Technical Progress Report (Period: Nov. 1989-Oct. 1990)

Fundamental Properties of Spin-Polarized Quantum Systems

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The principle thrust of this research project is to observe Bose Einstein condensation (BEC) in a gas of spin-polarized atomic hydrogen. After the stabilization of hydrogen by Silvera and Walraven¹ a decade ago, a number of straightforward attempts to Bose condense hydrogen were thwarted by the large recombination rates on the cell surfaces and in the bulk, at high densities. Currently there are several very promising approaches to BEC, and we are intensively developing some of these ideas. In addition we continue to carry out research to further develop our understanding of hydrogen interactions, as our experience has shown that knowledge of the system parameters is vital for any attempt to achieve BEC.

I. Bubbles in Ultra High Fields (Ph.D. student, Eric Meyer;
Postdoc, Meritt Reynolds)

There are two promising ideas for achieving BEC at high densities. One is compression of hydrogen as micron sized bubbles in liquid helium; the other is after an idea of Kagan and Shlyapnikov, to create high density in the vicinity of a potential gradient at the tip of a needle. We have now built a cell which is designed to carry out both of these experiments in ultra-high magnetic fields at the Francis Bitter National Magnet Laboratory (FBNML). Our studies of the effects of eddy currents of the high fields (publication 1) have enabled us to build this cell completely of metal, to promote thermodynamic equilibrium. Our previous cell was made of plastic and performed poorly with regard to heat removal and attaining thermal equilibrium. The new cell, which includes a number of novel devices for manipulating the liquid helium at subkelvin temperatures (Kapton bellows, negative pressure generation, etc) has now been built and is undergoing the final tests before calibration and operation.

A high cooling power dilution refrigerator has been built up in the past year and a half. The heart of the refrigerator, dilution section, is on long term loan from a colleague. We built a high circulation rate pumping station, needed for high cooling power. The refrigerator was first tested some months ago and, after modifications, was able to deliver high cooling power on a test mixing chamber. Unfortunately a number of the old components of the dilution unit developed leak

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problems. Since it is necessary to have a high reliability system for the FBNML runs, with limited windows of scheduled running access, we decided to discard the faulty components and rebuild new ones. These are now being tested and we are aiming for our first runs with the cell in the refrigerator in the month of August (1990). This will have to occur in a superconducting test magnet as the FBNML will be closed down most of August.

FBNML has provided us with a large working space (cell 1) and office space. We have now outfitted and established a laboratory there for this research and moved our dilution refrigerator, pump station and electronics from Harvard to cell 1.

II. Microwave Trap

One method of improving conditions for BEC is to prevent the hydrogen atoms from having contact with the cell walls. This formidable goal has been achieved by other groups (MIT, Amsterdam) using a static magnetic field gradient with a field minimum. The problem with this trap is that only excited state atoms are trapped; this results in a rather low density of atoms and thus a very low critical temperature for BEC. Although the atoms can be cooled to about 1 mK by evaporative cooling in this trap, this temperature is not low enough. Thus, this approach, by itself, provides little hope for BEC.

As discussed in last year's report, we have conceived of a new type of atom trap, a resonant microwave trap, which is the most promising means of achieving BEC, because ground state atoms can be trapped and much higher densities are achievable in principle. The main problem here is that the potential well depth of the trap is very shallow (5-10 mK well depths are probably achievable) and thus it cannot be loaded from a usual source of atoms which at best can be cooled to a temperature of 70-100 mK. During my sabbatical year in France, I conceived of a way of loading a microwave trap with atoms. The idea is to imbed a microwave trap in a static trap and adiabatically transfer the cooled atoms from one trap to the other. This system is now being studied and designed for construction (both a static trap and a microwave trap). It is our intention to first build an x-band trap and use it to trap laser cooled sodium atoms (200 microkelvin) provided through our NIST collaboration. This will enable us to learn how to use such a trap in advance, which is a great advantage for such a complex system.

III. Cooling with Lyman-alpha Radiation

Atomic hydrogen can be cooled by laser cooling using Lyman-alpha radiation. To directly cool a gas to BEC requires a powerful Lyman-alpha

laser source. A less powerful source can be used to cool hydrogen held in a static magnetic trap. We have started a collaboration with W. Phillips (NIST) and T. McIlrath (U. of Maryland) to carry out this research. They have now built the laser source and it is our role to develop the cryogenics and the static trap (used also with the microwave trap). Harvard University has provided two new laboratories which have been renovated for this research. We have applied for an instrumentation grant for the cryogenics and are currently awaiting the results. We expect to start this work in the fall.

IV. Third Sound on Hydrogen Surfaces (Ph.D. Student, John Brisson)

We have been studying third sound of helium on a molecular hydrogen substrate. The idea here is that we would like to be able to study the 2-dim analogue of BEC on a surface, i.e. study the Kosterlitz-Thouless transition to 2-dim superfluidity of atomic hydrogen on helium. In order to attempt such an experiment, one must first know and understand the third sound properties of helium on a molecular hydrogen substrate (in an experiment with atomic hydrogen, the atoms recombine to form molecules which condense under the helium, as the substrate of the helium). The third sound measurements of superfluid helium on a molecular hydrogen substrate have now been completed, and we have been able to determine the Van der Waals constant between helium and hydrogen. An article is now being prepared, and John Brisson defended his thesis on the last week of June.

V. Scattering of Spin Polarized Hydrogen (Ph.D. Student, John Mester; Visitor, Tito Huber)

The study of hydrogen interacting with helium films is vital for our research objectives. It is particularly important to determine the sticking coefficient of hydrogen on helium down to very low temperatures (mK). This experiment is currently being carried out in our dilution refrigerator. We have built a system in which a beam of atoms can be reflected off of a surface of liquid helium in a magnetic field and detected, at low temperatures. A detector with about 4 orders of magnitude more sensitivity than previous ones has been developed. Our remaining difficulty in carrying out this experiment has been with a beam chopper which must work at low temperatures and high fields. Our original design, using a piezoelectric drive, failed to seal properly. We have now made a chopper based on a different principle and it will be tested in the coming months.

VI. Cryogenic Hydrogen Maser (Ph.D. Student, Ron Walsworth)

A few years ago the PI was approached by Prof. Steven Weinberg, who was working on a new theory to test the fundamental assumption of quantum mechanics of linearity. Our discussion led us to believe that his ideas could be tested with a hydrogen maser, taking advantage of the precision and stability of the atomic hydrogen transitions. We felt that testing of such a fundamental hypothesis would be worth a temporary change in this part of our program, for about one year.

The hydrogen atom is different than the case which Weinberg had studied (single spin system) with its composite spin arising from both the nucleus and the electron. We extended his analysis (publication 2) and carried out measurements (publication 3). These showed that to within our high precision no nonlinearity could be detected. This result is of fundamental importance for all fields of physics in that the assumption of linearity of quantum mechanics is so fundamental.

Other

The PI has been on sabbatical leave for the year 1989-90 at the Ecole Normale Supérieure in Paris where he has done research on spin-polarized ^3He and laser light trapping and cooling of metastable helium. In addition, time has been devoted to the design of the new experiments using traps at Harvard.

Publications

1. "Eddy Current Shielding and Heating: Reduction of Dissipation for Very Low Temperature Experiments in the Presence of Magnetic Field Ripple" E.S. Meyer, I.F. Silvera and B.L. Brandt, Rev. Sci. Instrum. 60, 2964 (1989).
2. "Nonlinear Quantum Mechanics of Systems of Composite Spin", R.L. Walsworth and I.F. Silvera, Phys. Rev. A 42, 63 (1990).
3. "Test of the Linearity of Quantum Mechanics in an Atomic System with a Hydrogen Maser", R.L. Walsworth, I.F. Silvera, E.M. Mattison, R.F.C. Vessot, Phys. Rev. Lett. 64, 2599 (1990).

Ph.D Thesis

"Third Sound Studies of Helium on Molecular Hydrogen," John G. Brisson, Harvard University, June 1990.

Research 1990-91

The research plans for the coming year are to push forward with the experiments described in I, V, and VI of the previous section. These are approaching completion of the development stage and should produce results in the coming period. We plan to enter into a large build-up of the experiment to encompass the laser cooling, the static magnetic field trap and the microwave trap. This will include the development of the cryogenic station (proposal pending). The construction is a major project and will require an estimated time of one year. Once this is complete and tested, NIST will truck the (large) Lyman-alpha laser to Harvard for the experiments.

The experimental work on third sound has just been terminated, although there will be some effort in preparing articles for publication. At present we do not plan to further pursue this line of research, so that we can concentrate on the projects above. Due to the demands of developing the new high field facility, we have also deferred research on the spin-polarized electron project.

At this time the PI has openings for one to two new Ph.D. students. Since it may take some months after returning from sabbatical leave to identify qualified students for this research, it is the intention to hire a new postdoc in the fall, to give a large overlap with Dr. Reynolds.

The current personnel and projects are:

<u>Personnel</u>	<u>Support</u>	<u>Project</u>
Meritt Reynolds (postdoc)	DOE	I, II and III.
John Mester (grad. student)	DOE	V
John Brisson (grad. student until summer 1990, two months as postdoc)	DOE	IV and II
Eric Meyer (grad. student)	NSF and DOE	I
Ron Walsworth (grad. student)	NASA	VI
New Post Doctoral Fellow (to be hired)	DOE	II and III
New Graduate Student	DOE	II and III

The steady state situation will be to have one postdoc and three graduate students supported by the DOE grant.

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