Experimental projects

E1  Characterisation of tuneable diode lasers

The aim of this experiment is to characterise the emission spectrum from cw diode lasers. In the experiment the operating parameters of the diode laser will be changed.

(1) *Emission as a function of driver current.* Changing the current through the laser its power will change, and with it the operation of modes under the gain profile.

(2) *Emission as a function of laser temperature.* Changing the temperature of the laser chip the cavity length is altered and the gain profile is affected; hence, the wavelength of the laser changes. For a few appropriate settings of temperature the laser spectra will be recorded, to demonstrate tuning and mode hopping.

E2  Coherent Optical Processing  –   NOT for 2007/2008

This experimental project is based upon the phenomenon of Fraunhofer Diffraction (experiment 246 @ Level 2). A modification of the apparatus for that experiment will allow the image of an object (e.g. a single or multiple slit geometry) to be changed by deliberately modifying the Fraunhofer Diffraction Pattern. This effect will be studied systematically and comparisons made with expectations.

*Useful general text: Fundamentals of Optics – Jenkins and White.  More specific information: Optical Physics – Lipson and Lipson*

E3  Foam Phenomenology  –   NOT for 2007/2008

Foams occur in nature and as man-made phenomena in a variety of environments. In their simplest form they are an intriguing solid, but dynamic, structure. We will explore aspects of the geometry of foams, both from a theoretical and experimental perspective. We will compare the structure and behaviour of laboratory foams with expectations from theory.

*Useful text: The Physics of Foams – Weaire and Hutzler*

E4  Laser spectroscopy

Laser spectroscopy has become an important tool in research and in applications in the real world. Two techniques in particular are widely used, namely absorption and laser-induced fluorescence spectroscopy. An experiment to implement either of the two techniques for the study of molecules will be set-up, which only requires relatively simple and inexpensive apparatus yet demonstrates essential laser spectroscopy methods. Observation of the molecular spectrum demonstrates basic principles of quantum mechanics: molecular parameters (such as bond length, force constant, anharmonicity of the interatomic potential, etc.) may be obtained from the analysis of the data. Finer phenomena, such as intensity distribution of spectral lines or collisional energy transfer between rotational levels, can also be studied, time permitting.

*Useful general text: Demtröder – Laser spectroscopy.  Specific information: see for example P Sikora et al; European Journal of Physics 18 (1997) – Laser-induced fluorescence in an undergraduate student experiment*

E5  Making and studying high-T$_C$ superconductors
The so-called high-$T_C$ superconductors become superconducting above liquid nitrogen temperatures ($\sim 77 \text{ K}$), rather than at the unwieldy temperatures of liquid helium ($\sim 4 \text{ K}$). However, while simple in principle the process of making these superconductors is a delicate balance of homogenising the mixture of ingredients. The goal in this project is to make superconducting specimen and test their superconducting properties using the Meissner effect (a magnet is floating above a superconductor).

E6 Positron Doppler and lifetime measurements

In general materials like metals and semiconductors are not perfect but contain small defects. For instance, when an atom is missing form the crystal structure a vacancy is left behind. Dependent on the material temperature these vacancies can move through the crystal and form either large clusters of vacancies, or migrate to the surface and subsequently disappear. When a positron annihilates with an electron, the annihilation photons gain extra momentum originating from the speed of the annihilating electron. Positron spectroscopy is very sensitive to vacancies due to the fact (i) that the electron momentum in a vacancy is smaller then in the bulk material and (ii) that positrons are easily trapped in a vacancy.

In this project, a radioactive positron source, in close contact with a metal, will be used in order to study the behaviour and concentration of defect vacancies. The techniques to accomplish this are so-called positron Doppler broadening and positron lifetime spectroscopy.

E7 Stellar Spectrometer

The aim of this project is to install and use a recording camera and spectrometry system on the department's 6-inch telescope. You will adapt the telescope output for linkage to a high-resolution CCD camera or a spectrometer. Once a satisfactory setup has been achieved in the laboratory, images and spectra of astronomical objects will be taken and studied (weather permitting).

E8 The physics of levitation

The ability to levitate objects without the input of energy relies on the property of diamagnetism (the intrinsic ability of many materials to expel a portion of an external magnetic field). This property is responsible for the suspension of permanent magnets above perfectly diamagnetic High Temperature Superconductors (and vice versa), and the levitation of weakly diamagnetic living material e.g. frogs and mice, in strong magnetic fields. In contrast, Earnshaw's theorem states that it is impossible to achieve stable levitation of a magnet in a system governed by stationary electric, magnetic and gravitational forces.

However, it is possible to 'cheat' nature by (i) using additional diamagnetic material to stabilise the levitating magnet or (ii) spinning the levitating magnet above a moderately sized permanent magnet (a device known as a levitron). Both of these forms of magnetic levitation are readily accessible since they do not require low temperatures or powerful external magnets. Your project will be to design and build both types of magnetic levitation devices and explore the parameters that give rise to stable levitation.

Specific information: see for example E H Brandt, Physics World 10 (1997) 28 – Theory catches up with flying frogs

E9 Understanding the impact of projectiles

The impact of solid projectiles is probably one of the most fundamental processes that shape the surface of planetary objects in the solar system. It is the aim of this project to simulate the dynamics of such impacts, using a simple model system. When a steel ball is dropped on carefully prepared fine sand an impact crater will form. This crater in turn will collapse and will give rise to a directional jet of material ejected straight into the air above the crater. A second jet propagates downwards into the air bubble entrained during the process, thus pushing surface material deep into the ground. With time, the air bubble rises slowly towards the surface, causing a volcano-type eruption. In this project the experimental setup will be tested, and specifically the interfacing the drop of the steel ball and a
camera, which records the impact, with a computer and data analysis program. An attempt will be made to quantify the measurement data and establish a link to theoretical expectations.

Theoretical projects

T1 Critical dynamics in the QCD phase diagram

The phase diagram of the theory of strong interactions (QCD) has been studied intensively as a function of temperature and chemical potential (baryon density). There are strong suggestions that a critical point exists, similar as in the liquid-gas phase diagram. A critical point is characterized by large fluctuations which manifest themselves in e.g. critical opalescence. The aim of this project is to investigate the dynamics of fluctuations around the critical point of QCD.

T2 GPS

The Global Positioning System, GPS, has revolutionised navigation on earth. A set of satellites equipped with atomic clocks emits signals which are picked up by hand held receivers. This project will investigate several of the theoretical aspects of these systems.

Specifically, the project may entail to investigate the algorithms necessary to determine one’s (three dimensional) position and evaluate the possibilities for future use of such derivates in differential GPS.

Alternatively, one could investigate the role which Einstein’s General Relativity plays in a GPS system. Remarkably, the sensitivity of the system is such that corrections to timing due to both Special and General Relativity are necessary. In fact this system probably provides the most accurate scientific test of General Relativity.

T3 Ion Propulsion

One exciting possibility for “inter-galactic” travel is the use of a rocket powered by an ion propulsion source. In this method, ionised atoms are accelerated by an electric field and ejected from the rear of a space vessel. This provides a small forward acceleration to the rocket, which, over a long period of time, can lead to extremely high velocities. The purpose of this project is to understand the physics involved in this proposed method of transportation, eventually leading to estimates of the time required to reach nearby stars, etc.

T4 Quarkonia

Quarkonium, i.e. the bound state of a heavy quark with its anti-quark, can be described using non-relativistic quantum mechanics with a phenomenological confining potential. This project involves calculating the energy levels of quarkonium bound states with different potentials and comparing to the experimental data on the masses of hadrons such as the Psi and Ypsilon, which are bound states of the charm and bottom quarks.

T5 Scaling Laws In Physical Systems

Scaling relations are ubiquitous in the world around us and in particular in biological systems. For instance the metabolic rates of organisms scale as $M^{3/4}$, where $M$ is the mass of the organism (for bacteria to whales). In fact this kind of quarter-power scaling is pervasive in biology. The aim of the project will be to understand the origin of these kinds of scaling relations. We will be led to a picture involving fractal-like networks which effectively endow life with an additional fourth spatial dimension. The ultimate goal of the project will be to find some application of the theory to other physical systems (one suggestion is the way that the efficiency of companies scales as their size).

T6 Statistical Description of Nuclear Fragmentation

In medium-energy collisions between nuclei a study of the size distribution of the resulting fragments hints at behaviour very similar to the phase transition between a liquid and its vapour. This suggests that for many purposes nuclear matter may be considered as a drop of liquid which when disrupted
can break up into smaller droplets. This project will use a computer program of a statistical process known as percolation to model the distribution of the fragments formed, as the size of the nucleus is varied, the goal being to look for evidence of a "critical point" at a particular critical temperature where the distinction between liquid and vapour phases vanishes.

**T7  Superstring Theory**

One of the most urgent open problems in theoretical physics is the unification of general relativity with quantum mechanics. The most promising candidate for such a theory is (super-) string theory. The fundamental principle behind string theory is that elementary particles are not point-like objects but one-dimensional vibrating strings. The aim of the project is to become familiar with the basic principles of (open and closed) superstring theories and to be able to calculate simple string theory amplitudes.

**T8  Surf and Tsunami**

Small water waves are of great interest to surfers, while massive tsunamis pose a serious risk to vulnerable coastal areas. This project will investigate the basic properties of water waves analytically and then investigate numerical solutions of the hydro-dynamical equations to simulate surf and tsunami.

**T9  The Bag Model of Hadrons**

A simple model of strongly-interacting particles envisages them as collections of free quarks confined within a spherical region of size approximately 1 femto-metre ($10^{-15}$) known as a "bag". While not based on any fundamental quantum theory, this provides a simple and economical description of hadron masses and magnetic moments, and helps to understand the phase transition between hadrons and a new state known as quark matter once temperature and/or baryon density are increased to large values. The project will develop the Bag Model using simple theoretical tools, namely the Schrödinger equation and the Born-Oppenheimer approximation, to see how far the predictions may be pushed.
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