Measuring the Pressure of Light:
Pure Science at Dartmouth

by Trevor Jensen 05

In the mid to late nineteenth century, a revolution was taking place in physics. While Quantum Physics and Special Relativity were yet to be discovered, the age of modern physics was set to begin. The physics community was saturated with ideas; what still remained was to show whether or not the theories held up under experimental scrutiny. Physicists around the world recognized that their area of study could make great leaps if only the necessary experiments were performed. After all, the most persuasive argument in science is a theory backed by experimental data. Yet skepticism remained about proving Maxwell's equations experimentally. Many called for physical states that were still beyond the capabilities of experimental science. One of these possible experiments involved measuring the pressure of light, with the hope that it would match what Maxwell's equations postulated. However, it was generally thought that this experiment could not be done unless there was a collection of super-physicists working on the problem. (Nichols, 1925) Just such an environment was created when G. F. Hull and Ernst Fox Nichols met at Dartmouth College around the turn of the century. By 1901, the two physicists had begun experimentation, and by 1903, they had results.

Nichols and Hull came from very different backgrounds. Hull was known at Dartmouth as an enthusiastic young physicist, but had not yet left a significant mark on the physics community. On the contrary, Nichols was known in "both Europe and America as a physicist of extraordinary ability." (Brown, 1974) Nichols had recently established himself among physicists with his development of a new radiometer. What set this radiometer apart was its accuracy and the fact that it could operate at the nearly vacuous state of 0.05 mmHg. Like other radiometers, Nichols' instrument relied on absorbing radiation on oxide-coated vanes, which induced heat energy into the system. This absorbed heat created convection currents in the gas, which eventually turned the vanes. The energy could then be calculated by measuring the torque of the vanes. Nichols was so pleased with the accuracy of his instrument that he thought it could be used to determine the pressure of light.

Wilder Laboratory, which is now the home of the Physics and Astronomy Departments at Dartmouth College, had recently been completed in 1900 under the assistance of Nichols. The building was conceived for the primary purpose of scientific research. As a result, it consisted mainly of laboratories, with only a few class and lecture rooms. The new laboratories provided Nichols and Hull everything they needed for their work. They quickly took advantage of the new facilities and began research within a year of the opening. In fact, the measurement of light pressure would be the first experiment ever performed in Wilder's electrical lab. Fittingly, the experiment would become one of the most important Physics discoveries made at Dartmouth.

From a theoretical point of view, the experiment was relatively undemanding. Twenty-five years before the experiment, Maxwell had made a leap in the understanding of light. He had deduced that since light had an electromagnetic momentum, it should also have a mechanical momentum [p=mv; momentum=mass*velocity]. Therefore, the pressure of light had to be measurable by ordinary means.[1] However, there was a complication that had troubled various attempts at the experiment for years. This problem had to do with the very nature of a radiometer. As

[1] Ordinary- Methods well established for pressure measurements of common substances.

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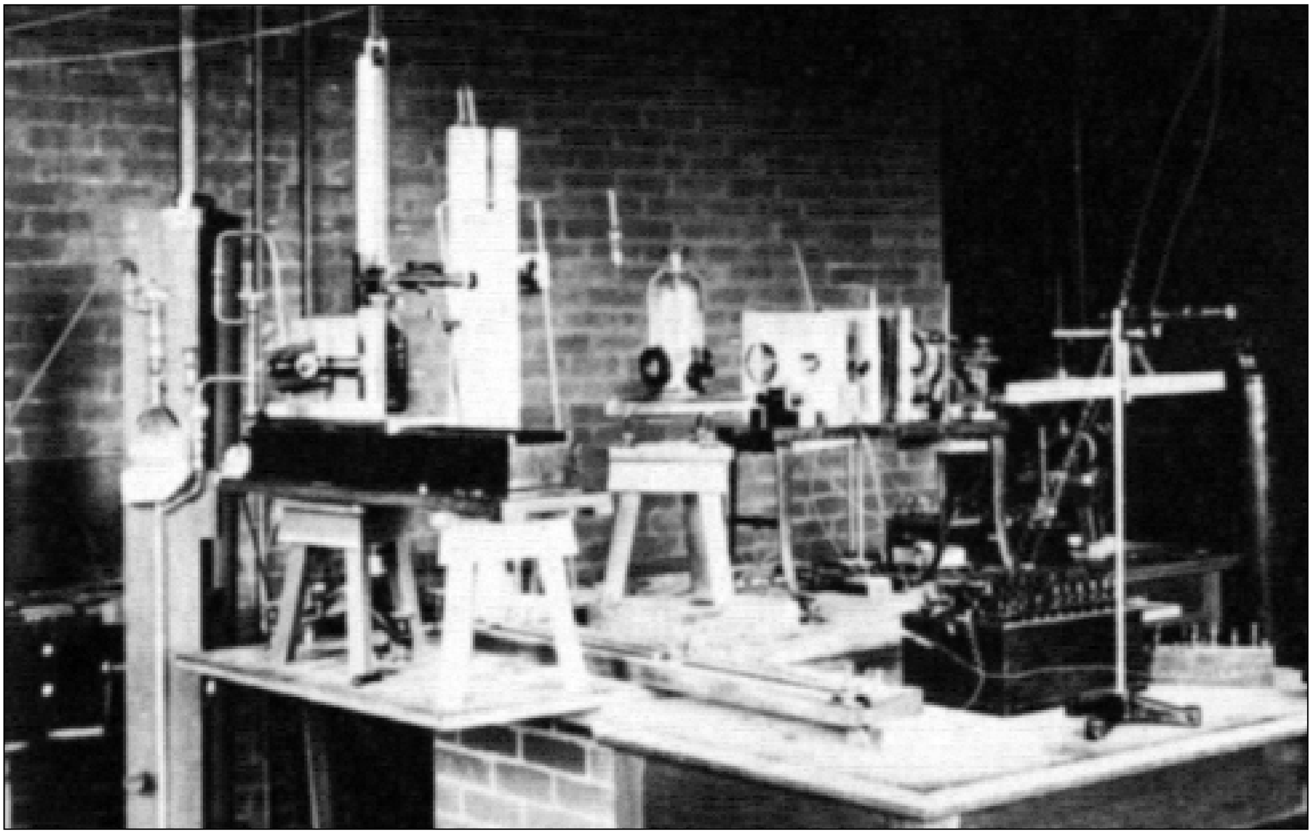

Nichols' and Hull's Instrument

described above, radiometers rely on absorbing heat. Nevertheless, the pressure of light was an instantaneous event, rather than a cumulative one. In the measurement of light pressure, "radiation absorbed is only half as effective as radiation reflected." (Nichols, 1925) As a result, instead of aiding the experiment, the heated gas would cause errors in intensity measurements. Nichols' radiometer would not work as it was built. The ideal instrument would need to have perfect reflection and the ability to operate in a total vacuum.

When Nichols and Hull began, they had the most accurate radiometer in the world and a state of the art laboratory at their disposal. Nevertheless, there remained much work to do in constructing a new instrument to measure light pressure. Nichols had already partially addressed the problem of gas action in his latest radiometer. To further reduce cumulative gas effects, the experimenters added a mass to the system with a magnetic device to control and reduce the period of torsion. Beyond this, the physicists saw little they could do to achieve a vacuum. Eventually, they had to settle for calculating the lingering effect of the gas and subtracting it from the obtained pressure values. The scientists also made improvements to increase the measured energy. Among these were larger vanes that were silvered on one side for reflection, which multiplied the effect of light pressure, and made measurement and calculations easier. At the end of four years, the radiometer they had built was specifically engineered for the measurement of light pressure. Nichols and Hull then subjected this instrument to a beam of light of known intensity for a period of six seconds. The final pressure was calculated using common mechanics and its relation to Maxwell's equations.

The final measurement was the most accurate ever recorded, and the calculated pressure deviated just ten percent from Maxwell's theoretical value of 4.7×10^{-6} N/m^2. This disparity was well within the experimental error. The experiment had been a long process. In fact, preliminary data was achieved as early as 1901, but the courtesy Rauner Special Collections Library

Wilder Hall, ca. 1900

The work of Nichols and Hull ushered Dartmouth into the era of modern experimental science. The results also made an important contribution to modern physics. At this time the wave-particle duality of light was first being explored. This experiment documented a particle nature of light in an age where wave theory was fast becoming the standard. In the end, it was empirical data such as this that convinced scientists of light's duality. The experiment to measure the pressure of light began with the hopes of final results were not achieved until 1903. The findings were first presented to the public at the Denver meeting of the American Association for the Advancement of Science. The results were later published in *The Physical Review* in July of 1903. Their results, along with those of the Russian physicist Lebedev, who was performing a concurrent experiment independently of them, supported the electromagnetic theory of light by agreeing with Maxwell's equations and gave the first clear evidence that light had a measurable pressure.

The experiment drew attention from not only the general physics aficionados, but also from the elite physics community around the world. The confirmation of a theory that had gone unproven for twenty-five years was not something that would go unnoticed. While not everyone could understand the precision of the experiments or the work involved, many knew about Maxwell's equations and understood to some extent what a feat it was to confirm this theoretical value. Those who did understand the calculations and precision were even more enamored of the experiment.

proving Maxwell's equations. With the help of other experiments at the time, it set the groundwork for the theory of light that is still held today. Nichols and Hull had started their work in an effort to bring pure scientific research to Dartmouth. Yet as often happens, the experiment turned out to have implications and applications far beyond what they could have imagined. ■

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