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Possible Experiments:

1. Michelson Interferometer and Fourier Transform Spectroscopy:

The Michelson interferometer used in the experiment has its adjustable mirror driven by a motor, so that it can scan automatically. The interferometer is calibrated using monochromatic light from a He-Ne laser. The light detector at the output of the interferometer gives a sinusoidal signal from monochromatic light because the path difference changes to produce alternatively constructive and destructive interference. When light of many wavelengths, such as the light from a Hg-discharge lamp, is passed through the interferometer as the moving mirror is driven by the motor, a complicated signal is produced by the detector. Fourier transforming the signal gives a spectrum. This technique of Fourier transform spectroscopy is particularly useful when the source is weak, since most of the light is used, in contrast to scanning with a grating spectrometer. The properties of the fast Fourier transform (FFT) and the use of "windows" (not the operating system) are both investigated in the analysis of the data.

2. Charge to Mass Ratio of the Electron:

The ratio of e/m was first measured by J.J. Thomson. The method used in this experiment follows the same general principle as Thomson's measurement, but is different in detail. Electrons are "evaporated" from a heated metal filament, accelerated by a steady high-voltage, and formed into a narrow beam. The electron beam is sent into a circular orbit by the magnetic field of a Helmholtz coil and the beam hits a particular mark on the fluorescent screen where details of the path can be measured. These values, along with several other quantities, allow one to plot a graph and calculate the value for e/m. This experiment requires quite a high vacuum in the tube, so that the mean free path of the electrons through the remaining air molecules is greater than the distance the electrons have to travel from the filament to the target screen. Experience is gained with producing high vacuum using a mechanical vacuum pump and an oil diffusion pump, and the precautions needed to achieve a high vacuum. Considerable care is needed to get an accurate value for e/m.

3. Pulsed NMR :

A sample of liquid which is rich in protons is placed in a strong magnetic field. Perpendicular to the steadily applied field, an oscillating magnetic field is applied for brief (carefully timed) intervals and sequences. In response to these stimuli the sample emits alternating magnetic fields orthogonal to the other two externally applied fields and thereby reveals details of the proton's local environment. The basis of MRI imaging.

4. Laser Absorption Spectroscopy of Rubidium:

A sample of rubidium gas is exposed to light at or near its natural emission at 780 nanometers. The wavelength of the light is varied until some of the light is absorbed, reducing the intensity of the original light beam measurably. This method of spectroscopy offers advantages over the traditional method of causing the sample to emit light which is then analyzed. By applying the external light source from two directions simultaneously, the absorption is limited to a specific population within the sample. It is thus possible to eliminate the effect of Doppler-Broadening, revealing fine structure which can be compared to quantum mechanical predictions.

5. Single Photon Two Slit Interference:

A beam of intense light is applied to a close-spaced pair of slits. The response is an interference pattern which is checked against wave predictions and used as a calibration. The intensity of the light is reduced to the point where only a single photon exists within the device at a time. A photomultiplier is used to identify the arrival position of these individual photons. The resulting particle-flux versus position function is compared to the initial wave-interference pattern.

6. Laser light and the He-Ne laser:

The experiment involves assembling a laser from the discharge tube and special mirrors, aligning it and getting the apparatus to lase. The alignment procedure must be done with great care and requires some patience. It is rare to get the laser operating in the first lab period. Once the laser is working, some properties of laser light are investigated, including the range of wavelengths in the laser's output, the phenomenon of speckle, and holograms. An important component of the experiment is to understand how lasers work, in terms of stimulated emission, population inversion, and other relevant concepts.

7. Applications of High Resolution Gamma-ray Spectroscopy and the Compton Edge:

Sources of gamma radiation can be identified by their characteristic spectra. This experiment uses detectors of different resolution to illustrate their relative advantages. The signal from the detector is a pulse with a height corresponding to the energy of the gamma-ray photon. A multi-channel analyzer (MCA) is used to produce a spectrum that shows the frequency of pulses as a function of energy. The MCA must be calibrated with a known gamma source before being used on an unknown source. The processes of gamma absorption include the photoelectric effect, Compton scattering, and pair production. The spectra obtained show the Compton Edge and other effects. The spectra are displayed by a fairly sophisticated computer program that allows quite detailed analysis of the data, but it is the task of the experimenter to interpret the spectra based on knowledge of the various processes that take place as a gamma photon is absorbed.

8. Calculation of Boltzmann's Constant from Random Noise:

The random motion of electrons produces electrical noise in two related ways: Johnson noise in resistors (random current fluctuations in a resistor produce random voltage changes across the resistor) and shot noise (due to the random time arrival of the electrons that form a current). Johnson noise is temperature dependent, since the average speed of the electrons increases with the temperature. The experiment involves measuring the noise from resistors at a broad range of temperatures, using an amplifier whose gain as a function of frequency has to be calibrated carefully – a fairly time consuming process. Measurements of the noise, however, can be largely automated using a digital voltmeter even to the extent of getting a computer to record the data if one takes time to setup the system.

9. Superconducting Quantum Interference Device (SQUID):

Superconductivity is a fascinating phenomenon that can only be explained by quantum mechanics. One aspect of superconductivity is the tunneling effect by which a current in a superconductor can tunnel through a very thin layer of insulator, called a Josephson junction. Two tunneling currents can give interference effects in a circular conductor and can demonstrate quantization of magnetic flux, since the effects are dependent on the magnetic field. The experiment uses high-temperature superconducting material, which goes superconducting at liquid nitrogen temperatures. Values of some fundamental constants can be obtained from the experiment.

10. Speed of Light

The challenges faced by investigators in the 1800's are revisited here to gain a respect for the power of simple optics and mechanical systems to measure time of flight over a distance of only a few meters of a faint beam of white light.

11. Ramsauer-Townsend Effect:

Ramsauer and Townsend independently noticed a strange effect when studying the scattering of electrons by the atoms of molecules of a low-pressure gas: at certain speeds of the electrons, the electrons would pass through the gas with very little scattering. Quantum mechanics provides an explanation of the effect, which classical ideas cannot explain. The measurements are made with a commercial electron tube that contains argon at low pressure. The argon can be removed temporarily, without breaking the tube, by dipping the tube into liquid nitrogen so that the argon condenses out on the cold part of the glass. The calculations that are needed include the mean free path of the electrons that move among the gas atoms, and the approximate wavelength of the wave function of the electron in the region of a gas atom.

12. Cosmic Ray Telescope / Lifetime of Muon:

Cosmic rays are charged particles from outer space, some of extremely high energy, that interact with the upper atmosphere. Among the resulting particles are muons, which travel fast enough to reach the Earth. The telescope in this experiment consists of two scintillation counters mounted about a meter apart on a frame to record the passage of charged particles. If both counters record a charged particle simultaneously (to within a fraction of a millisecond), one can assume that the particle passed through both counters and so one can define the direction of the particle within a few degrees. By setting the frame at different angles to the zenith and measuring the count-rate, one can measure how the number of cosmic rays detected varies with zenith angle. The scintillation material in the counters produces a small flash of light when a charged particle goes through. A photomultiplier tube converts the flash into an electrical pulse. Pulses of the right (electrical) height from the two counters are recorded only if they arrive at the same time (coincidence). The cables must be of the right length to keep the timing accurate. The cables must also be terminated properly to ensure there are no reflections. When the frame is almost horizontal, such that the counters count relatively few coincidences, long periods of collecting data are necessary in order to get enough counts for a significant sample. In that case, the equipment can be left running overnight or longer. How the most energetic cosmic rays get their extremely high energy is still not well understood. This experiment has had an addition to it which emphasizes that the muons are traveling at relativistic speeds. A dense block of scintillator material sometimes captures a muon. At rest, muons have a lifetime of only a few microseconds. This is verified by recording a histogram of decay-times of these captured individuals. To have reached our counting equipment at the surface of the earth, after having been launched from approximately 100 kilometers up in the atmosphere requires that the muons experienced relativistic time-dilation.

13. Optical Pumping of Rubidium, using Radio-frequency and Steady-state Magnetic Fields:

The technique of pumping of optical states in order to create a population inversion is central to the operation of lasers, and is a promising tool in quantum computing. It was the original method of investigating hyperfine structure of atomic spectra, and formed the basis of a high-precision magnetometer flown on the first satellites. Rubidium is chosen because it has a high enough vapour pressure to permit almost room-temperature operation. It is an interesting element because natural samples of it consist of two stable isotopes (85 and 87) which exhibit slight differences in the fine structure and hyperfine structure of their emission (and absorption) spectra – two experiments in one. Fine and hyperfine structure are caused by the local magnetic field of the nucleus. If the gas sample is exposed to any additional magnetic field from an external source (Helmholtz-coils carrying current) we can expect Zeemann-splitting of the spectral lines, creating additional structure which is under our control. Hijinx ensue…
The experiment takes place in a gas sample which is placed within two orthogonal sets of coils and lies along an optical axis which provides a source of light of the correct

wavelengths to be absorbed by the gas. The light is passed through a circular polarizer, guaranteeing that only one specific s-orbital to p-orbital transition can absorb it. By applying an alternating magnetic field at exactly the difference energy between two transitions, we can select a different transition than the initial light was tuned to. An electronic light sensor provides a record of the exact currents and frequencies which produce the absorption effects. Larmour frequencies, Briet-Rabi equation and Rabi oscillations are calculated.

14. Quantum Analogs :

The pressure waves which build up at the wall of a spherical cavity are described by the same wave symmetries as the quantum mechanical description of the hydrogen atom. This analogy can be extended to crystal lattice. The data are gathered automatically by the sound-card of your computer, so more time can be spent investigating the model, less on analysis.

15. Fourier Methods :

The choice between displaying information in time domain or frequency domain dictates the depth of our understanding of it. While we are very familiar with oscilloscope displays of time-varying signals, here is an opportunity to become familiar with the spectrum analyzer. Investigation of chaotic systems (Lorentz attractor) , signal processing techniques such as modulation (both AM and FM), the measurement and elimination of random noise, are all offered, as well as example instruments including coupled oscillators, flux-gate magnetometer, and cavity resonator. There is likely only enough time to investigate a subset of the exercises – more details are available.