A Different Facet

High Intensity Pulsed Lasers

The group of G. Mainfray at Saclay has investigated in great detail the novel effects that high intensity pulsed laser fields produce in multiphoton ionization where the atom is placed in an environment where it is able to absorb simultaneously several photons. If the laser field frequency approaches an atomic transition frequency, resonant enhancement produces such a strong coupling between the radiation and the atom that the interacting, or "dressed" atom has a new excitation spectrum: energy levels are shifted, broadened or split from their bare, unperturbed values. The Saclay group have been able to produce 15 ps high intensity single mode neodymium glass laser pulses free from intensity or frequency modulation. These clean pulses can be used to investigate coherent nonresonant and resonant multiphoton ionization, with the multimode complications, which made analysis of earlier experiments so difficult, now entirely absent. Three-photon resonantly enhanced four-photon ionization of caesium has been studied, with surprisingly good agreement between the experiment and current theoretical work which included AC Stark Shifts and power broadening of participating hyperfine structure levels. In particular, the change in the order of the nonlinearity as the laser frequency is tuned through multiphoton intermediate resonance seems now to be well understood. The role of multimode action on the multiphoton absorption has been studied exhaustively. A particularly spectacular example of multiphoton ionization of xenon was presented.

Superfluorescence

Q.H.F. Yrehen has performed some beautifully clear experiments which demonstrate the cooperative process known now as superfluorescence (SF) in caesium at infrared wavelengths. Superfluorescence is the coherent radiation produced by the cooperative decay of a system of completely inverted atoms. A pulse is detected whose emission is delayed (relative to the initial excitation), whose intensity is proportional to the square of the number of radiating atoms and whose spatial distribution exhibits a strongly shape-dependent anisotropy. The process was first predicted by Dicke 25 years ago, was theoretically investigated by a very large number of authors ten years ago and first observed by Feld and coworkers five years ago in HF emission. Feld's three-level technique for establishing an inversion has formed the basis of most later experiments using for the most part metal vapours. To see "pure" SF requires a non-degenerate level structure, with SF delay time t_D less than any of the relaxation times T_1, T_2, T_2' and T_2^*, with an excitation pulse short compared with t_D and with a small Fresnel number geometry.

All these requirements can be satisfied using dye laser excitation of Cs atoms to the 7p level in a cell or atomic beam. At low densities a single pulse of SF is observed but as the density increases two pulses are produced. The SF field is coherent : two different transition frequencies can be persuaded to radiate and consequent SF quantum beats have been observed. The dependence of the process on the initial "triggering" of the emission was explored by injection of a weak SF signal field into a second inverted sample, which then emitted a pulse delayed by an amount governed by the size of the injection signal. Theoretical work on the very difficult problem of the initiation of the SF decay was discussed. From one viewpoint, using an antinormally ordered operator technique the process of coherent Bloch-vector decay is seen to be triggered by vacuum fluctuations in the distributed sample ; the results agree with an alternative normally ordered operator approach which emphasises the role of the initial incoherent radiation emitted from each atom which then interacts with nearby atoms. Propagation effets have also been investigated.

Important advances have been made in the past few years in the development of the excimer and exciplex VUV laser systems. These are now as developed technologically as dye lasers were five years ago, and have great potential, including their utilization in resonantly enhanced nonlinear processes to develop shorter wavelength sources. Potential and realized applications of VUV lasers are to atomic and molecular spectroscopy, photofragment spectroscopy using the laser as a bond-breaker, and to plasma diagnostics.

Scientific applications range from two-photon spectroscopy, to the determination of third-order susceptibilities and there are many other uses in the industrial field.

Environment Probing

A topical subject concerned the way lasers can be used for remote sensing in environmental diagnostics. Remote sensing of polluants such as SO_2, NO, NO_2, CO, H_2S from the 10^{-6} to the 10^{-9} level and the detection of particles of radius 0.1 to 10μm are of current interest. Humidity and windspeed, temperature (from Raman backscatter) and cloud heights are all measurable. Long path absorption of laser light using Beer's law and known cross sections (analogous in use to a giant spectrophotometer) is actively used to detect hydrocarbons and freons, with heterodyne detection if backscatter is small. LIDAR measurements of particle densities emitted in oil refinery smoke-stack plumes were described. The ability to distinguish different types of fuel oils (and their geographical origin e.g. Forties, Oman, etc.) is of great potential. From their different wavelength and lifetime fluorescence patterns detected from airborne LIDAR, ocean oil slicks may be measured and fingerprinted. This may be of use in detecting oil discharges caused by tankers washing-out their tanks at sea after discharge of their cargo.

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Phase Transitions

Phase transitions is a wide subject that has implications in many domains of physics ; for example structural or magnetic phase transition, polymer transition, molecular and plastic transition, order-disorder systems, non-equilibrum phase transitions, metastable states. Problems relate to :

— dimensionality of the system, of the order parameter
— competing order parameters
— central peak artefact.

Papers presented in the symposium at York were mainly theoretical and essentially devoted to renormalization group and mean field theory, structurally incommensurate phases, magnetic systems and hydrodynamics and critical aspects.

Mean Field

Mean field (e.g. Laudau theory) is the simplest theory of phase transition. In this framework one can derive the temperature behaviour of all thermodynamic properties like the order parameter, correlation length, magnetic susceptibility near the critical point. As an example, the classical exponent of the order parameter is found to be equal to $1/2$, the exponent related to the magnetic susceptibility, γ. is found to be equal to 1. The application of mean field theory to a phase transition is valid only if the Ginzberg criterion is satisfied, that is roughly if the fluctuations of the order parameter are not too large at the transition. The Ginzberg criterion leads to a relation between the critical exponents :

$$\nu d > 2\beta + \gamma$$

where ν is the critical exponent related to the correlation length and d is the space dimensionality. $\nu = 1/2$ in the mean field theory.

The concept of "marginal dimensionality" d^* emerges from this inequality. With the values of ν, β, γ for a critical point, the marginal dimensionality is 4. In the same way, for a tricritical point, $d^* = 3$. When $d < d^*$ mean field theory is inconsistent, for $d = d^*$ there are logarithmic corrections to the mean field exponent and when $d > d^*$ mean field theory is correct.

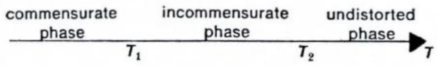
As an example in magnetic systems near the critical point, it has been experimentally proved that the Laudau theory is inconsistent; actually at the critical point the correlation length becomes infinite and we can no longer neglect the fluctuations of the order parameter of the system. At this stage, the renormalization group theory has to be invoked. This powerful mathematical tool was first introduced in particle physics and about eight years ago it has been applied by Wilson to critical phenomena. In the framework of the group renormalization it is possible to write an expansion of thermodynamic variables where the terms higher than the zeroth do not diverge.

It has been shown that in the case of a magnetic system, the ε expansion ($\varepsilon = d^* - d$) of the critical exponent γ can be calculated to a very high order. This calcualtion has led to a value of γ which is in very good agreement with the experimental result.

Incommensurate Phase

There is a great interest now in "incommensurate phase transition". A structurally incommensurate phase is characterized by the amplitude of a distortion of the crystal described by a wave vector that cannot be expressed as a simple rational fraction of a reciprocal lattice vector.

The phase diagram of such crystals is the following



Neutron scattering experiments in Na NO_2, in the incommensurate phase, have shown a peak in the intensity at a wave vector $\vec{q} = \delta 2M/\vec{A}$ where δ is an irrational number.

Near the T_2 transition point (undistorted $\longleftrightarrow$ incommensurate) a mode of excitation can be either an amplitude mode or a phase mode.

Amplitude mode has been shown experimentally but it seems that this is not the case for the phase mode.

Near the T_1 transition temperature (incommensurate $\longleftrightarrow$ commensurate) the concept of soliton is needed to describe the excitation of the incommensurate phase. Solitons appear as a solution of the Sine Gordon equation. The picture of the incommensurate phase described by solitons is the following : domains with periodic displacement of the atoms (the periodicity is the one of the commensurate phase) separated by domain walls. The domain walls are periodically distributed over the crystals. The number of domain walls is related to the order parameter of T_1 transition, and as T_1 is reached, the crystal becomes unstable against the domain walls which disappear, and a periodicity is restored all over the crystal.

Experimentally there is not much evidence for the existence of solitons. The most direct in critical systems was carried out on the one dimensional ferromagnet $CsNiF_3$ by neutron scattering experiments.

Magnetic Systems

In magnetic systems, competing interactions lead to a diversity of magnetic structures and critical phenomena. In particular, if we deal with magnetic dilute alloys we can distinguish two types of magnetic ordering for the low temperature phase: the spin glass phase and the giant "moment ferromagnetism". In both cases, in the disordered phase, the system is characterized by localized magnetic moments with an interaction depending on the distance between them, the interaction being either positive or negative.

In the case of giant moment, because of the little distance between the moments, the interaction is mainly positive, and while approaching the transition temperature ferromagnetic clusters arise. At the transition temperature these clusters overlap creating a giant moment.

In the case of spin glass, at the transition temperature, there is a freezing out of the localized moments. That means that the net magnetization is zero while there is a local magnetization. The spin glass transition is still not clearly understood from a theoretical point of view. In fact, at the transition temperature the magnetic susceptibility shows up as a well defined peak and one should expect a similar behaviour for the specific heat and this is not the case. Are we dealing really with a phase transition?

An interesting experiment has been done in a PdMnFe alloy where by raising the concentration of Fe impurities, the system changes its behaviour from spin glass phase to giant moment ferro magnetism.

Hydrodynamics

In a quite different area — hydrodynamics, the transition to turbulence has been developed in the framework of the renormalization group. A very interesting experiment on the Rayleigh-Bénard convection has been described leading to an analogy between the convective properties and a second order phase transition within the Laudau theory.

A few posters dealt with the influence of impurities or defects on the phase transitions. Impurities can change the transition temperature to an extent depending on their nature and their concentration (for example, in TMMC and in $SrTiO_3$). We have observed also the disappearance of the central peak in KDP by a suitable annealing, indicating the role of defects on central peak.

An interesting study of the phase transition in a fluoro-perovskite structure has shown that in the cubic phase, domains with quadratic symmetry exist above the transition temperature.

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