Hamiltonian in Neutral-atom quantum computers

Delon 1 July 6, 2023, 8:13am

Hello,

In the article Neutral-atom quantum computers (**Neutral-atom quantum computers**)

The drive Hamiltonian is describe with a cos and sin function of the phase but in the reference given **QUANTUM COMPUTING WITH NEUTRAL ATOMS (arxiv.org)** (page 13)
Those functions are not present.
Why the difference ?

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isaacdevlugt 2 July 6, 2023, 1:50pm

Hey @Delon !

Great question! This really boils down to a choice of representation that doesn't have affects on the physics. The Rydberg atom Hamiltonian's interaction part is proportional to PauliZ-PauliZ interactions, since we can write

n_i = \frac{1 - \sigma_z}{2}.

The drive term just needs to be *transverse* to the interaction (i.e., \sigma_x or \sigma_y). In our demo (**Neutral-atom quantum computers**) the choice for a transverse field is more general (a linear combination of \sigma_x and \sigma_y), whereas the paper you referenced is choosing a specific value of \phi.

Another way to think about it: both Hamiltonians are a unitary transformation away from each other, where the unitary is a Pauli Z rotation 🙂.

Delon 3 July 6, 2023, 2:17pm

Thank you for your answer ! But I'm sorry, I don't really understand the idea behind the transverse field.
Do you think you could explain it or share some ressources so that I could learn about it ?

isaacdevlugt 4 July 6, 2023, 2:33pm

The transverse field is something that's there to represent the energy cost of exciting / unexciting your degrees of freedom (small aside: the Rydberg Hamiltonian is *extremely* similar to the infamous transverse-field Ising model — **Transverse-field Ising model - Wikipedia**). It's present in the Rydberg Hamiltonian to quantify the energy difference between a Rydberg atom in its ground state and in an excited state (where \Omega — the thing that is coupled to the transverse field — is called the Rabi frequency).

I wouldn't get too lost in terminology here — the transverse field is something that quantifies the energy required to excite things 😁.

Delon 5 July 25, 2023, 11:47am

Thank you for the details @isaacdevlugt

There is one last point I'm still confused.
What is the detuning term exactly ? What does it do ?

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isaacdevlugt 6 July 25, 2023, 1:31pm

The explanation of the detuning in our demo is all that is needed here. Is there something that's confusing here? Let me know 🙂

$$H_d = \Omega(t) \sum_{q\in\text{wires}} (\cos(\phi)\sigma_q^x - \sin(\phi)\sigma_q^y) - \frac{1}{2}\delta(t) \sum_{q\in\text{wires}} (\mathbb{I}_q - \sigma_q^z).$$

Here, the detuning $\delta(t)$ is defined as the difference between the photon's energy and the energy E_{01} needed to transition between the ground state $|0\rangle$ and the excited state $|1\rangle$:

$$\delta(t) = \hbar\nu(t) - E_{01}.$$

We will call H_d the **drive Hamiltonian**, since the electronic states of the atoms are being "driven" by the light pulse. This Hamiltonian is time-dependent, and it may also depend on other parameters that describe the pulse. PennyLane's `pennylane.pulse.ParametrizedHamiltonian` class will help us deal with such a mathematical object. You can learn more about Parametrized Hamiltonians in our documentation and in this pulse Programming demo.

Delon 7 July 25, 2023, 3:03pm

Ah yeah that's the formula I'm still a bit confused about :

1. Why is there a "-" in front of the detuning ?
2. If the detuning drives the transition between the ground state and the rydberg state, why do we need the Ω term ?
3. What does $\frac{I_{q}-\sigma^{z}_{q}}{2}$ represent ? I know it's either 0 or 1 and that σ^{z}_{q} is the Pauli Z operator of the q-th qubit but why do we need that formula ? Why not just $\sum_{q\in wires}^{}\sigma^{z}_{q}$? Also why Pauli Z and not X or Y ?

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isaacdevlugt 8 July 26, 2023, 6:18pm

Your 1st and 3rd questions are related:

The answer to your third question is that it represents the occupation number (i.e., is the Rydberg atom excited — value of 1 — or not — value of 0). That's the equation that's in my first response to you:

$n_i = \frac{1 - \sigma^z_i}{2}$.

That's the Rydberg occupation operator 🙂.

For your first question, the detuning δ couples to this term in the Hamiltonian, meaning that for a positive value of δ, the drive Hamtiltonian favours Rydberg atoms that are "occupied" (excited) — it lowers the energy. The opposite is true if δ is negative.

> If the detuning drives the transition between the ground state and the rydberg state, why do we need the Ω.

The detuning is accounting for the "leftover" / "excess" energy from incident photons. So, the roles of the detuning and the Rabi frequency Ω are different.

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