Z24 - Optical Pumping

Physics Laboratory II
Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University

The point of this exercise is to familiarize students with the technique of optical pumping. This technique was invented by Alfred Kastler in the 1950's (he received the Nobel Prize in 1966). The mechanism of optical pumping comes from the angular momentum of photons. In this laboratory exercise students will practice optical pumping on a gas of rubidium atoms. The experimental setup (made by Teach Spin company) consist of rubidium RF discharge lamp as a light source, polarization optics, interference filter (D1 rubidium line, 795 nm wavelength), heated glass cell with rubidium droplet, photo-diode with amplifier and the set of magnetic coils with amplifiers and controllers. The additional radio – frequency magnetic field is applied to drive transitions within the Zeeman levels and depolarize rubidium gas. The primary goal of the experiment is to measure the Zeeman splitting of the ground states of rubidium atoms (for the two: 85Rb and 87Rb isotopes) in a weak magnetic field and to determine from recorded data the Landé g-factors for these states. In addition, the direction and magnitude of the local geomagnetic field will be determined.

Preparatory questions

1. light emission and absorption by atoms [1, 3, 4]
2. the energy-level structure of a one valence electron atom (i.e. rubidium atom)[1, 4]
3. the fine structure and the hyperfine structure of rubidium atoms, the Zeeman splitting [1, 4]
4. the cross – section for light absorption [3, 4]
5. the technique of optical pumping [3, 4]
6. magnetic resonances [3, 4]
7. magnetic coils, the Helmholz setup for magnetic coils
8. the direction and magnitude of the local Earth magnetic field
9. linear and circular polarization of light, the linear polarizer, the quarter waveplate [2]
10. the interference filter [2, 3]
11. the optical setup [2]
12. plano – convex lenses, collimation of light [2]

Computational assignments

1. Express the spectral range in eV and in Hz of:
   - $5^2S_{1/2} - 5^2P_{3/2}$ optical transition in Rb,
   - $5^2S_{1/2} - 5^2P_{3/2}$ fine structure splitting in Rb,
   - $5^2S_{1/2}(F=2) - (F=3)$ hyperfine structure splitting in ^{85}Rb (I=5/2),
   - $5^2S_{1/2}(F=2, m_F=-1) - 5^2S_{1/2}(F=2, m_F=0)$ splitting in magnetic field $B = 10^{-4}T$.
2. Calculate the population of the $5^2S_{1/2}$ state in 1 mol of Rb atoms at temperature of 300 K (thermodynamic equilibrium). Express the difference in populations of the lowest and highest magnetic sub-levels of the Rb ground state in magnetic field $B = 10^{-4}T$ and temperature $T = 300K$.
3. Explain the role of the linear polarizer and the quarter waveplate in producing circular polarization of light.

Apparatus and materials

Experimental setup (made by Teach Spin company) consist of:

- a RF excited rubidium lamp,
- a plano – convex lens as the light collimator,
- a linear polarizer and a quarter waveplate,
- an interference filter (D1 rubidium line, 795 nm wavelength),
- a heated glass cell with Rb droplet,
- a next plano convex lens and photodiode with preamplifier
- the set of magnetic coils (with controllers) to minimize the effect of the Earth's magnetic field,
- the set of RF coils with tunable generator and amplifier.

Student has in her/his disposal an oscilloscope, a PC computer and the copy of Teach Spin manual.

Figure 1: The experimental setup made by Teach Spin company [5]. The optical bench is equipped with: rubidium lamp (1), lens – condenser (2), interference filter (3), polarization optics (4), heated rubidium cell (5) in the center of magnetic coils (6), lens – collimator (7), photo-detector with preamplifier (8).

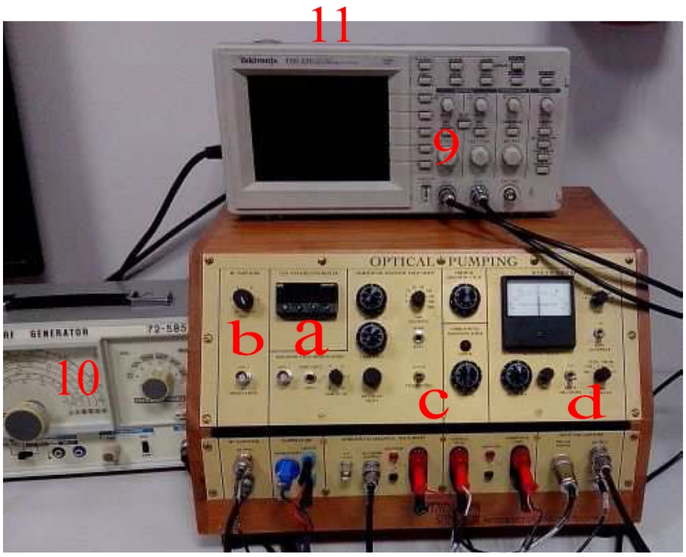

Figure 2: The control unit (9) with built-in: temperature controller (a), RF amplifier (b) and power supply units for magnetic coils (c), signal amplifier with filters (d); the control unit is connected to tunable RF generator (10) and oscilloscope (11).

Experiment

A typical scenario of the experiment (please contact the supervisor for details):

- getting familiar with the experimental set up (set the cell temperature in 50˘90^0C range),
- setting both plano – convex lenses to find signal on photo – detector entrance window, all optic elements (lenses, polarizers, filter and the glass Rb cell should be set in one line with Rb lamp and photodiode),
- producing the circular polarization of light (with correct orientations of the linear polarizer and the quarter waveplate; an additional linear polarization is disposal),
- measuring transmission of resonance light (D1 transition) as a function of cell temperature,
- determination of Rb atoms density versus cell temperature,
- compensating of Earth's magnetic field,
- measuring the Zeeman splitting of the ground states of rubidium atoms.

Data analysis

Determine from recorded data the Landé g-factors for ground states of both rubidium isotopes. Determine the direction and magnitude of the local geomagnetic field using magnetic coils constants (see Teach Spin manual) and recorded currents supplying these coils.

References

[1] G. K. Woodgate, *Elementary Atomic Structure*, 2nd ed., ISBN-13: 978-0198511564, ISBN-10: 0198511566

[2] E. Hecht, *Optics*, 4th ed., ISBN-13: 978-0805385663, ISBN-10: 0805385665

[3] W. Demtröder, *Laser Spectroscopy 1: Basic Principles*, 5th ed. 2014 Edition, ISBN-13: 978-3642538582, ISBN-10: 3642538584

[4] H. Haken, H.C. Wolf, *The Physics of Atoms and Quanta: Introduction to Experiments and Theory*, 4th ed. 1994 Edition, ISBN-13: 978-3642975691, ISBN-10: 3642975690

[5] http://www.teachspin.com/optical-pumping.html