Trapped-Ion Physics

Spring 2023, Examiner: Daniel Kienzler

1. **Summary:**
Ion Trapping
1. Can we confine a particle with a static electric field?
2. What can we do about it?
3. Explain how the Paul trap works.
4. When does the pseudopotential approximation hold?
5. Explain stability with the appropriate diagram.
6. What textbook system can we use do describe our trapped particle? (QHO)
7. How does it look like for 2 ions? (normal modes)
8. Describe decoherence mechanisms for the system (dephasing, heating)

Spin motion coupling
9. Let's talk about spin motion coupling. (free to lead from here, I started from the trapped ion interaction Hamiltonian in the z direction and did the Lamb Dicke Expansion)
10. In the atom field interaction, what is the field? (laser controlled by us)
11. What is z_0? (ground state wave packet size)
12. Why can we expand $e^{ik_z Z}$? (η small, which we can see from typical laser wavelengths and ground state wave packet sizes)
13. What does this give to us now? (sidebands)
14. We have all the Hamiltonians now, but none of them include frequency. How do we get the sideband frequencies? (switch to interaction picture)

Laser cooling
15. How does cooling with the red sideband work?
16. Can we just use the carrier and red sideband to drive the cooling process? Why do we need a dissipative (non-unitary) process?

State dependent forces
17. How can we use the sidebands to implement state dependent forces?
18. Where does the state dependency come from?

Exam atmosphere:
The atmosphere was relaxed, the examiner sometimes asked specific questions, sometimes also just gave a broad topic you can jump off from.

Spring 2021, Examiner: Daniel Kienzler

1. **Summary:**
Hey! here my exam:
Trapping:
-why can't we trap in 3D with only static potentials
-what we can do about this
-effect of noisy electric field
-trap stability
-motion of multiple ions in the same trap + noise for com mode and stretch mode
Laser cooling:
-doppler for going into LD regime
-sideband cooling
-why we need the dissipation and we can't use carrier
   - QCCD:
-what it is, what are the challenges, what problems of the long string approach it fixes e State dependent forces in X-basis:
-how are they implemented
-how can you use these for performing and entangling gate
-one loop vs two loops in ms gate
   - Quantum logic spettroscopy:
-protocol for studying H2+ (very very briefly)

2. **Summary:**
Hi! Just had my exam and we talked about the following:
Talk about trapping, specifically Paul trap
why can't we use static potential? (Laplace)
How does Paul trap overcome this problem?
How does trapping for 1 atom look like? Simple harmonic oscillator
How many oscillators do we have when trapping one ion?
What happens when we have two ions in the trap? How do they couple?
How does decoherence affect the ions? (heating and decoherence)
Explain heating further. (electrodes cause fluctuating E field)
How would that affect the 2 ions?
Interaction btw spin and motion (talked about Ch 3, atom field interaction, dipole approximation, Lamb-Dicke expansion, ...)
What does the LD parameter mean?
What limit are we looking at?
What happens to the Hamiltonian in this limit? Talked about carrier transition, red, blue, ... (only wanted me to write down the red side band H)
How can the RSB H be used for cooling?
Why can't we use the carrier and RSB H only?
Why non-unitary?
Talked about state-dependent forces (x dependent)

3. **Summary:**
Had my exam today, went as follows:
I) Start with trapping
-Why can't we just a static potential in 3D? (Laplace)
-HOW can we create confinement then?
-How does the RF potential create confinement?
2) On to stability in trapping
-Sketch the stability diagram (1.7). Started sketching it but he wasn't really that keen on drawing it in details, rather just the following questions:
-When do we have stable trapping?

-What are a and q params (axes)? What physical parameters are they related to?
-What boundaries do we have for the trapping? (Beta -> O or 1) and what is the physical meaning of that?
3) Had a brief talk about noise in trapping (noisy electric field).
-What two decoherence mechanisms that leads to (heating, dephasing). Gave the Lindblad operators for that.
5) Then on to how we can control the motion and the spin.
- Didn't quite not what he was fishing for. Mentioned carrier transition and sidebands so he went for that.
-He asked about what regime we are in? (LD) What does that mean, etc?
6) Then finally on to sideband cooling
-how can the red sideband be used to cool?
-Why do we need to scatter a photon?
-Why does it have to be non-unitary?
-Why can't we use a RSB and the carrier? How would that look for a thermal state? (ended up sketching it on a state ladder)
-Why do other transitions not scatter a photon, i.e. why only (predominantly) the carrier? (decay along sideband transition suppressed by eta^2)
He didn't show me any graphs or figures, just asked questions and maybe drew something on the blackboard.