Physics 331 - Projects

The project descriptions are presented in alphabetical order. The descriptions are intentionally vague and lacking essential details. No attempt has been made to make the projects sound “sexy”.

AC Susceptometry

This experiment is designed to study the transition of a material from its so-called normal state into a superconducting state as its temperature is lowered. In this experiment, a superconducting sample is placed within an oscillating magnetic field. When the material is cooled below its superconducting transition temperature, it expels the applied magnetic fields from its interior (the Meissner effect). A pair of identical, but counter-wound, coils are used to monitor the magnetic field within the superconducting sample to signal the onset of the Meissner effect and, therefore, superconductivity. The lower critical field can be investigated by applying a static magnetic field while the sample is in the superconducting state.

Some electromagnetism will be required to understand the experimental method and some circuit design will be required to acquire and process the necessary signals. This experiment will also require the use of a lock-in detector to measure small ac signals.

Chaos

Chaos is the study of the dynamics of systems that are highly sensitive to initial conditions. That is, small changes in the initial conditions of the system lead to widely diverging outcomes for chaotic systems. Although these systems are deterministic, meaning that their future behaviour is fully determined by their initial conditions, long-term prediction of the behaviour of these systems are practically impossible. Chaotic behaviour can be observed in many natural systems, such as the weather and a dripping faucet.

In this experiment, chaos in the current-voltage relationship of a varactor diode will be studied. A varactor diode is a circuit element whose capacitance is a nonlinear function of the voltage difference across the element. After characterizing the system, the chaotic behaviour can be modelled in a relatively simple numerical simulation. There are two independent copies of the chaos experiment.

Fabry-Perot Interferometer

In this project, you will design and construct a Fabry-Perot interferometer. The device will then be used to characterize the output of various lasers. A Fabry-Perot interferometer is an optical cavity whose length can be varied. A piezoelectric stack will be used to vary the cavity length. When a voltage is applied to the piezoelectric stack, its length increases, typically by tens of nanometers per volt. To allow light to enter and exit the cavity, mirrors that partially transmit light are used. The mirrors we have are approximately 85% reflecting.

During operation, when the cavity length is an integer multiple of half the wavelength of the light in the cavity a large output power is detected. You will characterize the interferometer that you build, characterize various laser we have in the lab, and conceive of and try experiments that you can do using these devices.

Faraday Rotation

Imagine vertically polarized light (electric field oscillating in the vertical plane) propagating through a dielectric material. Now, apply a dc magnetic field parallel to the direction of light propagation. After letting it travel some distance, you will find that the polarization direction of the light has been rotated. This phenomenon is called the Faraday rotation. This quantum effect is small but detectable and was one of the first experiments that showed a link between light and magnetism.

In this experiment, you will investigate Faraday rotation in various materials using a diode laser, solenoid, and a photodetector. Initially, you will make crude measurements to determine the so-called Verdet constant of a material which determines how much the polarization plane rotates for a given applied magnetic field and length of material. After these initial measurements you will work to improve the measurement technique. A couple of possibilities: 1. Take into account that the magnetic field along the length of the solenoid is not constant, 2. apply an ac magnetic field and use lock-in detection to measure resulting small ac signals from the photodetector.

Fourier Methods

Fourier transforms offer a very powerful way to quickly go between the time and frequency domains. Consider, for example, a series *LRC* circuit. You studied both the transient (time domain) and frequency response of this circuit in PHYS 231. To determine the frequency response, it was necessary to manually adjust the frequency of a signal generator and then measure the output signal at each setting. Using Fourier methods, the full frequency response of this type of circuit can be determined nearly instantaneously. This is achieved by driving the circuit with white noise which has a flat frequency spectrum and thus simultaneously excites the circuit with a very broad range of frequencies of equal amplitudes.

The Fourier methods apparatus will also allow you to explore acoustic resonators, coupled oscillators, chaos, among other things.

Gravitational Constant

Using an extremely sensitive torsion balance, it is possible to measure the force of attraction between a set of lead spheres (force in the nN range!). After assembling all of the required equipment, a rough measurement of G may only take a single lab period. More sophisticated schemes to determine G more accurately can then be implemented.

This experiment replicates the measurement first made by Cavendish in 1798 (more than 200 years ago!) which he described as "weighing the world". This is a project for a patient person or persons capable of making careful measurements with a sensitive apparatus. This is not a project for someone who cannot sit still or suffers from "restless leg syndrome"!

The Hall Effect

Imagine a current-carrying sample placed in a dc magnetic field with the field applied perpendicular to the current direction. A Lorentz force will act on the charge carriers and a potential difference will develop in the sample along the direction that is perpendicular to both the current and the magnetic field. In equilibrium, this potential difference is a measure of the charge carrier density and also gives the sign of the charge carriers.

You will first measure the conduction electron density of doped semiconductor samples. With a separate measurement of the resistivity of the samples, the mobility of the charge carriers can also be determined.

Next, you will measure the Hall effect in copper. This measurement is much more challenging as the Hall voltages will be very small. A detection scheme to measure sub-microvolts will need to be developed and employed.

Millikan Oil Drop

By measuring the terminal velocity of microscopic charged oil drops in the presence of both gravitational and electrical forces, one can determine the elementary electric charge. This experiment will also clearly demonstrate the quantization of charge. The tiny oil droplets are produced by an "atomizer" and a single oil droplet can be manipulated and observed over a long period of time. The electric field in the vicinity of the droplets is established by allowing the droplets to fall between the parallel plates of a capacitor that are charged using a high-voltage power supply. This experiment will require that you take into account viscous drag and the buoyancy force due to the surrounding air.

You should be able to observe both singly and multiply charged droplets. You should be able to observe both positively and negatively charged droplets. There are two copies of this experiment.

Muon Lifetime

Using a scintillator, photomultiplier tube (PMT), and suitable electronics the lifetime of cosmic ray muons (essentially heavy electrons) can be measured. When a muon enters the scintillator it will leave a trail of light that will be detected by the PMT. Some of the muons will stop in the scintillator. Those that do stop will decay a short time later producing a second burst of light. The goal of this project will be to record the time between the two light pulses.

In this experiment, you will use the classic coincidence counting technique. Here, muon decays are only counted if a pair of PMTs at opposite ends of the scintillator both detect the muon decay. This detection scheme suppress false signals arising from electronic noise. While collecting muon lifetime data, you will use a "muon telescope" to study the angular dependence of the muon flux at Earth's surface.

Nuclear Magnetic Resonance (NMR)

You will use a pulsed NMR system to measure properties of nuclear spins of various samples (like mineral oil). Clever sequences of pulses can be used to measure the characteristic time it takes for a sample to become fully magnetized in a static magnetic field (T_1). Using a spin-echo experiment, one can also measure the spin-spin relaxation time T_2 which characterizes the effect of the local magnetic field in the region of the nuclear spins.

Time permitting, it is also possible to use the NMR apparatus to set up an 1-D imaging experiment (MRI). By placing a linear sample in a nonuniform static magnetic field (i.e. a gradient field), the nuclear spins in different regions of the sample will have different rates of precession. A Fourier analysis of the NMR signal can be used to determine the positions of the NMR-active regions of the linear sample.

Transmission Lines

When working at high frequencies, or when trying to shield sensitive electrical signals from the external environment, coaxial cables are commonly used. These cables possess both a characteristic capacitance per unit length and a characteristic inductance per unit length. These properties of coaxial transmission lines lead to a number of intricate responses that can be manipulated by varying the experimental conditions. Experiments can be setup to determine the per-unit length capacitance and inductance of the transmission line, its characteristic impedance, and the signal propagation speed.

In this experiment you will study both the transient and frequency responses of transmission lines. Through the experimental measurements, you will be able to uncover important non-ideal (lossy) behaviour of transmission lines. A realistic model can be developed to take these losses into account.

Water Sensor

In this experiment a loop-gap resonator (LGR) is used a sensitive sensor capable of monitoring the temperature and conductivity of water. The idea is to incorporate a toroidal LGR into a flange that joins to sections of copper pipe. In this way, the sensor takes up minimal space while allowing the user to actively monitor the fluid in the pipe. This project will make use of a vector network analyzer (VNA). The VNA generates an rf signal that is incident on the resonator and then makes sensitive measurements of the signal that is reflected back to the source. The changes in the resonance frequency and the width of the resonance can be used to deduce the temperature and conductivity of the fluid, respectively.

Although we have done related measurements in the PHYS 331 lab, this particular project has never been attempted. For this reason, it provides the student an opportunity to experience a more authentic research experience. While we have an idea of what to expect, there may be some technical hurdles to overcome!

Wireless Power Transfer

Wireless technology is everywhere in modern society. All of our wireless devices require a battery to operate. Because batteries have limited capacity, they must be recharged almost daily. Currently, most of our devices must be plugged in to be charge the batteries. If the charging in wireless, the device must be placed very near a charging station that is itself plugged in (think of electric toothbrushes, for example).

In 2007, a group of researchers at MIT experimentally demonstrated wireless power transfer using a pair of resonant coils. They wirelessly transmitted enough power over a distance of a few meters to light an incandescent light bulb (60 – 100 watts). In this experiment, you will attempt to wirelessly transfer power through water using a pair of identical loop-gap resonators (LGRs). The efficiency of the power transfer is expected to depend both on the distance between the resonator and the conductivity of the water. You will study both of these effects. The measurements will be made using a vector network analyzer (VNA). The VNA is a two-port device. One port provides the incident rf signal to the transmitter and the second port detects the signal transmitted to the receiver.