isamp
NEWS LETTER

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CONTENTS

FROM THE EDITORS' DESK

Advances in the study of atoms and molecules are often associated with a revolution in technology. High-end gadgets such as mobile phones, laptops and lasers have entered our day-to-day life with a bang. The primary research that brought these technologies to this level remains invisible; nonetheless, humans as a global society continue the forward march.

It is heartening to note that the physics community, which was responsible for many advances in 20th century, continues to play a lead role in 21st century as well. Quantum Mechanics and Statistical Mechanics, pillars of the developments in the last century merged to form a powerful and wide-spanning branch of Quantum Statistical Mechanics. Practical realisation of the concepts therein has taken a while, blooming into the hot topics of today: nanotechnology and quantum computation. A common thread in all these frontier areas, perhaps, is the application of lasers; which is also something common in the two articles of this issue. Pleasantly, both are about experiments performed in India.

Light, in the form of lasers, has become a powerful tool for micromachining and micromanipulation of a medium. During the past few decades, lasers have entered the field of medicine, micro-etching, cleaning, coating and many other areas of industry. The stride of the 'laser rule' into the nano domain continues. The article on **'Optical Vortices'** discusses the possibility of 'light engineering' in nano domain in the form of optical tweezers, pluckers etc., besides its application in generation of 'optical logic gates.'

It is said that "*physics is reinvented at every step of research in **cold atoms***". December 2005 issue (Vol.1, issue 5) of this newsletter published an article about soliton waves in Bose-Einstein condensates. In this issue, we have an article presenting precise details of weak interaction among atoms as measured in ultra-cold atom clouds bouncing on magnetic surfaces.

Useful information on the mega-project **ITER** is featured in this issue.

Before closing, we note that a recent paper on ***Quantum Evaporation of Naked Singularities*** *(with two Indians among the authors)* was recently in news. Hearty congratulations to them!

K.P. Subramanian
EDITOR, ISAMP Newsletter

Dilip Angom
Guest Editor

February 21, 2006

Hyperlinks in text

From this issue onwards, we are providing active hyperlinks in the newsletter articles. The embedded link, generally in a different colour, could be identified by placing the cursor over the link.

However, it should be noted that text in changed colour need not always be a hyperlink, as multicououred layaout is also used for the better visual appeal of the presentation material.

Editor, ISAMP N.L.

LETTERS TO THE EDITOR

INFORMTION NEEDED

Date: Wed, 01 Feb 2006 16:52:24 +0530
From: Kusum Gulati
<rjab2005@hotmail.com>
To: isamp@prl.res.in
Subject: *Information Regarding MOUs signed with Universities Abroad.*

Dear Editor,

Overseas Employment Cell, Punjab has been set up by the Department of Employment, Government of Punjab. Apart from placement services, the Cell renders free educational and vocational guidance to the students desirous of pursuing higher studies abroad.

Some of the Indian Universities have signed MOUs with Foreign Universties.

It will be appreciated if you could give us the information about the MOUs your University has signed for different courses so that it may be displayed on the Cell's Website which is being designed.

With regards,

Kusam Gulati
Incharge
Overseas Employment Cell, Punjab
S.C.O. 1118-1119 Sector 22-B
Chandigarh (India)
Telephone No.+91-172-2702460

Quotes

Niels Henrik David Bohr
(1885-1962)

"Every sentence I utter must be understood not as an affirmation but as a question."

Bohr liked to think things through out loud, using some student or colleague as a sounding board. Once when Bohr had just arrived at Princeton's Institute for Advanced Study following a week-long ocean voyage from Denmark, he suffered from having spent so many days alone with his thoughts. When he entered the Institute he spotted two physicists, Abraham Pais and Wolfgang Pauli, in the hallway. Corralling them into an office and making them sit down, Bohr proceeded to spill out his thoughts on quantum theory for two hours before either one was able to interrupt.

ABSTRACTS OF PAPERS

Abstract#1

The Effect of Misalignment Errors in Optical Elements of VUV Polarimeter

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We have designed a Vacuum Ultra Violet polarimeter for Indian Synchrotron Radiation Source Indus-1. This polarimeter will be installed on a toroidal grating monochromator-based beamline. Polarimeter consists of four-mirror phase retarder and three-mirror linear polarizer. Three-mirror linear polarizer has glancing angles of incidence 230, 460 and 230, working in 200-1100 A0 wavelength region, with linear polarizence greater than 90%. Detailed Ray tracing analysis was carried out to find the effect of various misalignment errors in each of the optical element of polarimeter. It is found that misalignment errors in optical element of polarimeter affect only the beam spot position and do not affect the spot size, polarization state and photon flux of outgoing beam, substantially. Accuracies in the linear and angular positions of optical elements in phase retarder and linear polarizer must be very precise to perform ellipsometric experiments. Tolerance limit for various misalignment errors have obtained. Required accuracy in angular position around X-axis is more than that required in angular position around Z-axis.

PACS CODE: 42.79.Ci; 41.50.+h

Status: Nuclear Instrumenation Method A (2006) Accepted

Abstract#2

Study of Amplification without inversion in H_2 molecule: Effect of homogeneous and inhomogeneous broadening in three level L system considering bidirectional pumping

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We have studied (ab-initio) the feasibility of amplification without inversion (AWI) with resonant and off-resonant driving and probe fields by using density matrix equations both numerically and analytically in H_2 molecule. We have derived (ab-initio) the analytical expressions for coherences and populations in steady state limit in three-level L scheme without any approximation i.e. keeping all orders of probe field Rabi frequency (Γ) and coherent field Rabi frequency (Ω). Previously approximate expressions for coherences and populations have been derived keeping only the first order terms in probe field Rabi frequency (Γ) and all orders of coherent field Rabi frequency (Ω). Hence AWI was studied under the condition that coherent field Rabi frequency (Ω) will be at least two orders of magnitude greater than the probe field Rabi frequency. Here we have explored the feasibility of AWI when coherent field Rabi frequency (Ω) is of the same order of probe field Rabi frequency and we have shown that AWI is more efficient than that in the previous case (when $\Omega >> \Gamma$). From the time evolution of the coherences and populations, we discuss the conditions of transient light amplification mechanism with and without replenishment (i.e. bidirectional pumping) of the ground state. We found that when the replenishment of the ground state is considered AWI can be obtained at resonance of both the fields only when spontaneous decay rate on the coherent transition is greater than that on the probe transition. But when the replenishment of the ground state can be neglected, this condition between spontaneous decay widths need not be satisfied to get AWI at resonance of both fields. However under off-resonant condition AWI is realized in both the cases (with and without replenishment) and there is no such restriction on the spontaneous decay widths. Dependence of AWI on the choice of vibrational levels as the upper lasing level has been explained. We have explored the effect of both the homogeneous and inhomogeneous broadening of levels under the condition of bidirectional pumping in H_2 molecule. It has been shown that in molecules AWI can be obtained on probe field of smaller wavelength than that of the coherent field, which has not been observed in atoms so far.

Status: Int. J. Theo. Phy., Grp Theo. & Nonlin. Opt. (in press)

Quotes

"It is also a good rule not to put overmuch confidence in the observational results that are put forward until they are confirmed by theory."

Arthur Stanley Eddington
(1882-1944)

ANNOUNCEMENTS

15-17 September, 2006
Coimbra, Portugal

This Workshop is designed for early-to mid-career professionals who are interested in radiation detection. Twenty one world experts will present the state-of-the-art in radiation detection and Monte Carlo simulation techniques as these apply to detectors. Five general-purpose Monte Carlo codes will be described and participants will have a chance to work with the code of their choice during a hands-on session.

The Workshop immediately precedes the 10th International Symposium on Radiation Physics (ISRP-10), giving workshop participants the opportunity to present their own work. Two Symposium sessions in particular, one on Sources and Detectors and the other on Modeling and Simulation of Radiation Transport, should appeal to workshop participants. A reduced fee is offered for attendance at both events.

Enrollment is limited.
Contact at workshop@lipc.fis.uc.pt if you have questions.
The poster can be downloaded from
http://pollux.fis.uc.pt/isrp10/workshop/imagens/poster.pdf

10th International Symposium on Radiation Physics (ISRP -10)

17-22 September, 2006
Coimbra, Portugal

SCIENTIFIC PROGRAMME

The ISRP-10 will consist of both oral and poster sessions. The oral sessions will include invited and contributed papers. The latter will be selected by the Programme Committee amongst the poster submissions whose authors indicate their preference for oral presentation. A prize for the best young researcher paper presented orally will be awarded.

The presentations will cover all aspects of radiation physics encompassing, but not limited to:

- fundamental processes
- sources and detectors
- materials science
- medicine and biology
- space, earth and environmental sciences
- art and cultural heritage
- new technologies and industrial applications
- modeling and simulation of radiation transport.

PROCEEDINGS

The proceedings of the symposium will be published after being fully refereed in the journal Nuclear Instruments and Methods in Physics Research A.

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1st announcement may be downloaded from http://pollux.fis.uc.pt/isrp10/imagens/First_Announcement.pdf

ITER: The International Tokamak Experimental Reactor

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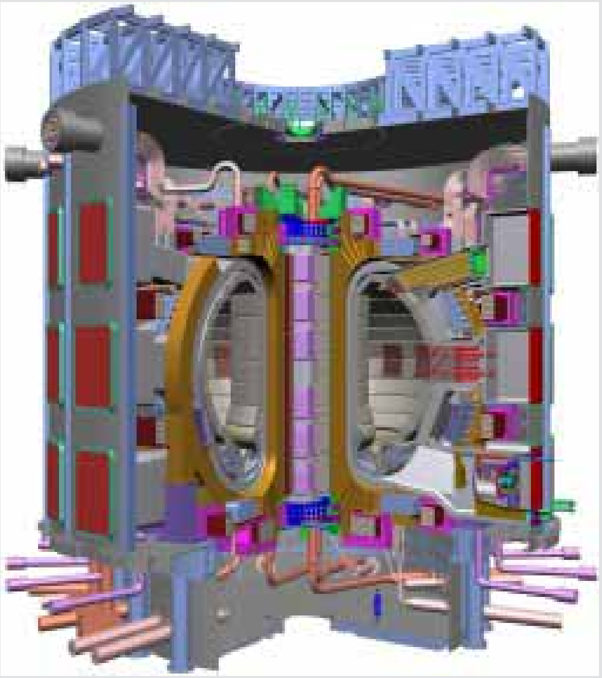
A programme with more than half the world's population behind them !

In December 2005, India became the seventh nation to join the prestigious international experiment called ITER. The other six partners are: China, European Union, Japan, South Korea, Russian Federation and the United States. ITER's mission is to establish the basic ideas behind a future power reactor: Generation of ten times more fusion power than what is consumed for plasma heating, demon-stration of a driven-burn, good heat and particle exhaust and sustained high performance. With a major radius of 6.2 metres and a plasma current of 15 MA, ITER will be the largest tokamak built so far. It is expected to produce about 500 MW of fusion power.

The design-effort of this experiment alone, is known for its phenomenal details and takes into account the depth of knowledge gained over four decades of experiments in various areas of fusion research. The word 'tokamak' stands for its original description in the Russian language meaning: Toroidal chamber and magnetic field. Basically, tokamaks are toroidal magnetic bottles, created for confining a hot (~10 keV) and dense (10^{14} particles/cc) state of matter called plasma. Charged particles are confined by the magnetic field for a sufficient time to allow a chance collision amongst the deuterium and tritium ions, which releases about 17 MeV of fusion energy with about 14 MeV carried by the neutron produced in the D-T fusion reaction.

Turbulence is natural to plasmas and it manifests itself in myriad ways as plasma particles strongly interact with each other through electromagnetic effects.

One of the long standing issues in controlled thermonuclear fusion is to improve the thermal insulation offered by the magnetic field so that the plasmas can be heated to high temperatures economically. Dedicated experiments on other tokamaks have established new regimes of tokamak operation where the confinement quality is greatly improved. Massively parallel computing efforts and deep analytic insights have revealed a complex web of processes that lead to confinement degradation, the role of multi-scale instabilities driven by the gradients, effects of magnetic curvature and the effects of shear in fields and flow. The experiments went way beyond mere understanding. They established the robustness of the good regimes, showed how to actively control their transition and sustenance and established scaling laws for extrapolation to their dream - ITER.



Objectives

The overall programmatic objective of ITER is to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes.ITER will accomplish this objective by demonstrating high power amplification and extended burn of deuterium-tritium plasmas, with steady-state as an ultimate goal, by demonstrating technologies essential to a reactor in an integrated system, and by performing integrated testing of the high-heat-flux and nuclear components required to utilise fusion energy for practical purposes. These objectives maintain the strategy to take a single step between today's experiments and the first plant (often called DEMO) to demonstrate reliable electricity production using fusion power.

Cutaway of the ITER Tokamak (Courtesy: *http://www.iter.org*)

A great role has been played in this by the enabling technologies like superconducting magnets, high power radio-frequency sources, and the development of energetic neutral beams. These technologies allowed plasma parameters to be pushed to their limits. Only then was it possible to uncover phenomena which were never seen till then. For example, magnetically diverted clean plasmas allowed a new regime of operation with high confinement mode (H mode). After suitable boundary modifications the H-mode was later obtained in non-diverted tokamaks also. Experiments with hollow current profile revealed a dramatically improved core-confinement regime called the internal transport barrier (ITB). Long pulse experiments were the only ones which could bring out the role of slow-timescale instabilities and their threshold. Some experiments showed how the very energetic particles (similar to the alpha particles in a real fusion reactor) would excite new kind of waves and create a new loss channel for heat.

ISAMP and ITER: Any Mutual Role to Play?

What is crucial here is the extensive role of plasma diagnostics, in particular, spectroscopy, combined with numerical modeling for the interpretation of a number of plasma phenomena. Plasmas are rich with highly ionized heavy and light atoms, although as a small fraction of the main fuel ions. Electronic interactions with atoms and molecules at the boundary and with ions in the core region result in a rich variety of line emissions, some of which can be used for inferring plasma parameters like electron and ion temperatures and densities. ITER device has a rather complex wall structure which faces the plasma. One expects carbon, tungsten, beryllium and a few other metals to contribute as impurities along with oxygen and helium. Their ionization states depend on the plasma density and temperature and therefore radiation from them can reveal information about local plasma conditions. This will bring out new information about profiles, their sensitivity for control and an understanding at a fundamental level-something that the fusion community is eagerly awaiting.

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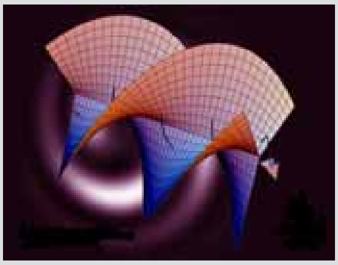

Optical Vortices

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Vortices are manifestation of phase singularities, points where one cannot define the phase. Therefore, these are generic to all waveforms. At macroscopic scale one can observe these structures in tornadoes, typhoons, water whirlpools while at microscopic scale they appear as quantum vortices in superconductors, super-fluids, and Bose Einstein condensates. In optics these structures are usually called as optical vortices, also optical tornadoes in some popular articles. Optical vortices are generated as natural structures when light passes through a rough surface or due to phase modifications while traveling through a medium. We may generate them in the laboratory in a controlled manner, study their properties, explore various applications and all this does not cost a fortune. It requires very simple experimental setup, however, it can provide rich variety of physics that has yet to be explored [1-4]. It is not the love of physics alone that is driving the research in this very new area of study, rather its myriad applications in optical trapping and spanning [5-7], micro-machining [8], communication [9] and to top it all applications in astronomy [10]. The list does not stop here, it goes to quantum world as well, with applications in quantum information and quantum computation [11].

Optical vortices are recognized as points of zero intensity that makes them easy to recognize in a bright background. In a three dimensional view, it becomes a line of darkness. Therefore, sometimes they are referred to as points and lines of darkness [12]. However, they have very peculiar phase structure and wave front. If one goes around such a dark point and finds that topological phase changes by $2m\pi$, it is called a vortex of order m or a vortex with topological charge $\pm m$ depending on if the phase change is achieved by going anti clock wise or clock wise (figure 1). It can be easily visualized that a wave with such a phase structure will have a helical wave front and consequently each photon in the beam with a vortex of order m carries an orbital angular momentum of $m\hbar$ [13]. It should not be confused with spin angular $\hbar$ momentum carried by circularly polarized photons known since long time rather they are quite independent. It should be noted that while beam with spin angular momentum can transfer an angular momentum of $\hbar$ per photon, the beams carrying orbital angular momentum can transfer angular momentum of $m\hbar$ per photon where m can be any integer. So these beams have greater potential of rotating a trapped particle or a molecule. Also, when spin angular momentum is transferred to the object, rotation is around the axis of the object; whereas in case of orbital angular momentum, it is around the beam axis.

$\hbar$= Planck's constant/2π
m = Topololical charge (or Order of Vortex)
Going around center, the phase changes by

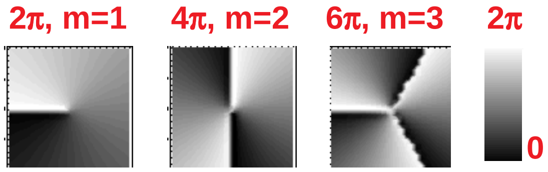


Fig. 1 Phase plots of optical vortices of different orders

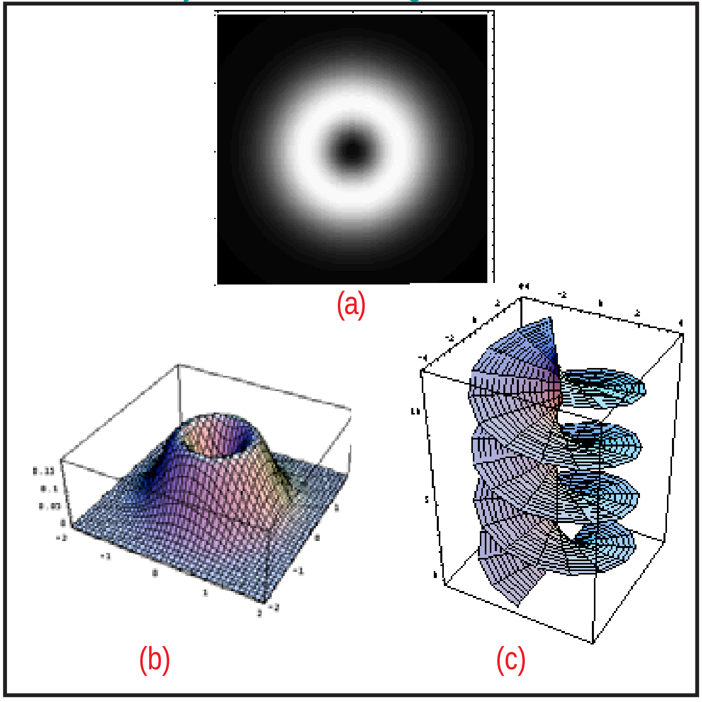
There are various methods available for producing optical vortices in a controlled manner [2], however, use of computer generated hologram is the most popular and the most economical method [14,15]. In this technique one generates a computer pattern that in principle is an interference pattern of the required vortex and the plane wave. This pattern is imprinted on a holographic sheet and chemically processed to get better diffraction efficiency from the pattern. Shined by the plane wave it generates the vortex in the first diffracted order. One can print the pattern on a transparency, optimizing the size of the pattern with respect to the beam will generate the vortex to start with [16], of course with lower diffraction efficiency.

The field of an optical vortex can be written as,

$$E(x,y) = \left(x + Sign(m)iy\right)^{|m|} F(x,y,z) \qquad (1)$$

where $F(x, y, z)$ is the host beam for the vortex. In most of the experiments it is a Gaussian beam. There is ample scope for experimentation with vortex sitting in some other beams like flat top beam, Mathieu beam and other exotic structures since host beam plays an important role in the behavior of the vortex as it propagates. In Eq. (1), m is the order of the vortex and $Sign(m)$ defines the nature of the topological charge whether it is positive or negative. Below shown are the intensity plots - contour plot as well as three dimensional or surface plot for a vortex of order one in a Gaussian host beam and the related helical wave front (figure 2).

If the vortex is at the center or axis of the beam, such a vortex is called an axial vortex. But this is not the case always. The vortex might be shifted from the centre making it a non-axial vortex. It is interesting to note that the properties of axial and non-axial vortices are quite different [17]. However, not much of the work has been done on this aspect. A non-axial vortex that is sitting at (x_0, y_0) instead of sitting at the center (0, 0) of the host beam can be written as


(a)

(b)

(c)

Fig. 2 Optical vortex of topological charge '1'. (a) and (b) intensity polts and (c) helical wavefront

$$E(x,y) = ((x-x_0)+Sign(m)i(y-y_0))^{|m|}\,F(x,y,z), \qquad (2)$$

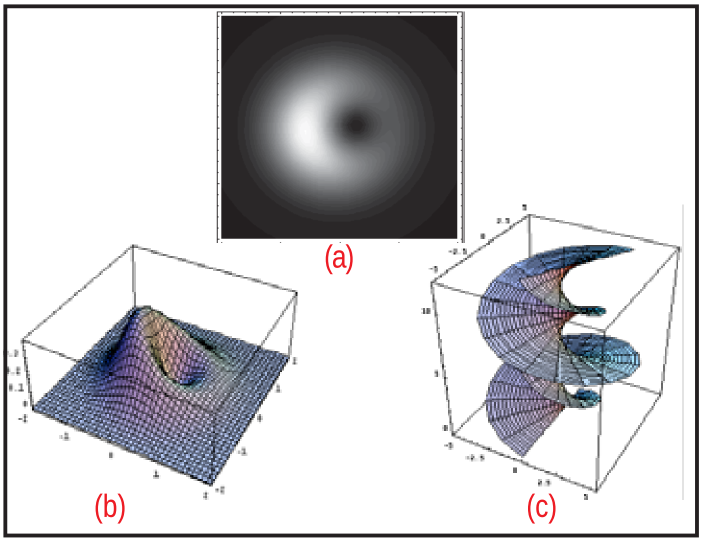
and respective intensity plots and wave front change as shown below (figure 3).

The difference in structure in the helical wave front of the shifted vortex suggests that angular momentum properties of a non-axial vortex are going to be different from an axial vortex.

Let us now consider how to generate these vortices in the laboratory. The case being considered is a vortex embedded in a Gaussian beam, TEM_{00} mode of a He-Ne laser beam, of wavelength 632.8 nm. For such a vortex Eq. (1) modifies to

$$E(x,y) = (x+Sign(m)iy)^{|m|}\, e^{-(x^2+y^2)/w^2}. \qquad (3)$$

The *z* dependent term is dropped since we are going to observe the vortex in a fixed plane and *w* is the beam size at this plane. Now a uniform plane wave at an angle can be written as


(a)

(b)

(c)

Fig. 3 A non-axial vortex: (a) and (b) Intensity plots and (c) wavefront

$$E(x) = e^{ikx\sin\theta}, (k = 2\pi/\lambda), \qquad (4)$$

where λ is the wavelength of light. The interference pattern of the plane wave, Eq. (4) and the vortex of order one *(m=1, Sign(m)= +)* is given below (figure 4).

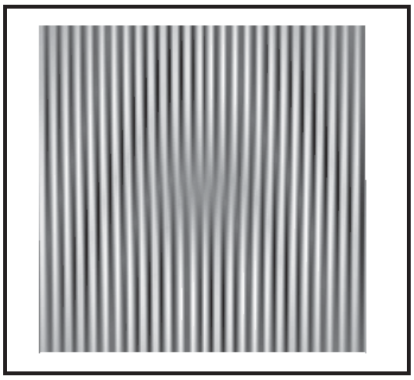


Fig. 4 Computer generated forked grating to produce vortex of topological charge '1'

The method discussed so far is the starting point for producing a vortex in the laboratory. We now move on to the generation of interference pattern for a vortex of any order. When a forked pattern (see figure 4) is shined by the reference plane wave, a well collimated laser beam, one gets the desired vortex in the first diffracted order. The beam should pass through the branch point of the forked grating and the beam size should be optimized to produce a good diffraction pattern. Shown below (figure 5) is the optical micrograph of our CGH (grating element of 185 μm) and the produced diffracted orders.

The first diffracted order is the vortex of order one. Using an iris one can select this vortex and then explore its properties or applications.

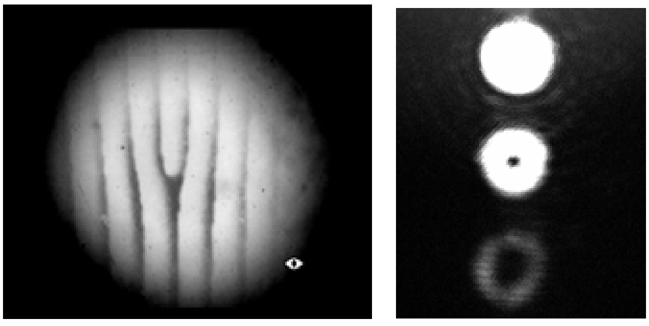

(a) (b)

Fig. 5 (a) Optical micrograph of CGH
(b) Diffracted orders at 70 cm from CGH

For the determination of the charge or order of the vortex produced experimentally, a **Mach-Zehnder** interferometer is used. The experimental set up is shown below (figure 6). **B1**, **B2** are beam splitters; **M1**, **M2** are mirrors, **CGH** is computer generated hologram; **A** is aperture; **L** is the lens. First one observes the interference pattern on a screen which is then recorded by the **CCD** camera. For a vortex of order one, the pattern recorded in experiments as well as those produced in theoretical simulations produced interferograms are shown in figure 7.

The possibility of inversion of the sign of topological charge has certain practical application. The optical vortices, whose topological charges could be manipulated offers possibility of their use in optical NOT gate. There are other optical elements which can do this job; the simplest one being the mirror. In fact, one can use this property to implement other logic gates like CNOT gate [18].

Once the technique for embedding a single vortex is perfected, one can go for composite vortices. One can embed two, three or more vortices in a single beam, the vortices may be of the same charge or of the different charges, and see their evolution as the beam propagates. The propagation of such structures have not been studied experimentally even in free space, leave alone the nonlinear medium. Further, properties of a symmetric vortex are different from an asymmetric vortex and their propagation dynamics will be different in free space as well as nonlinear medium. This entire area remains unexplored.

So far we have discussed structures with integer topological charges. However, one can have structures with fractional topological charges [19]. Also, one can have monochromatic vortex as well as polychromatic vortex [20]. Shown in figure 8 is a polychromatic vortex while figure 9 shows the interferogram confirming that it is a vortex of charge 1. The polychromatic vortices and fractional topological charge structures, still in infancy, are rapidly growing areas of research. The field is expanding so much that now it has become a branch in itself called 'singular optics'. The phase singularities and phase defects are everywhere; starting from BEC, liquid crystal to cosmos. And some of the ideas generated through the study of these structures in optics can be translated to other branches of physics.

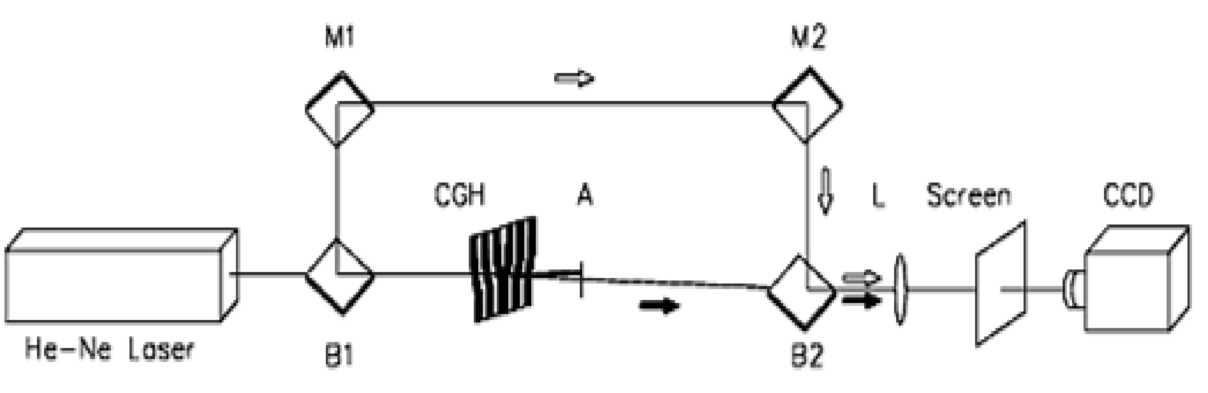


Fig. 6 Experimental setup (schematic) to determine the topological charge of an optical vortex

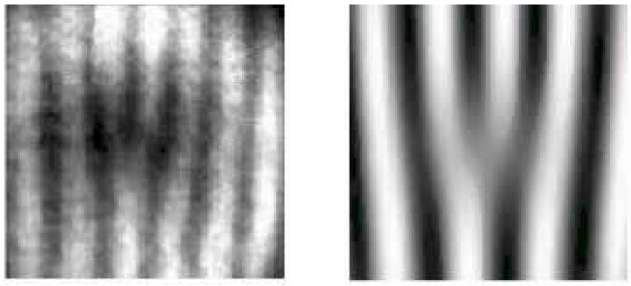

(a) (b)

Fig. 7 Pattern produced when vortex of charge '1' is interfered with a reference beam obtained from a beam splitter (a) experimental (b) theoretical

It is worthwhile to mention the potential of the vortex for optical tweezing and spanning. Because of its

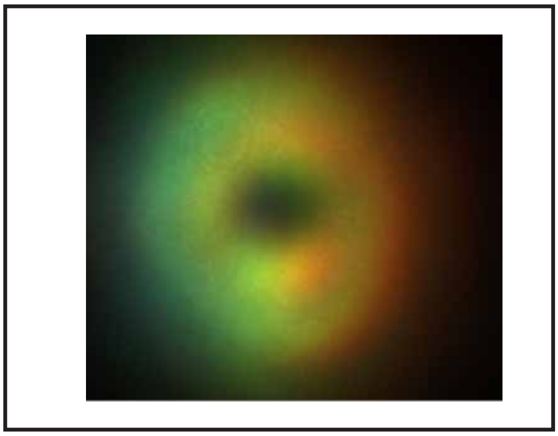


Fig.7 Polychromatic vortex obtained using a quartz tungston halogen (QTH) lamp

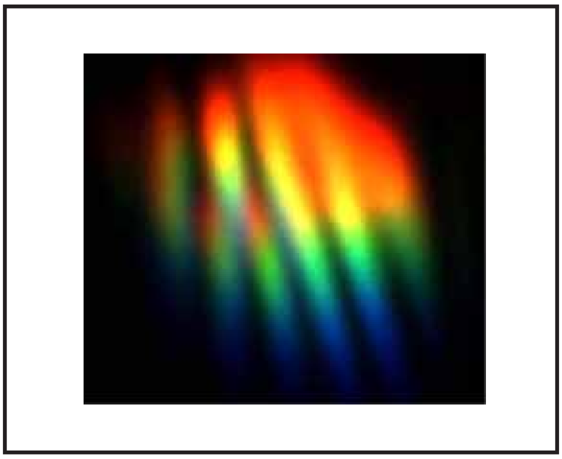


Fig.8 Interferogram showing polychromatic vortex of charge '1'

specific spatial structure it provides better trapping efficiency than usual optical tweezers by offering less scattering force and less heating. Also, one can trap particles which are reflective, absorptive or with refractive indices smaller than the surrounding medium, which is difficult otherwise. Using dynamic holographic optical tweezers implemented through spatial light modulators one can do so many things that is limited only by ingenuity of the individual [21].

We conclude by ascertaining that the field of optical vortices is full of treasures and we must go for the treasure hunting. There is so much yet to be found out.

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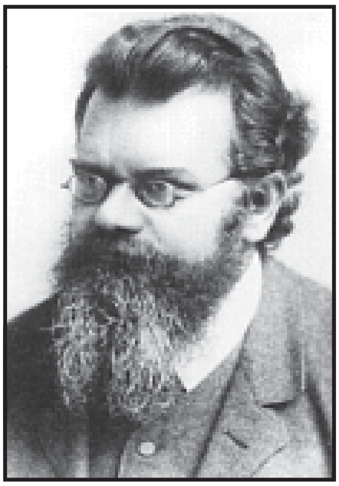
Quotes

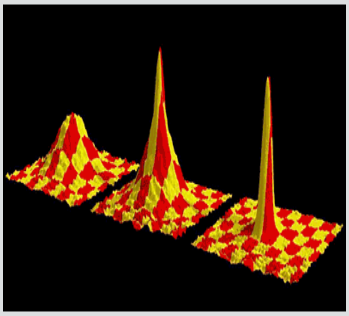
"It must be splendid to command millions of people in great national ventures, to lead a hundred thousand to victory in battle. But it seems to me greater still to discover fundamental truths in a very modest room with very modest means-truths that will still be foundations of human knowledge when the memory of these battles is painstakingly preserved only in the archives of the historian."



Ludwig Boltzmann (1844-1906)

Vol. 1 ISAMP News Letter Issue: 6

Study of atom-surface interactions employing ultra-cold atoms and Bose-Einstein condensates



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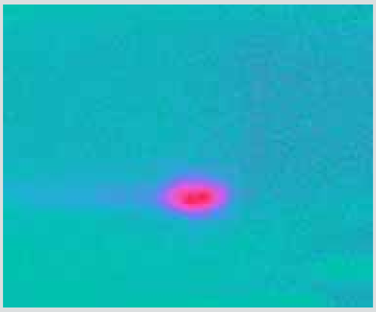

Abstract: This is a brief discussion on the experimental study of atom-surface interactions, especially the quantum electrodynamical van der Waals and Casimir-Polder forces on atoms in their ground state near metallic and dielectric surfaces, employing neutral atoms laser cooled to ultra-low temperatures.

1 Introduction

The study of the fundamental interactions of matter with matter, supposedly through fields, is the theme of the standard model of particle physics. While much is known about these interactions at macroscopic distances (gravity, electromagnetism) and at the nuclear scale (weak and strong forces) study at the microscopic scale of 1 mm to the atomic scale has become significant due to several reasons. The zero point energy associated with the field modes are formally infinite in the present theoretical scheme, and it is in direct conflict with cosmology, provoking the need for a better and detailed understanding of the quantum vacuum which induces quantum fluctuations and corresponding physical effects ranging from spontaneous emission in excited atoms to the Casimir-Polder force between atoms and surfaces. Further, new ideas in physics with more than 3 space dimensions allow the possibility of modifications of the gravitational force at short ranges up to the atomic scale. Thus, the study and precision measurements of atom-surface interactions are of importance to a variety of topics ranging from precision spectroscopy to nanoscience, and to even particle physics. The dominant short range electromagnetic interactions in this context are the van der Waals force and the Casimir-Polder force. The electrostatic interaction of a quantum-fluctuating atomic dipole with its image near a conducting surface follows the $1/r^3$ van der Waals law of the interaction potential. The full QED treatment of the van der Waals force including finite speed of light leads to the long distance $1/r^4$ law known as the Casimir-Polder force [1].

Interaction of atoms with surfaces and other atoms can be probed by measuring spectral shifts in these atoms, modification of their dynamics and trajectories, and phase shifts in atom interferometers. Neutral atoms cooled to a temperature of a few micro-Kelvin or even lower are the ideal tools for probing directly and precisely the effects of short range interactions. Coherent Bose-Einstein condensates obtained using laser cooling and trapping techniques have started to aid in improving the precision of such measurements to unprecedented levels. Matter wave interferometry using ultra-cold atoms and Bose-Einstein condensates is another new avenue for precision measurements of atom-surface interactions.

We have been exploring various experimental possibilities to probe short range interactions between neutral atoms and surfaces, with emphasis on the measurements of van der Waals and Casimir forces. These measurements have a long history, and only recently the precision in experiments and theoretical calculations have reached a stage for direct comparison and good agreement, contributed well by the surge in new measurement techniques based on laser cooling and Doppler-free methods in spectroscopy, as well as by the progress in new and efficient imaging and detection techniques. A short survey and relevant reference to the experiments and calculations are available in references [1, 2, 3]. The earlier measurements employed thermal atomic beams, whereas the most recent measurements use ultra-cold atoms and even Bose-Einstein condensates. Some early experiments to measure the van der Waals force between neutral atoms and a surface were done by passing a thermal atomic beam near a metallic cylinder. Other significant measurements include high resolution spectroscopy on Rydberg atoms inside a micron sized parallel plate metallic cavity and the verification of the energy level shift due to the van der Waals force, measurement of the Casimir-Polder force by measuring the transmission of atomic beams through a cavity, measurement of the van der Waals interaction of inert gases with Silicon Nitride by measuring the diffraction intensity of atoms through a transmission grating, measurement of the van der Waals interaction of alkali atoms with Silicon Nitride using atom interferometry and diffraction experiments, and the measurement of the large deflection of metastable noble gas atoms due to the change in their internal energy state arising from the quantum mechanical perturbation by the atom-surface van der Waals force when the atoms pass through a fine grating. There have also been some recent measurements on atoms in ultra-thin vapor cells. The recent measurement in TIFR made use of the modification of reflectivity of cold atoms from magnetic thin film mirrors due to the attractive van der Waals force.

Before adopting laser cooling techniques for such measurements we explored the transmission of noble atoms like Argon and Xenon (where the polarizability and the signal are low) through a wedge shaped micro cavity in an attempt to measure the Casimir-Polder force, and in fact measured the transmission down to a cavity separation of 5 microns [4]. To see the effects of the Casimir-Polder force one needs to go below a cavity width of one or two microns and this turned out to be very difficult. However, experience from these experiments have contributed much to the planning and execution of similar experiments based on laser cooled slow atoms.

Advances in laser cooling of neutral atoms have opened up possibilities to significantly increase the sensitivity of such measurements by better control of the atomic trajectories and velocities [5]. Some notable experiments include the measurement of the van der Waals and Casimir-Polder force from the modification of the reflectivity of cold atoms from a blue detuned evanescent wave atom mirror, and from the quantum reflection of cold Neon atoms from Silicon and BK7 surface at grazing incidence. The statistical errors in these experiments range from 30% to 5%. The recent high precision measurement by Harber et al [6] of the Casimir-Polder force using magnetically trapped ^{87}Rb Bose-Einstein condensate, by detecting the perturbation of the frequency of center-of-mass oscillations of the condensate perpendicular to the surface, highlights the new possibilities in precision measurements in the field, and also indicates the efficacy of using BECs for such measurements. The detailed citations for measurements using laser cooled atoms may be found in [2, 3].

2 Cold atoms for the experiments

We discuss very briefly the production of trapped cold atoms using laser radiation pressure and magnetic field gradients before discussing the experiments. References [2, 7] contain detailed descriptions of all the techniques involved. Slowing down neutral atoms by radiation from a tunable laser is accomplished by tuning the laser frequency slightly below the resonance such that atoms moving in the opposite direction will feel a velocity dependent radiation force. Unidirectional momentum transfer from photons followed by randomly directed spontaneous emission causes the cooling and slowing down. This is the optical molasses. Adding a quadrupolar magnetic field, the magnitude of which increases linearly outwards from the centre then provides a spatially varying Zeeman shift of resonance and hence a spatially varying radiation force providing confinement in the presence of appropriately circularly polarized light. This is the popular Magneto-Optical trap (MOT) that is the basic device for producing large number of ultra-cold atoms; one can get a sample of about 10^8 atoms confined to about 1 mm, at a temperature less than 50 μK, amounting to a velocity spread of 10 cm/s. Further cooling to a few μK (3 cm/s) can be accomplished by changing the detuning and intensity of the laser in the absence of magnetic field, and deep cooling to 100 nK or so can be achieved by evaporative cooling in a strong magnetic gradient trap or in an optical dipole trap at the focus of a far detuned high power CW laser [7].

Typical experiments probing short range interactions between material surfaces and atoms measure the change in the trajectory, spectral frequencies or phase of the atomic matter waves. Using cold atoms improve the potential sensitivity by an enormous factor, as compared to the experiments with thermal beams. For example, the deflection of an atomic trajectory near a surface depends on the atom-surface force at a particular distance as

$$d \approx \frac{F(r)}{2m} t^2 \qquad (1)$$

where m is the mass of the atom and t is the time spent near the surface. $t \propto 1/v$, where v is the average velocity. With laser cooled atoms the decrease in average velocity can be by about 10^3 with consequent improvement in sensitivity by factors exceeding a million. Similarly, in interferometry with atomic matter waves, the phase shift depends on the interaction energy and time as $\Delta\varphi \approx Et$, and the measured shift in the fringes scales with the de Broglie wavelength as $\delta \approx \Delta\varphi\,\lambda \approx 1/v^2$, as in the case of the deflection of the trajectory.

3 Experiments at TIFR

The experiments at TIFR employing laser cooled atoms are aimed at the following physics goals: measurements of the van der Waals and the Casimir-Polder forces between neutral atoms in their ground states and dielectric and metal surfaces of various types including superconducting surfaces, study of interactions of neutral and excited state cold atoms in lower dimensional traps and in optical lattices, study of atom-cavity-light interactions in the strong coupling and in the weak-to-strong transitional regime, exploring issues in the physics of fundamental interactions from precision measurements of atom-surface interactions (higher dimensional gravity, properties of the quantum vacuum etc.), single atom quantum dynamics, and the exploration of quantum phases through matter wave interferometry, quantum tunneling and quantum entanglement. These experimental goals are also related to the theoretical work in the group on fundamental issues connecting gravity, cosmology, quantum vacuum and inertial interactions. For these studies we will use ultra-cold atoms as well as Bose-Einstein condensates. Current experimental facilities include two magneto-optical traps for Rubidium, one of which is fed from a high intensity 2D+ MOT beam source with a flux exceeding 10^{10} atoms/s at an average velocity below 15 m/s [8]. We produce cold atoms clouds with atom number ranging from 10^7 atoms to 2×10^{10} atoms, with their temperature ranging from 7μK to 300 μK.

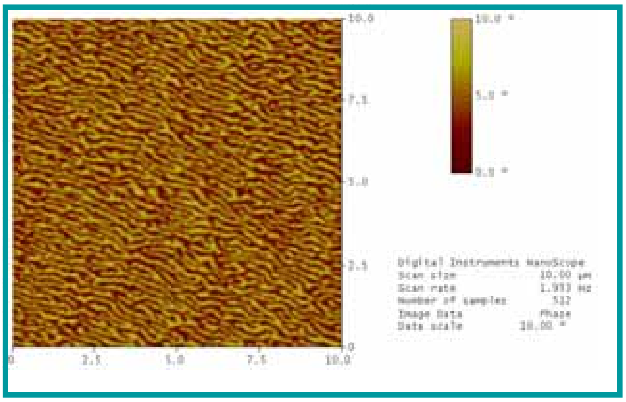

Figure 1: Magnetic Force Microscope image of the typical quasi-periodic magnetic domain structure in Cobalt thin films. The out-of-plane magnetisation alternates in sign and the magnitude of the magnetic field decreases exponentially above the plane of the film.

In addition, expertise is being developed for optical dipole traps in beams of CO2 laser (10.6 μm wavelength) and a fiber laser (1.083 μm wavelength) aimed at the production of Rb BEC. These facilities will be later extended for studies, especially those relevant to quantum phases, on fermionic atomic species (Potassium is a natural possibility with the existing facilities and expertise). The details of publications and experimental facilities may be found at the website ***www.tifr.res.in/~filab.***

4 Measurement of the van der Waals force

Our earlier attempts to observe quantum reflection of cold atoms from a variety of surfaces including superconducting thin films led to experiments to explore ferromagnetic thin films as atom mirrors. Ferromagnetic surfaces with periodic magnetization structures have been extensively used as efficient and smooth atom mirrors in cold atom optics for about a decade [9]. The important aspect of these structures is that the magnitude of the magnetic field decays exponentially above such surfaces, and therefore the quantized Zeeman energy of the atomic dipoles, $\mathbf{\mu \bullet B}$ also increases exponentially as the cold atoms approach the surface leading to strong magnetic reflection for the appropriate magnetic substates.

Recently we performed a new measurement of the van der Waals force between a ground state atom and a conducting wall employing a novel technique involving reflection of laser cooled Rubidium atoms from a thin film magnetic atom mirror. The typical magnetic domain size in such thin films is of the order of the thickness of the films. When demagnetized appropriately the domain structure has well defined periodicity of alternating magnetizations (see figure 1). The magnitude of the magnetic field above such a magnetic film decreases exponentially with a decay constant of $2\pi/\lambda$ where λ is the magnetization periodicity. In most cases of cold atom magnetic reflection experiments the magnetic moment of the slowly moving atom follows the magnetic field direction adiabatically. In the linear Zeeman regime, atoms in a magnetic state with positive value of $m_F g_F$

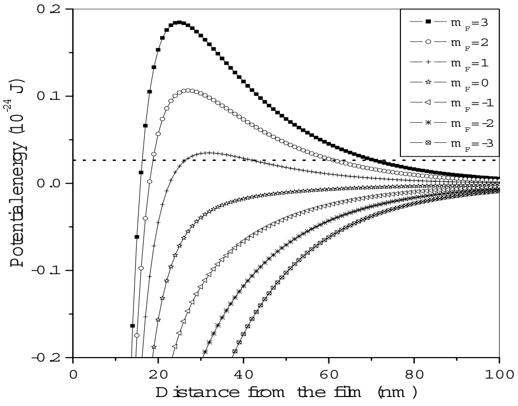

Figure 2: The interaction potentials resulting from the competition between the repulsive magnetic interaction and the attractive van der Waals interaction as a function of the distance of the atom from a magnetic thin film of thickness 45 nm. The different plots are for different magnetic substates. The dotted horizontal line indicates the average kinetic energy of the freely falling atoms at the surface of the film.

are reflected by the quantized Stern-Gerlach force $\nabla(\mu \cdot \mathbf{B})$ arising from the gradient of the field above the magnetic surface. Since the magnetic field above the film decreases exponentially with a decay length smaller than about 100 nanometer, the closest approach of the atoms before reflection is also of the same order. When the cold atoms approach the surface, the Casimir-Polder and the van der Waals forces start to become appreciable. At closer distances the short range attractive force can exceed the magnetic repulsion for some spin states, and it is this competition between the attractive van der Waals force and the magnetic repulsion that is exploited in our measurements. In addition, there are significant modifications of the reflectivity due to the quadratic Zeeman effect, leading to good reflectivity for even those atoms in the negative m_F states.

In our experiments Cobalt thin films of thickness in the range 200–20 nm were used. The periodicity of the stripe like structure changes with the thickness of the film *(d)* and obeys the law $\lambda \propto \sqrt{d}$. The magnetic field at a distance z above such a mirror with periodicity lambda can be approximated as

$$B(z) \approx B_0 e^{-2\pi z/\lambda} \qquad (2)$$

where B_0 is the magnetic field at the mirror surface (see [3] for more exact expressions including the correction for finite thickness). Since the surface field of Cobalt is expected to be few kilo Gauss, quadratic Zeeman effect becomes important very close to the surface. The magnetic interaction potential for the atoms in various Zeeman sub levels can be calculated using the Breit-Rabi formula. However, for the case of thin film atom mirrors, atom-surface attractive interaction becomes significant, and the effective potential is the sum of the repulsive magnetic potential and the attractive van der Waals $-C_3/z^3$ potential, as plotted in figure 2. Atoms in a Zeeman sub level with their kinetic energy less than the corresponding barrier height are reflected back. Close to the surface, the van der Waals attraction can dominate over the magnetic repulsion. Hence the reflectivity changes with the thickness of the film used as the atom mirror.

We used ^{85}Rb atoms for the experiments, cooled and trapped in a magneto-optical trap (MOT), formed in a SS octagonal chamber equipped with glass view ports. The MOT was loaded from Rb vapour from a heated getter source at a pressure less than 1×10^{-9} Torr for about 10 seconds to obtain the cold atomic cloud with about 10^7 atoms. The rms size of the freely falling, slowly expanding atom cloud (figure 3) grows to about 3 mm at the surface of the mirror with dimensions 1 cm × 1 cm.

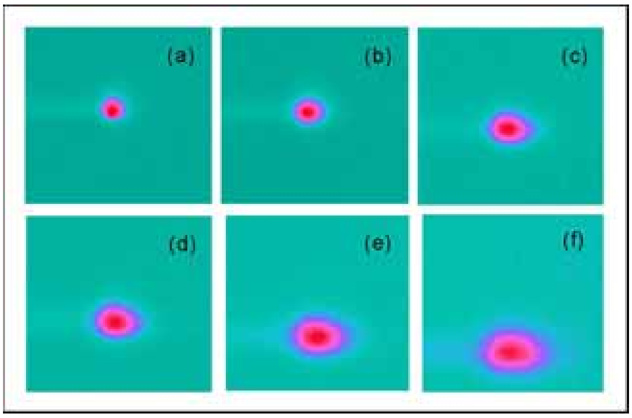

Figure 3: Fluorescence images of the falling atomic cloud. The initial size is about 1 mm.

The atoms were detected using a thin probe laser beam kept between the MOT and the mirror, as in figure 4, with uniform intensity over a rectangular area of 20 mm × 0.5 mm, resonant to the $5S_{1/2}\ F_g = 3 \rightarrow 5P_{3/2}\ F_e = 4$ transition. The frequency of the probe was modulated by modulating the current to the laser at 17 KHz. The absorption of the probe intensity was detected by a photodiode and a low noise amplifier feeding a lock-in amplifier with the reference derived from the

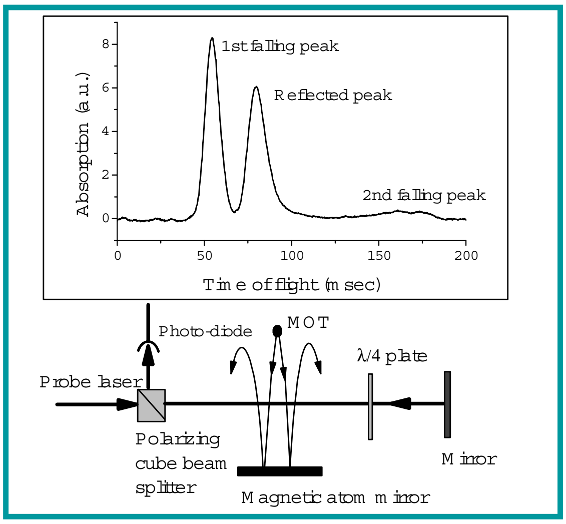

Figure 4: Scheme of the measurement (lower panel). The upper panel shows the time-of-flight signals of the cold atom cloud passing through the probe beam before and after reflection from the magnetic thin film.

laser current modulation. The sensitivity achieved in this novel and simple arrangement is exceptional, and it is sufficient to detect a few hundred atoms in the probe beam [2]. The schematic of the experimental set up and the corresponding time-of-flight signal are shown in figure 4. The reflectivity from the magnetic thin film atom mirrors was measured for unpolarized atoms as well as for atoms spin-polarized in the states $m_F = +3$ and $m_F = -3$ from the ratio of the absorption signals taken during the free fall and during the first bounce from the mirrors (**CLICK HERE** ***to see a movie of the reflection of the cold atoms from the magnetic atom mirror made from a sequence of fluorescence images.***)

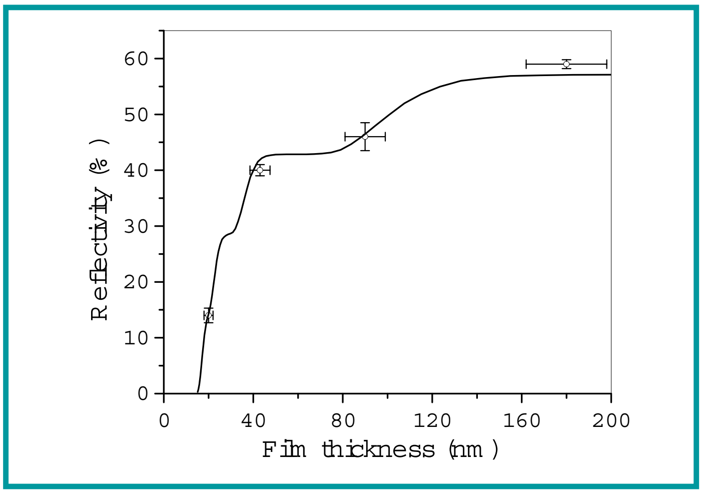

Fig: 5 Reflectivity as a function of the thickness of the magnetic thin film mirror. The measured data are fitted with the function (solid curve) computed using the quantized Stern-Gerlach repulsive force and the attractive van der Waals force for the specific kinetic energy of the atoms

Cobalt thin films were prepared on silicon substrates by sputtering. In the experiment, we used thin films of four different thickness -- 180 nm, 90 nm, 45 nm, and 20 nm -- as the atom mirrors. To do a comparison of the observations with the theoretical expectations, the data need to be least square fitted with a computed reflectivity function that includes the short range attractive interaction and the quantized second order Zeeman effect. The barrier peak of the effective potential for a Zeeman sub level was determined by using the van der Waals force coefficient (C_3) and the surface field (B_0). The distribution of cold atoms released from the molasses in various Zeeman sub levels was assumed to be uniform. The data and the fitted curve are shown in figure 5.

The best fit value of the coefficient of the van der Waals potential is 1.75×10^{-48} Jm^3, with an estimated 1 σ error of 15%. The theoretical value, after correction for the finite conductivity of Cobalt, is 1.63×10^{-48} Jm^3, which is in good agreement with the value measured in our experiment.

It is possible to separate out the dual role played by the Cobalt film, as the magnetic atom mirror and also as the conducting surface that interacts quantum electrodynamically with the atom, by using a magnetic mirror with artificial periodic magnetic structure that reflects strongly at a larger distance, like 1 mm, and by using a movable thin metallic surface above the mirror as the conducting boundary. Also, the kinetic energy of the atoms can be varied over a range by controlling the position of the MOT, or by using a moving molasses. These ideas as well as the availability of a BEC in future will enable improved measurements of the short range interactions and also will help us to conduct a detailed and accurate study of the retarded Casimir-Polder force.

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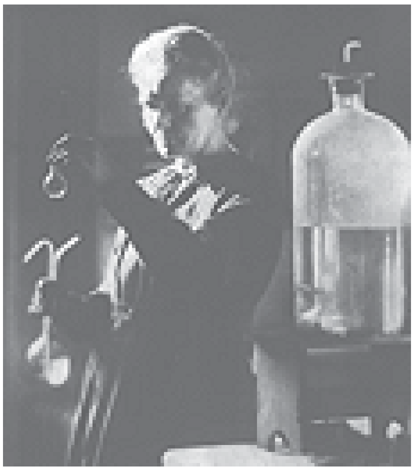
Quotes

"The life of a great scientist in his laboratory is not, as many may think, a peaceful idyll. More often, it is a bitter battle with things, with one's surroundings, and above all with oneself. A great discovery does not leap completely achieved from the brain of the scientist, as Minerva sprang, all panoplied, from the head of Jupiter; it is the fruit of accumulated preliminary work."



Marie Curie (1867-1934)

[After the sudden death of her husband, Pierre Curie, Marie Curie was asked by the Sorbonne to assume his physics chair. On the day that Pierre's lecture class was to resume, the room was crowded with celebrities, politicians, and most of the faculty of the university. There was even a stenographer ready to record what were sure to be her historic opening remarks. Upon entering the room, Curie was met with a thunderous round of applause. Without fanfare, she waited for the applause to subside before speaking. Foregoing all formalities and introductory remarks, Marie Curie began her lecture at the very point where Pierre had left off months before.]

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