Optical pumping: observation of the pumping signal

Objects of the experiment

- Observation of the pumping signal with rapid reversal of the polarity of the Zeeman magnetic field.

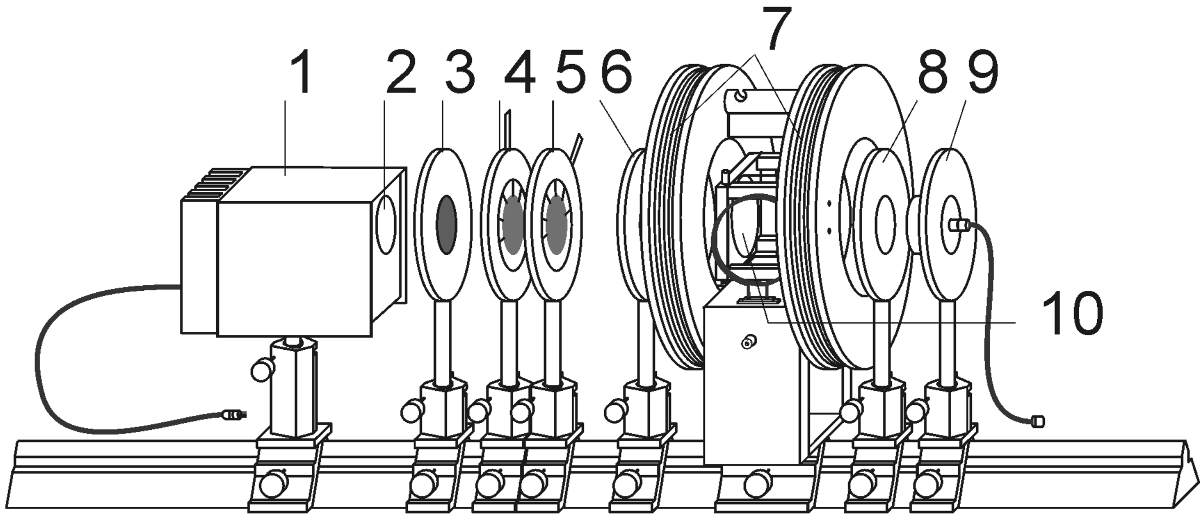

Fig. 1: Optical and magnetic components for the experiment "optical pumping"

1 Rubidium high-frequency lamp
2 Lens, f = + 50 mm
3 Line filter, 795 nm
4 Polarisation filter for red radiation
5 Quarter wavelength panel, 200 nm
6 Lens on brass stem, f = + 100 mm
7 Helmholtz coils, pair
8 Lens on brass stem, f = + 50 mm
9 Silicon photodetector
10 Absorption chamber with rubidium absorption cell

Method

Optical pumping [1,2,3] permits spectroscopic analysis of atomic energy states in an energy range not accessible to direct optical observation.

In weak magnetic fields, the differences in the population number between the Zeeman levels in the ground state of ^{87}Rb are extremely slight, as the energy interval is less than 10^{-8} eV. Optical pumping produces a population which deviates greatly from the thermal equilibrium population. To accomplish this, rubidium vapor is irradiated in an absorption cell with the circularly polarized component of the D_1 light from a rubidium lamp. The population of the Zeeman level depends on the polarity of the incident light. When the cell is irradiated with a high-frequency alternating magnetic field, we observe a change in the transparency of the rubidium vapor for rubidium-D_1 light.

A rubidium high-frequency lamp is used as the pumping light source. Rubidium atoms in a glass ampule are excited in the electromagnetic field of an HF transmitter.

The combination of an interference filter, a polarisation filter and a quarter-wavelength panel separate the desired circularly polarized component of the D_1 line from the emission spectrum of the light source. Depending on the position of the quarter wavelength panel, we obtain either σ^+ or σ^- polarisation.

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A system of convex lenses focuses the pumping light on the center of the absorption cell (also filled with rubidium vapor) and the transmitted component of the pumping light on a photodetector (cf. Fig.4).

The Zeeman magnetic field is generated using Helmholtz coils. Depending on the polarity of the coil current, the field lines are oriented either parallel or antiparallel to the optical radiation.

In its ground state, rubidium, like all alkali metals, has a total spin of the electron shell with the spin quantum number $J = \frac{1}{2}$. The ground state thus splits into two hyperfine states with the total angular momenta $F = I + \frac{1}{2}$ and $F = I - \frac{1}{2}$ respectively.

In the magnetic field, the hyperfine states are each split into $2F + 1$ Zeeman levels with the magnetic quantum numbers $m_F = -F,...,F$. Fig. 2 shows an example of the level diagram for ^{87}Rb.

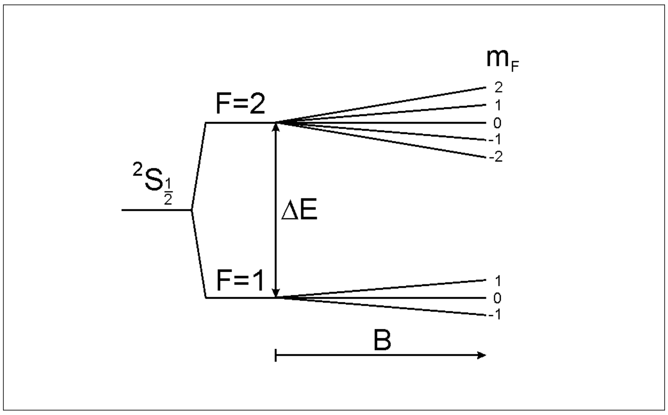

Fig. 2 Schematic representation of Zeeman levels in the ground state of ^{87}Rb Hyperfine splitting ΔE and Zeeman splitting are not drawn to scale.

The energy E of the Zeeman levels can be calculated for the magnetic fields used here with the help of the Breit-Rabi formula [4,5]:

For $F = I \pm \frac{1}{2}$

$$E(F, m_F) = -\frac{\Delta E}{2(2I+1)} + \mu_K g_I B m_F \pm \frac{\Delta E}{2}\left(1 + \frac{4m_F}{2I+1}\xi + \xi^2\right)^{\frac{1}{2}}$$

where $\xi = \frac{g_J \mu_B - g_I \mu_K}{\Delta E} B$ (I)

F : Total angular momentum
I : Nuclear spin
J : Angular momentum of the electron shell
m_F : Magnetic quantum number of the total angular momentum F
g_I : g-factor of the nucleus
g_J : g-factor of the electron shell
ΔE : Hyperfine structure spacing
μ_B : Bohr magneton
μ_K : Nuclear magneton
B : Magnetic flux density

When irradiated with σ^+ pumping light, the Zeeman levels within a hyperfine state which have positive quantum numbers m_F become enriched at the expense of the levels with negative quantum numbers. In the ground state ^{87}Rb for example, the level with $F = 2$, $m_F = +F$ has the greatest population. The result is a population which deviates from the thermal equilibrium population.

When σ^- pumping light is used, the Zeeman levels with negative quantum numbers predominate. In the ground state of ^{87}Rb the level with $F = 2$, $m_F = -F$ has the greatest population.

When the polarisation is changed from σ^+ to σ^-, transitions between the Zeeman levels with $\Delta m_F = -1$ become possible. The transparency of the rubidium vapor changes during these transitions of the Zeeman levels.

In an experiment, we can alter the polarisation of the pumping light most easily by changing the orientation of the magnetic field. To achieve this, the direction of the Helmholtz coil current is reversed using a switch.

The intensity of the transmitted light is measured using a silicon photodetector to determine the change in transparency. A current/voltage converter amplifies the photodetector output signal. The transmitted intensity is recorded as a function of time.

Safety notes

Protecting individuals

Danger of scalding: hot water can leak from insecurely fastened or defective water tubing between the circulation thermostat and the absorption chamber:

- Use only silicon tubing of the specified diameter.
- Clamp the tubes in the holder between the Helmholtz coils and secure them against slippage.

Protecting the equipment

The absorption chamber is made of acrylic glass and can be destroyed by heat:

- Fill the absorption chamber with distilled water only.
- Do not heat the absorption chamber above 80℃.
- Never clean the absorption chamber with solvents.

The homogeneity of the Helmholtz field is impaired if the Helmholtz coil cores become deformed:

- Protect Helmholtz coils from shocks or knocks.

The HF transmitter in the rubidium high-frequency lamp can be destroyed by excessive voltage levels:

- Only operate the rubidium high-frequency lamp with the operation device.

For best experiment results

The experiment setup is sensitive to interfering magnetic fields:

- Keep all power supplies and measuring instruments as far away from the experiment setup as possible.
- Remove ferromagnetic materials or devices which generate magnetic fields from the vicinity of the experiment setup.
- Use only lenses on brass stems (460 021 and 460 031).

Room lighting can drown out the measurement signal at the silicon photodetector. External light unnecessarily raises the DC component of the photodetector signal:

- Switch off the electric lighting in the room.
- Prevent the incidence of external light.
- Darken the experiment room.
- Turn the reflective side of the line filter so that it faces the rubidium high-frequency lamp.

The direction of flow of the heating water in the absorption chamber is determined by the experiment setup:

- Make sure the water inlets and outlets are connected in the proper direction.

High frequencies interfere with voltage-sensitive measuring instruments:

- Do not put a disassembled rubidium high-frequency lamp in operation.

Equipment list

1 Rubidium high-frequency lamp 558 823
1 Pair of Helmholtz coils on stand rider 558 826
1 Absorption chamber
with rubidium absorption cell 558 833
1 Silicon photodetector 558 835
1 I/U converter for silicon photodetector 558 836

1 Operation device for optical pumping 558 814
1 DC power supply, 0...±15 V 521 45
1 Circulation thermostat, +30℃ to +100℃ 666 768
1 Digital storage oscilloscope, e.g. 575 294
1 Plug-in power unit, 9,2V-, regulated 530 88
1 Digital-Analog Multimeter MetraHit24S 531 281
1 Two-way switch 504 48

1 Optical bench, standard cross-section, 1m 460 32
1 Line filter, 795 nm 468 000
1 Polarisation filter for red radiation 472 410
1 Quarter wavelength panel, 200 nm 472 611
1 Lenses on brass stem, f = +50 mm 460 021
1 Lens on brass stem, f = +100 mm 460 031
6 Optical riders 60/34 .... 460 370
1 Optical rider 95/50 .... 460 374

2 Silicone tubing, 1 m long, 6,0x2,0 ...... LN-Nr. 20066843
4 Connecting leads, black 50 cm 501 28
2 Connecting lead, black 200 cm 501 38
2 BNC cables, 1 m 501 02

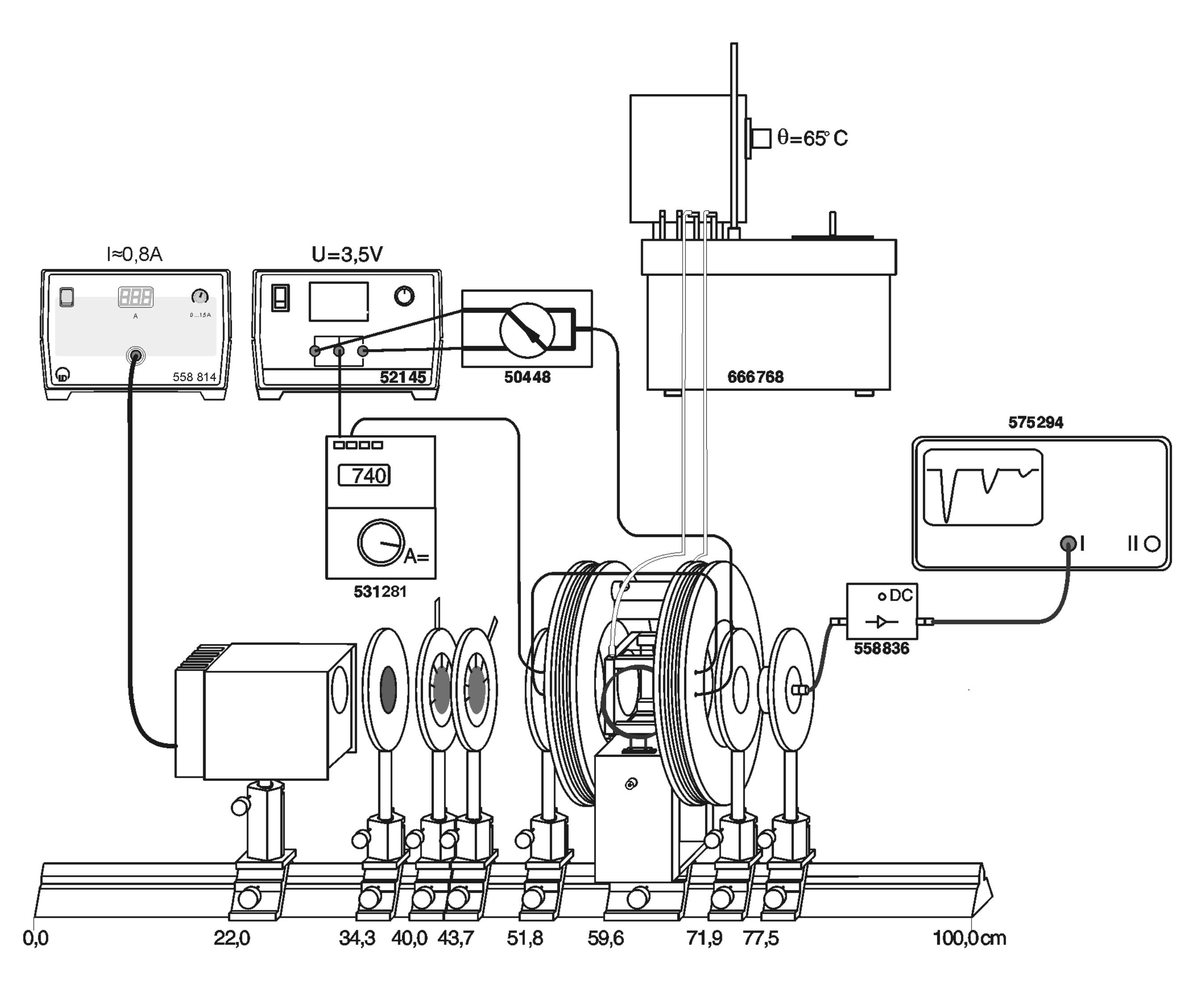

Fig.3: Overview diagram of the entire experiment setup; position specifications are measured from the left edge of the optical riders.

Setup

Optical and electrical setup

- Set up the optical and magnetic components on the optical bench with standard cross-section (460 32) as shown in Fig. 1 and Fig. 3.
- Connect the rubidium high-frequency lamp with the operation device for optical pumping (558 814).
- Connect the Helmholtz coils and the multimeter (531 281) in series to the power supply (521 45).
- Insert the two-way switch (504 48) in the circuit to permit easy reversal of the magnetic field.
- Connect the photodetector output to channel I of the oscilloscope (575 294) via the I/U converter (558 836).

Warming up the system

- Using silicon tubing, set up a heating water circuit between the absorption chamber and the circulation thermostat (666 768) as shown in Fig.3.
- Switch on the circulation thermostat and set the temperature θ to 65°C.
- Switch on the operation device for optical pumping and set the operating current to approx. 0,8 A (cf. instruction sheet for the rubidium high-frequency lamp 558 823).
- Switch on the stabilized power supply.
- Wait at least 15 min. until the operating temperature is reached.

If the light output of the rubidium high-frequency lamp is unstable:

- Increase the operating current by approx. 0,1 A.

Initial optical adjustment

- Remove the optical riders with line filter, polarisation filter and quarter wavelength panel from the optical bench.
- Remove the absorption chamber from the stand rider for the Helmholtz coils.
- Hold a white piece of paper in place of the absorption cell at the midpoint between the Helmholtz coils.
- Move the lense (6) and the rubidium high-frequency lamp so that the smallest possible evenly illuminated light spot is obtained (cf. Fig. 4).

- Remove the optical rider with the silicon photodetector from the optical bench.
- Using the piece of paper, find the point with the smallest evenly illuminated light spot.
- Move lens (8) to improve the illumination (cf. Fig.4).
- Mount the silicon photodetector at the point where the piece of paper is.

When the initial adjustment is complete:

- Remount all components you have removed on the optical bench.

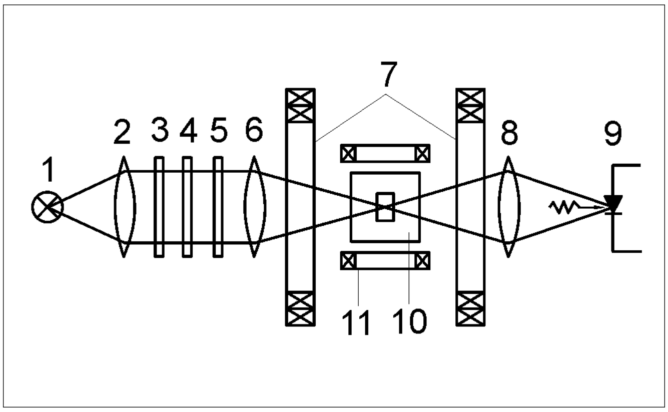

Fig. 4 Schematic representation of the radiation path in optical pumping. For designations of the optical and magnetic components see Fig. 1.

Fine adjustment

To obtain the maximum light intensity at the silicon photodetector:

- Observe the photodetector signal at the oscilloscope.
- Alternately adjust the height and position of the rubidium high-frequency lamp, lenses (6) and (8), the absorption chamber and the silicon photodetector so as to obtain the maximum photodetector signal.
- If necessary, use the offset potentiometer of the I/U converter to bring the signal back to the middle of the oscilloscope screen.

Settings:

Oscilloscope:

Channel I:	10-20 mV/DIV. (DC)

I/U converter:

Toggle switch:	DC

Measuring

Preparation

- Switch on the oscilloscope's storage mode.
- Adjust the horizontal deflection of the oscilloscope using the knob marked X-POS.
- Set the Helmholtz coil current (e.g. $I \approx 0{,}8$ A) to any level.
- Turn off the sensitivity of the Y-deflection of the oscilloscope.

Procedure

- Start oscilloscope storage mode.
- Toggle the two-way switch back and forth.
- Stop recording of the pumping signal.
- Maximize the pumping signal by changing the operating parameters of the rubidium high-frequency lamp and repeat recording.

Settings:

Oscilloscope:

Operating mode:	storage mode
Trigger:	Auto
Y-deflection, channel I:	0,1 V/DIV. DC
Timebase	1 s/DIV.

Polarisation filter:

Angle:	0°

Quarter wavelength panel:

Angle:	+45° or –45°

I/U converter:

Toggle switch:	DC

Measuring example

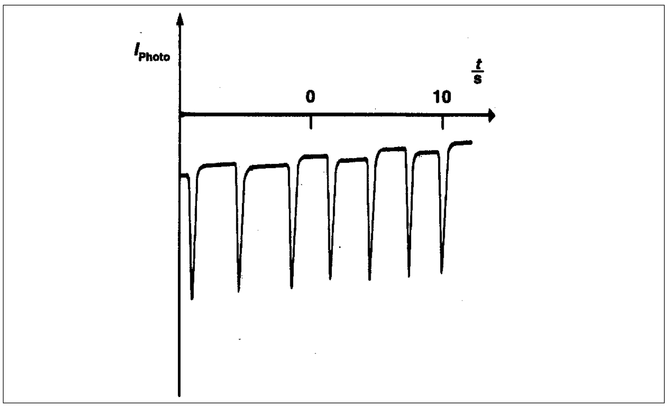

Fig. 5: Transmitted intensity as a function of time for multiple rapid reversals of the Zeeman magnetic field. The amplitude of the signal is a measure of the quality of the adjustment.

Literature

[1] A.Kastler: Journal de Physique, 11 (1950) 255

[2] H. Kopfermann: Über optisches Pumpen an Gasen, Sitzungsberichte der Heidelberger Akademie der Wissensschaften, Jahrgang 1960, 3. Abhandlung

[3] J. Recht, W. Klein: LH-Contact 1 (1991) pp. 8 -11

[4] G. Breit, I. Rabi: Phys. Rev. 38 (1931) 2002

[5] Kopfermann, H.: Kernmomente, 2nd ed., pp. 28ff