

REPORT DOCUMENTATION PAGE

Form Approved
OAS No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited. ②	
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE		4. PERFORMING ORGANIZATION REPORT NUMBER(S)	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)		5. MONITORING ORGANIZATION REPORT NUMBER(S)	
6a. NAME OF PERFORMING ORGANIZATION Research Laboratory of Electronics Massachusetts Institute of Technology	6b. OFFICE SYMBOL (if applicable)	7a. NAME OF MONITORING ORGANIZATION	
6c. ADDRESS (City, State, and ZIP Code) 77 Massachusetts Avenue Cambridge, MA 02139		7b. ADDRESS (City, State, and ZIP Code)	
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Office of Naval Research	8b. OFFICE SYMBOL (if applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-83-K-0695	
8c. ADDRESS (City, State, and ZIP Code) 800 North Quincy Street Arlington, VA 22217	10. SOURCE OF FUNDING NUMBERS		10. SOURCE OF FUNDING NUMBERS
	PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.
		4122019--	06
11. TITLE (Include Security Classification) Traps for Neutral Atoms			
12. PERSONAL AUTHOR(S) Prof. David Pritchard			
13a. TYPE OF REPORT Final Summary	13b. TIME COVERED FROM 9-1-83 TO 1-31-90	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
16. SUPPLEMENTARY NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	
19. ABSTRACT (Continue on reverse if necessary and identify by block number) Work by D.E. Pritchard and his collaborators is summarized here			
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Mary Greene - RLE Contract Reports		22b. TELEPHONE (Include Area Code) (617)258-5871	22c. OFFICE SYMBOL

DTIC
ELECTE
S APR 25 1990 **D**
lc **D**

Pritchard Group: Atom Trapping Progress 1983 -- 1989

Traps

We have demonstrated two atom traps — one magnetic [BLM87] and one using light forces, [RPC87].² In each case ours was the *second* trap of that type, embodying significant new conceptual contributions which permitted tremendous advances over the previous trap of that type (in each case by $\sim 10^5$ in number trapped, and 10^2 in time trapped). Both of our designs have been used without improvement by other groups; [HKD87] and [VBJ88] for the magnetic trap, and [SST89, SWW89] for the light force trap. Meanwhile, only one new trap has been demonstrated [GLJ88];² a light trap which performed less well than ours [RPC87]. This suggests that major advances in atom traps will no longer appear with regularity.

Cooling

Our proposal for cyclic cooling [PRI83] was the first cooling scheme designed to cool below the Doppler limit. Our discussion of phase space optical pumping [PHB87], which can cool below the recoil limit, was also seminal. So far we have succeeded in applying only Doppler cooling to our trapped atoms.

Several other groups have demonstrated sub-Doppler, and even sub-recoil cooling [LWW88, SWU89, AAK88], but in gasses or one-dimensional beams, not traps. Interestingly, the current explanations of the sub-Doppler cooling invoke a serendipitously occurring type of cyclic cooling.

Spectroscopy of Trapped Atoms

Our rf spectroscopy [MHB88] and laser spectroscopy of trapped atoms remains unique. The main emphases in this work has been on diagnostics and manipulating the atoms. We showed that the atoms originally trapped are so hot that they are very nearly evenly distributed in phase space, but that they can be cooled to ~ 2 mk by Doppler cooling.

Cold Collisions

Our observation of collisional loss of atoms in a light trap [RPC87] suggested that the laser excitation was involved in these collisions. In collaboration with Alan Gallagher

at JILA, we have developed a semi-classical theory of collisions in a weak near-resonant laser field [GAP89]; it is the first to consider the effects of spontaneous decay during the collision. Our theory treats absorption of near resonant photons to the attractive excited potential curve which dissociates to a pair of atoms, only one excited. This potential curve has a long range resonant dipole-dipole interaction which decreases as R^{-3} , the strongest interaction potential between neutral atoms. Consequently the trap lasers, typically detuned from resonance by one natural linewidth (10 MHz for Na) excite atom pairs with separations $R \geq 800 \text{ \AA}$! With only 1 mK of kinetic energy, these atoms travel only $\sim 150 \text{ \AA}$ in one spontaneous lifetime, rarely surviving to the region $R < 50 \text{ \AA}$ where trap loss collision processes can occur (ie. those which are sufficiently exoergic to expel atoms from the trap, causing the observed loss of trapped atoms). Our theory therefore assumes that the laser excites pairs of *stationary* atoms whose separation subsequently evolves due to the strong attractive force in the excited state.

This theory predicts that trap loss should grow with detuning since this causes the laser to excite atom pairs at smaller internuclear separations where the attractive force is strong enough to pull them into the region of strong interaction before they decay spontaneously. We found that previous suggestions that spontaneous decay in this region would be sufficiently red-shifted so that the energy difference between the absorbed and emitted photons (which is converted to translational energy) would expel the atoms from the trap [PRI86, VIG86] missed a much larger effect: we predict that fine structure changing collisions (which also liberate trap-expelling energy) will be the dominant loss mechanism in Na - Na* collisions.

Recently the frequency dependence for trap loss has been measured for Cs [SWM89] — it is in satisfactory agreement with the predictions of our theory for detunings from 0.3 to 1.5 GHz, but the theory becomes inapplicable (and inaccurate) closer to resonance (ie. for $\delta_\nu \leq 0.2 \text{ GHz}$).

Collective Effects

So far the idea of doing Bose Einstein condensation in a trap remains an elusive dream. If it is done soon it will be done with hydrogen. Our only contribution to this area is a calculation of the critical behavior of BEC in various traps. We showed that the type of trap strongly affects the critical number needed for BEC, and also influences the thermodynamic behavior - eg. whether or not there is a discontinuity in the specific heat [BPK87].

People

No assessment of the significance of our research program is complete without mentioning our most important product: people. Four people have "graduated from" our trapping experiments (Bagnato, Lafyatis, A. Martin, and E. Raab). Bagnato won Brazil's

Dist	and/or Special
A-1	

"Young Physicist of the Year" award in 1988, and Lafyatis has been named a Presidential Young Investigator. The P.I.'s group has been very productive of good people over the years, and several have made contributions to trapping work at NIST (W. Phillips, postdoc in 1976-77, P. Gould, Ph.D. 1986 and A. Migdall, Ph.D. 1984). The first authors on 4 of the first 6 papers demonstrating atom traps received their PhD's in the P.I.'s group.

References

- AAK88 A. Aspect, E. Arimondo, R. Kaiser, N. Vansteenkiste and C. Cohen-Tannoudji, *Phys. Rev. Lett.* 1, 826 (1988).
- BLM87 V.S. Bagnato, G.P. Lafyatis, A.G. Martin, E.L. Raab, R.N. Ahmad-Bitar, and D.E. Pritchard, *Phys. Rev. Lett.* 58, 2194-97 (1987).
- BPK87 V. Bagnato, D.E. Pritchard and D. Kleppner, *Phys. Rev. A.* 35, 4354 (1987).
- GAP89 Alan Gallagher and David E. Pritchard, *Phys. Rev. Lett.* 63, 957 (1989).
- GLJ88 P.L. Gould, P.D. Lett, P.S. Julienne, W.D. Phillips, H.R. Thorsheim, and J. Weiner, *Phys. Rev. Lett.* 60, 788 (1988).
- GLW89 P.L. Gould, et al., ed. S. Haroche et al., p. 215, *Atomic Physics 11* World Scientific, Singapore (1989).
- HKD87 H.F. Hess, G.P. Kochanski, J.M. Doyle, N. Masuhara, D. Kleppner and T.J. Greytak, *Phys. Rev. Lett.* 59 672 (1987).
- LWW88 Paul D. Lett, Richard N. Watts, Christoph I. Westbrook, William D. Phillips, Phillip L. Gould and Harold J. Metcalf, *Phys. Rev. Lett.* 61, 169-72 (1988).
- MHB88 A.G. Martin, K. Helmerson, V.S. Bagnato, G.P. Lafyatis and D.E. Pritchard, *Phys. Rev. Lett.* 61, 2431-4 (1988).
- PHB87 D.E. Pritchard, K. Helmerson, V.S. Bagnato, G.P. Lafyatis and A.G. Martin, in *Laser Spectroscopy VIII* edited by W. Persson and S. Svanberg (Springer, Berlin), pp. 68-72 (1987).
- PRI83 David E. Pritchard, *Phys. Rev. Lett.* 51, 1336-39 (1983).
- PRI86 D.E. Pritchard, in the *Proceedings of XIVth ICPEAC*, 1985, edited by D. C. Lorentz, W.E. Meyerhof, and J.R. Peterson (unpublished).
- RPC87 E.L. Raab, M.G. Prentiss, A.E. Cable, S. Chu, and D.E. Pritchard, *Phys. Rev. Lett.* 59, 2631 (1987);

- SST89 Fujio Shimizu, Kazuko Shimizu and Hiroshi Takuma, Phys. Rev. A. 39, 2758-2760 (1989).
- SWM89 D. Sesko, T. Walker, C. Monroe and C. Wieman, accepted by Phys. Rev. Lett.
- SWU89 Y. Shevy, D.S. Weiss, P.J. Ungar and Steven Chu, Phys. Rev. Lett. 62, 1118 (1989).
- SWW89 David Sesko, Thad Walker and Carl Wieman, private communication.
- VBJ88a R. van Joijen, J.J. Berkout, S. Jaakkola and J.T.M. Walraven, Conference on spin polarized quantum systems (Torino, Italy) June 1988.
- VBJ88b R. van Joijen, J.J. Berkout, S. Jaakkola and J.T.M. Walraven, Phys. Rev. Lett. 61, 931-4 (1988).
- VIG86 J. Vigue, Phys. Rev. A 34, 4476 (1986).

Office of Naval Research

DISTRIBUTION LIST

<u>Peter J. Reynolds</u> <u>Scientific Program Officer</u>	1 copy
Code: 1112A1 Office of Naval Research 800 North Quincy Street Arlington, VA 22217	
Administrative Contracting Officer E19-628 Massachusetts Institute of Technology Cambridge, MA 02139	1 copy
Director Naval Research Laboratory Washington, DC 20375 Attn: Code 2627	6 copies
Defense Technical Information Center Bldg. 5, Cameron Station Alexandria, VA 22314	2 copies