between experiment and theory. If Einstein based special relativity on the experiment, it is easy to draw a clear line of cause and effect and claim that this is how science works—new experiments inspire new theories. However, if Einstein did not know about the Michelson-Morley Experiment, this entire narrative must be reevaluated. Today, it seems fair to say that Einstein probably knew about the experiment and was affected by it, but that it was not the single determining influence on relativity. Trying to reduce Einstein's formulation of special relativity as a simple reaction to one event misses out on the rich complexity of his theoretical influences.

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