Project List 15c Spring 2018

Lorentz Invariance (Michelson interferometer)

The theory of special relativity is fundamental to our understanding of the relationship between space and time. Ever since it was theorized by Einstein in 1905, and refined in 1914, the theory of relativity has been a cornerstone in modern physics, and has been tested to great accuracies. Integral to special relativity is Lorentz invariance (LI), which states that all inertial frames are identical and light propagates within such frames at the same velocity. Lorentz invariance has been tested to a high degree of precision over the years, with many measurements based on the Michelson Morley interferometry test, first preformed in 1887 to test the ether theory. This invariance is a fundamental symmetry which is integrated in the standard model of particle physics. However, GR and the standard model in their current form are incompatible at the Plank scale. Many unifying proposals allow Lorentz symmetry to be broken, and extension to the Standard Model (SM), the Standard Model Extension (SME) has been created to account for Lorentz violations, as well as CPT violations.

In this experiment you will create a Michelson interferometer and attempt to place an upper bound on Lorentz Invariance.

References:
http://www.nature.com/ncomms/2015/150901/ncomms9174/full/ncomms9174.html

Sagnac Interferometer

The Sagnac interferometer is an interferometer capable of detecting rotational velocity. The sagnac interferometer is basically a Mach Zedner interferometer where the two split beams are directed back to the initial beam splitter and recombine there, creating a single looped path which both halves of the beam travel, each in opposite directions. This interferometer has an interesting relationship with relativity, and can be used to detect small absolute rotations. An ultimate goal of building such an interferometer is to measure the rotational speed of the Earth. This was first done by Michelson and Gale in a large field with free space optics in 1915!! These interferometers can be made in fiber optic cables. This configuration is called a fiber optic gyroscope, and is a robust and sensitive device used in countless inertial navigation, guidance, and geodesy devices. A more sensitive variant, the ring laser gyroscope, is the most sensitive and trusted gyroscope in use today, being found in all commercial airplanes as a GPS backup, and in submarines as a primary navigational instrument.

Your goal is to create an instrument sensitive enough to see the Earth's rotation.

References:
http://iopscience.iop.org/0957-0233/17/1/R01
http://journals.aps.org/rmp/abstract/10.1103/RevModPhys.39.475

Optical Quantum Eraser

In this experiment, the interference of light was explored down to the quantum level of energy to see if photons individually interfere in the same way as waves. A coherent source of single wavelength light with beam-splitters and mirrors was used to create an interference pattern from the light source, and then polarizers were used to remove and subsequently restore the interference as expected classically. Next, the laser was attenuated until at most one photon was in the system at a time and then a highly sensitive camera recorded the photons' location, showing that photons interfere with themselves and that erasing path information recreates the interference pattern.

Andor Technology Brochure. Andor_Low_Light_Brochure.pdf Describes electron multiplying technology.
Andor Luca-S Specifications. Andor_Luca-S_658M_Specifications.pdf Includes quantum efficiency graph.

Quantum Bouncing Droplets

A periodically driven dish of viscous fluid has been shown by Coudet and others to sustain bouncing droplets of ~ 1mm in diameter which fail to coalesce with the surface of the fluid and are maintained ad infimum by 'pilot' farady-like waves. These occur when the bath of fluid is driven just below the onset of the non-linear farady instability. Because these pilot waves are local, and are sized somewhat larger but comparable to the droplet diameter, the large scale motion of these bouncing droplets can display 'quantum' behavior, such as tunneling and single particle diffraction. This experiment realization is similar to 'hidden variable' or bohemian interpretations of quantum mechanics.

References:

http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=431290&fileId=S0022112006009190

http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.102.240401

Eigenmodes of a Violin Body

General exploration of the physics of violins/violin construction. Emphasis on the physical modes of the front and back plates of the violin as well as the violin body as a whole.

Investigation of resonances and nodal patterns of violin plates pre and post assembly. Investigation of resonance frequencies and vibrational patterns of the violin body once assembled.

Bowing a String Instrument

For this project, we are interested in exploring the mechanism by which bowing produces sounds on a stringed instrument and how it differs from plucking. Using our understanding of Fourier analysis and the harmonics of a string, predict the effects of loading a small mass onto the middle of a string. Utilize a high-speed camera to capture the motion of a bowed string. Observed that bowing drives the modes of a string by first pulling the string along with the bow at the point of contact (the "stick"), and then slipping quickly in the direction opposite to the bow's movement. Use various methods to investigate this slip stick motion and its coupling to the kink motion of the string to develop a detailed understanding of how bowing creates the typical violin sound. Theoretical simulations helps with this.

How do waves break as they approach a beach?

For this project a wave is created in a ripple tank and allowed to propagate toward a "beach". The water depth, wave energy, and steepness of the approach to the beach can be varied.

How hull shapes influence wake formation?

For this project a wave is created in a ripple tank and allowed to propagate toward a "beach". The water depth, wave energy, and steepness of the approach to the beach can be varied.

Fizeau Drag

How is the speed of light influenced by a moving medium?
http://www.mathpages.com/home/kmath702/kmath702.htm
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5063957/

We describe a simple realization of Fizeau's "aether-drag" experiment. Using an inexpensive setup, we measure the phase shift induced by moving water in a laser interferometer and find good agreement with the relativistic prediction or, in the terms of 19th century physics, with Fresnel's partial-drag theory. This appealing experiment, particularly suited for an undergraduate laboratory project, not only allows a quantitative measurement of a relativistic effect on a macroscopic system but also constitutes a practical application of important concepts of optics, data acquisition and processing, and fluid mechanics. VC 2012 American Association of Physics Teachers.
[http://dx.doi.org/10.1119/1.3690117] American Journal of Physics **80**, 497 (2012); doi: 10.1119/1.3690117

Ripple tank

1. Basic studies of water waves, using one of our ripple tanks.
2. Improved viewing, using swept laser, or sheet of light.

Phys. Teach. 52, 228 (2014); http://dx.doi.org.ezp-prod1.hul.harvard.edu/10.1119/1.4868938

Color Holography

Demonstrate the ability to use lasers of different wavelengths to generate multicolored holograms. We experiment with monochromatic transmission and reflection holograms, as well as multicolored reflection holograms. We then demonstrated the feasibility of "pop out" monochromatic and multicolored holograms. In theory three primary colors are necessary to span the color space of human vision.

Faraday instability

Suspend droplets on pilot waves atop an oscillating fluid. We now have a high quality shaker to make more reproducible surfaces. The droplet problem is kind of complex, but a project to study and characterize the conditions needed, which involve a "Faraday instability" might be good.

Ref: Annu. Rev. Fluid Mech. 2015. 47:269–92.

Rubens Tube

The experimental goal is to visualize standing sound waves in gaseous mediums. Our methods involved pumping combustible gases through a metal tube while modulating internal pressure with a speaker. Holes in the tube allow the gas to escape and be lit on fire, which enables the researcher to see standing waves represented by flames at specific frequencies. Use various frequencies, amplitudes, pressures, and hardware modifications.

http://www.physics.umd.edu/lecdem/services/demos/demosh3/h3-17.htm University of Maryland lecture demonstration.

R. J. Stephenson and G. K. Schoepfle, A Study of Manometric Flames, American Journal of Physics 14, 294-299, (1946).
Jerry L. Underfer, Misconceptions About Resonance in Vibrating Air Columns, The Physics Teacher 4, 81-83, (1966).
Roy Coleman, The Flaming Air Track, The Physics Teacher 13, 556-557, (1975).
Mario Iona, Pressure in Standing Waves, The Physics Teacher 14, 325, (1976).
Thomas D. Rossing, Average Pressure in Standing Waves, The Physics Teacher 15, 260, (1977).
Robert P. Bauman and Dennis Moor, More on Dancing Flames, The Physics Teacher 14, 389, 448, (1977).
Seymour Trester, Pressure Variation Along a Longitudinal Standing Wave in a Gas, The Physics

Teacher 15, 426-427, (1977).
George W. Ficken and Francis C. Stephonson, Rubens Flame Tube Demonstration, The Physics Teacher 17, 306-310, (1979).
George Spagna, Rubens flame tube demonstration: A closer look at the flames, American Journal of Physics 51, 848-850 (1983).
George Spagna, Erratum: "Rubens flame tube demonstration: A closer look at the flames," American Journal of Physics 51, 848-850 (1983), American Journal of Physics 52, 84 (1984).
Harold A. Daw, The Normal Mode Structure on the Two-Dimensional Flame Table, American Journal of Physics 56, 913-915, (1988).

Optical Tweezer

Built an optical tweezer to trap particles and experiment with trap properties

Holographic Optical Tweezer

Our experiment's goal was to discover how to trap particles using a laser beam. We started with a simple collimated laser and used diffraction patterns (with a spatial light modulator) to focus light onto an objective. We then prepared a slide with microsphere solution and placed it on the objective. It was possible to trap particles—so that they were drawn to the highest intensity of the diffraction order—by adjusting the position of the objective.

Sound of water drop

What is the sound of a "plop"? What determines the pitch? How is the sound produced?

Sound "holography"

We have 40kHz transducers. Make an acoustic zone plate and measure the sound field. We can automate the measurement with our new scopes and some stepper motors.

Self-oscillation

Many options here. There is a paper by Alejandro Jenkins (Phys. Reports 525(2013) 167-222).

Vortex shedding

This is a nice example of self-oscillation. Students have tried to make an Aeolian harp, in which wind excites strings to make audible sounds.

Sound synthesis

from recorded sound files. See this video:

http://boingboing.net/2013/02/05/the-speaking-piano.html
where discernable speech is produced by a piano.

Vowel synthesis

Use different method (tubes, clay, electric circuit) to synthesize the vowel sound produced by human.

On the quantal nature of speech, by Kenneth N. Stevens, Journal of Phonetics (1989) 17,3-45

Manuel for Bell lab speech synthesis kit:
http://www.beatriceco.com/bti/porticus/bell/pdf/speechsynthesis.pdf

Interferometric Scattering Microscope

Build an optical microscope that can detect and track nanoparticles by imaging the light that scatters off of the nanoparticles. Due to the strong size dependence of Rayleigh scattering, nanoparticles that are much smaller than the wavelength of light scatter very little light and are difficult to detect. The interferometric scattering microscope makes use of an interferometric (a.k.a. holographic) detection scheme to boost the signal coming from the nanoparticles and enables them to be readily detected.
http://pubs.rsc.org/en/Content/ArticleLanding/2012/CP/c2cp41013c
https://www.nature.com/articles/ncomms5495
https://www.nature.com/articles/nprot.2016.022