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October 17, 2011

Dr. Benjamin Bederson, Chair
APS Historic Sites Committee
Department of Physics
New York University
4 Washington Place
New York, NY 10003

APS Historic Site Application for the Nichols-Hull Experiment on the Pressure of Light, Wilder Physical Laboratory, Dartmouth College, Hanover, New Hampshire.*

Dear Dr. Bederson:

During the period 1900-1903, Ernest Fox Nichols and Gordon Ferrie Hull carried out the first precise measurement of the radiation pressure of light on a macroscopic body in the Wilder Physical Laboratory, Dartmouth College. James Clerk Maxwell had predicted this effect in 1873 based upon calculated stresses in the electromagnetic field. It was also predicted by Adolpho Bartoli in 1876 based on a thermodynamics argument. All earlier attempts to experimentally observe this effect had been thwarted due to the disturbing action of the residual gases surrounding the body upon which the radiation fell, even in the best vacuums achievable at the time. The radiation pressure was predicted to be the energy density in the light beam, independent of the wavelength. The experiments of Nichols and Hull succeeded, where others had failed, by making a detailed empirical analysis of the ubiquitous gas heating and ballistic effects. The published papers [Nichols, E. F., and Hull, G. F., *A preliminary communication on the pressure of heat and light radiation,* Phys. Rev. 13, 307 (1901); *The Pressure Due to Radiation. (Second Paper.),* Phys. Rev. 17, 26 (1903)] reveal the incredible experimental acumen of Nichols and Hull. The final results agreed with Maxwell's theory to better than one percent. The tiny force involved in their torsion balance radiometer was of order 10^{-4} dyne. (Remember that a dyne is approximately the weight of a postage stamp.) A considerably less accurate demonstration (about 20 percent) was carried out independently at around the same time by Pyotr Lebedev at Moscow State University in Russia [Lebedev, P., *Untersuchungen uber die Druckkrafte des Lichtes,* Ann. Phys. (Leipzig) 6, 433 (1901)]. So convincing were the results of Nichols and Hull that, as far as we know, no subsequent physicists sought to repeat their experiments. By 1910, review articles and textbooks, especially astronomy texts discussing the pressure of light as the force bending comets' tails, routinely referred to Maxwell's prediction and to Nichols' and Hull's experimental confirmation of light pressure [see Lewis, G., *A revision of the fundamental laws of matter and energy,* Phil. Mag. 6th ser., 16, 706 (1908); Page, L., *A century's*

progress in physics, Am. J. of Sci, 4th ser., 46, 316-17 (1918); Russell, Dugan, and Stewart, *Astronomy* (1927), 478].

These experiments came at the time of the revolutions in physics having to do with relativity and quantum mechanics, and were perhaps overshadowed by these events. Yet American physics circa 1900 was characterized by experimental virtuosity, by developing apparatus to measure extremely small effects. Henry Rowland's diffraction gratings, Michelson and Morley's interferometer, Millikan's oil-drop apparatus for measuring electric charge, and Nichols' and Hull's radiometer required extraordinary skills in instrument-making, experimental design, error reduction and patience, producing a kind of "measuring physics" that historians of physics have called peculiarly "American" in those years [Goldberg and Steuwer, eds., *The Michelson Era in American Science, 1870-1930* (1988)]. These experiments were a *tour de force* 110 years ago. They remain today a *tour de force*. Any experimentalist who reads the original papers (included on the enclosed CD) will be amazed at the skill, attention to detail and the level of sensitivity and numerical accuracy achieved by Nichols and Hull with such basic equipment.

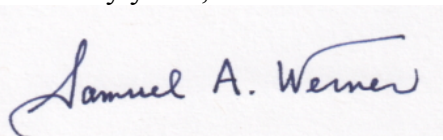
Radiative forces of light have since found many applications including laser cooling, trapping, and manipulation (optical tweezers) of neutral atoms and molecules. Radiative forces are used to manipulate atoms to form exotic states of matter, such as Bose-Einstein condensates, optical molasses and optical crystals, and to facilitate delicate high precision atom beam interferometers. The radiation pressure of soft x-rays is the basis for nuclear fusion confinement in the Teller-Ulam method of hydrogen weapon technology.

Recently, there has been a significant growing effort to perform the quantum version of the Nichols-Hull experiment, in particular to measure the photon shot noise force on a macroscopic object. Such a back reaction force sets fundamental limits to the sensitivity of force meters and is for example relevant for gravity wave detection. The pioneering work of Nichols and Hull, and of Lebedev, is cited in recent optomechanics papers, workshops, conferences and Nobel Lectures [see for example, the one of W. D. Phillips (1997)]. It is clearly recognized as the starting point for all modern radiative force techniques in the manipulation of atoms and macroscopic bodies.

It is therefore fitting, appropriate and timely to designate the Wilder Physical Laboratory at Dartmouth College an APS Historic Site. We note that the basic structure of the original Wilder Laboratory is still intact today and used for research and teaching. The paper describing this building by E.F. Nichols in the Physical Review is included on the CD enclosed with this application. Former students over several generations will recognize the location of the main lecture room on the drawings in this paper. The Nichols radiometer in its original bell jar is on display at the Smithsonian Institution in Washington, DC. A number of artifacts (galvanometers, Wheatstone bridges, ruling engines, etc) used by Nichols and Hull are preserved in the King Collection of historic physics instruments at Dartmouth [see Pantalony, Kremer and Manasek, *Study, Measure, Experiment: Stories of Scientific Instruments at Dartmouth College* (2005)]. The original log books of the Nichols-Hull experiment are preserved in the Rauner Library in Hanover. Two photographs of the experimental set-up, taken by Nichols, are on the attached CD.

Ernest Fox Nichols was awarded the Rumford Prize by the American Academy of Arts and Sciences in 1904 "for his research on radiation, particularly on the pressure due to radiation, the heat of the stars, and the infrared spectrum." He played a very significant role in American science and education through his activities at the National Academy of Sciences, the Presidencies of Dartmouth and of MIT, and as Director of Pure Science at the original General Electric research laboratories in Cleveland, Ohio. A biographical sketch of Nichols is included on the attached CD.

Sincerely yours,



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*In October, 2010 a preliminary version of this Historic Site Application was submitted to the APS electronically by one of us (Miles Blencowe).
** See the listing of members of this Board on the attached CD
