Neutral Atom QIV

Als Beispiele gewählt wurden
Experimente bei Bloch (Mainz), Grangier (Paris)

VOLUME 82, NUMBER 9 PHYSICAL REVIEW LETTERS 1 MARCH 1999

Entanglement of Atoms via Cold Controlled Collisions

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(Received 28 October 1998)

We show that by using *cold controlled collisions* between two atoms one can achieve conditional dynamics in moving trap potentials. We discuss implementing two qubit quantum gates and efficient creation of highly entangled states of many atoms in optical lattices. [S0031-9007(99)08537-3]

PACS numbers: 03.67.Lx, 32.80.Pj, 34.90.+q

VOLUME 82, NUMBER 5 PHYSICAL REVIEW LETTERS 1 FEBRUARY 1999

Quantum Logic Gates in Optical Lattices

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(Received 29 May 1998)

We propose a new system for implementing quantum logic gates: neutral atoms trapped in a very far-off-resonance optical lattice. Pairs of atoms are made to occupy the same well by varying the polarization of the trapping lasers, and then a near-resonant electric dipole is induced by an auxiliary laser. A controlled-NOT can be implemented by conditioning the target atomic resonance on a resolvable level shift induced by the control atom. Atoms interact only during logical operations, thereby suppressing decoherence. [S0031-9007(98)08347-1]

PACS numbers: 03.67.Lx, 32.80.Lg, 32.80.Pj, 32.80.Qk

Stehwellenfallen im Detail

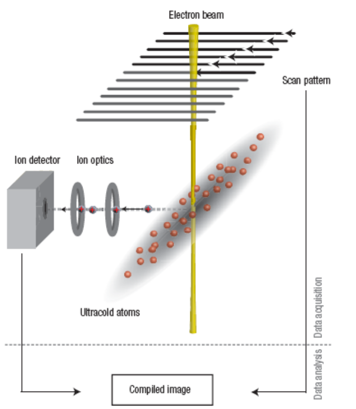

Figure 1 Working principle. The atomic ensemble is prepared in an optical dipole trap. An electron beam with variable beam current and diameter is scanned across the cloud. Electron impact ionization produces ions, which are guided with an ion optical system towards a channeltron detector. The ion signal together with the scan pattern is used to compile the image.

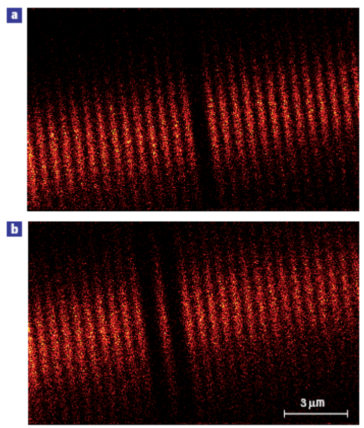

Figure 6 Single-site addressability. We first remove atoms from the optical lattice, pointing the electron beam at the specific sites for 35 ms. Thereafter the image is taken (200 × 325 pixels, 50 nm pixel size, 2 μs pixel dwell time). **a**, A single emptied site (sum over 127 images). The lattice depth of 18 recoil energies is enough to suppress refilling of the lattice site. **b**, The preparation of an isolated site (sum over 142 images).

Zustandsabhängige Potentiale

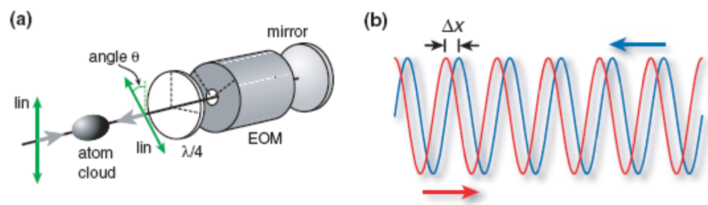

Fig. 2 (a) Schematic experimental setup. A one dimensional optical standing wave laser field is formed by two counterpropagating laser beams with linear polarizations. The polarization angle of the returning laser beam can be adjusted through an electro-optical modulator. The dashed lines indicate the principal axes of the wave plate and the EOM. (b) By increasing the polarization angle θ, one can shift the two resulting σ^+ (blue) and σ^- (red) polarized standing waves relative to each other.

Verschieben eines opt. Gitters

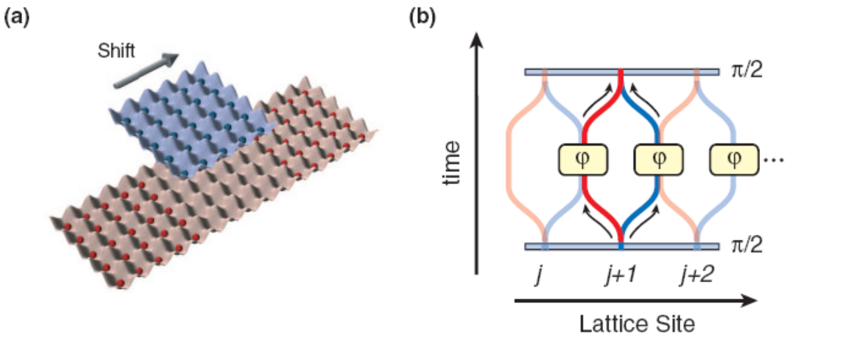

Fig. 4 (a) Controlled interactions between atoms on different lattice sites can be realized with the help of spin-dependent lattice potentials. In such spin dependent potentials, atoms in a, let us say, blue internal state experience a different lattice potential than atoms in a red internal state. These lattices can be moved relative to each other such that two initially separated atoms can be brought into controlled contact with each other. **(b)** This can be extendended to form a massively parallel quantum gate array. Consider a string of atoms on different lattice sites. First the atoms are placed in a coherent superposition of the two internal states (red and blue). Then spin dependent potentials are used to split each atom such that it simultaneously moves to the right and to the left and is brought into contact with the neighbouring atoms. There both atoms interact and a controlled phase shift φ is introduced. After such a controlled collision the atoms are again moved back to their original lattice sites.

Auftrennen der Wellenfunktion

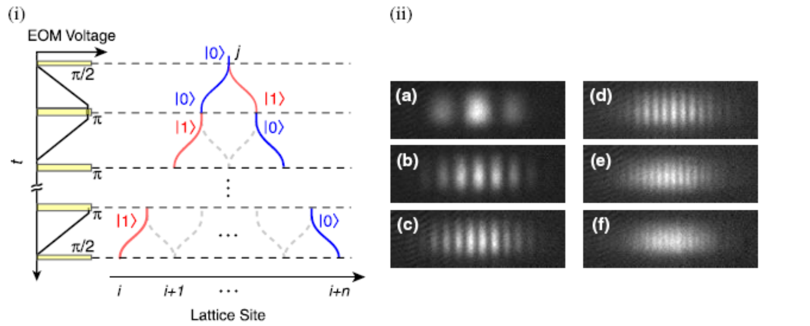

Fig. 3 (i) Schematic sequence used for the quantum conveyer belt. A single atom on lattice site j can be transported over an arbitrary number of lattice sites depending on its spin state (marked as blue and red curves). (ii) This has allowed us to split the wave function of the atom in a coherent way, such that a single atom simultaneously moves to the left and to the right. The coherence of the split wave-packets has been demonstrated in an interference experiment. For larger distances between the split wave-functions, the period of the interference pattern decreases.

Atom Pinzette

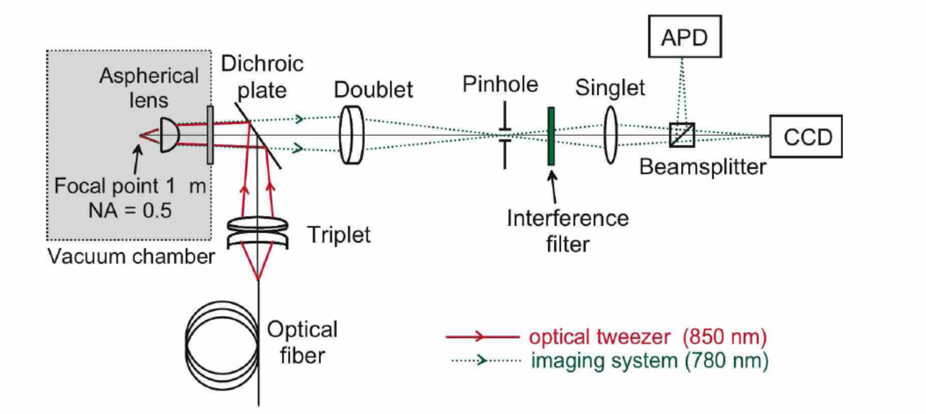

FIG. 1: (Color Online) Optical set-up of our trapping (solid line) and imaging (dotted lines) systems. For clarity, schematic is not to scale.

Zwei Pinzetten

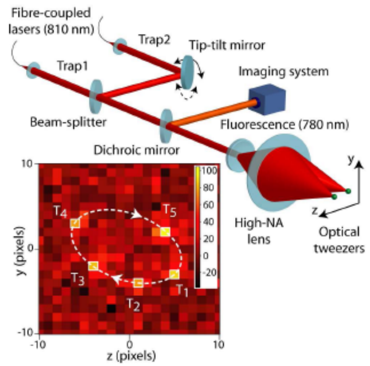

FIG. 1: Experimental setup. A large numerical aperture lens focuses two independent dipole trap beams at 810 nm each to a size of 0.9 micrometers. An optical power of 400 μW results into a trap depth of 500 μK and oscillation frequencies of 81 kHz and 15 kHz, in the radial and axial directions respectively. The two trapping lasers have the same linear polarization and their frequencies are separated by 10 MHz to avoid interferences. The moving tweezer is displaced by rotating a tip-tilt platform. The same large numerical aperture lens is used to collect the fluorescence light at 780 nm from the atom. This fluorescence light is separated from the trapping light by the dichroic mirror and sent to a single-photon counter module and a CCD camera. The insert shows a fluorescence picture of an atom moved along an elliptical trajectory in the y-z plane. The picture is a summation of 5 images taken at different times during the motion.

Atom Pinzette: 1 Atom / 2 Atome

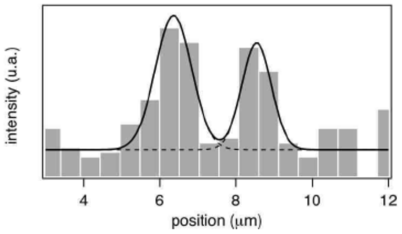

FIG. 7: Cross-section of a CCD image showing two single atoms trapped in two adjacent optical tweezers, corrected for the magnification (×25) of the imaging system. The distance between the two optical tweezers is 2.2 ± 0.1 μm. Each peak is fitted by a gaussian model (dashed lines) and exhibits a waist $w = 0.9 \pm 0.2$ μm. The solid line represents the sum of the fits of the two fluorescence signals emitted by each single atom. Vertical bars represent the intensity measured by each pixel of the CCD camera during a time window of 100 ms.

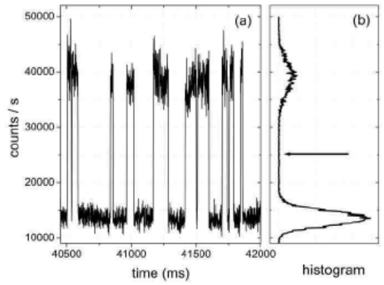

FIG. 6: (a) Fluorescence of a single atom measured by the APD. Each point corresponds to a 10 ms time bin. (b) Histogram of the measured fluorescence recorded over 100 s. The two Poisson distributions correspond to the presence and the absence of a single atom in the dipole trap. The arrow indicates the threshold that we use to discriminate between the two cases.

Rabi Oszillationen

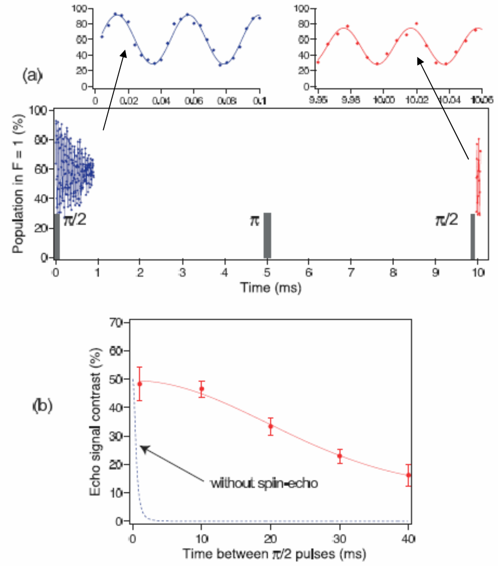

Fig. 4. Example of the spin-echo signal. Figure (a) shows the revival of the oscillations after the π pulse has been applied. Figure (b) shows the amplitude of the echo signal for different durations of the spin-echo sequence.

Rydberg Blockade

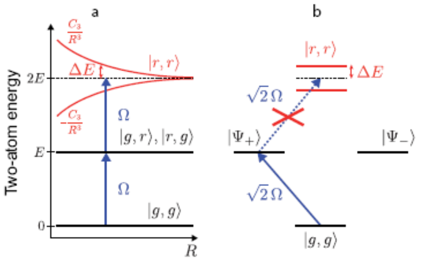

FIG. 1: (a) Principle of the Rydberg blockade between two atoms separated by a distance R. Two states $|g\rangle$ and $|r\rangle$ are coupled with Rabi frequency Ω. When the two atoms are in state $|r,r\rangle$ they interact strongly which leads to symmetrical energy shifts $\Delta E = \pm \frac{C_3}{R^3}$. When this shift becomes larger than $\hbar\Omega$, the laser is out of resonance with the transition coupling the singly and doubly excited states, and only one atom at a time can be transferred to the Rydberg state. (b) When the atoms are in the blockade regime, the state $|\Psi_+\rangle$, described in the text, is only coupled to the ground state $|g,g\rangle$ with a strength $\sqrt{2}\,\Omega$ while the state $|\Psi_-\rangle$ is not coupled by the laser to the states $|g,g\rangle$ and $|r,r\rangle$. The atoms are therefore described by an effective two-level system.

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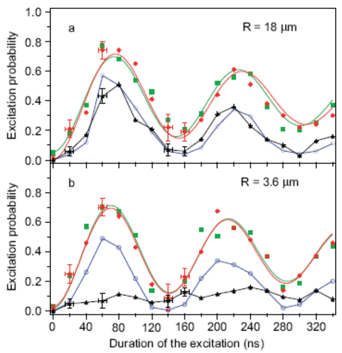

FIG. 3: Rydberg excitation of two atoms. In both figures, the red circles and the green squares represent the probability to excite atom a and atom b respectively, when the other atom is absent. We fit the data by the function $A - Be^{-\frac{t}{\tau}}\cos\Omega t$, shown as plain line. The error bars on the data are the RMS statistical error on the measured probability, as well as the error in the estimation of the pulse duration. The blue empty circles are the product of the probabilities to excite atom a and atom b when the other one is absent. The triangles are the probability to excite the two atoms simultaneously when they are driven by the same pulse. (a) Atoms separated by 18 μm. The frequencies of the Rabi oscillations are 6.5 MHz and 6.4 MHz for atom a and b respectively. The agreement between the triangles and the blue circles indicates that the atoms do not interact. (b) Blockade of the Rydberg excitation when the two atoms are separated by 3.6 μm. Due to the interaction between the atoms, this double excitation is greatly suppressed.