Oh

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Tous les fichiers svg :

Dedication

For those who hate looking at a template with 500 lines of code and an extra 300 lines commented out.

Declaration

Acknowledgements

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Comment on increasing power in TC (thésard marc chesnais)

1.1.2 Zeeman cooling

1.1.3 Blue MOT

1.1.3.1 The physics

1.1.3.2 How to optimize the superposition with the repumper

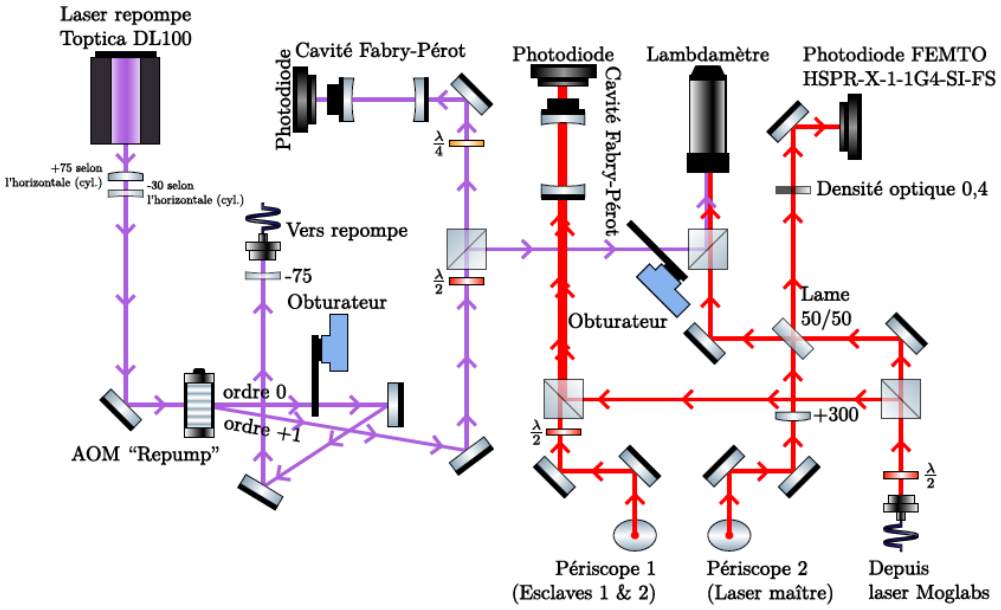


Figure 1.1: Caption

1.1.3.3 Comment on the hyperfine states (+boson 88)

1.1.3.4 Optical setup (blue + repump)

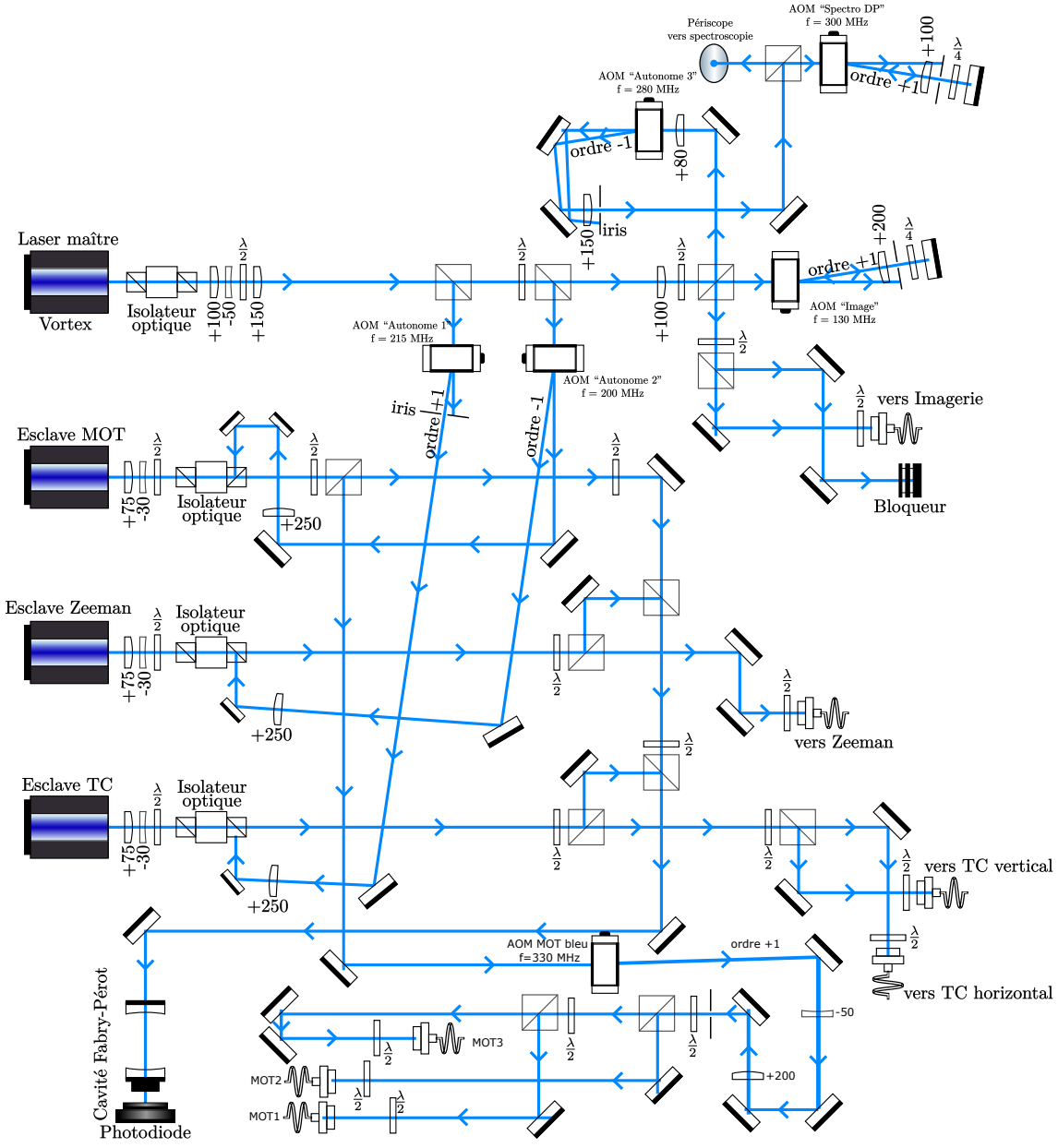


Figure 1.2: Caption

1.1.4 Repumper

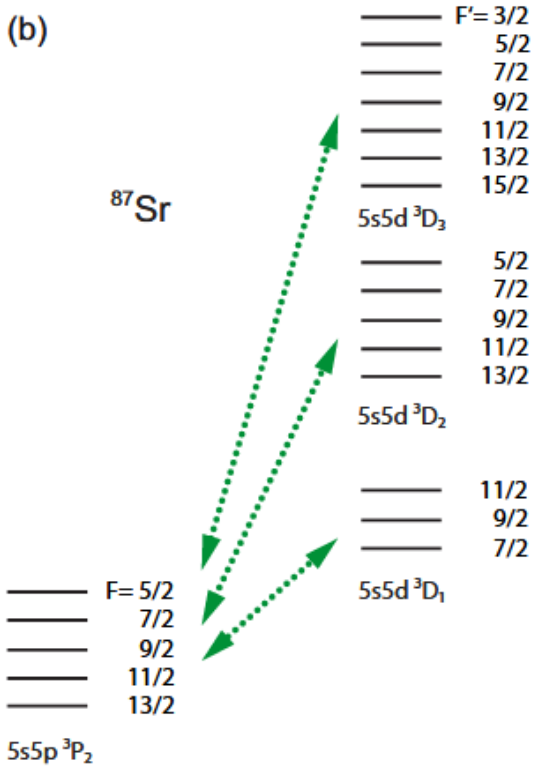


Figure 1.3: Caption

1.1.5 BB MOT

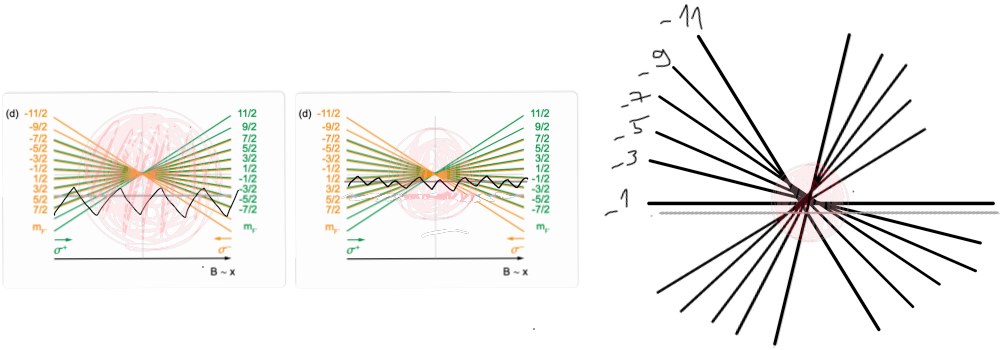


Figure 1.4: Caption

1.1.5.1 First step

1.1.5.2 Second step

1.1.6 Stir

Need a stir because :

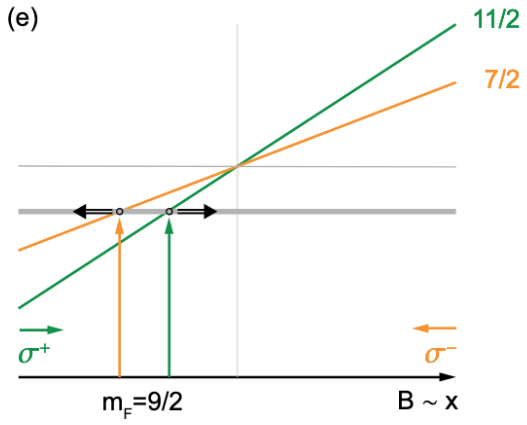


Figure 1.5: Caption

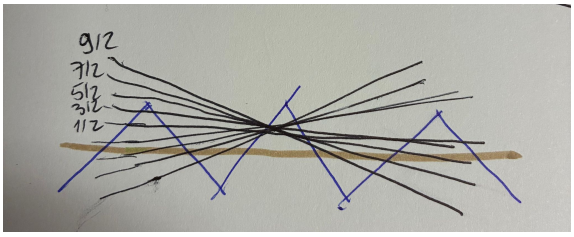


Figure 1.6: Caption

1.1.7 Narrow MOT

cf p.43 S.Stellmer thesis

1.1.7.1 Optimization of the narrow MOT (intensity, frequency, effect on the size of the cloud)

Include images of the cloud for different I and detuning ?

1.1.7.2 Optical setup

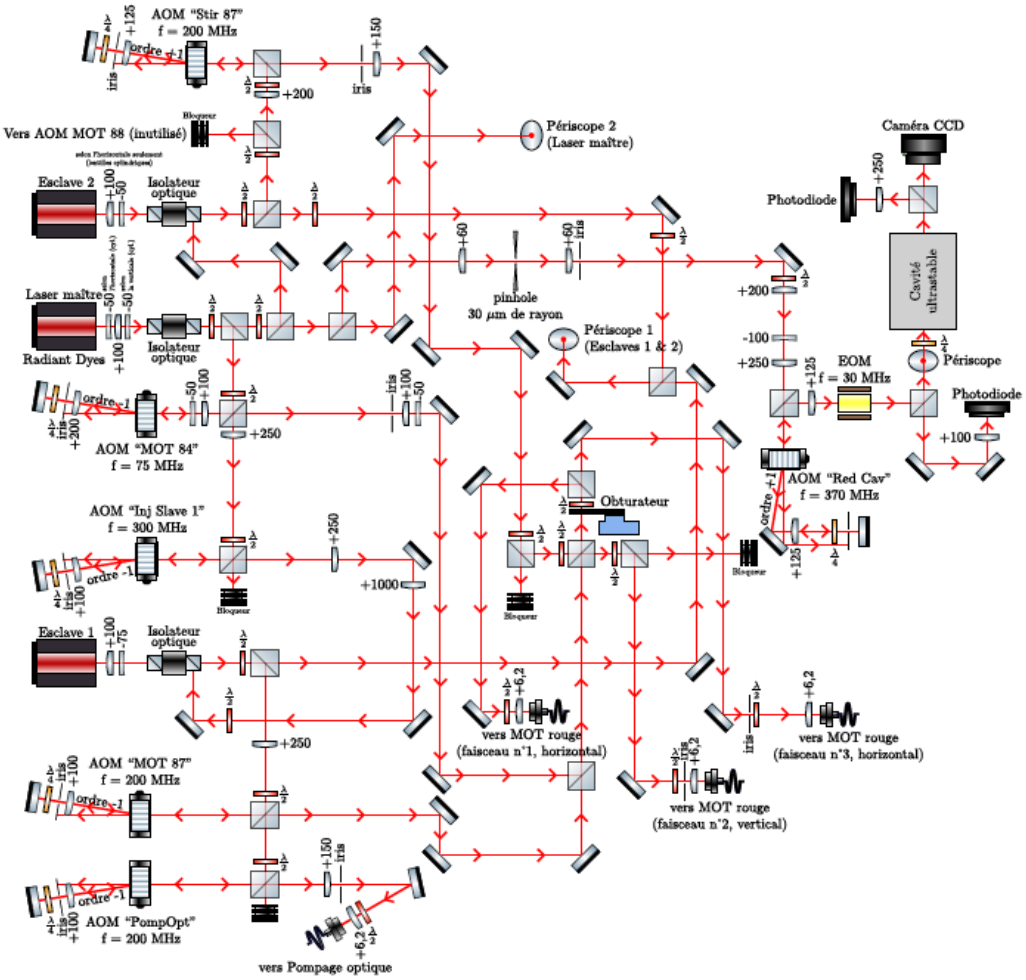


FIGURE 14 – Préparation des différents lasers rouges

Figure 1.7: Caption

1.1.8 ODT and evaporation

1.1.8.1 Charging the crossing

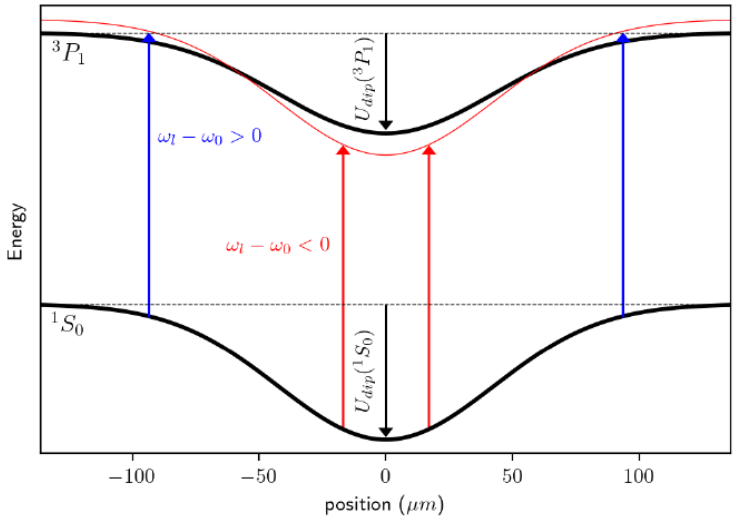


Figure 1.8: Caption

1.1.8.2 Optimization of the evaporation ramps : Dimple + reservoir, just reservoir, parameter to optimize (number of atoms, temperature)

Comment on the LS it does to each state

1.1.8.3 Optical setup

1.1.9 Optical pumping

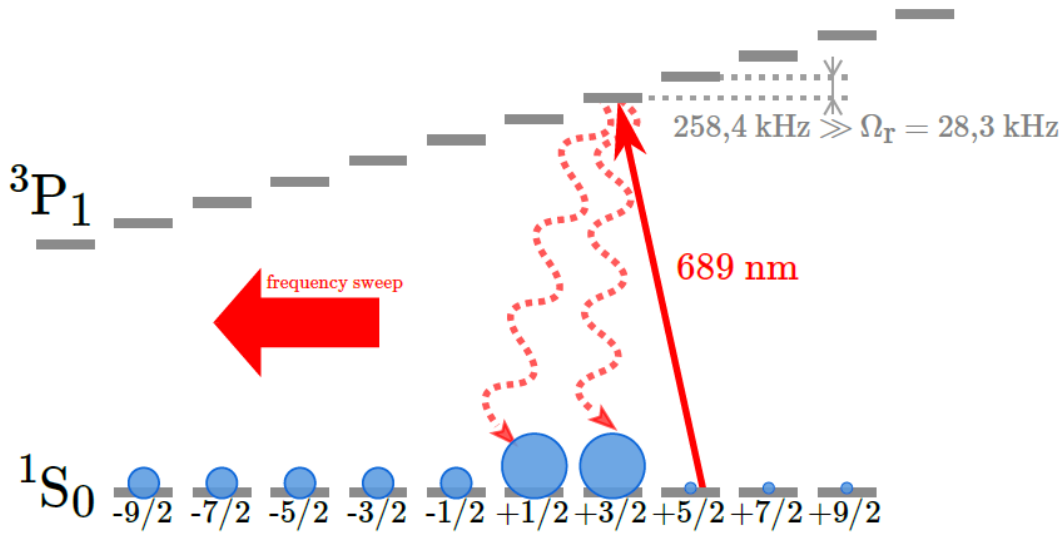


Figure 1.9: Caption

1.2 Spin measurement scheme

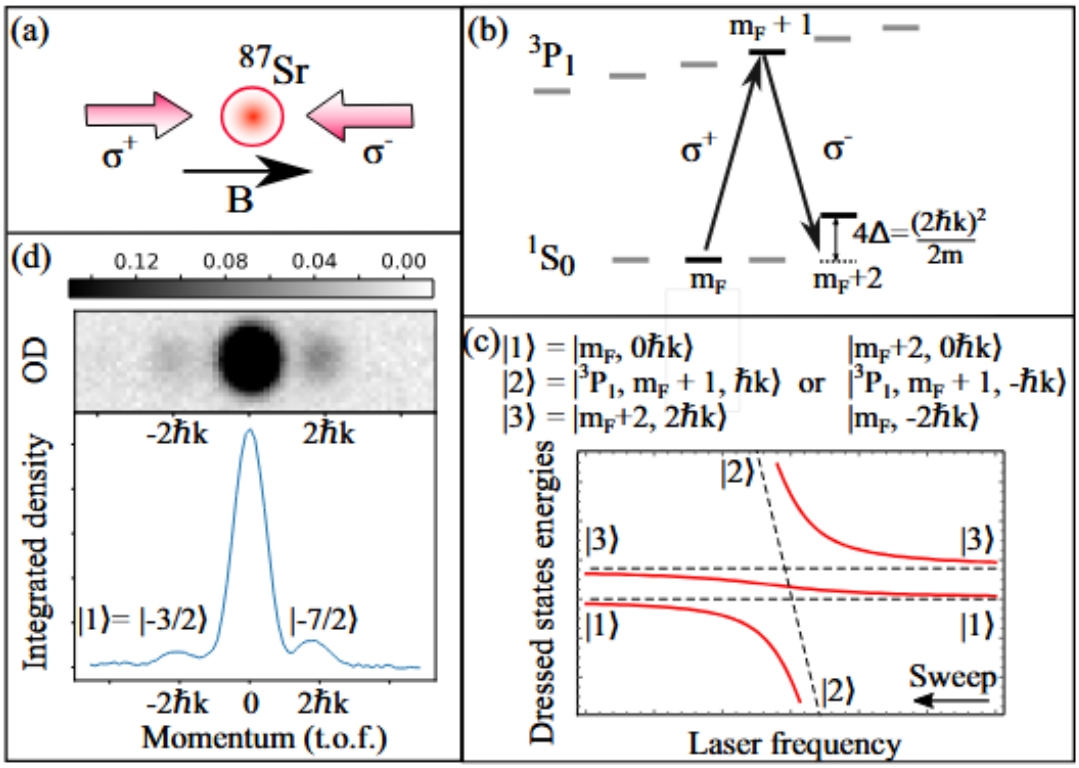


Figure 1.10: Caption

Chapter 2

Ramsey interferometers on qudit

2.1 Preparation of arbitrary dimension Hilbert space

2.1.1 Raman process

2.1.1.1 $\delta m_F = \pm 1$

2.1.1.2 $\delta m_F = \pm 2$

2.1.2 Moglabs chain without cavity

2.1.3 Purification of the laser spectrum with a FP cavity

blablablagtg

2.2 Interferometric sensing with multiple nuclear spin state

2.2.1 Driving long coherence time Rabi oscillations

2.2.1.1 Rabi oscillations

Comment on what the FP could add as a longer coherence time of the qubit

2.2.1.2 Interferometer of su(2) symmetry

2.2.1.3 Discussion on inhomogeneites

2.2.2 Measuring two quantites at a time

2.2.2.1 Physical principle

2.2.2.2 Results

2.2.3 Measuring two non commuting observables

2.2.3.1 Principle

2.3 SU(N) symmetry (ce qu'il faudrait pr la tester e.g densité gaz, alimentation bobines -¿ comment faire mieux que les chiffres actuels)

Chapter 3

Engineering highly entangled system of photoassociated 87Sr atoms

Engineering Dicke states

3.1 Introduction on photoassociation

3.1.1 What is photoassociation

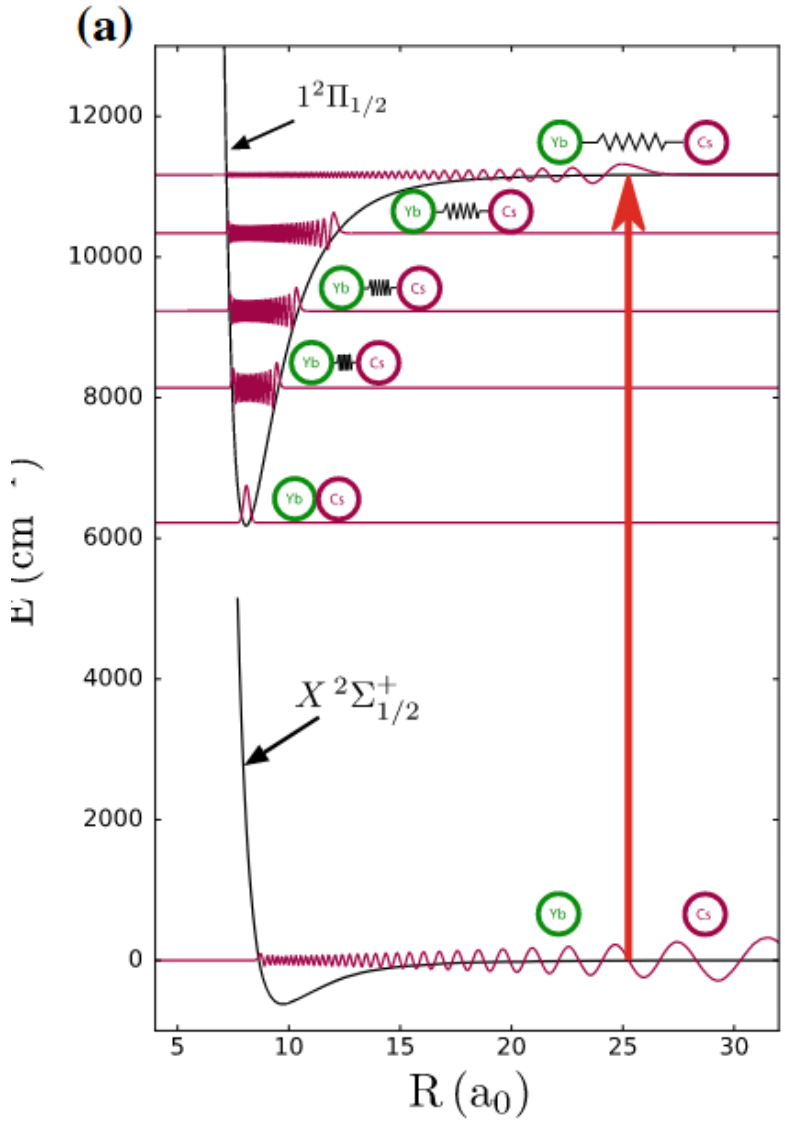


Figure 3.1: Caption

Photoassociating two atoms consists in bounding two colliding atoms with light that occurs mostly with two-body and three body losses.

The first necessity for photoassociating atoms is collisions. Each species has a specific cross section for which particles can collide with another, which is defined as

$$\sigma = 4\pi a^2 \tag{3.1}$$

with a the scattering length we will describe in the next section.

In ultracold gases, only s-wave atoms can collide because they do not have enough kinetic energy to pass the potential barrier of higher angular momentum states. It

imposes that for fermions -by parity of the total wavefunction being antisymetric- only atoms with even angular momentum can collide meaning their spin is in a singlet state as in the case of 87Sr. For bosons it is the contrary : from an even orbital wavefunction, the spin wavefunction should be antisymetric to collide.

The second element for PA is a resonant laser. As visible in 3.1 : from a free state of a two-atoms system we couple them via a laser with a molecular vibrationnal state. In the case of spectroscopy we usually start with the least bounded state to have the atomic state reference. From that we sweep the atom frequency to adress the molecular states red detuned from the atomic line.

PA is mostly used in Feschbach resonance field because determining the exact position of the vibrational states enables by changing the magnetic field to tune the scattering length of the atoms and thus the interactions in the system.

3.1.2 Molecular formalism/vocabulary (condon radius, optical length...)

Optical length is defined as the imaginary part of the scattering length and describes the strength of the photoassociation rate

$$K_2 = \frac{4\pi\hbar}{\mu} n l_{opt} \tag{3.2}$$

n the volumic density of the cloud, μ the reduced mass of the two atoms. This rate represents the ratio of the atoms that are lossed by 2-body losses.

The Franck Condon factor is the probability to transition from an initial vibrational i state to a final vibrational f state

$$F_{FC} = \left| \int_0^\infty \psi_i(R)\psi_f(R)dR \right|^2 \tag{3.3}$$

R the distance inter-nuclear. It depends directly with the overlap of the wavefunctions of the initial and final states. The Condon radius is the distance between the atoms for which this factor is maximum which also means that in a classical approachthe atoms spend the most time at this position.

The good quantum numbers
We write the total angular momentum of the molecule $T = R + F = R + I + J$, F being the total spin of the two atoms $f_1 + f_2$, and R the rotational angular momentum of the molecule. $R = 0, 2$ or 4 in our case because we have only s-wave collisions which means that the orbital part of the wavefunction should be odd and the spin one antisymetric

$$|\Psi\rangle = \left(|\phi_1\rangle_1 |\phi_2\rangle_2 + p(-1)^R |\phi_2\rangle_1 |\phi_1\rangle_2\right) \otimes |\chi\rangle \tag{3.4}$$

We are in Hund's case (c) because there is a strong spin-orbit coupling that couples

to the internuclear axis, and is quantified by Ω.

M_T is the projection of the total angular momentum T onto a defined quantization axis, sometimes being the internuclear axis depending on the Hund's case.
$J = j_1 + j_2$ is the angular moment of the electronic state of the molecule.
Ω is the projection of J on the internuclear axis.

The experiment presented in the following is photoassociation in the $F = 11/2$ hyperfine state. We will focus on this section in this state to simplify the discussion.

Say we have one atome in the $^1S_0$ state and one in the $^3P_1$ state: we can have a total spin of $J = 0, 1$ or 2. It gives possible values of total atomic angular momentum F:

$$\text{For } J = 0, \quad F = \frac{9}{2} \tag{3.5}$$

$$\text{For } J = 1, \quad F = \frac{7}{2}, \frac{9}{2}, \frac{11}{2} \tag{3.6}$$

$$\text{For } J = 2, \quad F = \frac{5}{2}, \frac{7}{2}, \frac{9}{2}, \frac{11}{2}, \frac{13}{2} \tag{3.7}$$

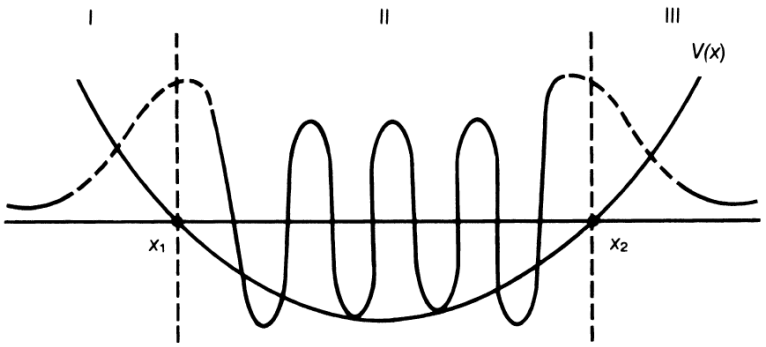
We have one atom with $f_1 = 9/2$ from the $^1S_0$ state and one in the $^3P_1$ state with $f_2 = 11/2$. The possible values of total angular momentum of the molecule are $F = 1, 2, 3, 4, 5, 6, 7, 8, 9$ or 10.

Ajouter une représentation de mon cas de Hund en particulier pour illustrer les nombres quantiques (cas a ou c)

3.1.3 External energy states

To describe two-body losses of a photoassociation process, we need to change our basis depending on the distance between the two atoms by approximating dominant couplings over others. (Hund's cases)

3.1.3.1 WKB approximation



IGURE 2.1. Schematic diagram for behavior of wave function $u_E(x)$ in potential well $V(x)$ ith turning points x_1 and x_2.

Figure 3.2: Caption

3.1.3.2

3.1.4 Internal energy states

3.2 About photoassociation on other species

3.2.1 Mass scaling (88Sr)

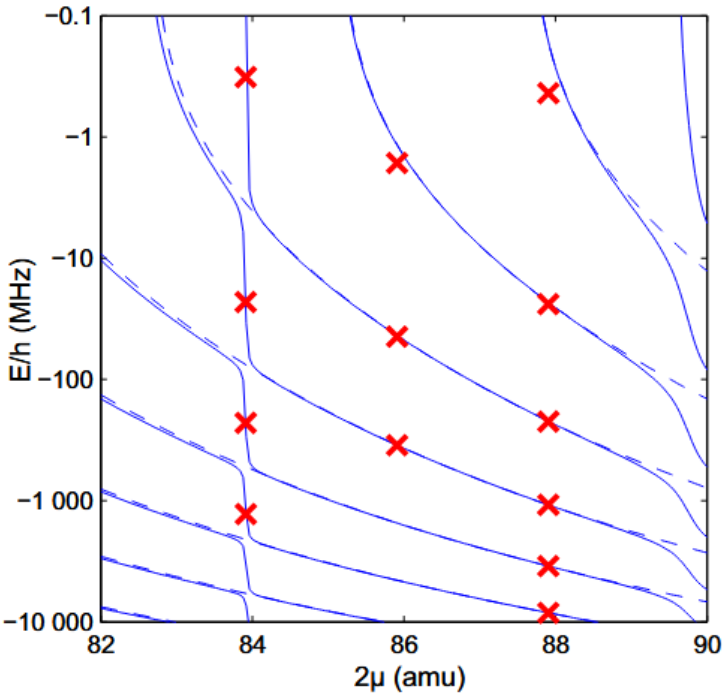


Figure 3.3: Caption

3.2.2 Ytterbium: hfs

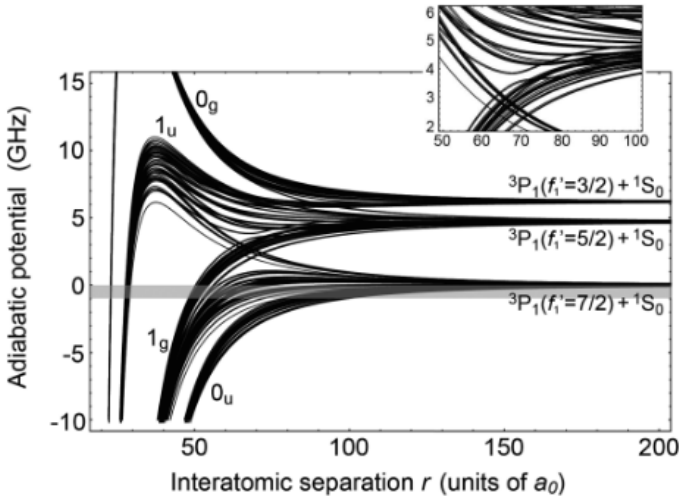


FIG. 2. Adiabatic molecular potentials for a $^{173}Yb_2$ dimer in the $^1S_0 + ^3P_1$ channel as functions of the interatomic separation r. The molecular potentials for 205 different (T, F, R) configurations are displayed, which are accessible via PA from the initial s-wave colliding atoms in the $^1S_0 + ^1S_0$ channel. At large r, the potentials converge to three asymptotic branches which correspond to excited atomic states with hyperfine numbers of $f_1' = 3/2,\ 5/2$, and $7/2$. Some of the potentials have a local minimum (inset), possibly hosting purely long-range bound states [14]. The energy offset is adjusted to the $f_1' = 7/2$ asymptote. The shaded region indicates the spectral range of our measurements.

Figure 3.4: Caption

3.3 Experimental setup

3.4 88Sr Results

Lopt, power broadening, thermal broadening...

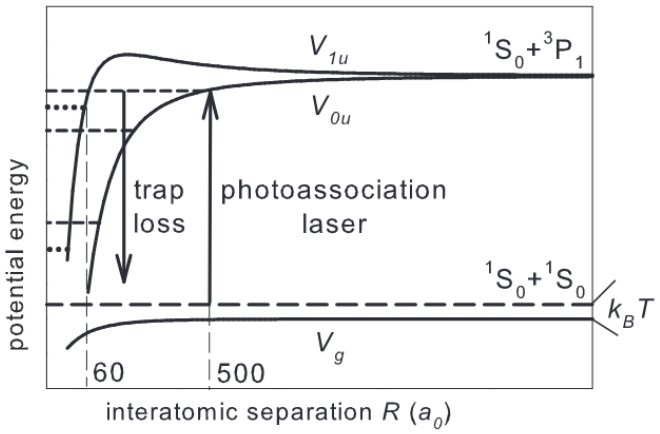


Figure 3.5: Caption

3.4.1 Technical issues of inhabilitation of photoassociation

3.4.1.1 Laser width

3.5 87Sr molecules

Lopt questions sur nb quantique / choix de pompage optique

3.5.1 Physical sources of inhabilitation of photoassociation

3.5.1.1 On F = 9/2 : predissociation

3.5.1.2 Coupling to more energetic state from the IR

3.5.1.3 Node of wavefunction for some vibrational states

3.5.2 Energy landscape of 87Sr-87Sr molecules

Conclusion

Bibliography

Appendix A

Algorithms