Physics 322
Description of Experiments

1. **Physics at Low Temperatures:**
Many fascinating physical phenomena occur at temperatures below ambient, including superfluidity, superconductivity, and exotic forms of magnetic ordering. Samples have been cooled to temperatures in the Kelvin, milliKelvin, and microKelvin ranges by using liquid cryogens, adiabatic demagnetization, dilution refrigeration, Pomeranchuk cooling or laser cooling. In this experiment we measure the electrical resistivity of four samples over the temperature range 1.5 – 300K using liquid helium and nitrogen cryogens. These measurements allow the student to study superconductivity in Pb and NbTi (an important material in superconducting magnets), ferro- and antiferromagnetism in Dy, and electron-phonon scattering in Cu, Pb, NbTi and Dy. Experience is also gained in vacuum and cryogenic technology.

2. **Measuring atomic excitation energies: The <u>Franck-Hertz Experiment</u>:**
This experiment provides a hands-on demonstration of atomic excitation by electron impact and measurement of atomic excitation energy of neon and mercury. Although the write up describes a method of automatic voltage incrementation and data collection, this experiment is best done with manual control of all potentials. The principle of the Franck-Hertz experiment involves the systematic increase of initial electron energy by increasing the acceleration potential, and measuring the final electron energy after it passes through a gas by means of a retardation potential. When the electron has enough energy to excite an atomic transition, it gives up most of its initial kinetic energy to the atom, with a resulting decrease of its final energy. Using the apparatus in the lab, excitation energies of the neon atom are easily found, providing verification of the quantum-mechanical model of the atom (discrete energy levels). James Franck and Gustav Ludwig Hertz received the Nobel prize for this work in 1925.

3. **Pulsed NMR:**
This experiment introduces the student to nuclear magnetic resonance (*NMR*), a method widely used to identify unknown compounds and deduce the molecular structure of molecules in chemistry and biology. In solid-state physics, *NMR* is used to study phase transitions and atomic hopping motions. More recently, magnetic resonance imaging has been developed into a premier method for medical diagnosis. It should be noted that two Nobel prizes have been given for the development of *NMR*. Topics covered in the experiment include:
    a) The classical and quantum mechanical pictures of *NMR* (in the reading references).
    b) The rotating frame,
    c) *rf* pulses and their effects on the spins,
    d) Spin echoes,
    e) Spin relaxation (how the spin magnetic moments return to equilibrium),
    f) Chemical shifts,
    g) Spin-spin couplings,
    h) Some imaging in one-dimension.

4. **Ultrasonics:**
In this experiment we examine the physics underlying the use of ultrasound as an interrogation probe for the determination of ultrasonic and mechanical properties of materials. The speed of propagation, the attenuation, and the backscatter of ultrasonic waves are three indices commonly employed to ascertain the inherent mechanical properties of a material by a nondestructive means. In addition, measurements of these acoustic properties can provide an indirect means by which to probe such mechanical properties of the material as Young's modulus, Bulk modulus, Poisson ratio, and Shear modulus. The use of ultrasound as an interrogation probe has proven useful commercially as a nondestructive tool in manufacturing, the aerospace industry and medical community. In this experiment you will measure the density, longitudinal signal velocity, acoustic impedance, and frequency-dependent attenuation coefficient using a broad-band ultrasonic measurement system. In addition, anisotropic acoustic properties of advanced engineering composites will be investigated

5. **Photoelectric Effect:**
One of the earliest experiments that demonstrated the presence of quantum effects, and that nature must often be understood in terms of quantum rather than classical descriptions. Light is not absorbed by atoms in a continuous manner, but rather in individual quanta (photons) whose energy is well-defined ($h\nu$). This classic experiment demonstrates the quantum nature of light and provides a value for Planck's constant h. Photoelectron spectroscopy is an important modern tool for measuring the electronic structure of solids. Both Albert Einstein (1921) and Robert Andrews Millikan (1925) were awarded Nobel prizes for their work on this effect.

6. **Scanning Tunneling Microscope:**
The first scanning probe microscope, the scanning tunneling microscope (*STM*), was developed in 1981 by Gerd Binnig and Heinrich Rohrer at the IBM research laboratory in Ruschlikon, Switzerland. For their groundbreaking work they were jointly awarded the Nobel Prize for physics in 1986. The *STM* microscope images the sample using a quantum mechanical effect called "electron tunneling". Features with atomic dimensions can be seen with the tunneling microscope. The *STM* and related devices are of vital importance in much current research on nanostructured systems. In this experiment you will learn how to operate an *STM* and then will use it to examine the surfaces of a number of interesting samples, including terraces and steps on gold, the positions of atoms on graphite, defects on the surface of a TiS_2 crystal, and charge density waves on TiS_2.

7. **Optically Detected Magnetic Resonance in Diamond**
This experiment introduces students to Optically Detected Magnetic Resonance (ODMR) and fluorescence imaging using nitrogen vacancy color centers in diamond. Nitrogen Vacancies (NV) are a type of crystallographic defect in diamond. They are formed by substituting out a carbon atom for a nitrogen atom and removing an additional adjacent carbon atom from the lattice. These NV centers are suitable for a number of applications in quantum information and metrology, as they feature an optical transition at 637 nm and microwave frequency transitions between magnetic ground states allowing optical pumping and ODMR. In this lab, green laser light (532 nm) is focused onto micro-diamonds to induce absorption on the 637 nm optical transition. Because the fluorescence depends on the magnetic ground state of the color center, the magnetic resonance of

the color center can be detected optically. Experiments such as magnetometry, thermometry, imaging of nano-diamonds and single color centers, and confocal microscopy are possible.

8. Fundamentals of Noise:

Fundamentals of Noise is an experiment for learning about electronic noise. The noise present in all electronic signals limits the sensitivity of many measurements. That, in itself, would be reason enough to motivate learning how noise can be quantified. But electronic noise can be much more than a nuisance, or a limit, sometimes *noise is the signal*. In fact, there are at least two cases in which the measurement of noise can give the values of fundamental constants. In this experiment you will:

- Detect and quantify Johnson noise, the Brownian motion of electrons
- Deduce Boltzmanns constant, kB, from the temperature dependence of Johnson Noise
- Observe and quantify shot noise in order to measure the fundamental charge e
- Configure front-end low-level electronics for a variety of measurements
- Investigate power spectral density and voltage noise density of signals, and their V2/Hz and V/Hz units
- Apply Fourier methods to digitally process noise signals into noise densities
- Explore amplification, filtering-in-frequency, squaring, and averaging-in-time
- Develop skills applicable across the breadth of measurement science

9. Diode Laser Spectroscopy:

This experiment was developed by TeachSpin, a company founded by an alumnus of the WU physics department. The centerpiece of this experiment is a grating-stabilized diode laser which is both temperature and current regulated. The apparatus includes controller electronics, photodiode detectors, a rubidium vapor cell module, Fabry-Perot interferometer, a CCD camera with monitor, plus all necessary optical parts. The possible experiments with this apparatus include: characteristics of a stabilized diode laser, Doppler-free spectroscopy of Rb vapor, calibration of laser sweep through Michelson interferometry, resonant Faraday rotation in Rb vapor, temperature-dependent absorption and dispersion coefficients of Rb vapor, Rb hyperfine transitions, and Zeeman splitting in Rb spectrum.

10. Fourier Methods:

Fourier analysis is a way of thinking differently about signals which vary in time, analyzing them not by time-of-occurrance of features, but instead by their frequency content. These signals may be represented by sums of trigonometric functions. Fourier analysis grew from the study of Fourier series, and is named after Joseph Fourier, who showed that representing a function as a sum of trigonometric functions greatly simplifies the study of heat transfer. In this lab you will learn how to use a Spectrum Analyzer and carry out experiments ranging from an acoustic resonator, fluxgate magnetometer, coupled oscillators, modulation, demodulation, and signal recovery under noise.