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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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WINTER COLLEGE ON
HIGH RESOLUTION SPECTROSCOPY

(8 January - 2 February 1990)

NEW MECHANISMS FOR LASER COOLING

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New Mechanisms for Laser Cooling

[illegible] optical molasses

- Simple theory predicts $k_B T \geq \frac{\hbar\Gamma}{2}$

- Experiments show $k_B T \ll \frac{\hbar\Gamma}{2}$

- Obvious "improvements" in the theory only make things worse.

- Sensitivity to polarization and to magnetic field suggests that magnetic sublevels are involved.

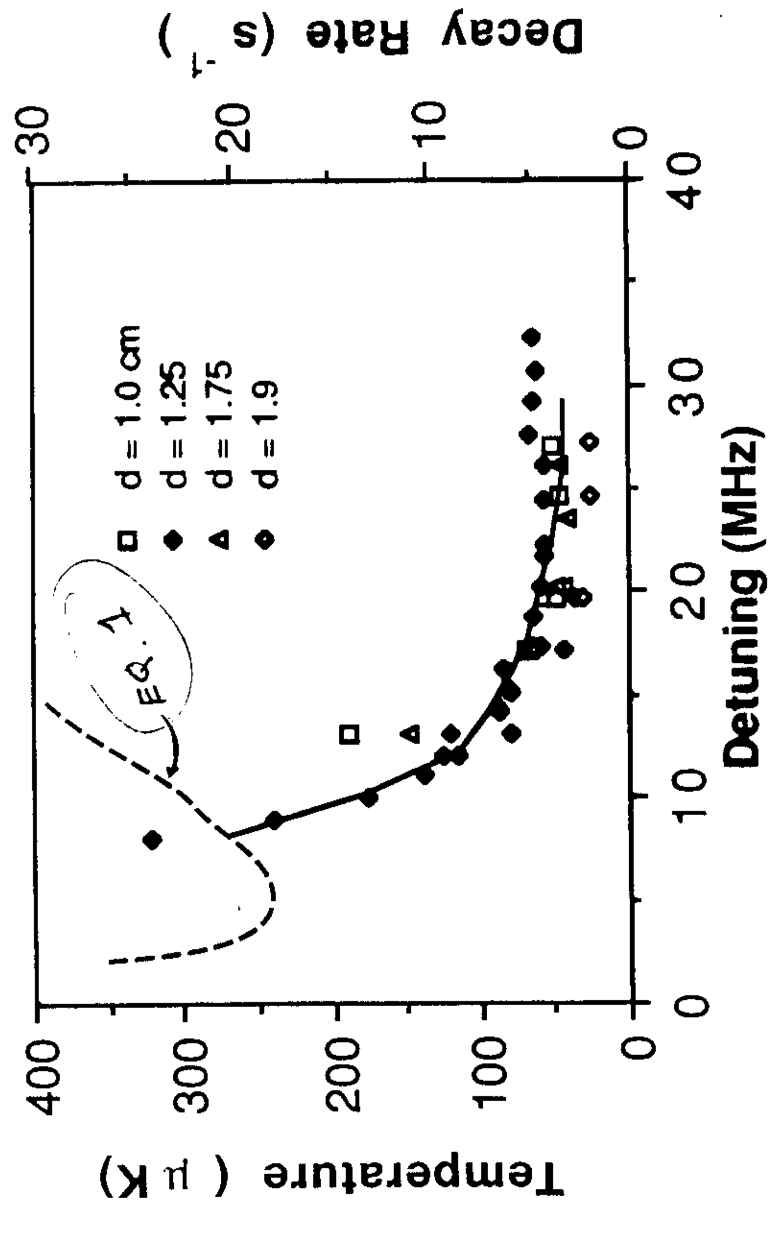
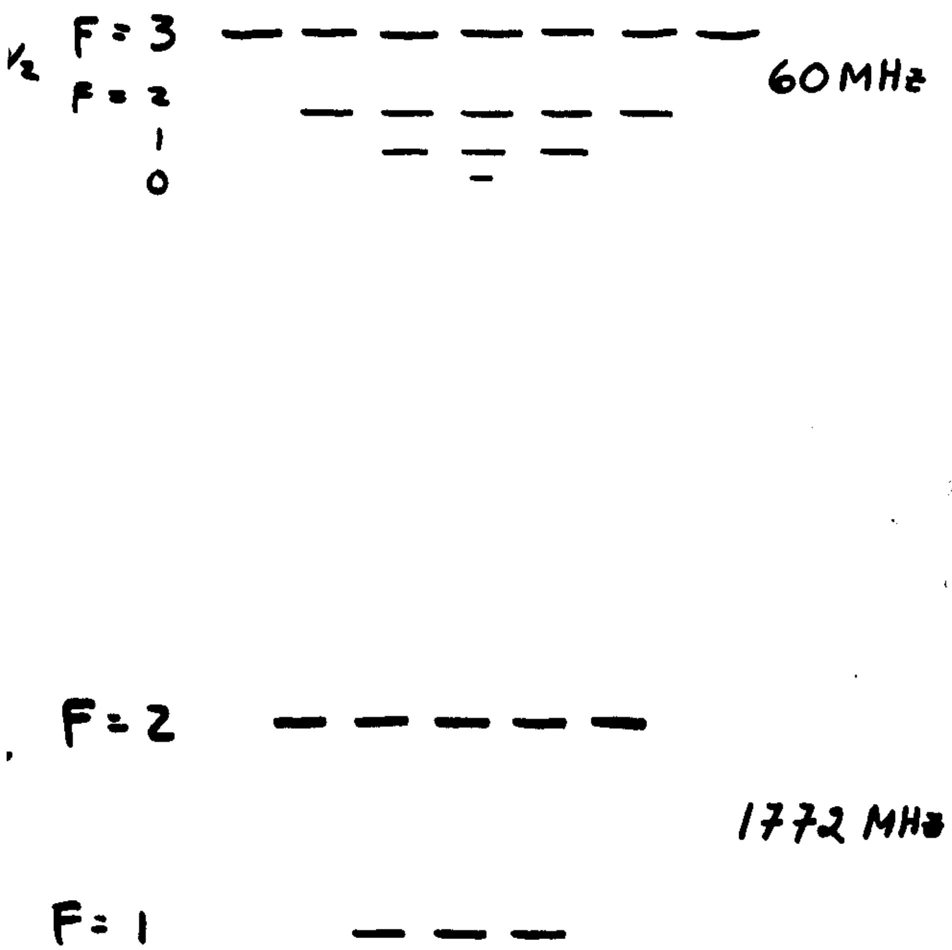


Fig. 2: Molasses temperature by the TOF method for various detunings and separations, d. The solid curve is the measured molasses decay rate; it is not a fit to the temperature data. The dashed line shows the expected temperature, Eq. (1).

Na Level Structure



A new kind of laser cooling

Theory due to:

Dalibard and Cohen-Tannoudji ENS

Chu et al. Stanford

The new cooling depends on:

- multiple, degenerate ground states
- optical pumping between ground states
- light shifts of ground states
- polarization gradient of the light

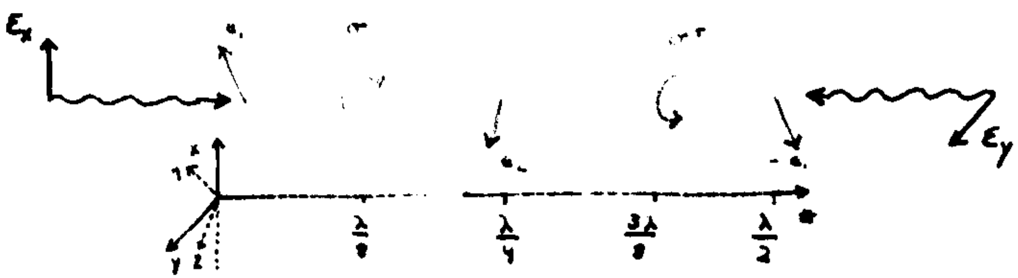
General consideration: $k_B T \sim \hbar/\tau$

where τ is the characteristic time.

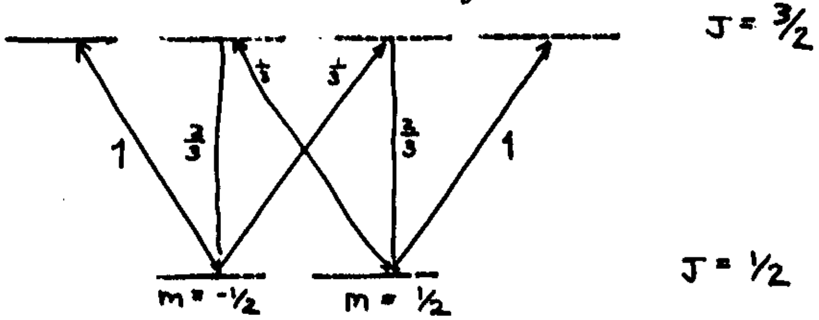
if τ is the natural lifetime: Doppler cooling limit

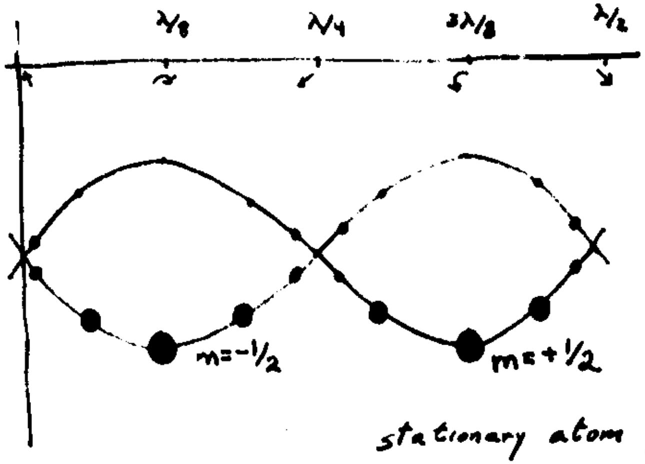
if τ is an optical pumping time: new cooling

Gradient of Polarization

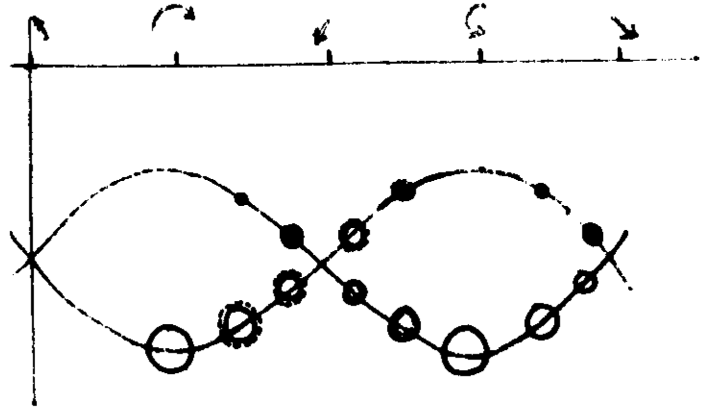


transition strengths

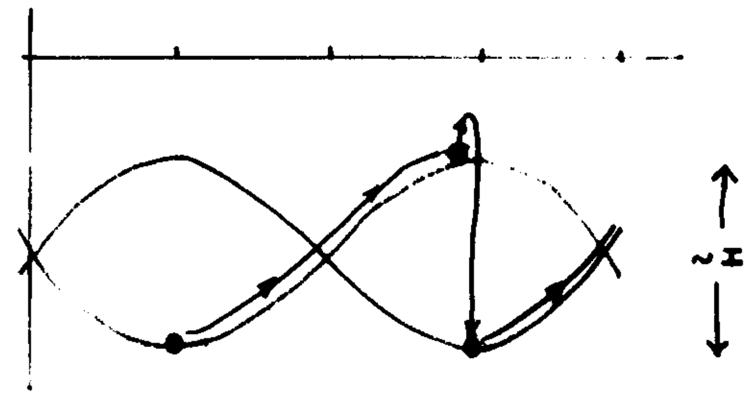




stationary atom populations



moving atom population lag



"Sisyphus" cooling

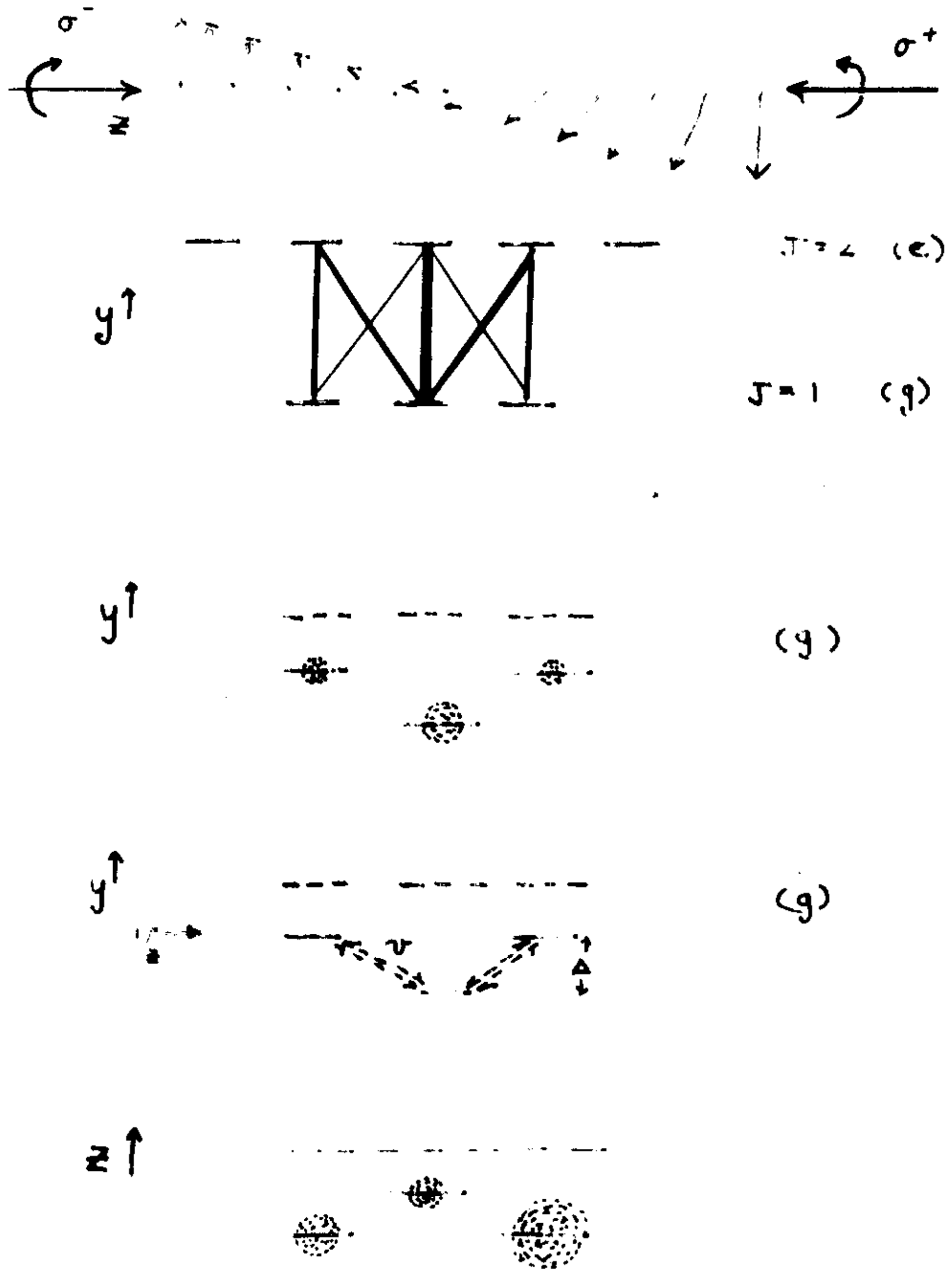
$F \propto v$ (friction)

friction coefficient independent of intensity

light shift ~ I ; lag ~ τ ~ $\frac{1}{I}$

POLARIZATION GRADIENT COOLING $\sigma^+\sigma^-$

[illegible]



POLARIZATION GRADIENT COOLING $\sigma^+\sigma^-$

FORCE ∝ (POP. DIFF.) × (INTENSITY)

(POP. DIFF.) ∝ (VEL.) × $\left(\frac{1}{\Delta} \sim \frac{1}{\text{INTENS.}}\right)$

so:

FORCE ∝ VELOCITY (FRICTION)

Independent of Intensity

(not like Doppler Cooling)

(Something for Nothing?)

No! $kv < \Delta \sim I \Rightarrow$

velocity "capture" range ~ I.

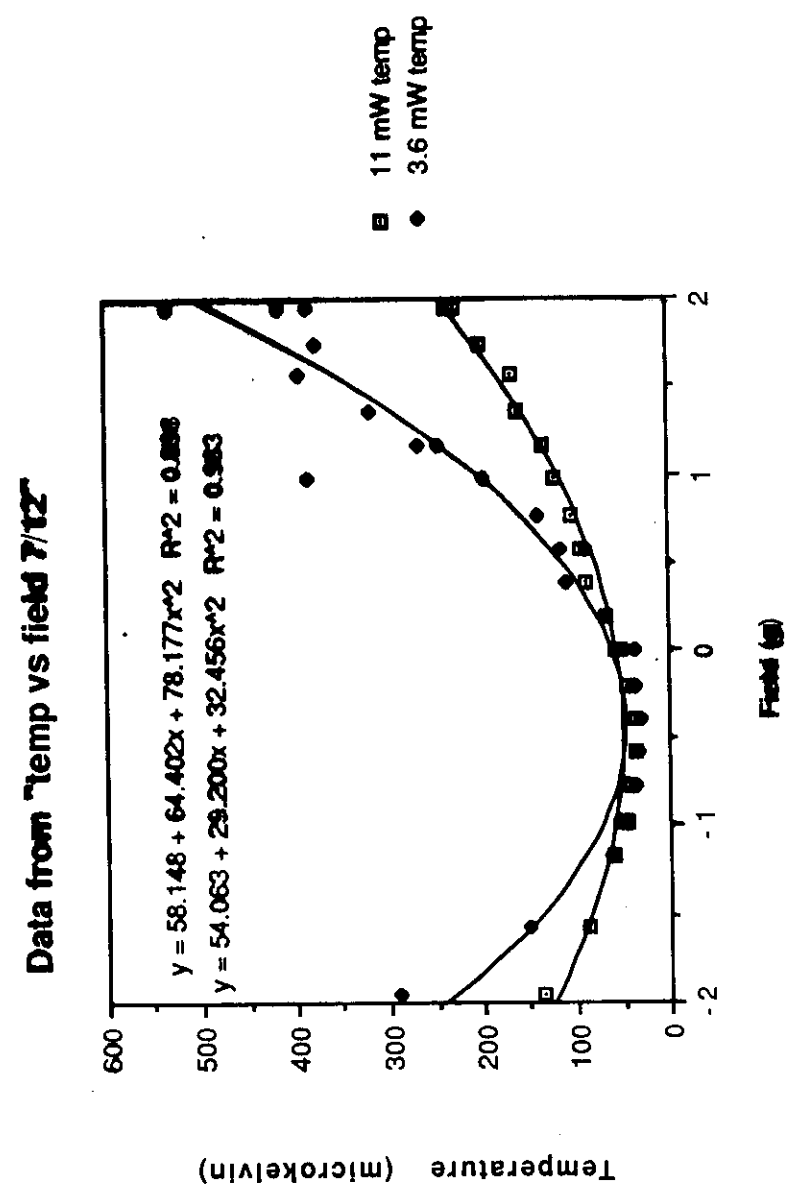
But: Heating ~ I, so

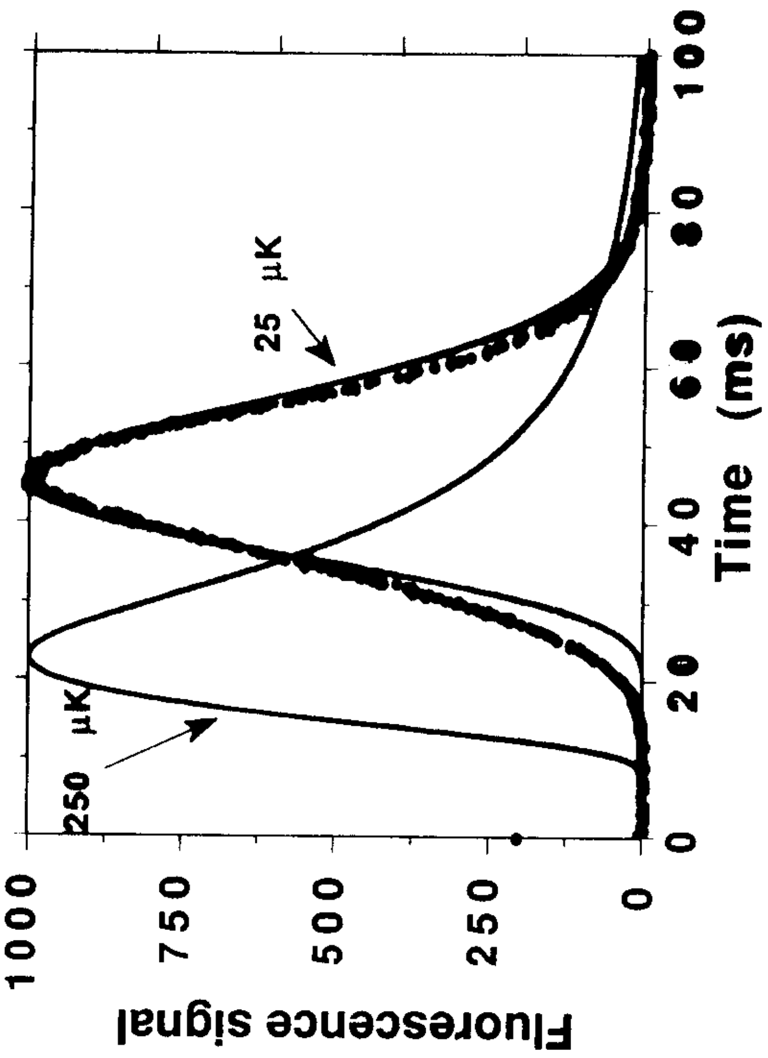
$T \sim \frac{1}{I}$.

Predictions of Polarization Gradient Cooling

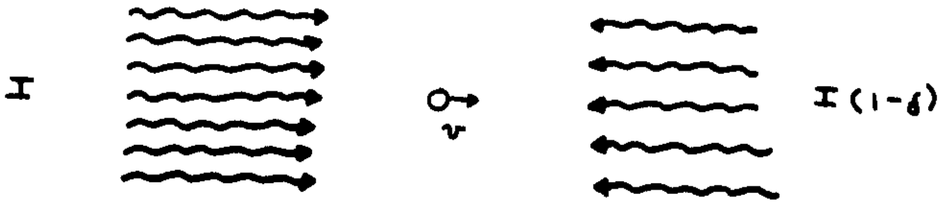
- $T < T_{Doppler}$
- $T \sim \frac{1}{I}$
- Polarization of Light is important
- Mixing of Sublevels (as with $\vec{B}$) should hurt cooling.
- Very strong friction force

6





Effect of Imbalance



estmate v:

$$F_{unbal} + F_{frict} = 0$$

$$\delta \frac{\hbar k \gamma}{4} - \frac{\hbar k^2 v}{4} = 0 \Rightarrow v = \delta \frac{\gamma}{k}$$

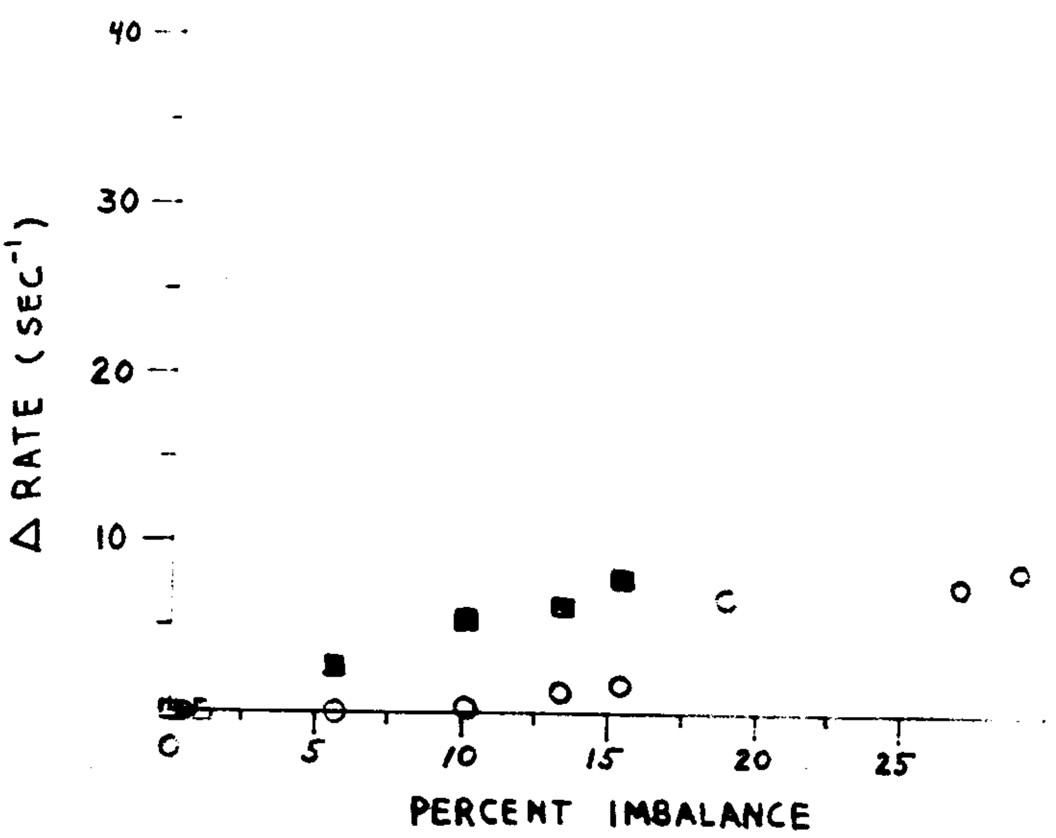
$$\gamma / k = 6 \text{ m/s}$$

exact: $$v = \frac{\delta \gamma}{4k} \frac{\frac{1}{4}(1 + I/I_0) + \Delta^2/\gamma^2}{\Delta/\gamma}$$

For optimum molasses ($I/I_0 \sim 1$, $\Delta \sim \gamma/2$)

$$v_{drift} = (2.2 \text{ m/s})\, \delta$$

10% imbalance ⇒ 23 ms lifetime in 5 mm



nolesses decay rate changes vs. imbalance ① expt.

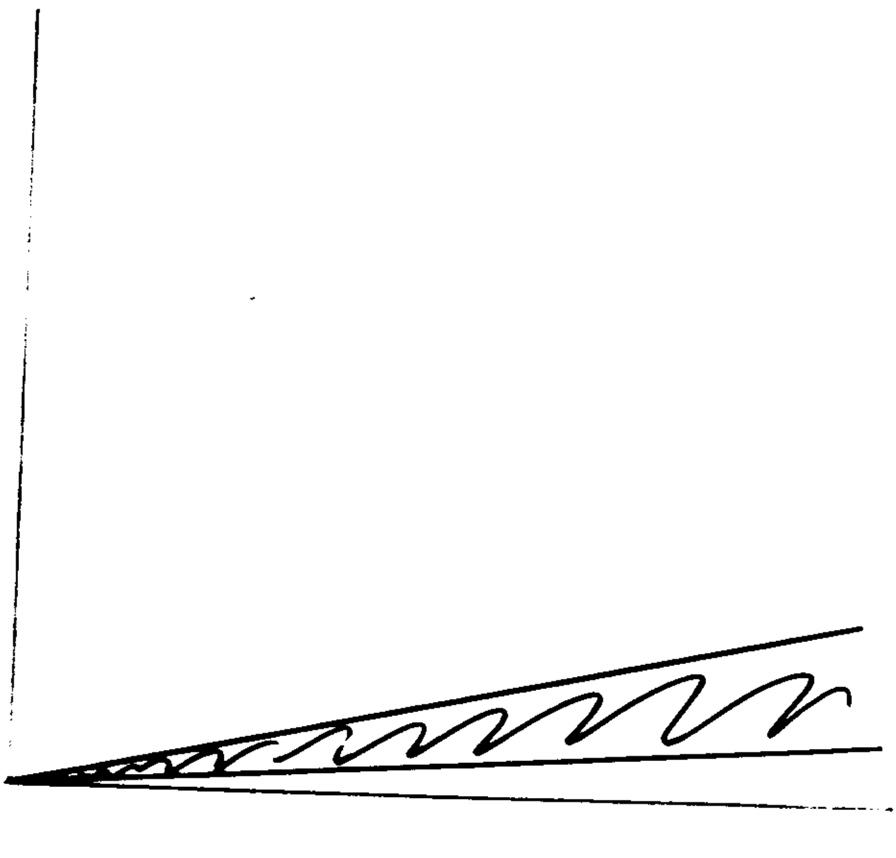
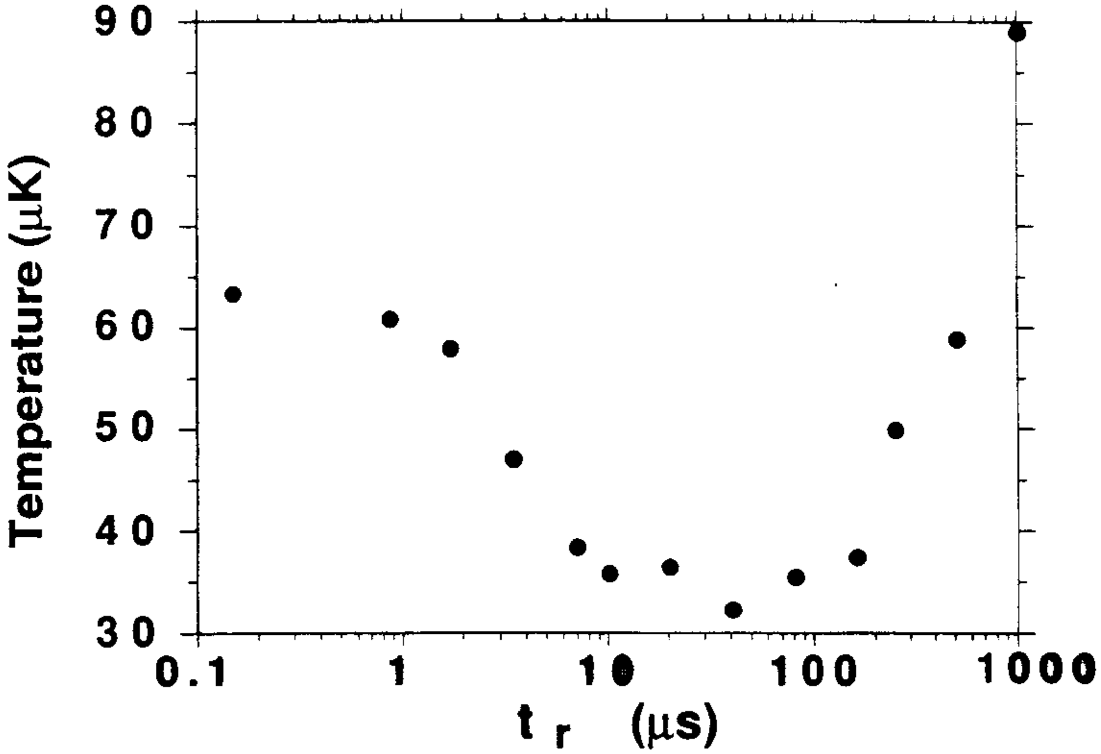


FIG 16



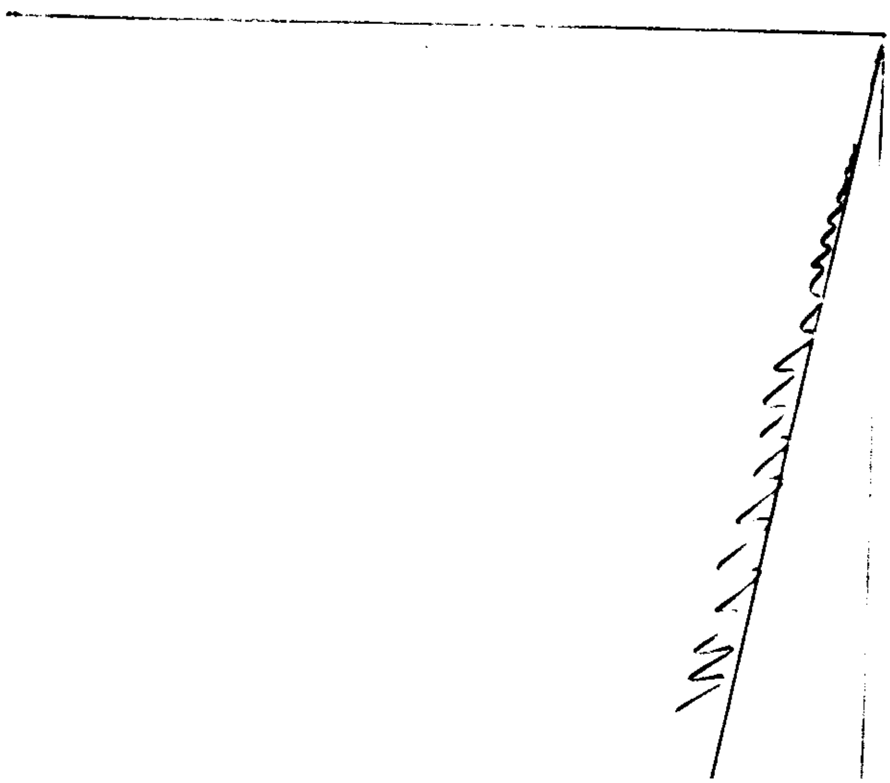
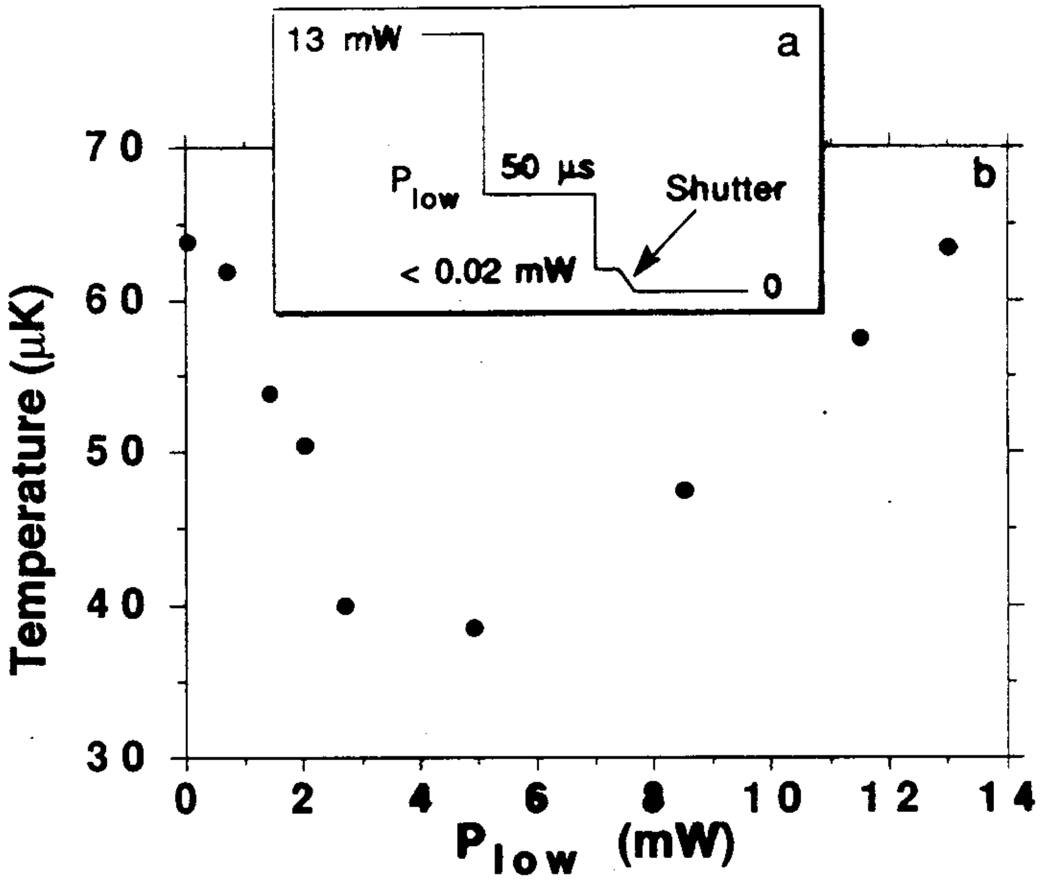
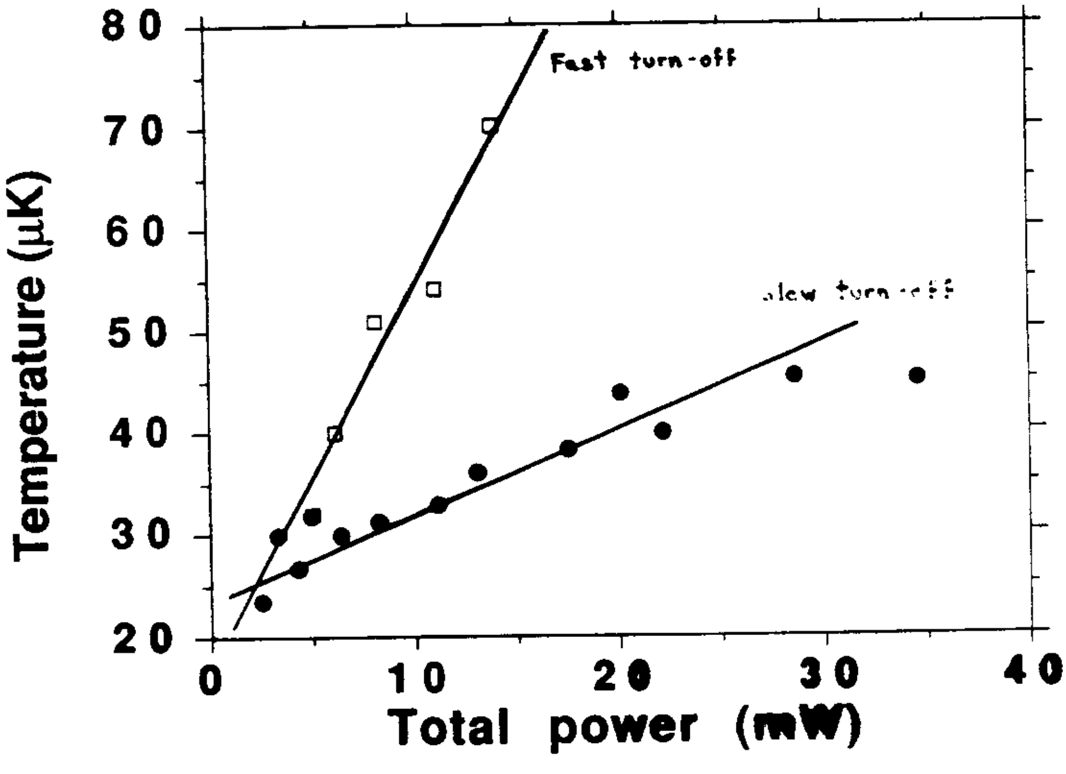


FIG 18



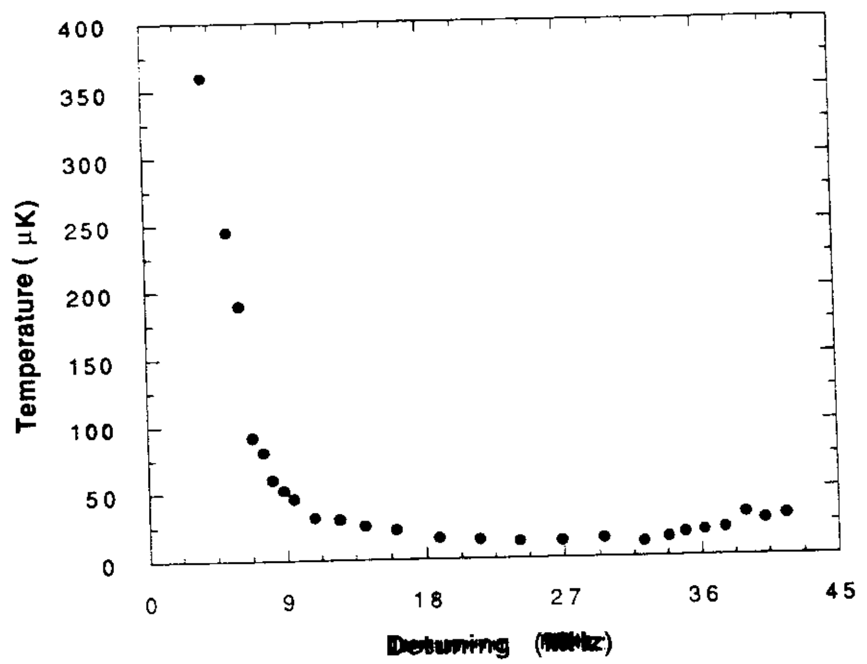
13 mW
a
P_{low}
50 µs
Shutter
< 0.02 mW
0
b
Temperature (µK)
70
60
50
40
30
0
2
4
6
8
10
12
14
P_{low} (mW)

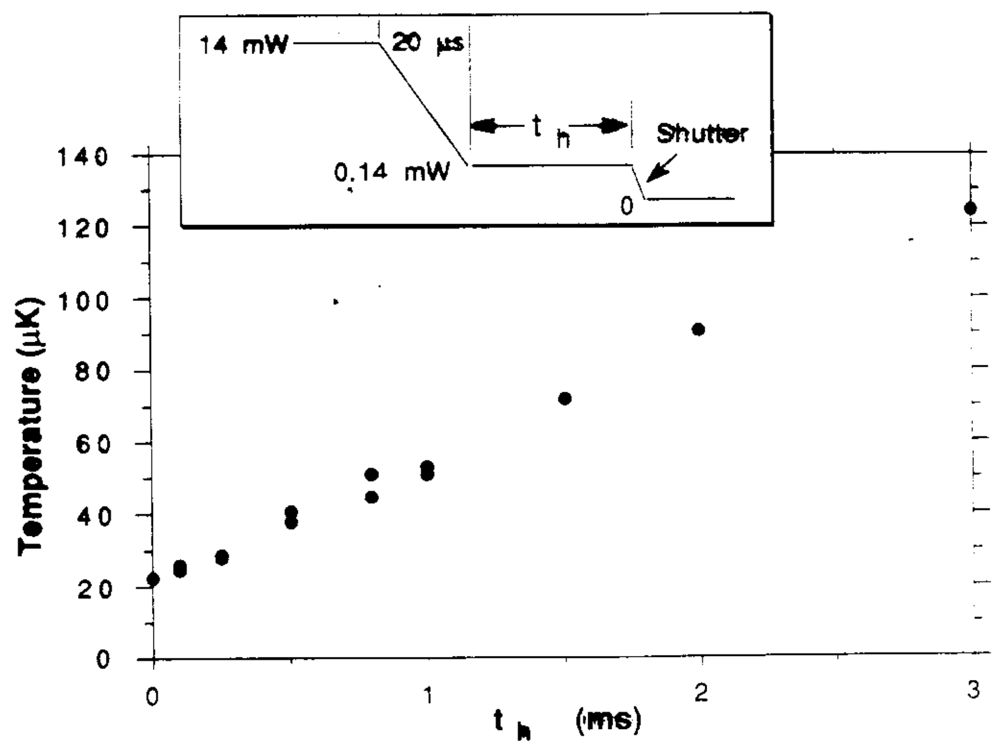
FIG 17

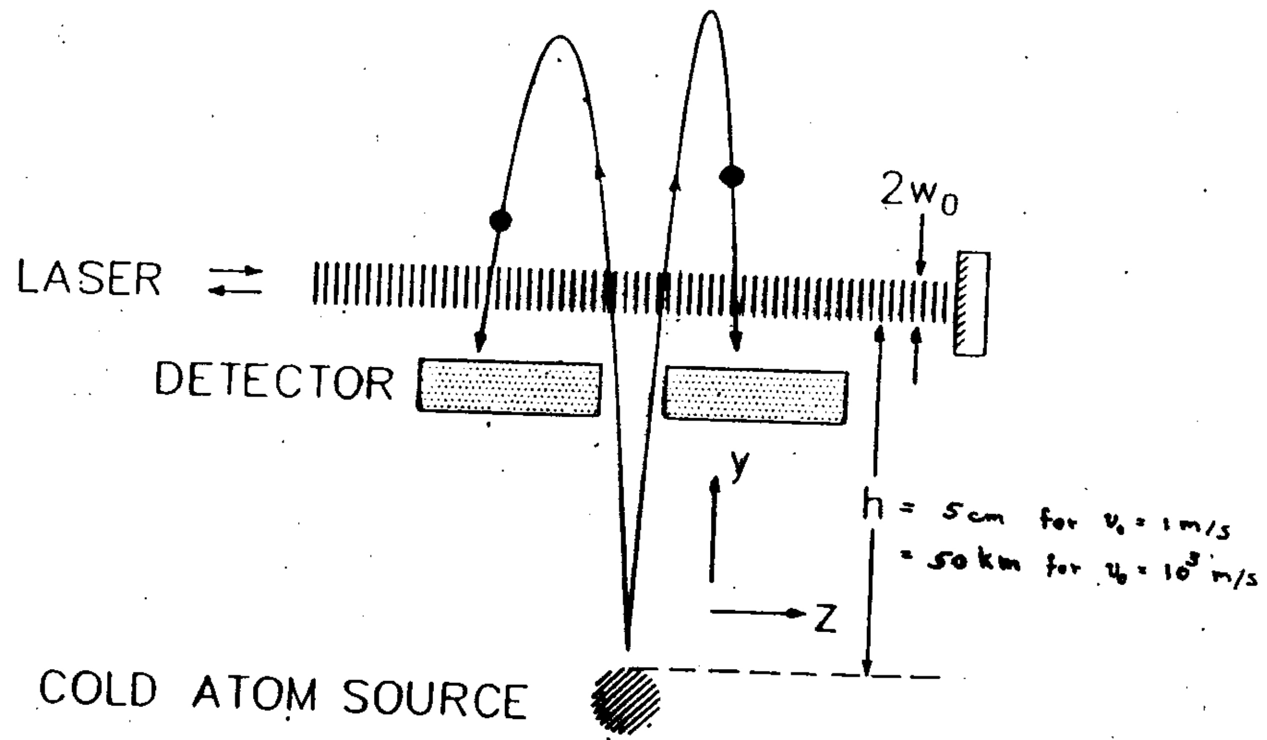


Fast turn-off
slow turn-off
Temperature (µK)
80
70
60
50
40
30
20
0
10
20
30
40
Total power (mW)

Results for Na - F'=2 level too close ; Cs is better

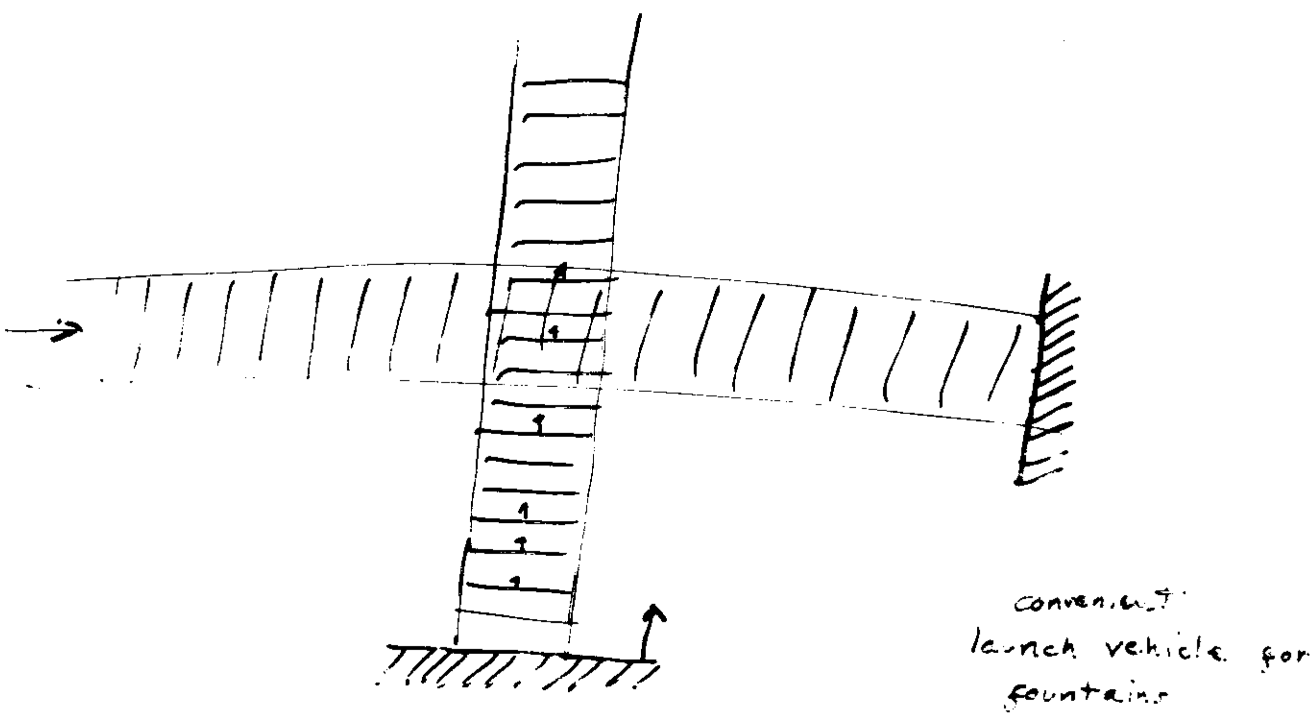




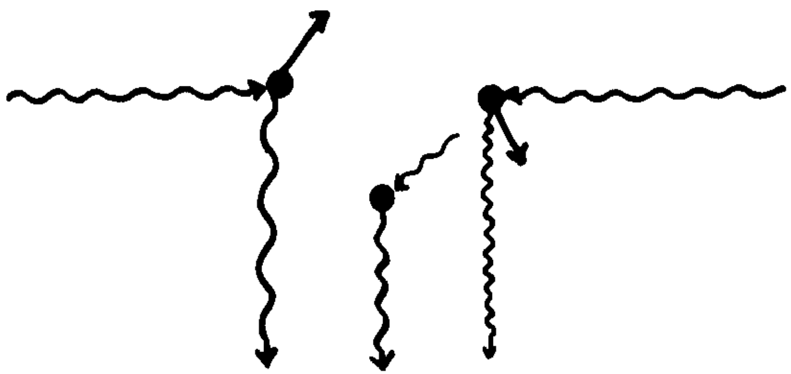


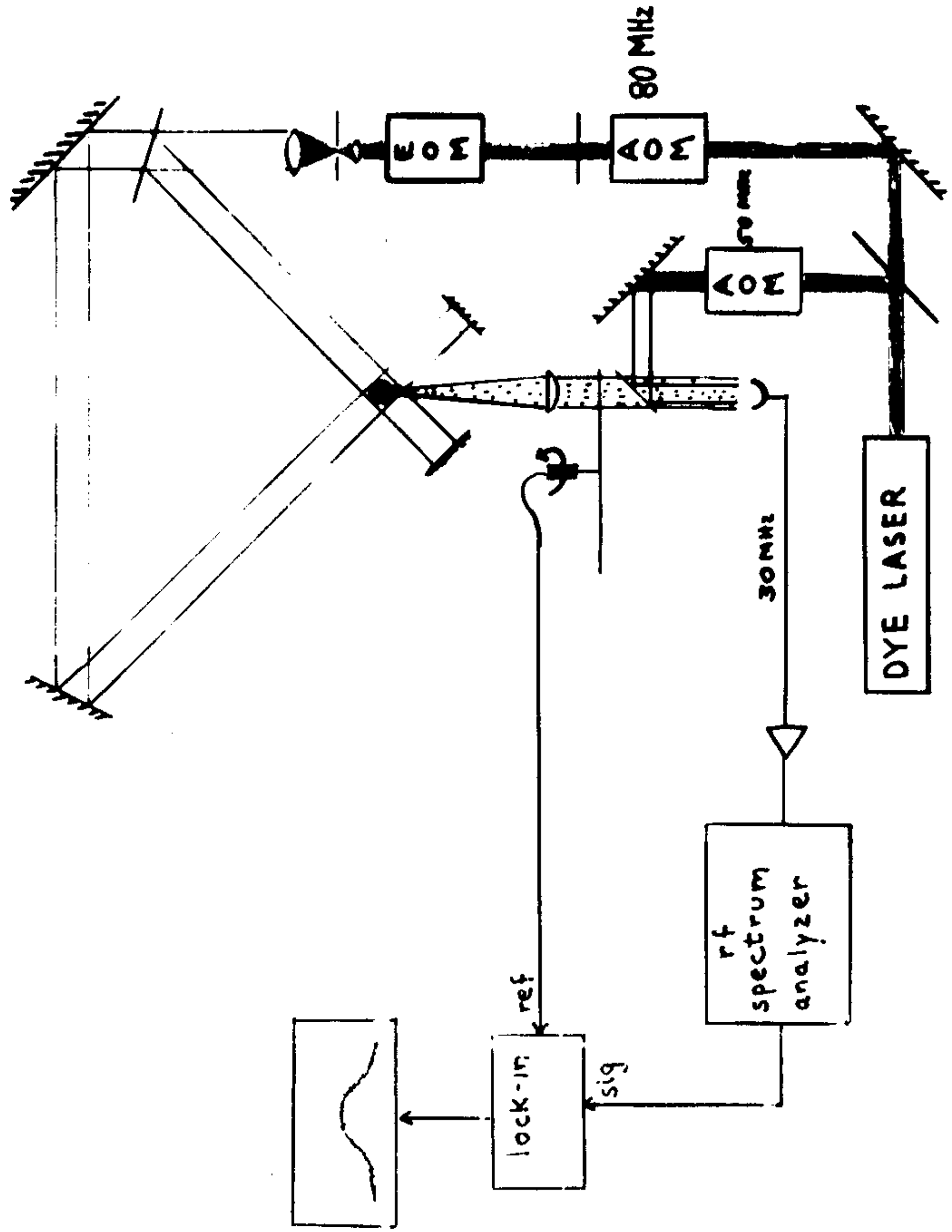
'ig. 1. Scheme for two-photon optical Ramsey spectrosco-
y of freely falling atoms.

Moving Molasses



Spectrum of Light from Optical Molasses

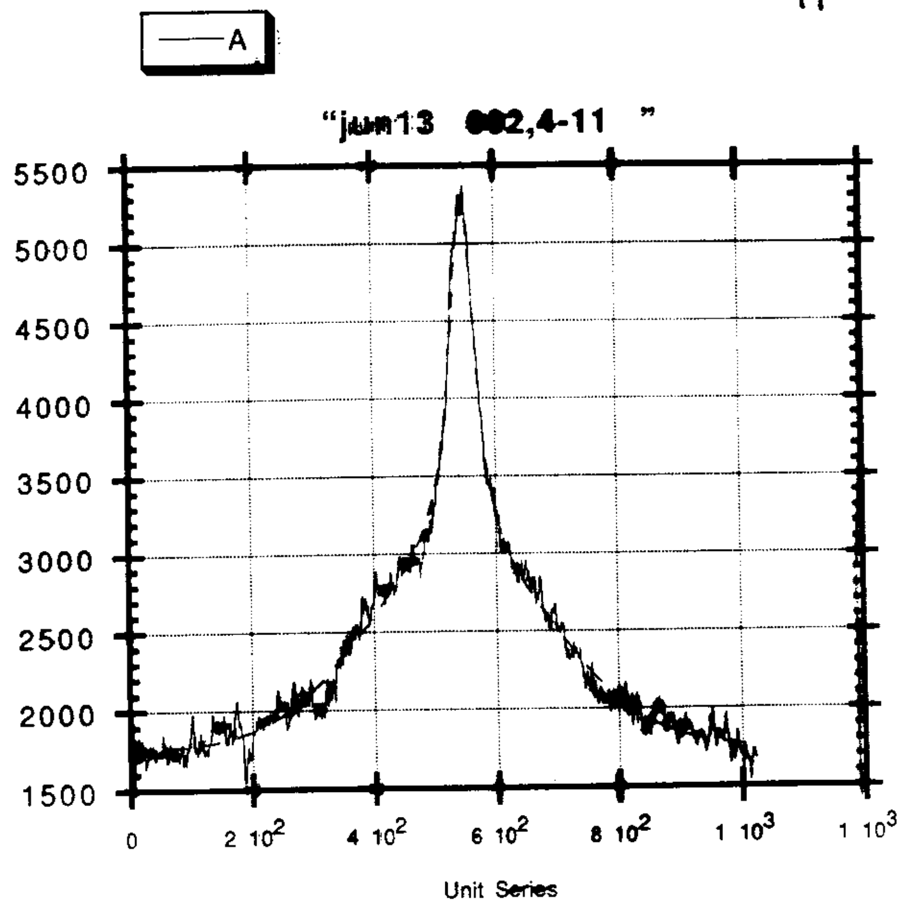




- elastic (Rayleigh) scattering (at low intensity)
- no natural width
- Doppler width a few hundred kHz +

T_{fit} = 8?μK

Doppler width : T = 84 μK



Channel [1] ____________________ Status: Acquisition Stopped_____

Range	1.0 V	Auto Scale	[Enabled]
Offset	400.0 mV	Store Mode	[Average] [256]
Probe	[1:1]	Coupling	[dc] [1 MΩ]

Graph [1] 125 mV/div 400 mV 10.0 ms/div 40.00 ms

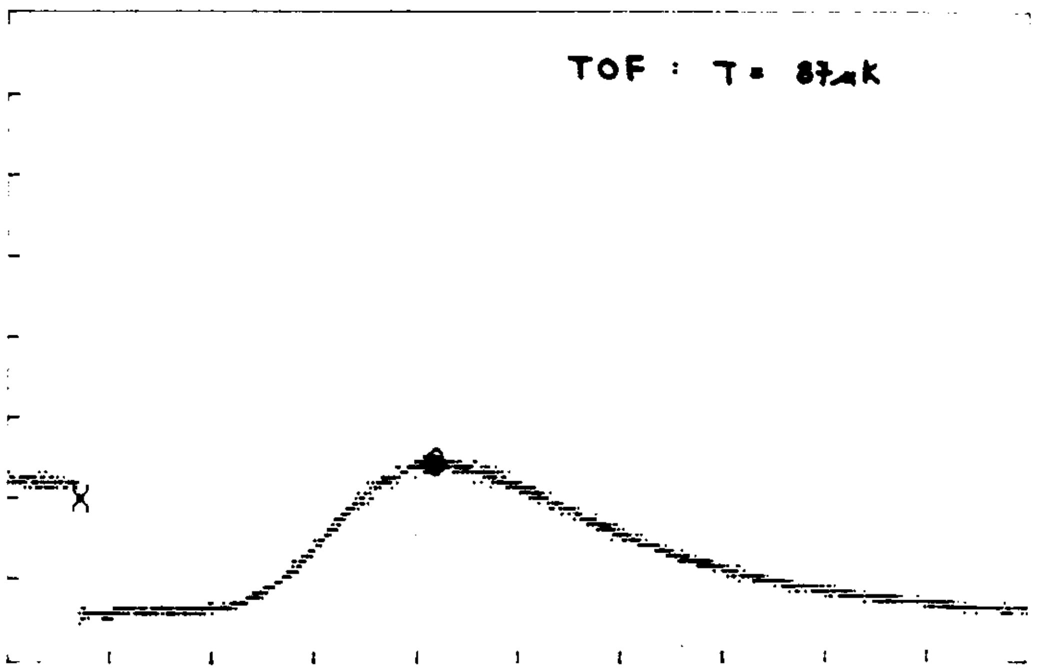
1:

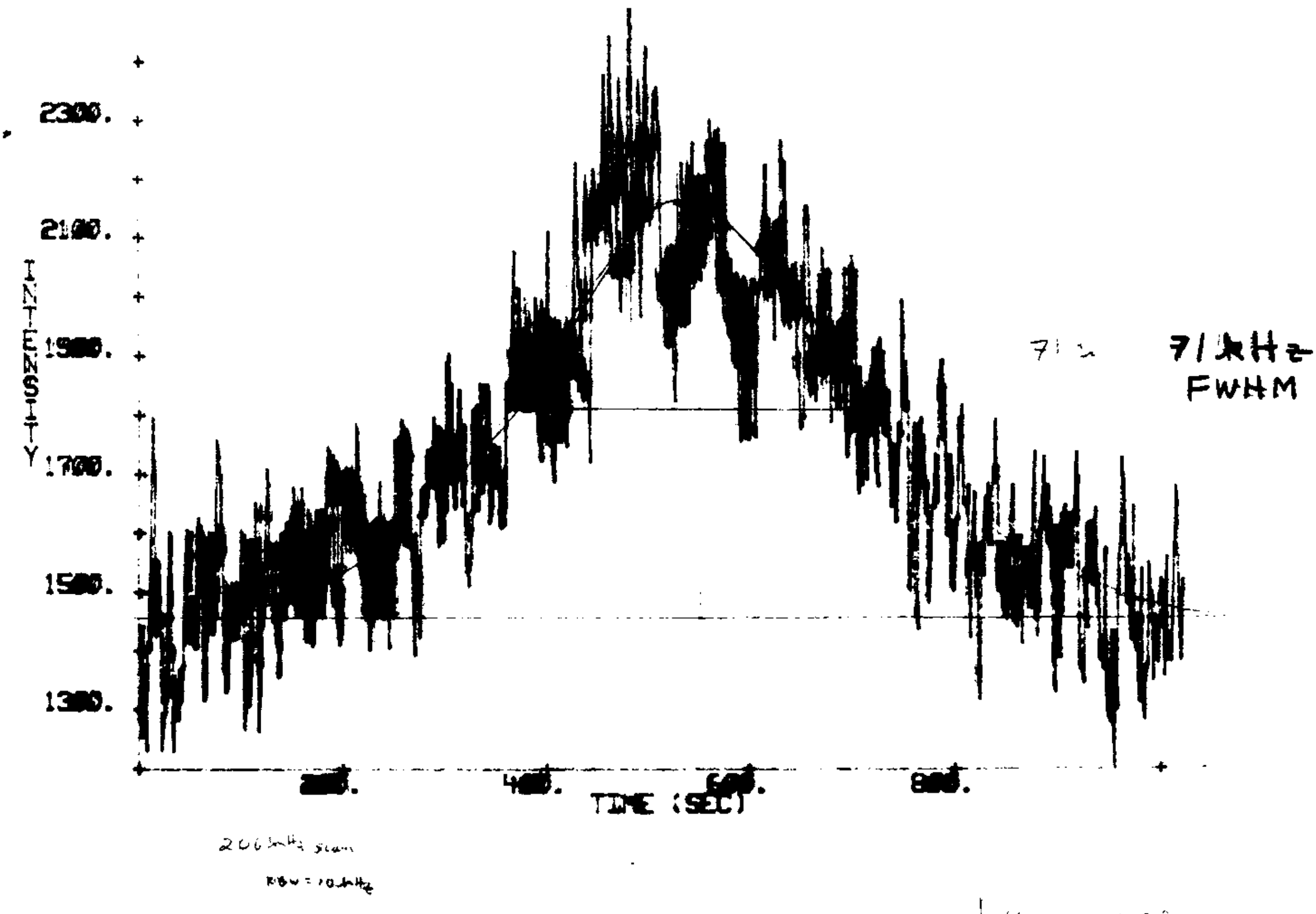
0 Selected

Cursor X
150 mV
47.0 ms

Cursor 0
210 mV
81.7 ms

Cursor 0-X
60.5 mV
34.7 ms





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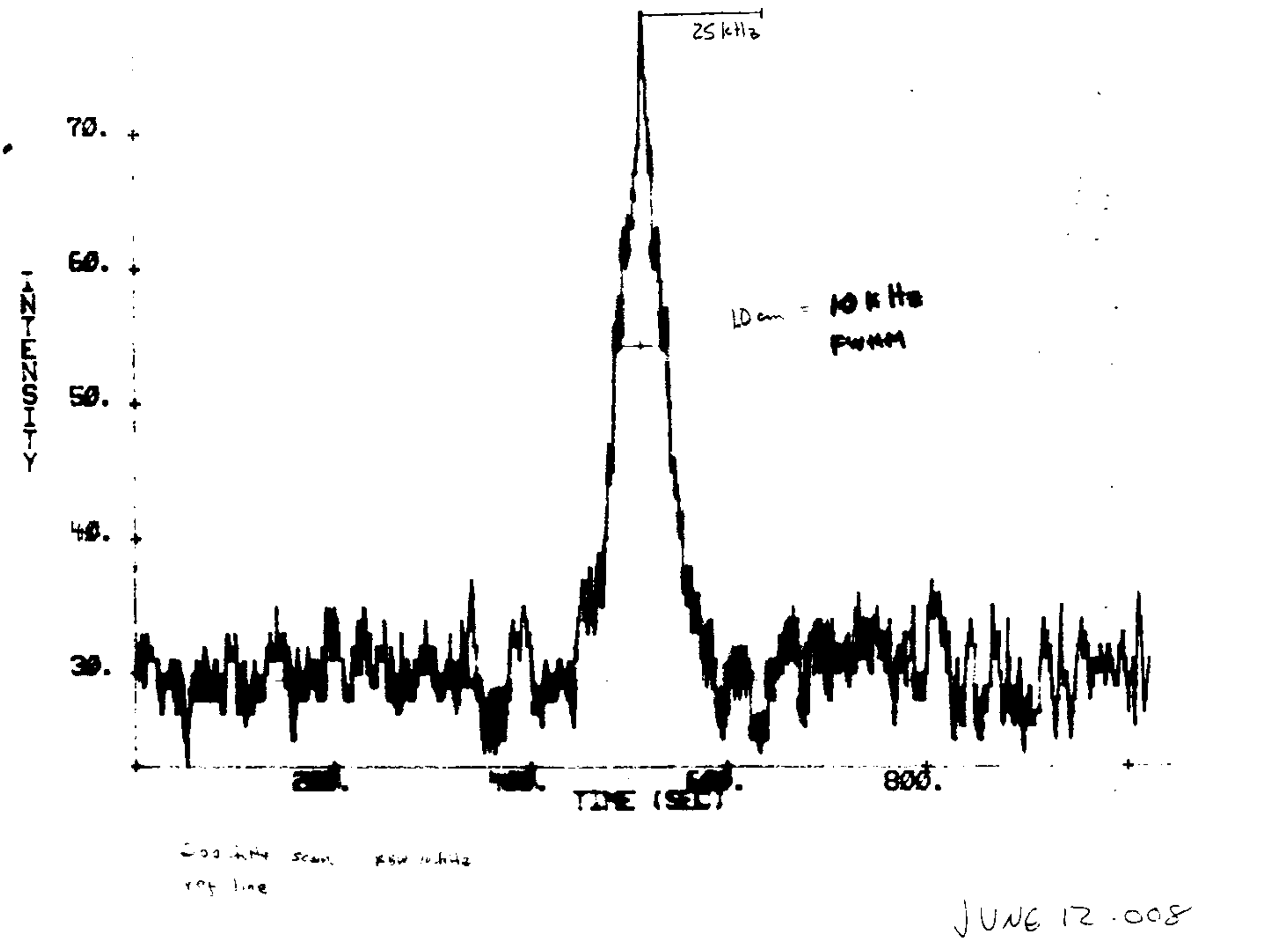

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Motional Narrowing
(Dicke Narrowing)

$E = E_0 \sin(\omega t + kx)$

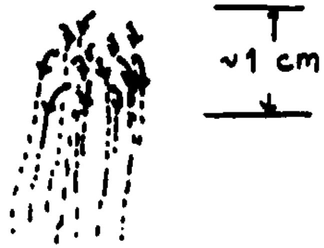
- Motion induces phase modulation
- Small <u>amplitude</u> of modulation $[x]$ gives small sidebands, even if <u>rate</u> of modulation $[\dot{x}]$ is large
- If atom confined to $x < \lambda\!\!\!^{-}$, then get narrow spectrum (Dicke narrowing)
- Confinement by viscous damping.
- Confinement by trapping in optical force potential wells.

Ballistic Temperature Measurement

lowest $T \sim 20 \mu K$ (NIST + ENS)

Release + Recapture (Bell Labs)

Time - of - Flight (NIST)



$mgh = k_B T$

$T \sim 250 \mu K$

(for Na; bigger for Cs)

- Hard to measure $T \leq 20 \mu K$ with g
- Measurements on <u>released</u> molasses
- Systematic uncertainties
- Spatial inhomogenieties not resolved