TELEPORTATION OF A QUANTUM STATE
USING TRAPPED RUBIDIUM ATOMS:

THE GORY DETAILS

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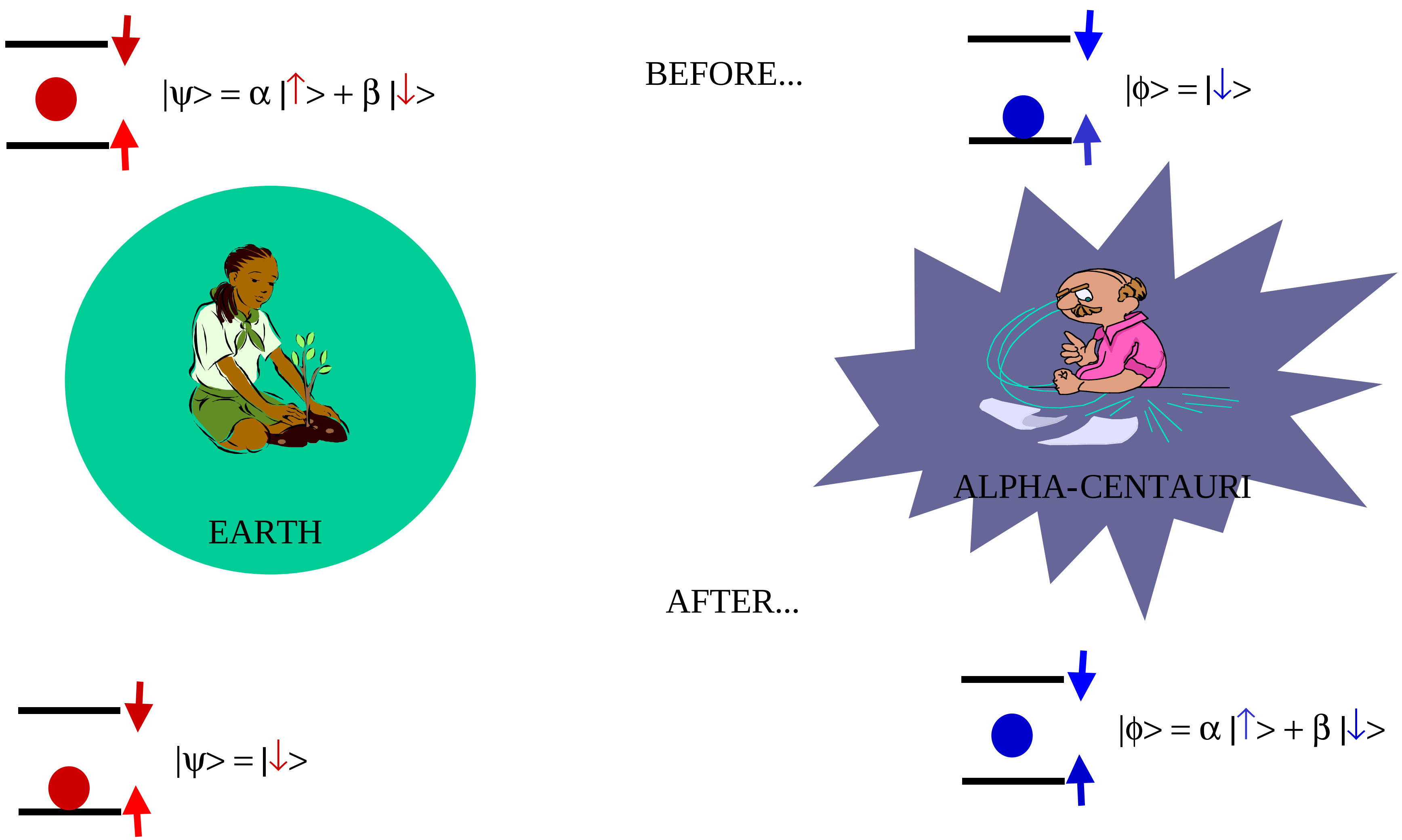
OUTLINE

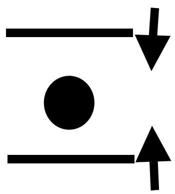
- TELEPORTATION: WHAT
- TELEPORTATION VIA BELL STATE MEASUREMENT
- ESSENTIAL TOOLS FROM LASER CONTROLLED SPIN EXCITATION
- COHERENCE TRANSFER VIA CAVITY QED
- ENTANGLING RUBIDIUM ATOMS
- BELL STATE MEASUREMENTS VIA SEQUENTIAL ELIMINATION
- EXPERIMENTAL PLAN / STATUS
- CLOCK SYNCHRONIZATION

TELEPORTATION: WHAT

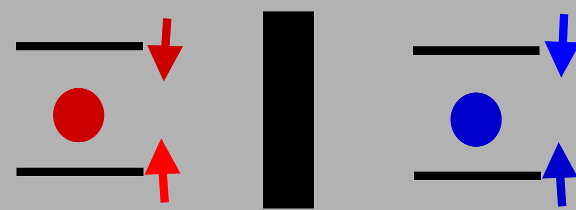


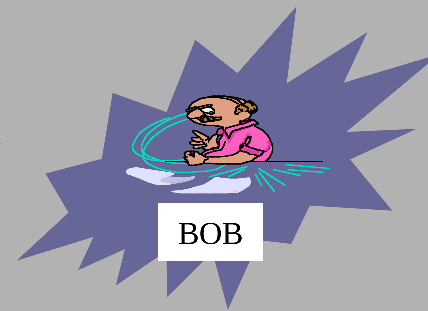
TELEPORTATION: VIA BELL STATE MEASUREMENT

$$|\Phi\rangle = \alpha\,|\uparrow\rangle + \beta\,|\downarrow\rangle$$



$$|\Psi\rangle = (\,|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle\,)\,/\sqrt{2}$$





$$\sqrt{2}\,|W\rangle = \alpha\,(|\uparrow\uparrow\downarrow\rangle - |\uparrow\downarrow\uparrow\rangle) + \beta\,(|\downarrow\uparrow\downarrow\rangle - |\downarrow\downarrow\uparrow\rangle)$$

BELL STATES

$$|B_1\rangle = (\,|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle\,)\,/\sqrt{2}$$

$$|B_2\rangle = (\,|\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle\,)\,/\sqrt{2}$$

$$|B_3\rangle = (\,|\uparrow\uparrow\rangle - |\downarrow\downarrow\rangle\,)\,/\sqrt{2}$$

$$|B_4\rangle = (\,|\uparrow\uparrow\rangle + |\downarrow\downarrow\rangle\,)\,/\sqrt{2}$$

DECOMPOSITION

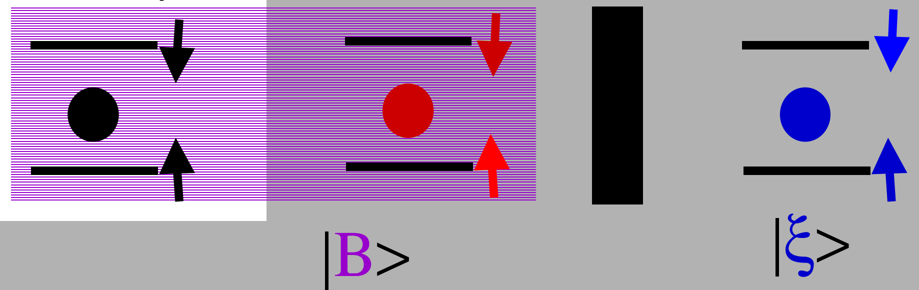
$$|\uparrow\uparrow\rangle = (|B_4\rangle + |B_3\rangle)\,/\sqrt{2}$$

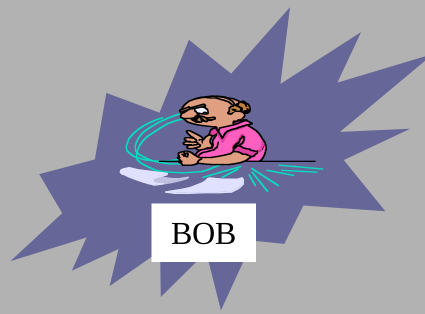
$$|\downarrow\downarrow\rangle = (|B_4\rangle - |B_3\rangle)\,/\sqrt{2}$$

$$|\uparrow\downarrow\rangle = (|B_2\rangle + |B_1\rangle)\,/\sqrt{2}$$

$$|\downarrow\uparrow\rangle = (|B_2\rangle - |B_1\rangle)\,/\sqrt{2}$$

$|\Phi> = \alpha\,|\uparrow> + \beta\,|\downarrow>$





$$2\,|W> = |B_1>|\xi_1> + |B_2>|\xi_2> + |B_3>|\xi_3> + |B_4>|\xi_4>$$

WHERE

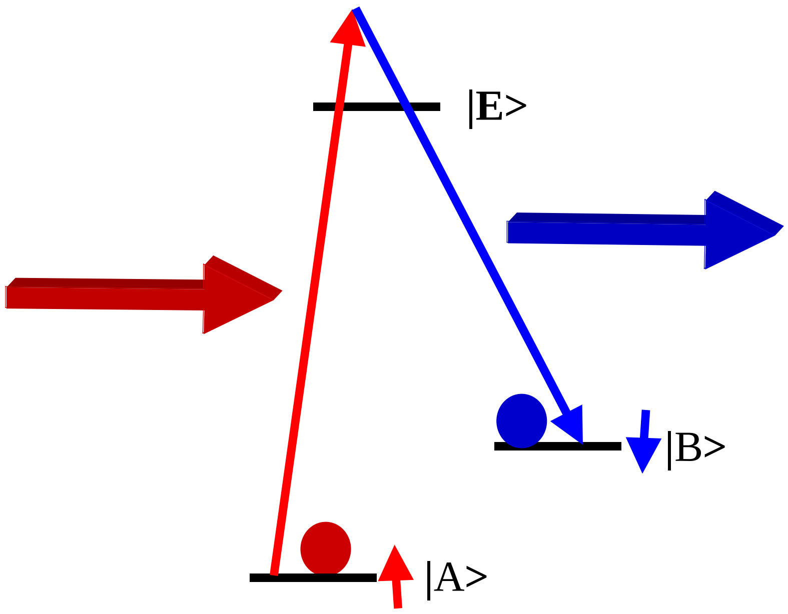
$$|\xi_1> = -\,(\alpha\,|\uparrow> + \beta\,|\downarrow>) = -\begin{bmatrix}\alpha\\ \beta\end{bmatrix} = -\,|\Phi>$$

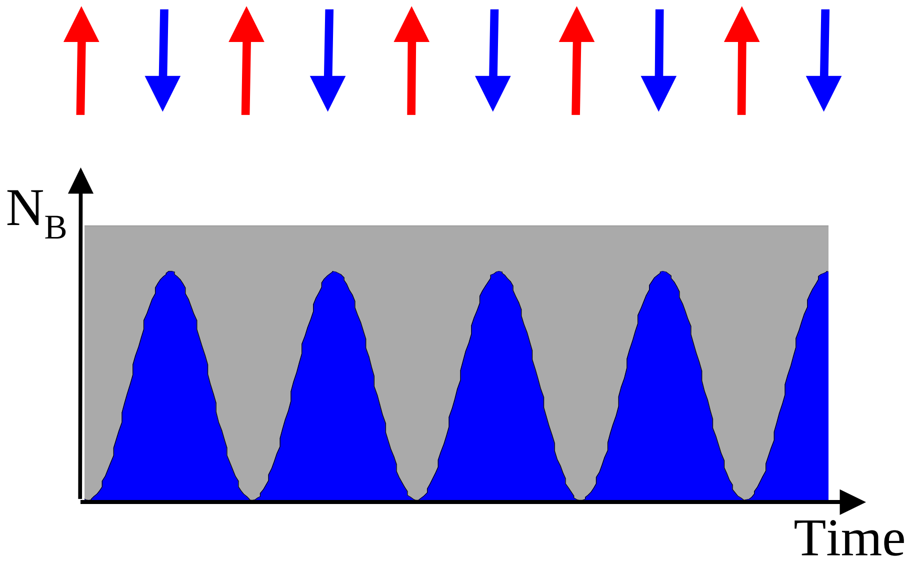
$$|\xi_2> = \begin{bmatrix}-1 & 0\\ 0 & 1\end{bmatrix}|\Phi>$$

$$|\xi_3> = \begin{bmatrix}0 & 1\\ 1 & 0\end{bmatrix}|\Phi>$$

$$|\xi_4> = \begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}|\Phi>$$

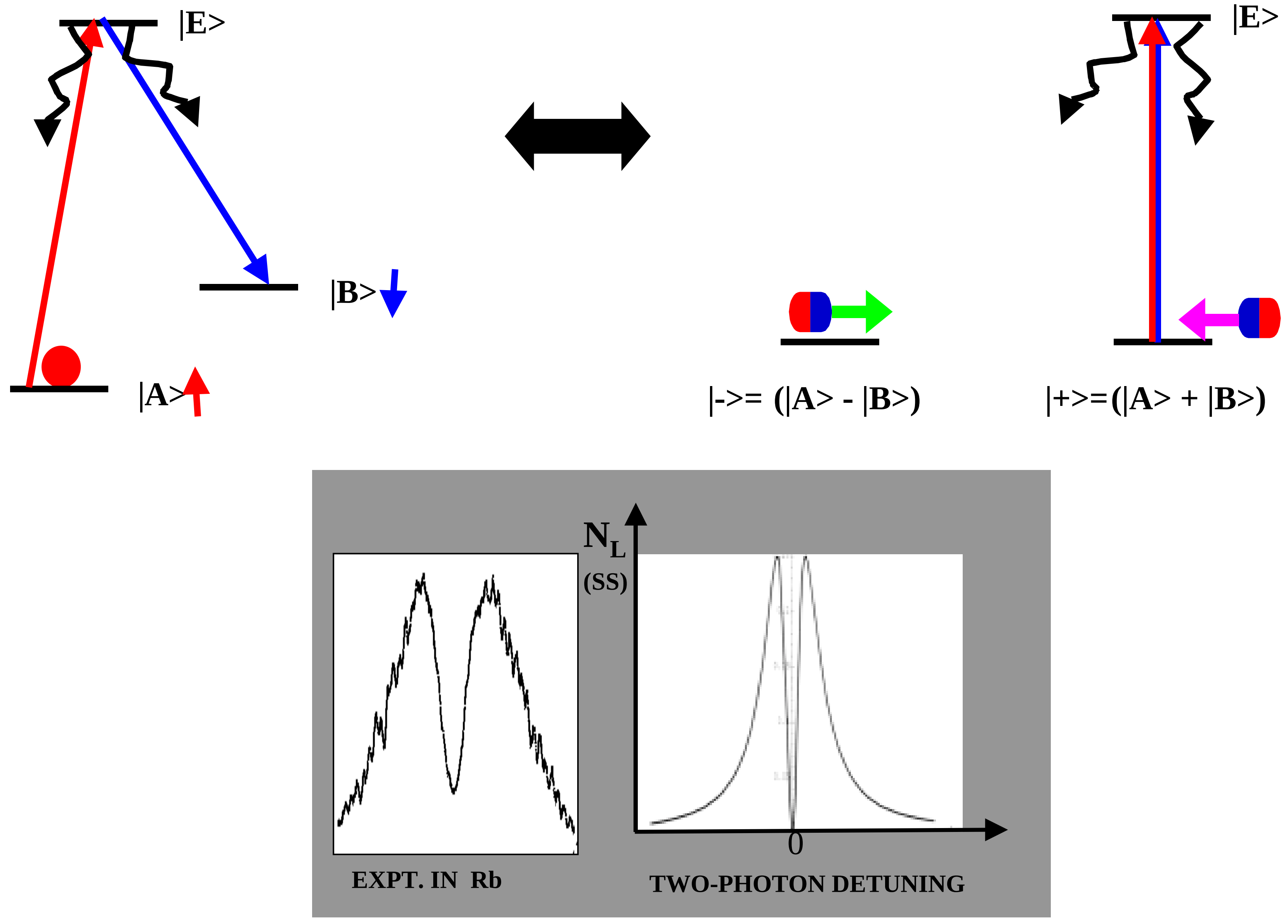
LASER-CONTROLLED SPIN EXCITATION | OFF-RESONANT



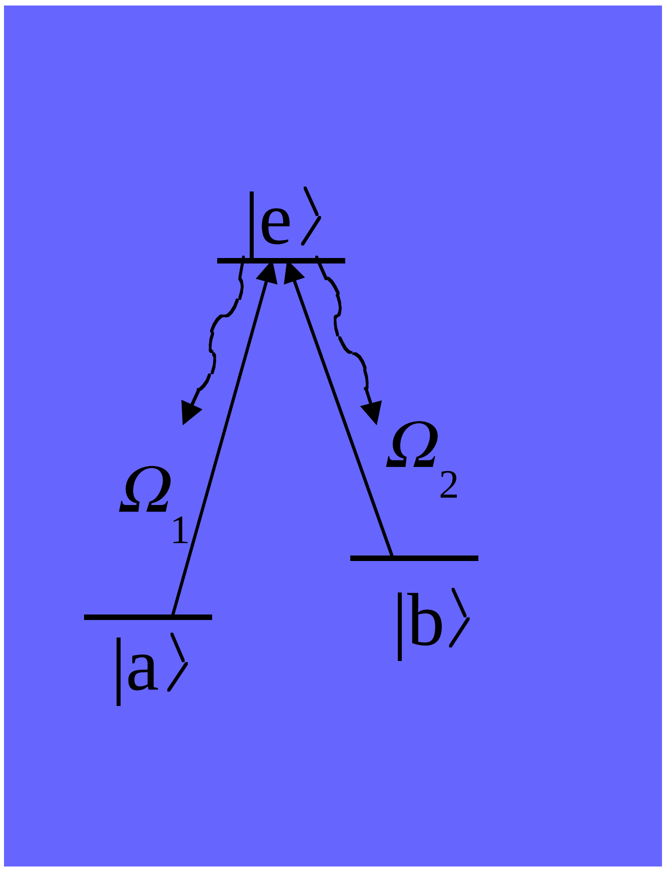


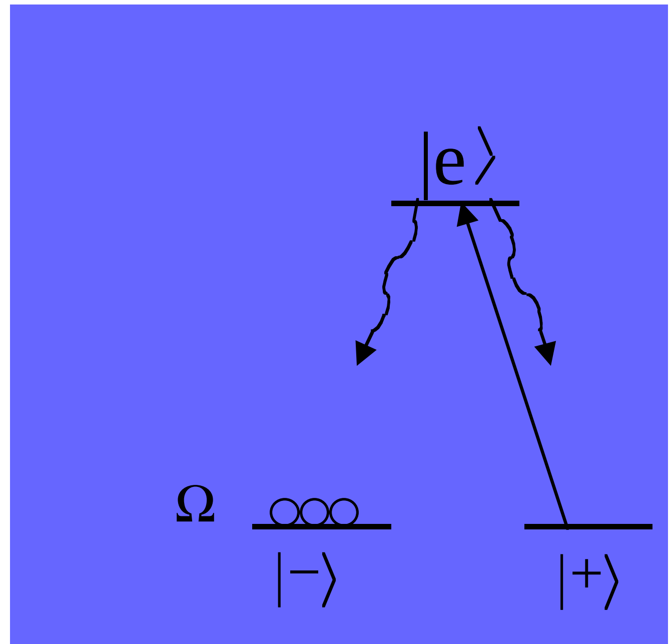
GOOD FOR SINGLE BIT OPERATION

LASER-CONTROLLED SPIN EXCITATION RESONANT



THE DARK STATE: GENERAL CASE

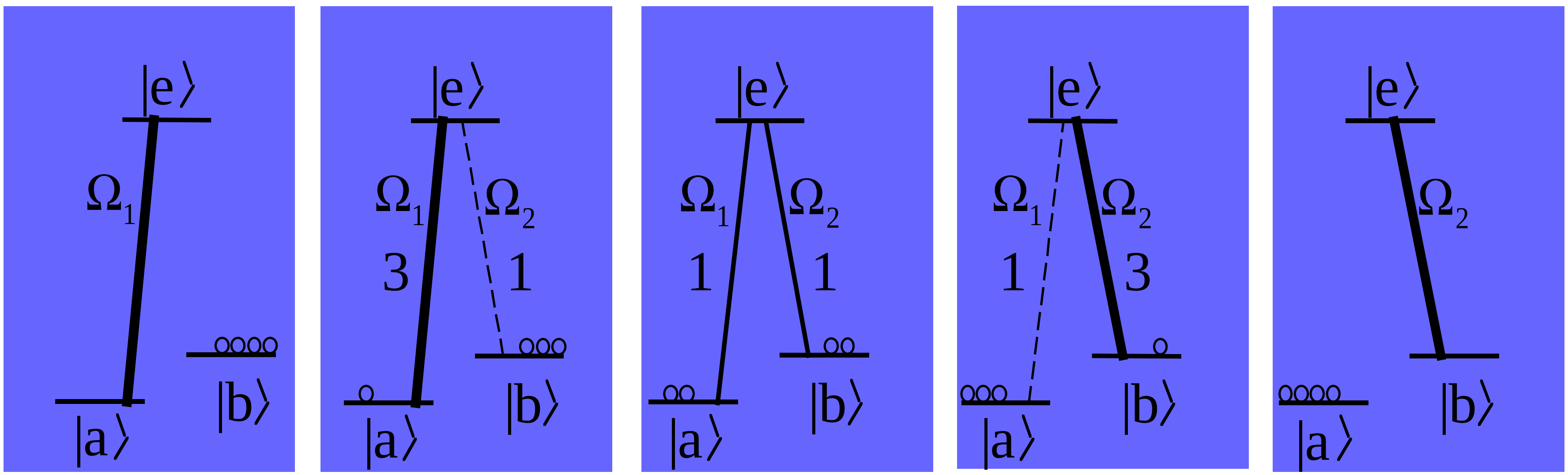




$$|-\rangle = \left(\Omega_2 |a\rangle - \Omega_1 |b\rangle\right) / \Omega$$

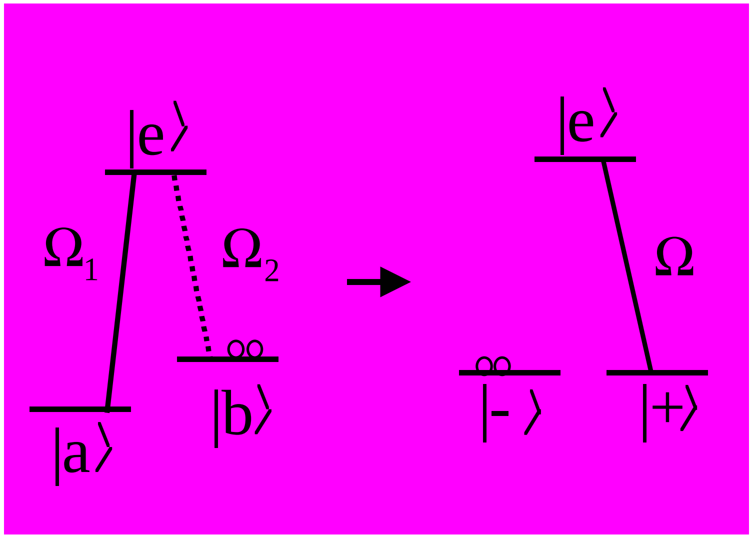
$$\Omega = \sqrt{\Omega_1^2 + \Omega_2^2}$$

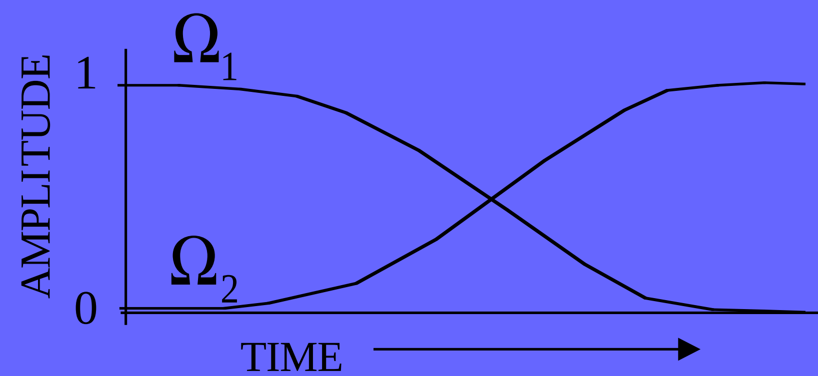
$$|-\rangle = (\Omega_2|a\rangle - \Omega_1|b\rangle) / \sqrt{\Omega_1^2 + \Omega_2^2}$$



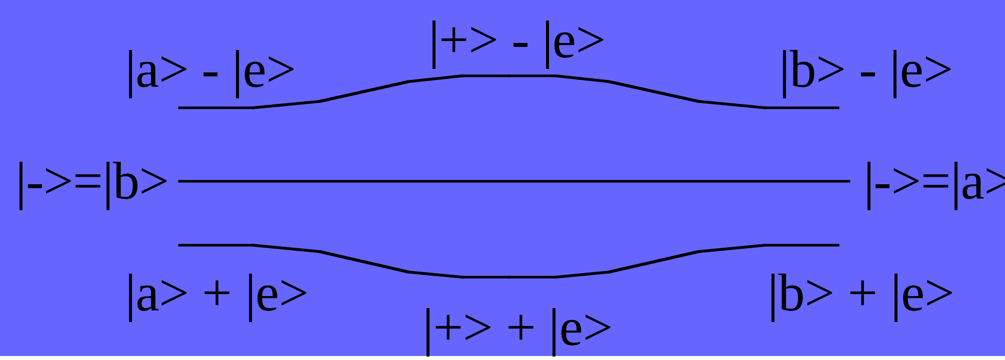
$|-\rangle \propto |b\rangle$ $\quad \frac{1}{3}|a\rangle - |b\rangle$ $\quad |a\rangle - |b\rangle$ $\quad |a\rangle - \frac{1}{3}|b\rangle$ $\quad |a\rangle$

ADIABATIC TRANSFER VIA THE DARK STATE





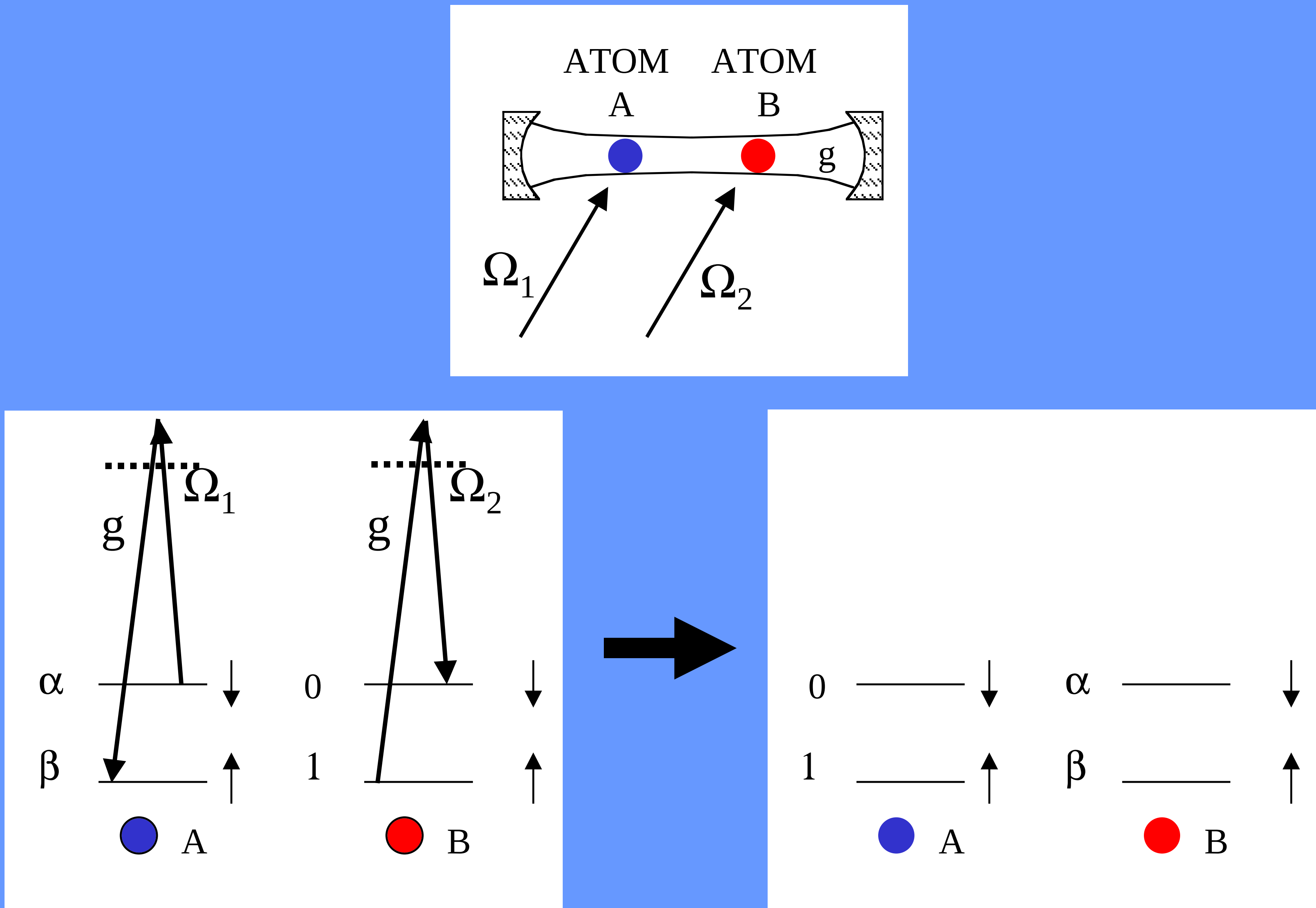
$$|-\rangle = (\Omega_2|a\rangle - \Omega_1|b\rangle)/\Omega$$
$$|+\rangle = (\Omega_1|a\rangle + \Omega_2|b\rangle)/\Omega$$



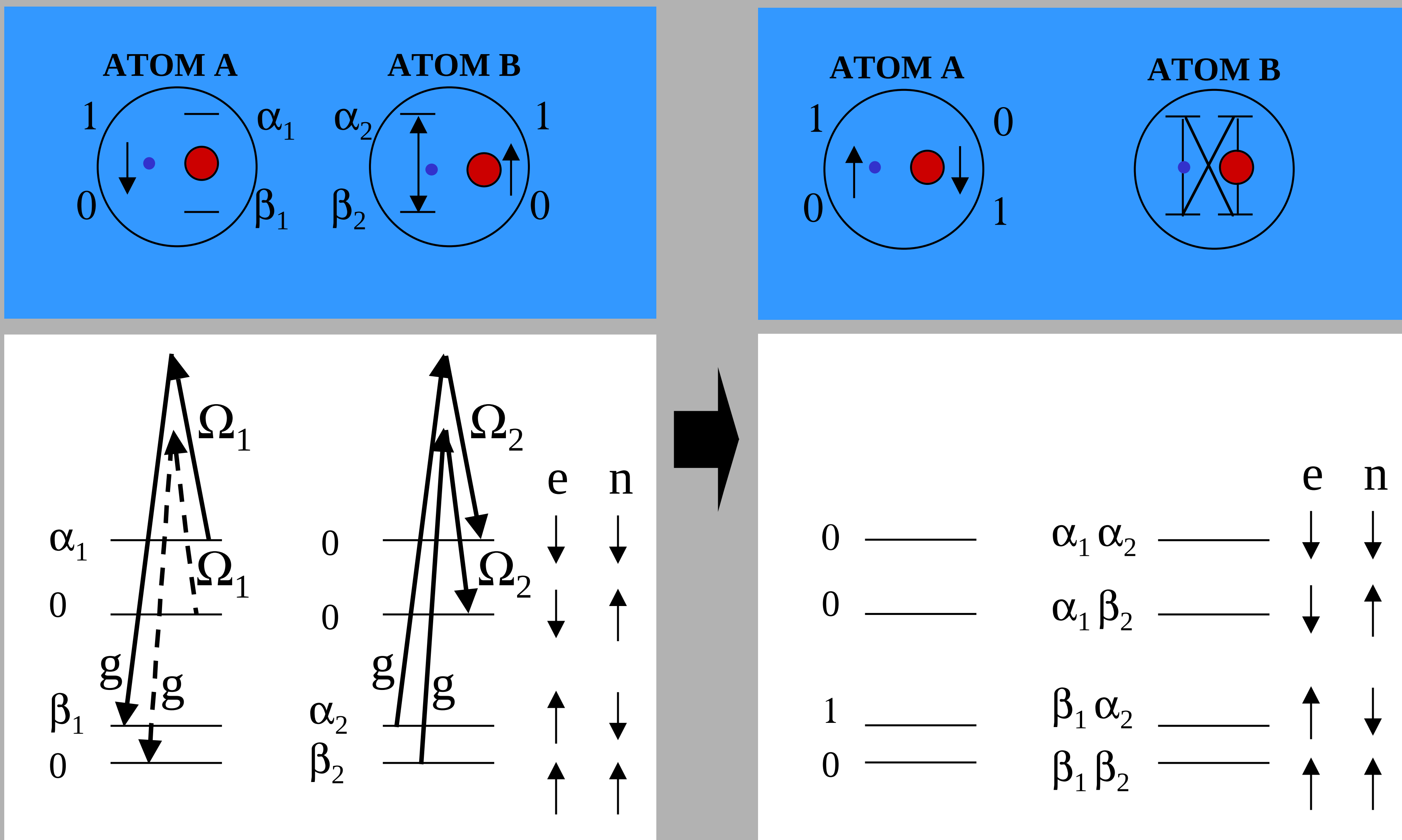
EQUIVALENT TO A π-PULSE

TOPOLGICALLY ROBUST

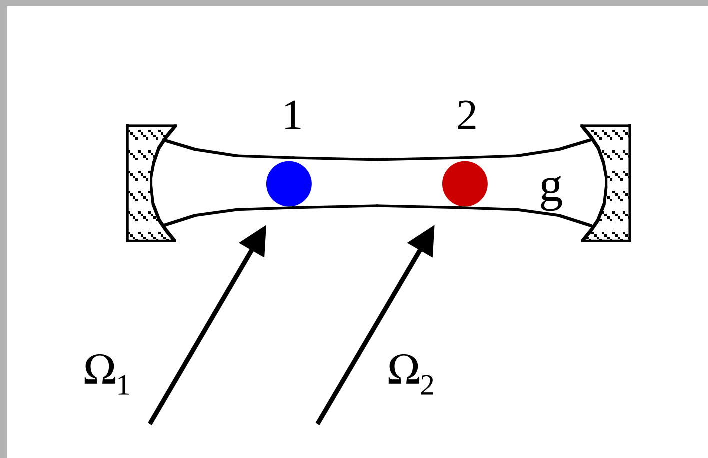
COHERENCE TRANSFER VIA CAVITY QED

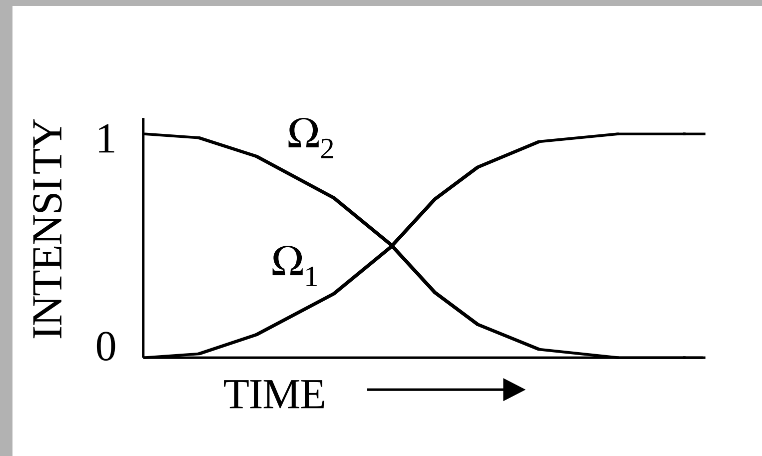


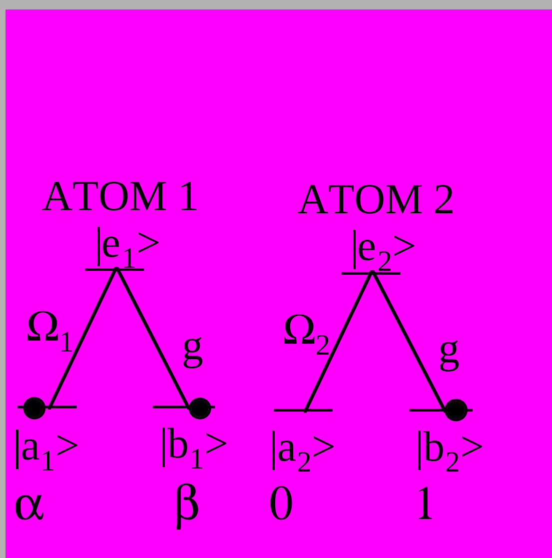
TRANSFERRING TWO BITS INTO A SINGLE ATOM VIA CAVITY QED

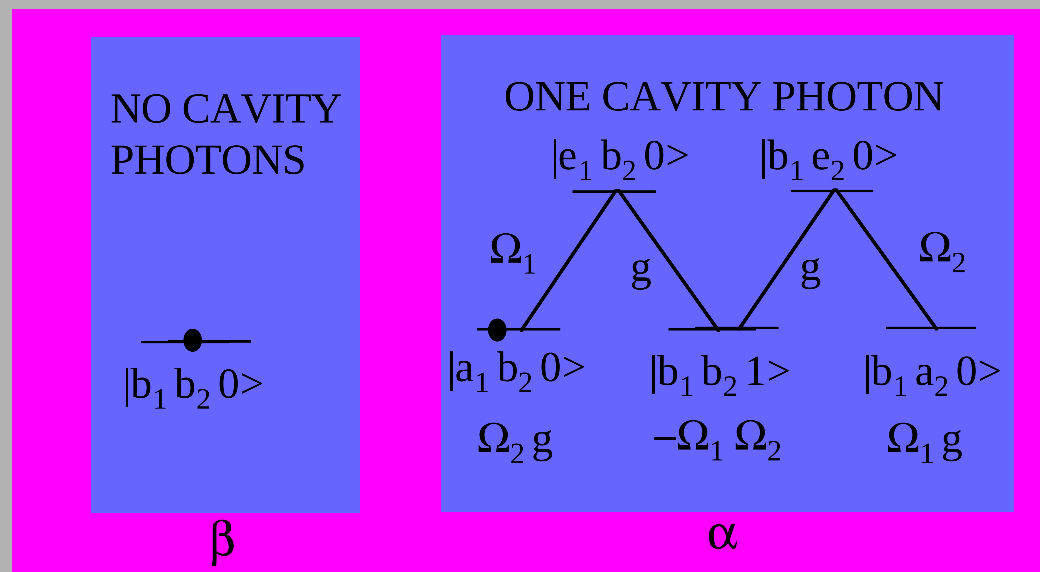


ADIABATIC COHERENCE TRANSFER VIA CAVITY-QED DARK STATE





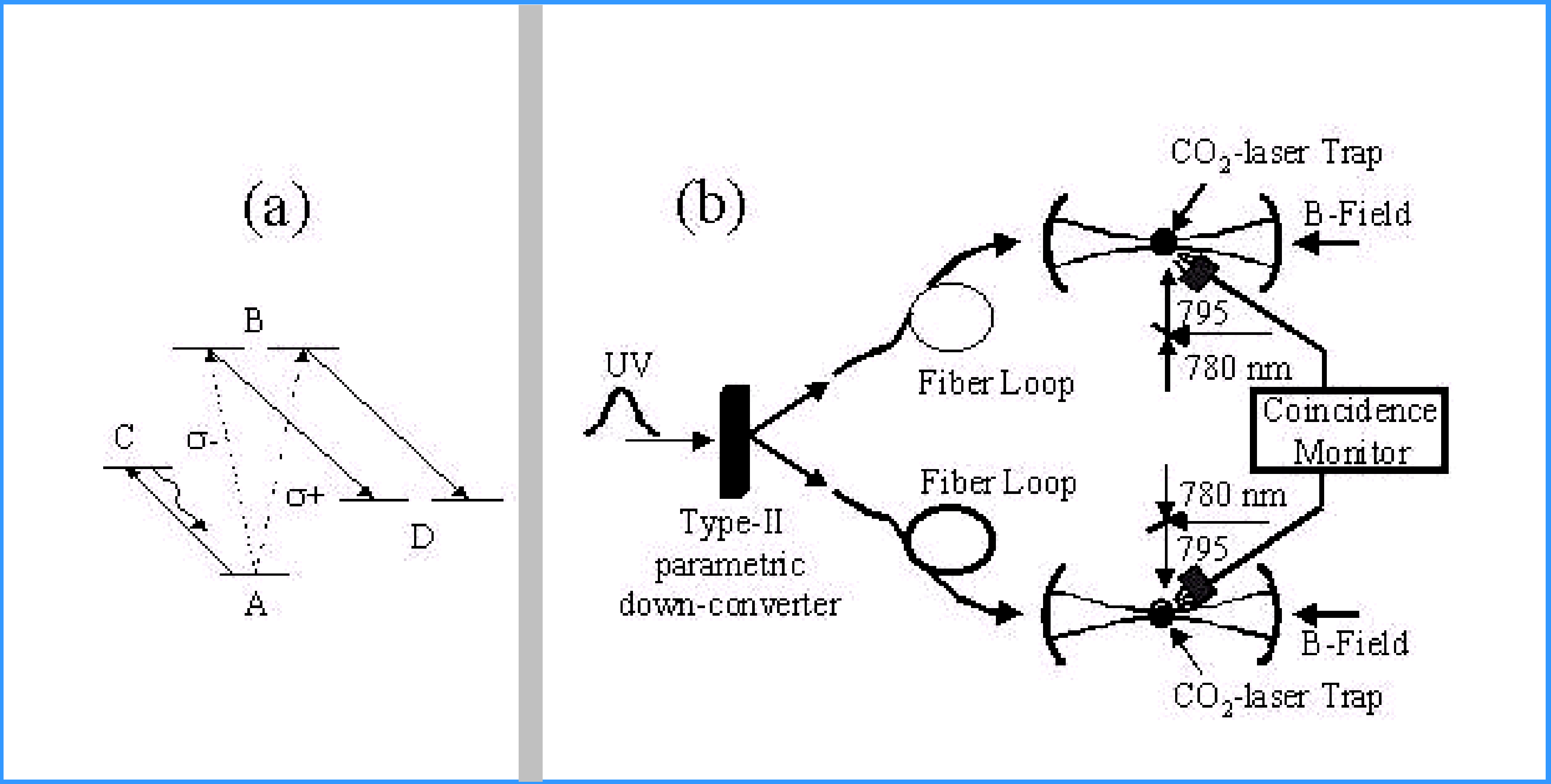




$|\psi\rangle = (\alpha\, |a_1\rangle + \beta\, |b_1\rangle) \otimes |b_2\rangle \otimes |0\rangle$

$|\psi\rangle = (\alpha\, |b_1\, a_2\, 0\rangle + \beta\, |b_1 b_2 0\rangle) = |b_1\rangle \otimes (\alpha\, |a_2\rangle + \beta\, |b_2\rangle) \otimes |0\rangle$

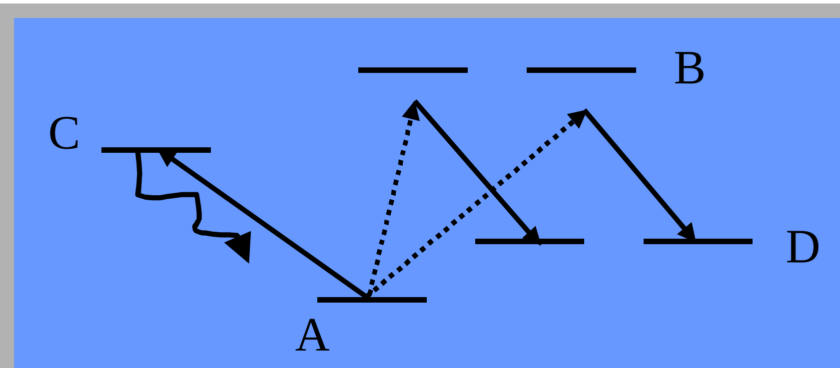
TRANSFER PHOTON ENTANGLEMENT TO ATOMIC ENTANGLEMENT

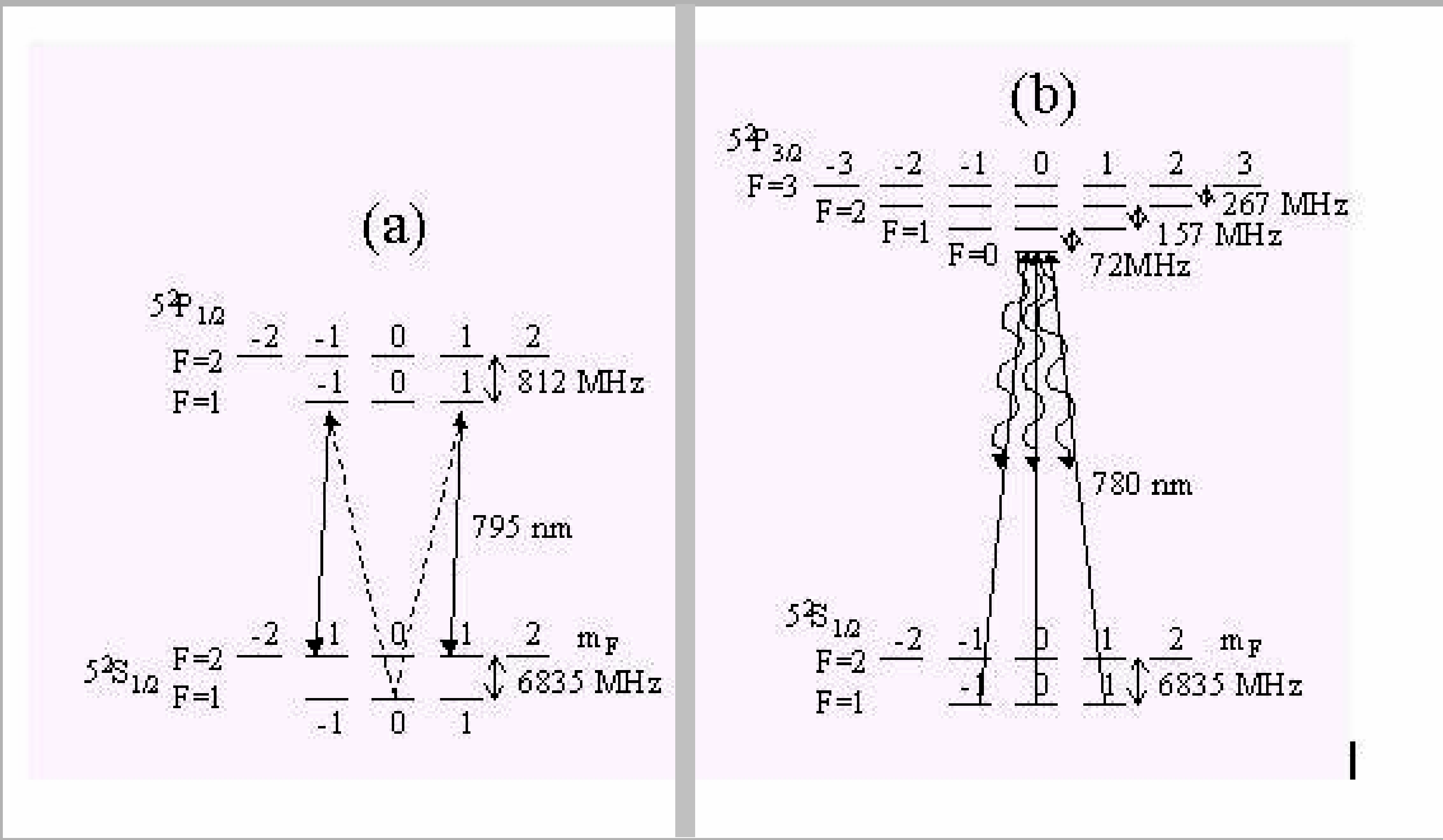


Ref 1: quant-ph/003147

Ref 2: J. Opt. B: Quantum Semiclass. Opt. 2 (2000) L1-L4

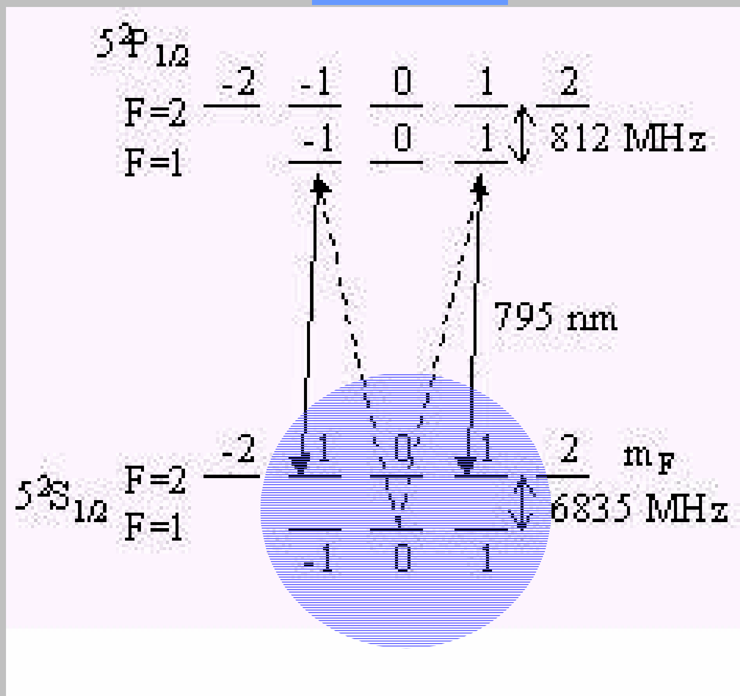
EXPLICIT SCHEME IN ^{87}RB



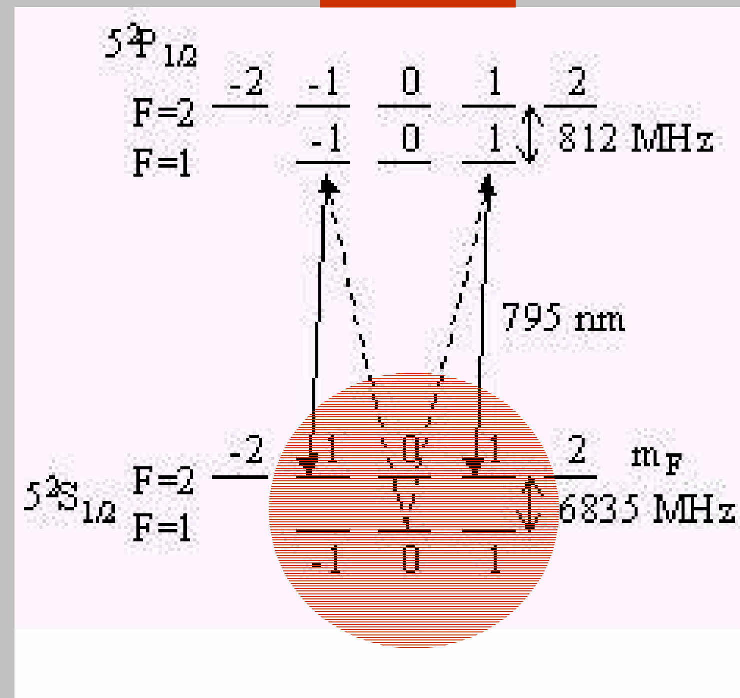


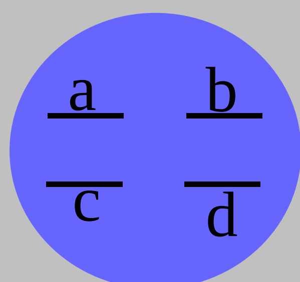
ATOMS 2 AND 3 ARE NOW ENTANGLED

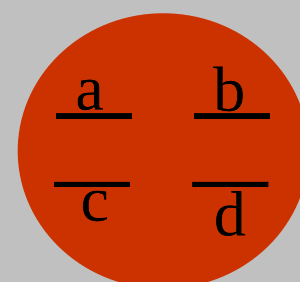
ATOM 2



ATOM 3

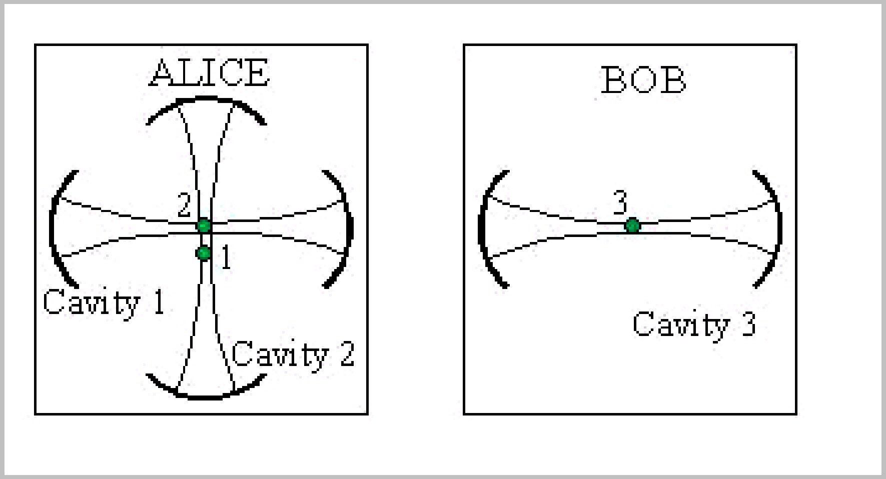


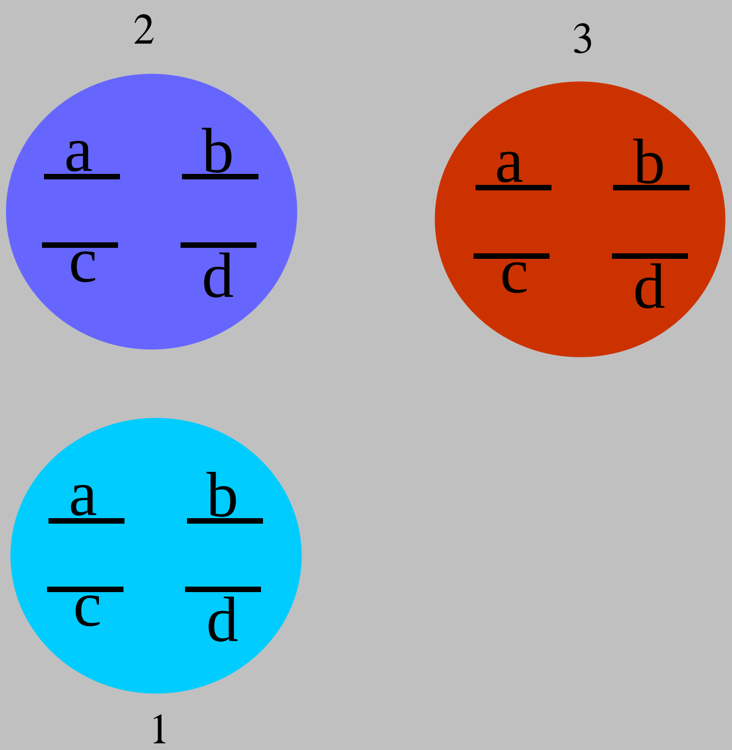




$$|\psi_{23}\rangle = \{\, |a\rangle_2 |b\rangle_3 - |b\rangle_2 |a\rangle_3 \}/\sqrt{2}$$

ATOM 1 IN ARBITRARY STATE: TO BE TELEPORTED

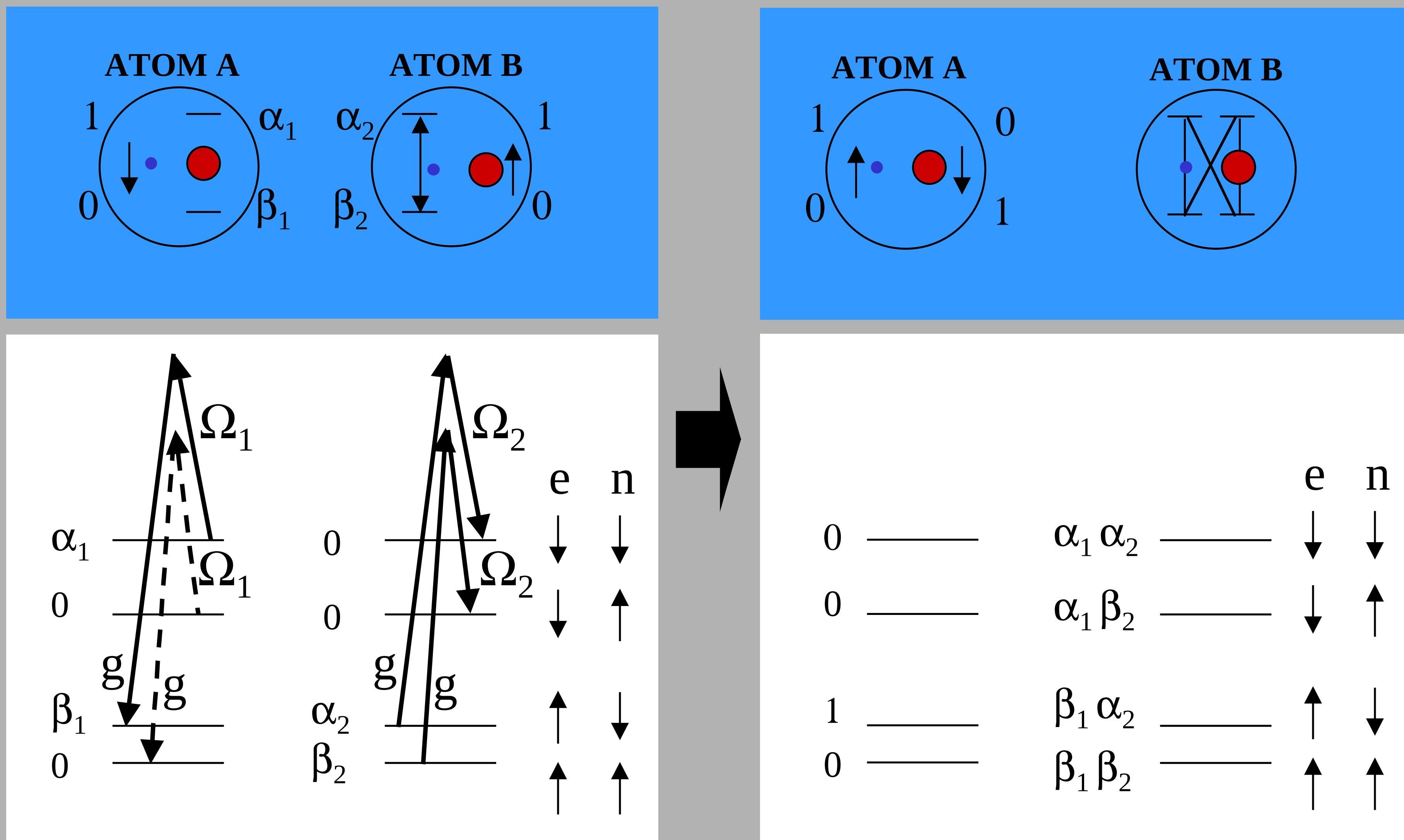




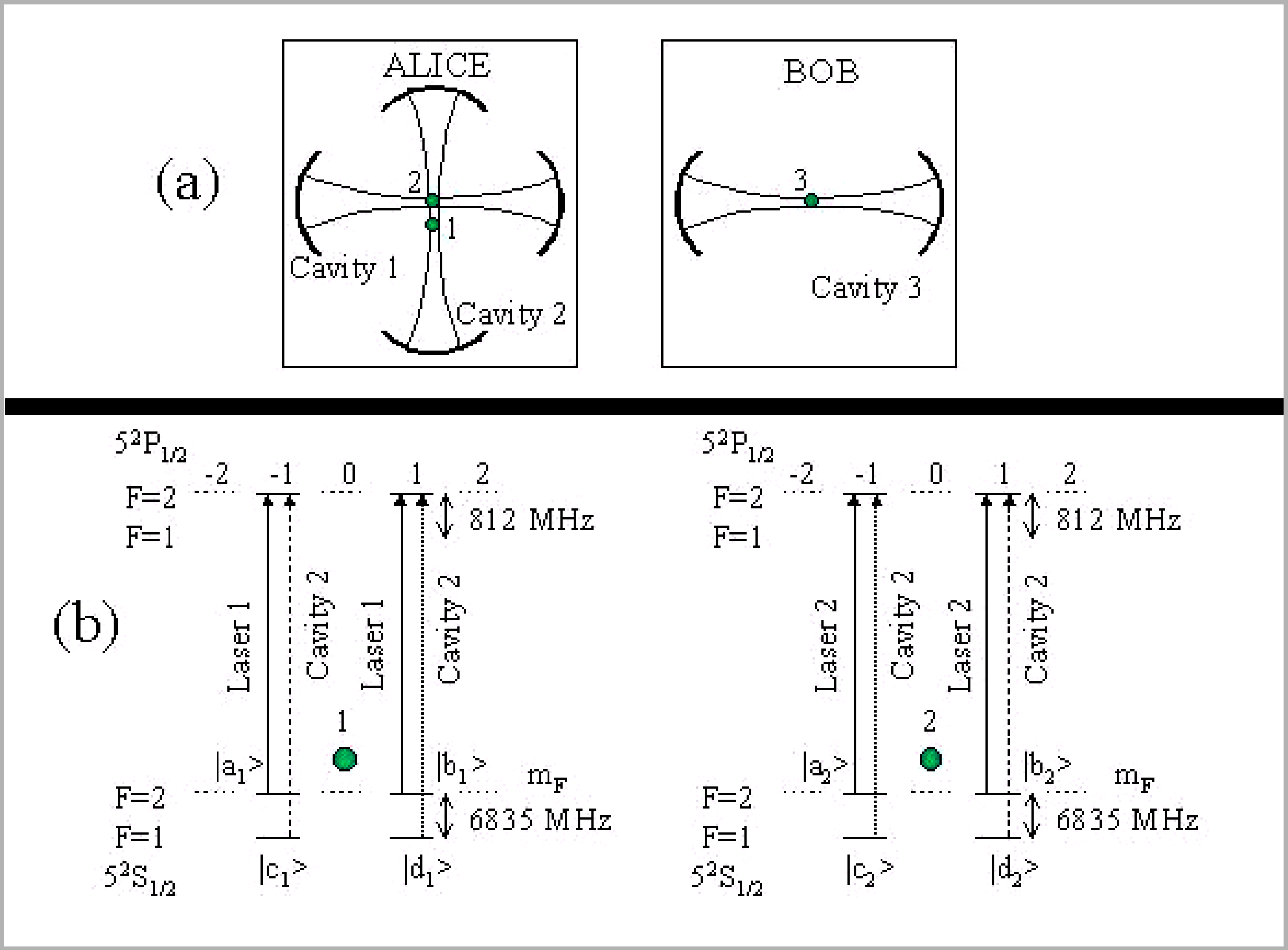
$$|\psi_{23}>=\{|a>_2|b>_3 - |b>_2|a>_3\}/\sqrt{2}$$

$$|\varphi_1> =\{\alpha|c>_1+\beta|a>_1\}$$

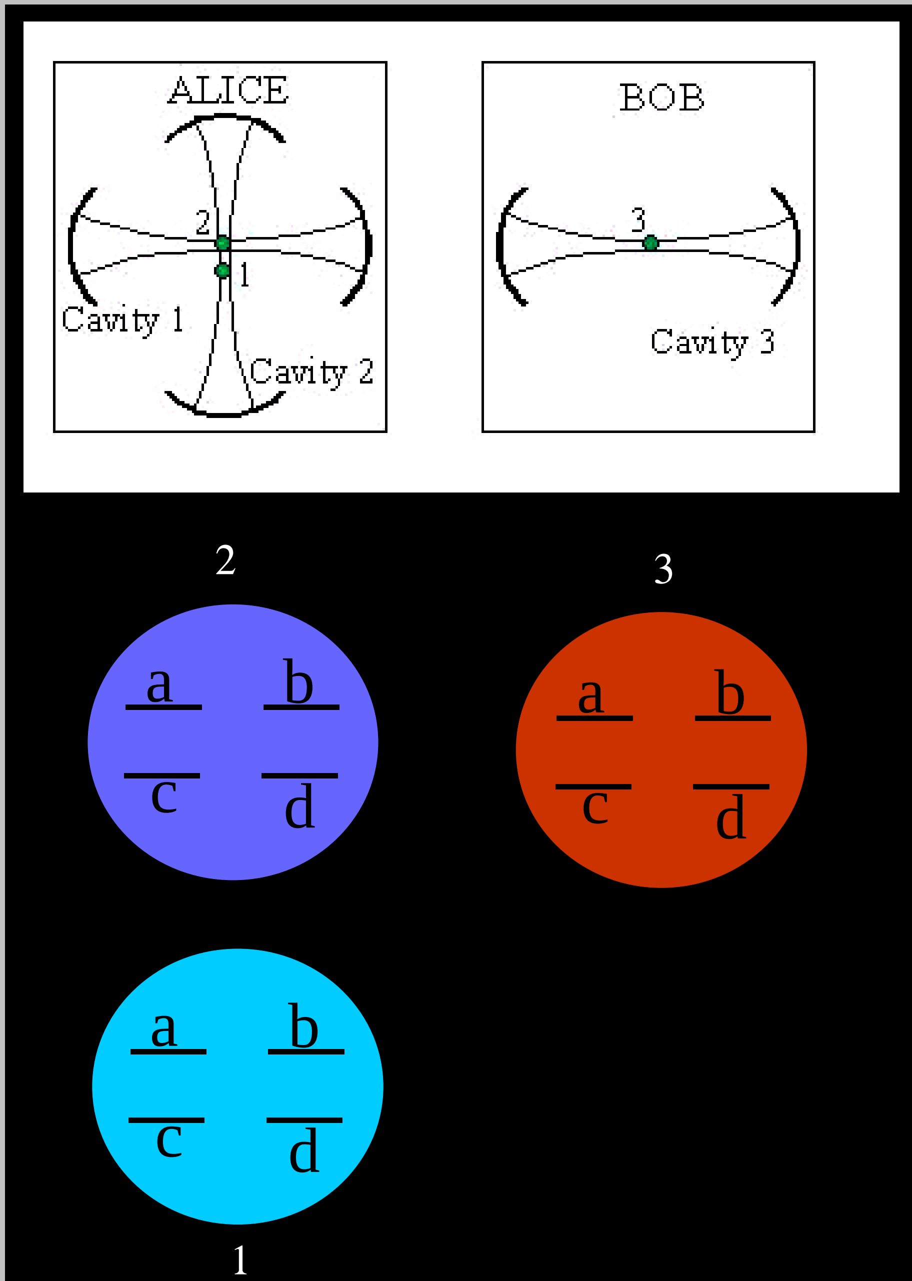
TRANSFERRING TWO BITS INTO A SINGLE ATOM VIA CAVITY QED



TRANSFER STATES OF 1 AND 2 INTO 2 ONLY



QUANTUM STATE AFTER THE TRANSFER



BEFORE TRANSFER

$$|\psi_{23}\rangle=\{|a\rangle_2|b\rangle_3 - |b\rangle_2|a\rangle_3\}/\sqrt{2}$$

$$|\varphi_1\rangle =\{\alpha|c\rangle_1+\beta|a\rangle_1\}$$

AFTER TRANSFER

$$|\psi_1\rangle = |c\rangle_1$$

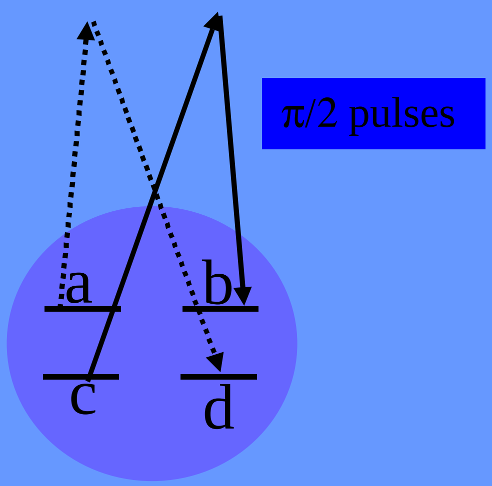
$$\begin{aligned}|\phi_{23}\rangle=\{&|A_+\rangle(\alpha|b_3\rangle+\beta|a_3\rangle) + \\ &|A_-\rangle(\alpha|b_3\rangle-\beta|a_3\rangle) + \\ &|B_+\rangle(\beta|b_3\rangle+\alpha|a_3\rangle)+ \\ &|B_-\rangle(-\beta|b_3\rangle+\alpha|a_3\rangle)\}/2\end{aligned}$$

BELL STATES

$$|A_\pm\rangle=\{|c_2\rangle\pm|b_2\rangle\}/\sqrt{2},$$

$$|B_\pm\rangle=\{|d_2\rangle\pm|a_2\rangle\}/\sqrt{2}.$$

ROTATE SUPERPOSITION-BASIS BELL STATES INTO PURE-BASIS BELL STATES



2

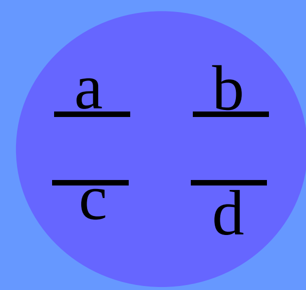
OLD BELL STATES

$|A_+\rangle = |c_2\rangle + |b_2\rangle$

$|A_-\rangle = |c_2\rangle - |b_2\rangle$

$|B_+\rangle = |d_2\rangle + |a_2\rangle$

$|B_-\rangle = |d_2\rangle - |a_2\rangle$.



2

NEW BELL STATES

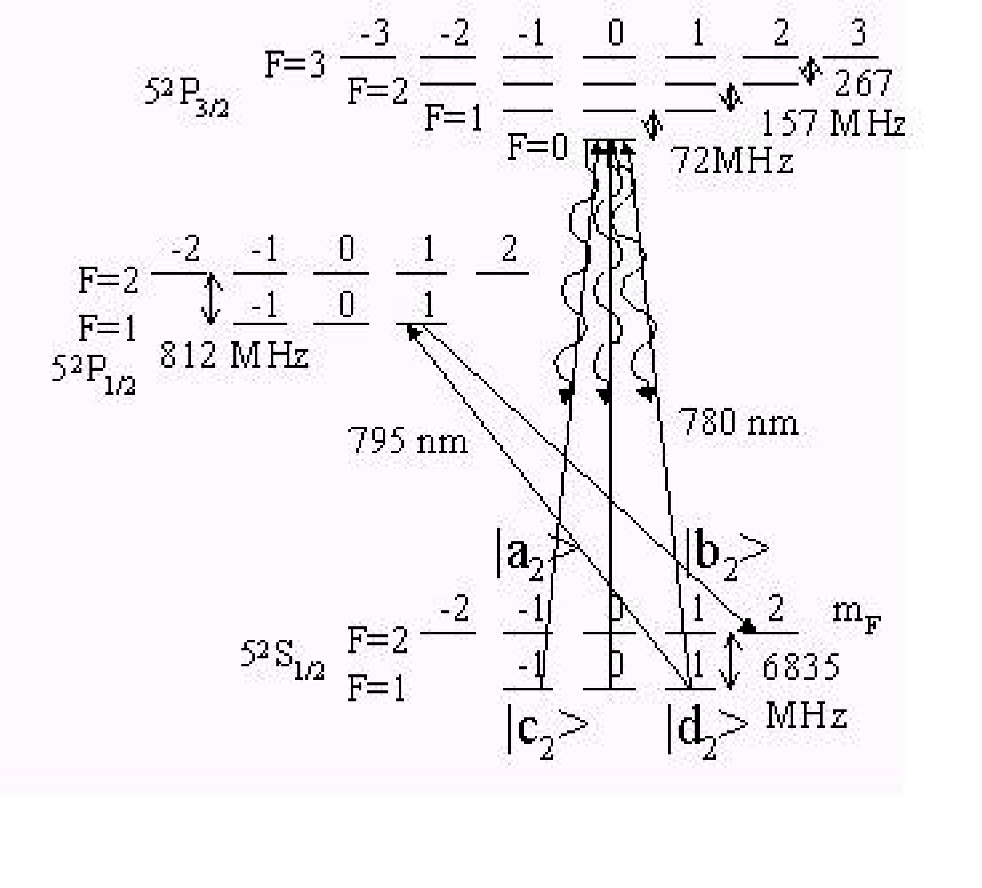
$|a_+\rangle = |c_2\rangle$

$|a_-\rangle = |b_2\rangle$

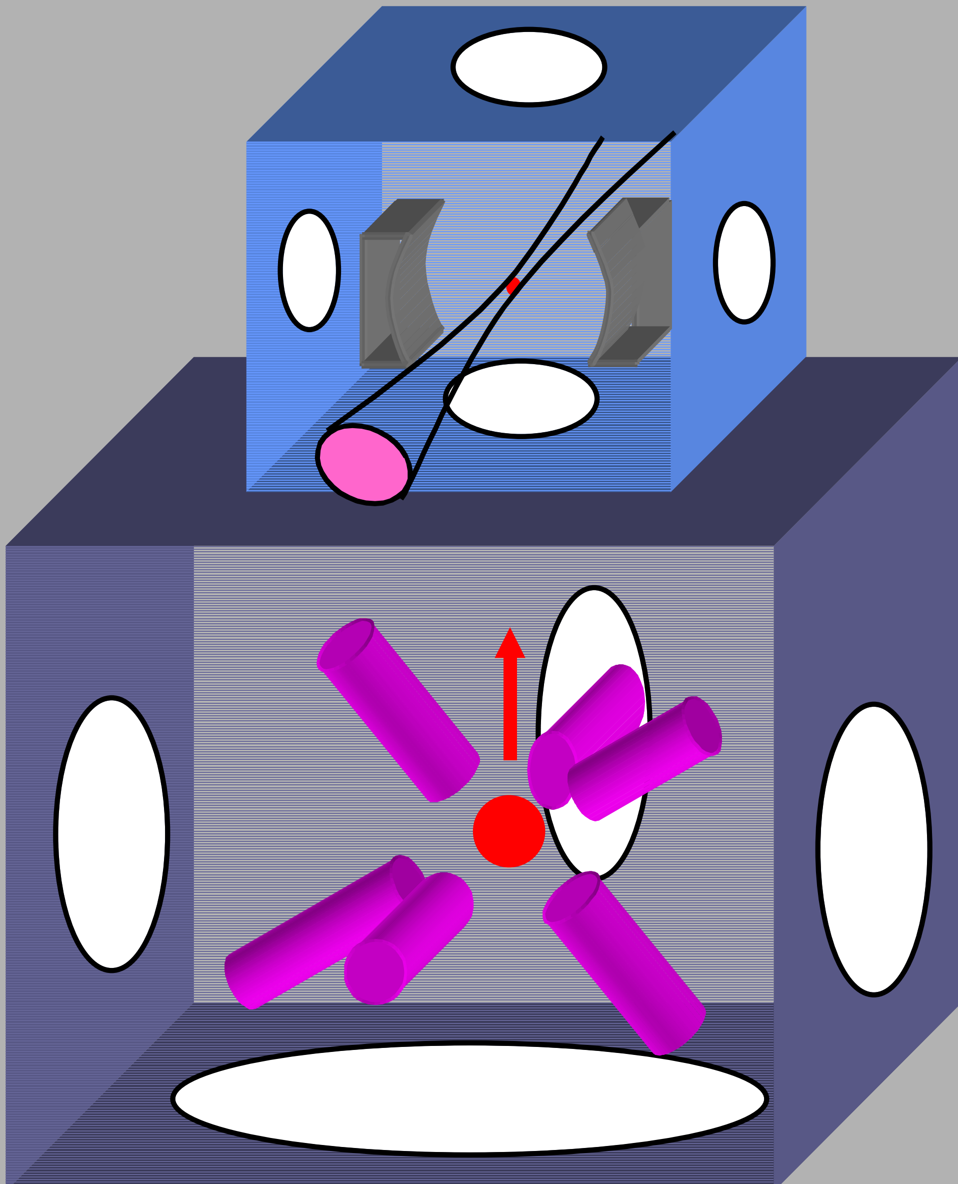
$|b_+\rangle = |d_2\rangle$

$|b_-\rangle = |a_2\rangle$.

MEASURING BELL STATES VIA SEQUENTIAL ELIMINATION



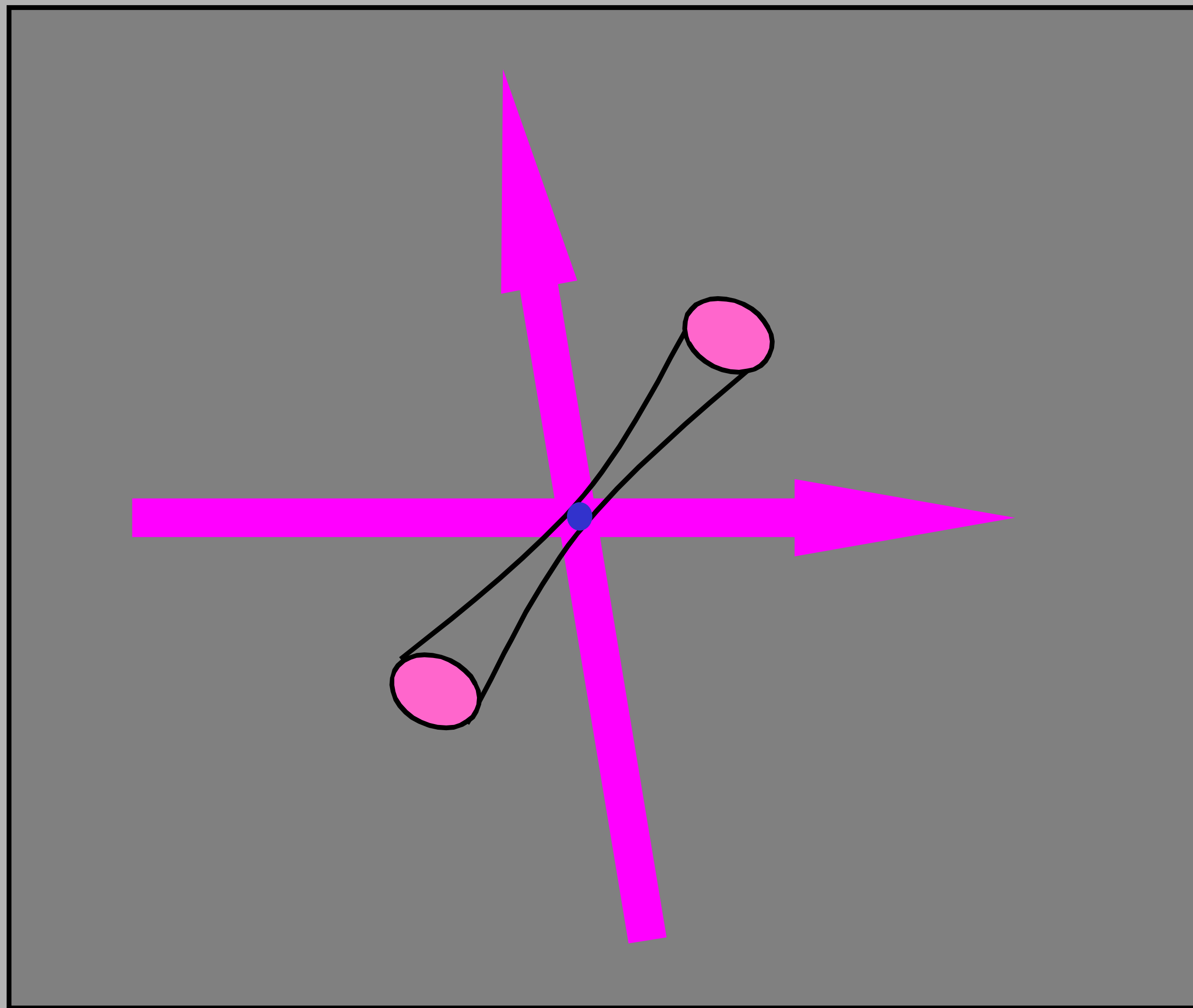
LOADING ATOMS INTO A FORT USING A FOUNTAIN



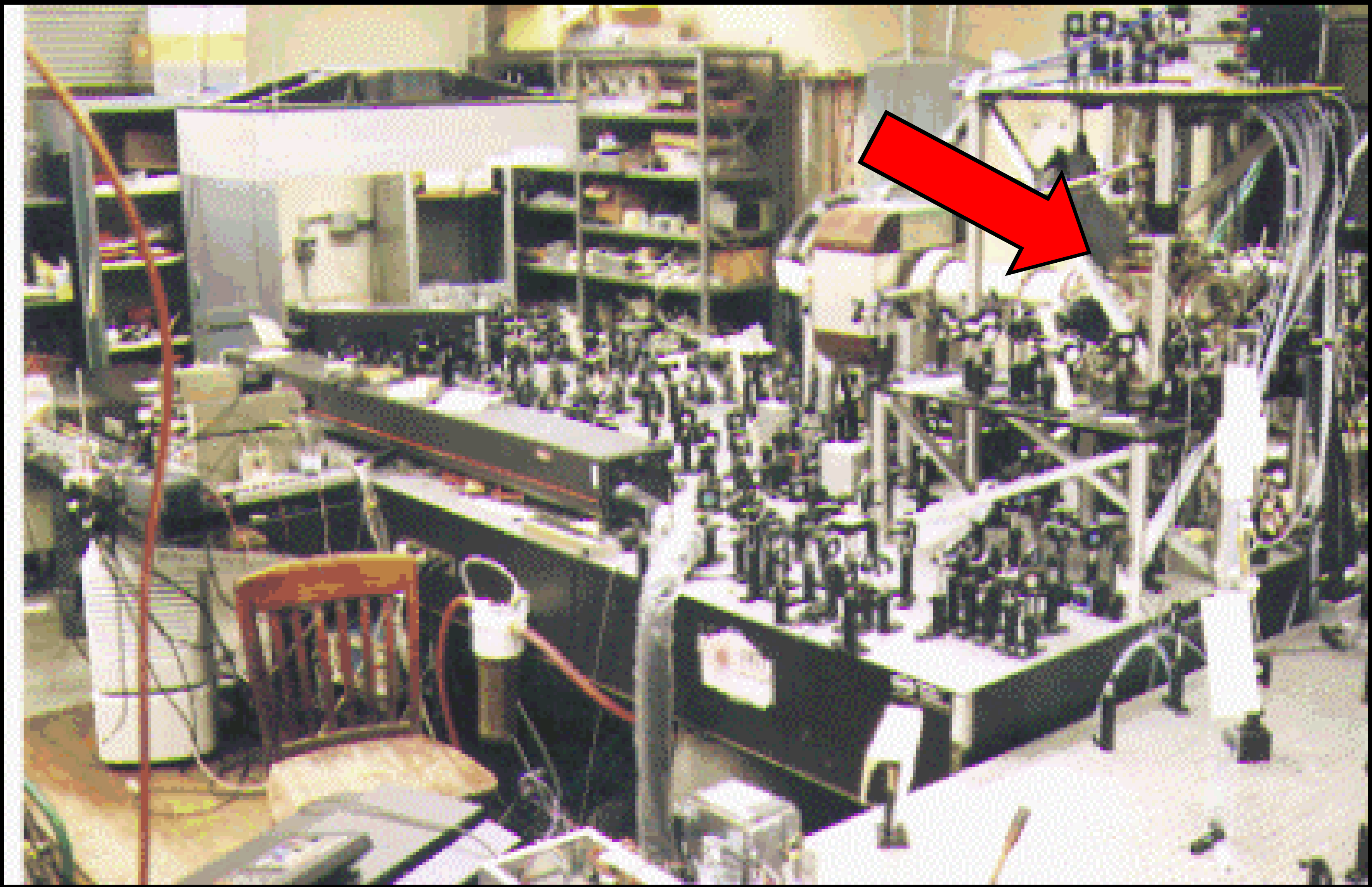
ALL DIODE LASERS POSSIBLE

CAN BE VERY COMPACT (5 CM^3)

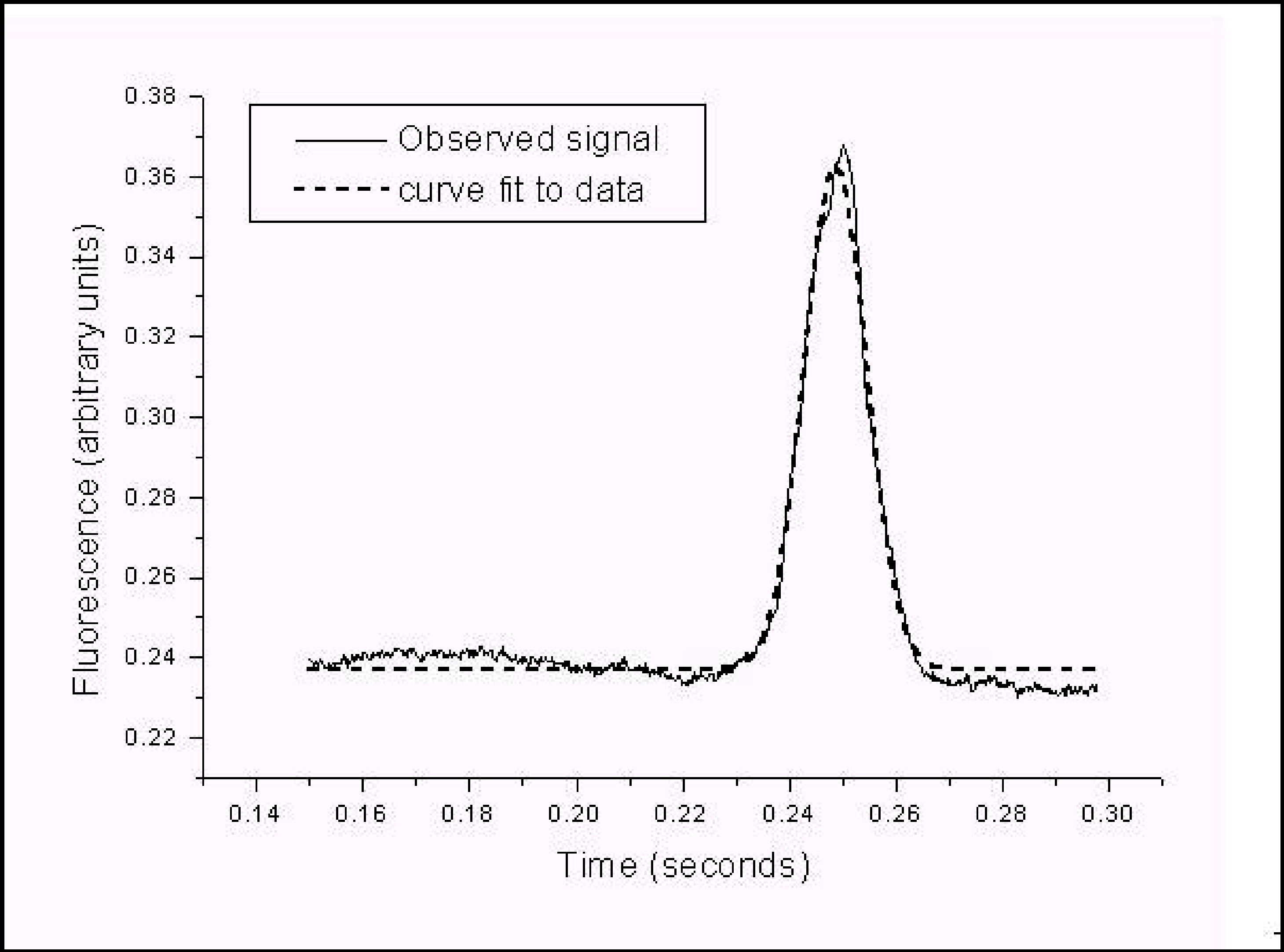
WAVELENGTH SCALE CONFINEMENT



PHOTOGRAPH OF THE TRAP



TIME-OF-FLIGHT TEMPERATURE DATA FROM OUR TRAP



POSSIBLE REALIZATION OF BASIC TEST FOR CLOCK SYNCHRONIZATION