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 Franck-Hertz Experiment:
   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. **X-Ray Scattering**

X-radiation is a form of electromagnetic radiation with wavelength in the range 0.01 nm to 10 nm and energies 120 eV to 120 keV. In many languages X-radiation is called Röntgen radiation after Wilhelm Conrad Röntgen who discovered them in late 1895 and named them "X-rays" since their origin was unknown. X-rays have a multitude of applications in medicine, science, and industry, some of which are explored in this experiment. A fully shielded, microprocessor-controlled X-ray generator is used which allows the accurate measurement of X-ray scattering off various samples both as a function of scattering angle and energy. The multitude of possible experiments includes: transillumination of X-rays through opaque objects, attenuation of X-rays, energy spectrum of a Mo X-ray source, Compton effect, diffraction of X-rays off single- and poly-crystalline materials, and X-ray fluorescence analysis.

5. **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.

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$_2$. 

revised 1/14/2016
7. **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, $k_B$, 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 $V^2/Hz$ 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

8. **Fuel Cells, Photovoltaics and Electrolysis (energy related experiments):**

Diminishing resources, more severe environmental impacts, and the ever-increasing demand for energy force us to reevaluate the structure of our energy supply system. Hydrogen technology is gaining increasing importance since it combines a sound energy supply with minimal impact on our natural resources. In this experiment the student explores the use of solar cells to generate electricity directly, electrolysis to separate water into hydrogen and oxygen, and fuel cells to utilize hydrogen gas for electric power generation. The performance of these elements under varying load levels is evaluated to determine the optimal operating conditions for each.

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. Metal Hydride:
There are few issues more important today than that of energy, specifically its generation and its storage. Energy can be generated using many different resources: sunlight, coal, propane, gasoline, hydrogen, wind power, water power, etc. Hydrogen is by far the most abundant element in the universe. Hydrogen gas under ambient conditions of pressure and temperature is easy to handle but, to be practical and compete with other energy sources, higher densities are required. This can be accomplished either by storing hydrogen under high pressure or as a liquid at cryogenic temperatures, both of which involve safety issues. A third way to store hydrogen at high density is by making use of the fact that certain materials, like the metallic compound LaNi$_5$, can absorb large amounts of hydrogen at near ambient conditions. In this experiment the amount of hydrogen absorbed into LaNi$_5$ will be determined as a function of pressure to 7 bar and temperature to 50°C.

11. Fourier Methods:
Fourier analysis is a way of thinking differently about signals which vary in time, analyzing them not by time-of-occurrence 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.

*The following experiments are given in conjunction with the department of Chemistry and will be performed in the Laboratory Science Building (rm 130B).*
Nuclear physics experiments offered for Physics 322 (Spring 2016)

Project 1
Construction of a Nuclear Decay scheme following beta decay

In this experiment the decay scheme of an "unknown" $\beta^-$ source will be determined. This requires calibration of NaI(Tl) and Ge $\gamma-$ray detectors for energy and efficiency measurements. The time-energy coincidence relationships $E \gamma - E \gamma - \Delta t$ coincidences for the $\beta$ emitter from the students’ unknown will be determined experimentally. From this information the decay scheme in the daughter nucleus will be determined. This type of experiment is typical of the techniques used to derive the nuclear structure of a large number of nuclei.

Simultaneously, the students will measure several $\gamma - \gamma - \theta$ angular correlations. These are measurements for deducing spins of excited nuclear states.

Some basic knowledge of C++ programming and use of theROOT (CERN derived) display package will be acquired in the course of this experiment.

Project 2 (Not offered this semester)
Construction of a Nuclear Decay scheme following alpha decay

In this experiment the decay scheme of an "unknown" $\alpha$ emitting source will be determined. This requires calibration of a Ge $\gamma-$ray detector and an $\alpha$ Si counter for energy and efficiency measurements. The time-energy coincidence relationships $E \alpha - E \gamma - \Delta t$ for the $\alpha$ emitter will be determined experimentally. From this information the decay scheme in the daughter nucleus will be constructed. This type of experiment is typical with those used to derive the nuclear structure of a large number of nuclei.

Some basic knowledge of C++ programming and use of theROOT (CERN derived) display package will be acquired in the course of this experiment.

Project 3
Measurement of Spin and life times of nuclear excited states

The spin and life-times of excited nuclear states are measured from $\gamma - \gamma(\theta)$ angular-distributions and fast timing measurements, respectively. Sources of $^{60}$Co and/or $^{207}$Bi are used for this purpose. Two $\gamma-$ray LaBr$_3$ detectors operated in coincidence may be used in these measurements. Sophisticated analysis for measuring both the nuclear spin and the multipole mixing ratios will be employed. Some basic knowledge of C++ programming and use of theROOT (CERN derived) display package will be acquired in the course of this experiment. In addition, further analysis of the data with the aid of Mathcad will be made.

Project 4 (Not offered this semester)
Fission of $^{252}$Cf

In this experiment the spontaneous decay of $^{252}$Cf by fission will be studied. The kinetic energy distributions of the fission fragments will be measured using a Si semiconductor detector. The neutrons emitted from the fragments will be detected in a liquid scintillation detector using a fast pulse shape discrimination technique. Then the angular distribution of the neutrons relative to the direction of the fission fragments will be determined. The absolute efficiency of the neutron counter will be measured experimentally and the neutron energy spectra measured by the time-of-flight technique. From this information an attempt to deduce the relative number of emitted neutrons from each fragment will be made. This is a little nuclear reactor on a laboratory bench. These are important quantities pertaining to nuclear mechanism of nuclear fission.

Some basic knowledge of C++ programming and use of theROOT (CERN derived) display package will be acquired in the course of this experiment. In addition, further analysis of the data with the aid of Mathcad will be made.
Project 5
Positrons, and the dynamics of formation and decay of the Positronium

In this experiment the dynamics of formation and annihilation of the positronium will be measured quantitatively. The formation and decay of the positronium into two $\gamma$ rays will be measured quantitatively. The inter-conversion of the positronium triplet into the singlet using fast timing will be explored. This will be done for annihilation in organic materials and compared with that in metals. The key parameters of the dynamics will be deduced and will be correlated with the electronic structure of the media where the annihilation of the positrons occurs. Some basic knowledge of C++ programming and use of the ROOT (CERN derived) display package will be acquired in the course of this experiment. In addition, further analysis of the data with the aid of Mathcad will be made.

Project 6
Positrons, Positronium and the Fermi energy in metals

In this experiment the properties of formation and annihilation of the positronium will be explored in order to measure the Fermi energy of electrons in several metals. For this purpose the directional correlation between the two annihilation quanta will be measured with high precision. From the width of this correlation function the Fermi momentum and thus energy of the electrons in the medium where annihilation takes place will be calculated. In this experiment students measure the Fermi energy of electrons in any two of Cu, Al, Ti, and amorphous graphite. Analysis of the data will be made with the aid of Mathcad.

Project 7 (not offered this semester)
X-ray Fluorescence

X-ray fluorescence will be used to measure the relative Pb content of plaster-of-Paris (Tibia) phantoms. The L vacancies in the Pb will be created using a pyroelectric X-Ray generator. A high resolution Si detector will be used to take spectra of the emitted K and L X-rays. It is similar to the one on the Spirit probe now analyzing the elemental composition of rocks and soil on the planet Mars. The data will be acquired with a portable pocket size pulse height analyzer coupled to a laptop, which in turn will be used in the data analysis.

A variant to this experiment is to a quick elemental analysis of materials in known and unknown samples. The students will explore new ideas of how to make these measurements quantitative.

A choice between the two options is offered to the students.

Project 8 (not offered this semester)
Mössbauer spectroscopy - an undergraduate laboratory experiment

The Mössbauer effect is the absorption of radiation by a solid which leaves the crystal phonon distribution unchanged. (This is often referred to as “recoilless absorption”). This resonance process can be used as a sensitive probe of the magnetic field and in-homogeneous field environment of various nuclei. The principles of Mössbauer spectroscopy will be outlined and students with measure the local magnetic field of various samples. The backscattering geometry will be used in this experiment which, although inefficient, is the only way to do “remote” sensing. A version of the present apparatus will be placed on a rover to be sent to MARS in the coming decade. It will provide information on the chemical composition of the soil on Mars.

Project 9
Compton scattering using $\gamma$ rays

The energy dependence and the angular dependence $d\sigma/d\Omega(E_\gamma, \theta_\gamma)$ of the Compton scattering of monoenergetic $\gamma$-ray source(s) $^{137}$Cs and/or $^{60}$Zn or the two photon $^{22}$Na source will be determined in detail. Two LaBr$_3$ or a CsF and a NaI(Tl) detector are used as the scattering and analyzing detectors, respectively. In this experiment both the ejected Compton electron and $\gamma$ ray are detected thus making the identification of the Compton scattering events unambiguous. Some basic knowledge of C++ programming and use of the ROOT (CERN derived) display package will be acquired in the course of this experiment. In addition, further analysis of the data with the aid of Mathcad will be made.
Project 10
Quantum Entanglement of the two positronium 511-keV annihilation photons

The quantum entanglement is quantitatively demonstrated using the two 511-keV photons emitted in the annihilation of the "positronium" spin-singlet state. This is the first confirmation of entanglement with high energy photons. Two LaBr$_3$ detectors collinear with a $^{22}$Na source detect the Compton electrons, while a NaI(Tl) -1 close to LaBr$_3$-1 at 90° defines the polarization plane. Three or preferably five additional NaI(Tl) detectors next to LaBr$_3$-2 serve as the Compton polarization analyzers. They are placed at $\theta = 90^\circ$, $\Delta \phi = 0^\circ$, 45°, 90°, 135° and 180°. Correlated coincident 2D maps $(E_{CsF}^{(1)}, E_{NaI}^{(1)})$ and $(E_{CsF}^{(2)}, E_{NaI}^{(2,3,4)})$ are constructed from the data. The simultaneous measurement of the Compton $\gamma$ rays and electrons makes the identification of the Compton events unambiguous. The simultaneous measurement of the same linear polarization of the entangled photons is forbidden by quantum mechanics. The data clearly show the presence of the entangled photon behavior of the annihilation photons as expected from quantum mechanics. Some basic knowledge of C++ programming and use of the ROOT (CERN derived) display package will be acquired in the course of this experiment. In addition, further analysis of the data with the aid of Mathcad will be made.