



HAL
open science

Optical pumping in rubidium-87 - Circular polarisation on the ($F g = 2 \leftrightarrow F e = 3$) transition in the D2-line

Fred Atoneche, Anders Kastberg

► To cite this version:

Fred Atoneche, Anders Kastberg. Optical pumping in rubidium-87 - Circular polarisation on the ($F g = 2 \leftrightarrow F e = 3$) transition in the D2-line. 2016, <10.6084/m9.figshare.3397681.v3>. <hal-01635970>

HAL Id: hal-01635970

<https://hal.science/hal-01635970v1>

Submitted on 16 Nov 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons CC BY 4.0 - Attribution - International License

Optical pumping in rubidium-87 — Circular polarisation on the ($F_g = 2 \leftrightarrow F_e = 3$) transition in the D2-line

Fred Atoneche

*Laboratory of Research on Advanced Materials and Non-linear Sciences,
Department of Physics, Faculty of Science,
University of Buea, P.O. Box 63, Buea, Cameroon*

Anders Kastberg

*Université Nice Sophia Antipolis, CNRS,
Laboratoire de Physique de la Matière Condensée
UMR 7336, Parc Valrose, 06100 Nice, France*

(Dated: November 16, 2017)

Abstract

We present results of a method for calculating optical pumping rates in ^{87}Rb , as described in [1]. We use circularly polarised light on the ($F_g = 2 \leftrightarrow F_e = 3$) transition to populate a stretched angular momentum state in the $F_g = 2$ hyperfine structure level of the ground state. The method is shown to function well for the the studied system. Explicit analytical equations for all level populations as functions of time, detuning, intensity and starting parameters are derived.

I. INTRODUCTION

In a separate publication [1], we have described a simplified method for quantitative calculations of the evolution of state populations in an atomic system undergoing optical pumping. In this short communication, we provide details for a specific case, including the evolution matrix, a link to the used programming code (using MathematicaTM) [2], and the obtained results.

The specific case studied is:

- Rb⁸⁷, with nuclear spin $I = 3/2$
- Preparation of the state $5s\ ^2S_{1/2}$, $F_g = 2$, $M_g = +2$.
- Pumping with circularly polarized light on the transition $F_g = 2 \leftrightarrow F_e = 3$ on the D2-line (upper fine-structure state $5p\ ^2P_{3/2}$).
- Pure polarization, no external magnetic field, and low saturation.

For the underlying theory, and also for some nomenclature, we refer to [*to be published*].

II. EVOLUTION MATRIX

We consider atoms populating a statistical mixture of the Zeeman states $M_g = +2$, $M_g = +1$, $M_g = 0$, $M_g = -1$, and $M_g = -2$. These five states will constitute our state space, and as derived in [*to be published*], the state population can be described by the matrix:

$$\frac{d}{dt}\mathbf{G}(t) = \frac{1}{225} \begin{pmatrix} 0 & 50 & 6 & 0 & 0 \\ 0 & -50 & 48 & 9 & 0 \\ 0 & 0 & -54 & 27 & 6 \\ 0 & 0 & 0 & -36 & 8 \\ 0 & 0 & 0 & 0 & -14 \end{pmatrix} R \mathbf{G}(t). \quad (1)$$

$\mathbf{G}(t)$ is a vector with the populations in the five states as its components, and R is the intensity dependent scattering rate:

$$R = \frac{\Gamma}{2} \frac{(I/I_{\text{sat}})}{1 + (I/I_{\text{sat}}) + (2\Delta/\Gamma)^2}. \quad (2)$$

Γ is the natural linewidth of the excited states (for all states belonging to the term $5p\ ^2P_{3/2}$, ($\Gamma = 2\pi \times 6.0666$ MHz [3]), I the intensity, I_{sat} the saturation intensity ($I_{\text{sat}} = 1.669$

mW/cm² for the case with a cycling transition and a coupling coefficient of one), and Δ is the detuning ($\Delta = 0$ for all calculations in the present article).

A. Solution of the evolution matrix equations

The evolution equations (Eq. 1) is simple to solve analytically. The last line gives a pure exponential decay, and once that is solved, its solution can be used to decouple the next line, and so on:

$$\begin{aligned}
G_{+2}(t) &= [G_{+2}(0) + G_{+1}(0) + G_0(0) + G_{-1}(0) + G_{-2}(0)] \\
&\quad + \left[-G_{+1}(0) e^{\frac{4}{225}Rt} + G_0(0) \left(11 - 12 e^{\frac{4}{225}Rt} \right) \right. \\
&\quad + \frac{1}{14} G_{-1}(0) \left(-116 e^{\frac{2}{25}Rt} + 333 e^{\frac{4}{225}Rt} - 231 \right) \\
&\quad \left. + \frac{1}{1540} G_{-2}(0) \left(2541 - 5060 e^{\frac{4}{225}Rt} + 4640 e^{\frac{2}{25}Rt} - 3661 e^{\frac{8}{45}Rt} \right) \right] e^{-\frac{6}{25}Rt} \\
G_{+1}(t) &= \left[G_{+1}(0) e^{\frac{4}{225}Rt} + 12 G_0(0) \left(e^{\frac{4}{225}Rt} - 1 \right) \right. \\
&\quad + \frac{9}{14} G_{-1}(0) \left(28 - 37 e^{\frac{4}{225}Rt} + 9 e^{\frac{2}{25}Rt} \right) \\
&\quad \left. + \frac{1}{385} G_{-2}(0) \left(238 e^{\frac{8}{45}Rt} - 810 e^{\frac{2}{25}Rt} + 1265 e^{\frac{4}{225}Rt} - 693 \right) \right] e^{-\frac{6}{25}Rt} \\
G_0(t) &= \left[G_0(0) + \frac{3}{2} G_{-1}(0) \left(e^{\frac{2}{25}Rt} - 1 \right) \right. \\
&\quad \left. + \frac{1}{220} G_{-2}(0) \left(33 - 120 e^{\frac{2}{25}Rt} + 87 e^{\frac{8}{45}Rt} \right) \right] e^{-\frac{6}{25}Rt} \\
G_{-1}(t) &= \left[G_{-1}(0) + \frac{4}{11} G_{-2}(0) \left(e^{\frac{22}{225}Rt} - 1 \right) \right] e^{-\frac{4}{25}Rt} \\
G_{-2}(t) &= G_{-2}(0) e^{-\frac{14}{225}Rt}. \tag{3}
\end{aligned}$$

The mathematical expressions are lengthy, but they are explicit and exact, and are easily handled by desktop mathematical packages. In [2] we provide an annotated code for this in MathematicaTM.

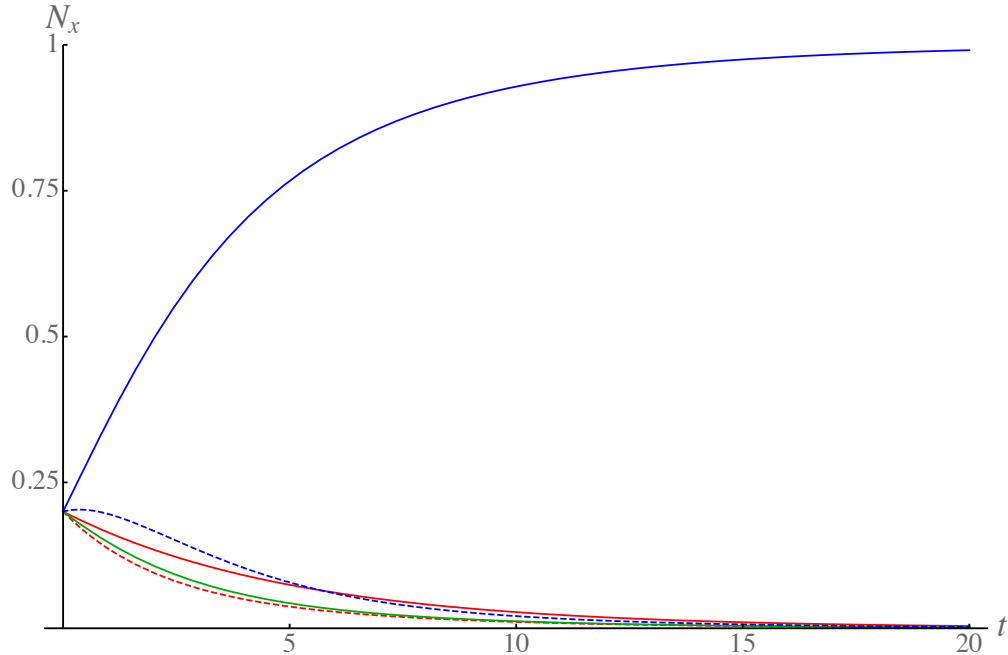


FIG. 1. Relative populations in the five sub-levels, as functions of time in microseconds, computed from Eq. 3. Full blue line G_{+2} , dashed blue line G_{+1} , full green line G_0 , dashed red line G_{-1} , full red line G_{-2} .

III. RESULTS

A. Explicit solution

Solving Eq. 1 gives the evolution of the five involved Zeeman states given by Eq. 3. In these equations, the subscripts refer to the value of the M_g quantum number. Note that the only specific atomic characteristic that is included in the analysis, which is different from another alkali atom with the same nuclear spin ($I = 3/2$), is the natural linewidth Γ . This means that Eq. 3 will be equally valid for all alkali isotopes with the same nuclear spin, such as: ${}^7\text{Li}$, Na , ${}^{39}\text{K}$, and ${}^{41}\text{K}$.

B. Numerical results

Figure 1 shows an example of evolutions of the populations of the involved levels, based on Eq. 3. In this example, we have assumed that the initial populations are the same in all five levels, and that the total population is normalized to unity ($G_{-2} = G_{-1} = G_0 =$

$G_{+1} = G_{+2} = 0.2$). Furthermore, we set the intensity to a fifth of the saturation intensity ($I = I_{\text{sat}}/5 \Rightarrow R \approx \Gamma/10$), and the detuning to zero. The population of the optically pumped level, G_{+2} , grows monotonically towards 1, as all other levels are depleted.

IV. CONCLUSION

Using the method developed in [1], we have calculated the state population evolution for optical pumping to a stretched state on the ($F_g = 2 \leftrightarrow F_e = 3$)-transition, using circularly polarized light. The method works well when applied to this system and yields exact and explicit expressions for the level populations. It is suitable and convenient for quickly estimating population dynamics in an optical pumping experiment.

-
- [1] F. Atoneche and A. Kastberg, *Eur. J. Phys.* **38**, 045703 (2017), URL <http://stacks.iop.org/0143-0807/38/i=4/a=045703>.
 - [2] A. Kastberg and F. Atoneche (2016), URL https://figshare.com/articles/Optical_pumping_with_circularly_polarized_light_for_the_D2_transition_in_Rb-87_Fg_2_-_Fg_3_-_Mathematica_code/3750531.
 - [3] D. A. Steck, *Rubidium 87 D Line Data* (2001), URL <http://steck.us/alkalidata/rubidium87numbers.pdf>.