

Aim

Design a phase gate for the polarization degree of freedom using cold Rydberg atoms

using

EIT

Map light into polariton - storage and retrieval

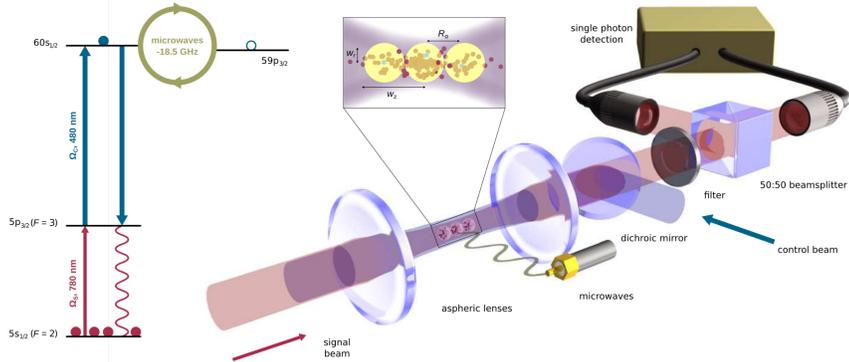
Rydberg interactions

Long range dipole-dipole interactions between polaritons

Microwave control

Control state of the polariton to switch interactions on/off

Physical principles



Electromagnetically Induced Transparency

Via this phenomenon, light is coherently mapped into a spin wave (polariton).

$$\Psi(z, t) = \cos\theta\mathcal{E}(z, t) - \sin\theta\sqrt{N}\rho_{rg}(z, t)e^{i\Delta kz}$$

light \rightarrow atomic excitation

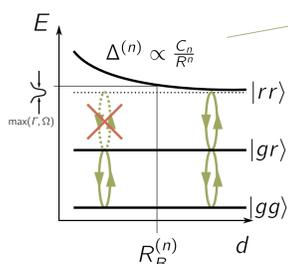
$$\tan^2\theta = n_{gr} - 1 \quad \text{Group index } n_{gr} \propto \frac{1}{\Omega_c^2}$$

Rydberg interactions

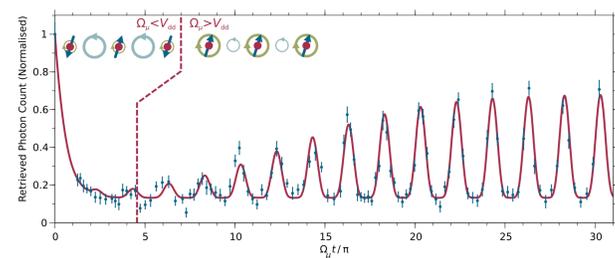
Excitation of multi-polariton states is shifted out of resonance within a certain region characterized by the **Blockade radius**.

$$R_B^{(n)} = \sqrt[n]{\frac{C_n}{\Omega}}$$

C_6 van der Waals
 C_3 resonant dipole-dipole



Microwave control



Microwaves turn on resonant dipole-dipole interactions

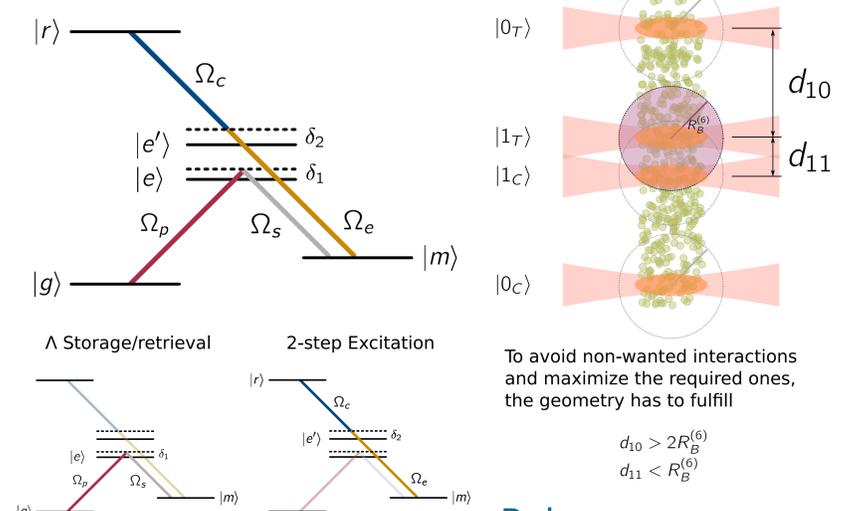
Two different scales:

$$R_0 \quad \text{Coherence length of vdW interaction}$$

$$R_\mu = \sqrt[3]{\frac{C_3}{\Omega_\mu}} \quad \text{Microwaves}$$

Two possible implementations

N-type system

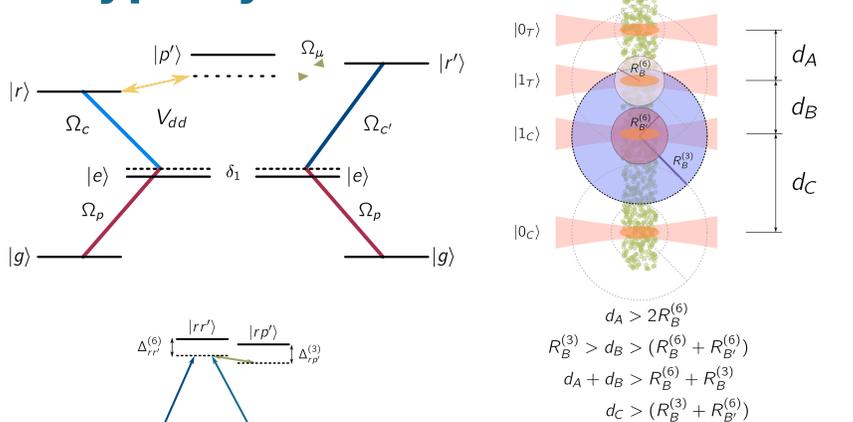


Pulse sequence

- Level scheme as in [4,5,6]
- The excitation scheme works in way similar to [2,3,4,5]:
First **store light** in the metastable state, then **make it interact** through the Rydberg state.

	$(\pi)\tau$	$(2\pi)c$	$(\pi)\tau$
$ 1\rangle 1\rangle$	$i r\rangle 1\rangle$	$i r\rangle 1\rangle$	$- 1\rangle 1\rangle$
$ 1\rangle 0\rangle$	$i r\rangle 0\rangle$	$-i r\rangle 0\rangle$	$ 1\rangle 0\rangle$
$ 0\rangle 1\rangle$	$i r\rangle 1\rangle$	$-i r\rangle 1\rangle$	$ 0\rangle 1\rangle$
$ 0\rangle 0\rangle$	$i r\rangle 0\rangle$	$-i r\rangle 0\rangle$	$ 0\rangle 0\rangle$

P-type system



It is important to avoid dephasing due to the resonant interactions

Pulse sequence

	$(2\pi)\mu$	
$ 1\rangle 1\rangle$	$ 1\rangle 1\rangle$	
$ 1\rangle 0\rangle$	$- 1\rangle 0\rangle$	
$ 0\rangle 1\rangle$	$- 0\rangle 1\rangle$	
$ 0\rangle 0\rangle$	$- 0\rangle 0\rangle$	

- Controllable interactions between one pair of states
- Prevent interactions between the rest

Some implementation details

Change encoding to take advantage of the spatial-dependence of the interactions: Polarization encoding to dual-rail.

$$\alpha|H\rangle + \beta|V\rangle \rightarrow \text{PBS} \rightarrow \alpha|1\rangle + \beta|0\rangle$$

Strongly focused beams individually address different parts of a cloud of cold atoms

References

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- Review of EIT
Implementation of a CNOT gate in ions
Review of Quantum information with Rydbergs
CNOT gate for atoms
CNOT gate for atoms
N-level system using Rydbergs
Latest results on coherent control using microwaves

Acknowledgements

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