Hyperfine Paschen–Back regime of potassium D₂ line observed by Doppler-free spectroscopy

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Abstract

Selective reflection of a laser radiation from an interface formed by a dielectric window and a potassium atomic vapour confined in a nano-cell with 350 nm gap thickness is implemented for the first time to study the atomic transitions of K D₂ line in external magnetic fields. In moderate B-fields, there are 44 individual Zeeman transitions which reduce to two groups (one formed by σ⁺, the other one by σ⁻ circularly-polarised light), each containing eight atomic transitions, as the magnetic field increases. Each of these groups contains one so-called ‘guiding’ transition whose particularities are to have a probability (intensity) as well as a frequency shift slope (in MHz G⁻¹) that are constant in the whole range of 0–10 kG magnetic fields. In the case of π-polarised laser radiation, among eight transitions, two are forbidden at B = 0, yet their probabilities undergo a giant modification under the influence of a magnetic field. We demonstrate that for B-fields > 165 G a complete hyperfine Paschen–Back regime is observed. Other peculiarities of K D₂ line behaviour in magnetic field are also presented. We show a very good agreement between theoretical calculations and experiments. The recording of the hyperfine Paschen–Back regime of K D₂ line with high spectral resolution is demonstrated for the first time.

Keywords: nano-cell, potassium D₂ line, selective reflection, Doppler-free spectroscopy, narrow optical resonance, magnetic field

(Some figures may appear in colour only in the online journal)

1. Introduction

It has recently been demonstrated that the selective reflection (SR) of a laser radiation from an interface of dielectric window and atomic vapour confined in a nano-cell (NC) with a thickness of a few hundred nanometres is a convenient tool for atomic spectroscopy [1–3]. The real-time derivative of SR signal (dSR), where each frequency position of the recorded peaks coincides with the atomic transition one, is used and provides a 30–50 MHz spectral resolution with linearity of the signal response with respect to the transition probabilities [1]. The large amplitude and the sub-Doppler width of a detected signal in addition to the simplicity of the dSR-method make it appropriate for applications in metrology and magnetometry. In particular, the dSR-method provides a convenient frequency marker for atomic transitions. Experimental and theoretical spectra of the SR and dSR signals (which have very different shapes) are presented in [1]. With the dSR-method, a complete frequency-resolved hyperfine Paschen–Back (HPB) splitting of ten atomic transitions (four for ⁸⁷Rb and six for ⁸⁵Rb) was recorded in a strong magnetic field (B > 2 kG) [1]; similar results for Cs have been reported in [2]. In [3], we have implemented the dSR-method for atomic layers having thicknesses of a few tens of nanometres to probe atom-surface interactions and we have observed a 240 MHz red-shift for a cell thickness L ~ 40 nm.
One of the reason why K atomic vapours are less frequently used as compared to Rb or Cs ones is the following: for a temperature \( \sim 100 \, ^\circ\text{C} \) the Doppler-broadening is \( \sim 0.9 \, \text{GHz} \), which exceeds the hyperfine splitting of the ground and excited levels (\( \sim 462 \, \text{MHz} \) and \( \sim 10-20 \, \text{MHz} \), correspondingly) such that the transitions \( F_1 = 1, 2 \rightarrow F_2 = 0, 1, 2, 3 \) of \( ^{39}\text{K} \) are completely masked by the Doppler-profile. Therefore, there is a small number of papers concerning the laser spectroscopy of potassium: the accurate identification of atomic transitions of K was reported in [4, 5]; saturated absorption (SA) spectra of the \( D_1 \) line of potassium atoms have been studied in details both theoretically and experimentally in [6]. Potassium vapours were used for the investigation of nonlinear magneto-optical Faraday rotation in an antirelaxation paraffin-coated cell [7], polarisation spectroscopy and magnetically induced dichroism for magnetic fields in the range of 1–50 G [8], formation of dark resonance having a sub-natural linewidth [9], electromagnetically induced transparency (EIT) in a nano-cell [10] and four-wave mixing process [11]. A theory describing the transmission of Faraday filters based on sodium and potassium vapours is presented in [12]. Feshbach resonances in ultracold \( ^{39}\text{K} \) have been reported in [13].

In external magnetic field, there is an additional splitting of the energy levels which causes the formation of a number of atomic transitions spaced by a frequency interval of \( \sim 100 \, \text{MHz} \) in the HPB regime; that is why a Doppler-free method must be implemented to perform an efficient study of atomic transitions of K vapours. In this paper we demonstrate that the dSR-method is a very convenient one to investigate the behaviour of an individual transition of \( ^{39}\text{K} \) \( D_2 \) line (energy levels are shown in figure 1(a)). The particularity of \( ^{39}\text{K} \) is a small characteristic value of magnetic field \( B_0 = A_{hf} / \mu_B = 165 \, \text{G} \) at which the HPB regime starts as compared to other alkalis such as \( ^{133}\text{Cs} \) \( (B_0 = 1700 \, \text{G}) \) and \( ^{85}\text{Rb} \) \( (B_0 = 700 \, \text{G}) \), \( ^{87}\text{Rb} \) \( (B_0 = 2400 \, \text{G}) \) isotopes [14–17]; where \( A_{hf} \) is the magnetic dipole constant for \( ^{4}\text{S}_{1/2} \) ground level and \( \mu_B \) is the Bohr magneton. Hence, there is a significant change in atomic transition probabilities of \( ^{39}\text{K} \) \( D_2 \) line for relatively small magnetic fields, at least by an order smaller as compared to other alkalis. To our best knowledge, the recording of the HPB regime of K \( D_2 \) line with high spectral resolution is demonstrated for the first time. Note that in the work [18], a 1 mm thick cell filled with \( ^{87}\text{Rb} \) has been used to detect the HPB regime for magnetic fields about 6 kG. Although the Doppler linewidth of the atomic transition is \( \sim 600 \, \text{MHz} \), \( ^{87}\text{Rb} \) atomic transitions have been spectrally separated thanks to the large frequency interval (\( \geq 1 \, \text{GHz} \)) between them. Meanwhile in the case of \( ^{39}\text{K} \) vapour, the Doppler linewidth is about 900 MHz, while the frequency interval between the atomic transitions is nearly 100 MHz (for magnetic field \( \sim 500 \, \text{G} \)), that is why a 1 mm thick cell is not appropriate.

2. Experimental arrangement

Figure 1(b) shows the layout of the experimental setup. A frequency-tunable cw narrowband (\( \gamma_L \sim 2\pi \cdot 1 \, \text{MHz} \)) extended cavity diode laser with \( \lambda = 766.7 \, \text{nm} \) wavelength, protected by a Faraday isolator (FI), emits a linearly polarised radiation directed at normal incidence onto a K nano-cell mounted inside the oven. A quarter-wave plate, placed in between the FI and the NC, allows to switch between \( \sigma^- \) (left-hand) and \( \sigma^+ \) (right-hand) circularly-polarised radiation. The NC is filled with natural potassium that consists of \( ^{39}\text{K} \) (93.26%) and \( ^{41}\text{K} \) (6.73%) atoms, and the details of its design can be found in [19, 20]. The necessary vapour density \( N \sim 1.2 \times 10^{13} \, \text{cm}^{-3} \) was attained by heating the cell’s thin sapphire reservoir (R) containing metallic potassium to \( T_R \sim 150 \, ^\circ\text{C} \) [21] (we took into account that there is 93.26%
of $^{39}$K), while keeping the window temperature some 20 °C higher.

A longitudinal magnetic field $\mathbf{B} \parallel \mathbf{k}$ up to 1 kG, where $\mathbf{k}$ is the wavevector of the laser radiation, was applied using a permanent neodymium–iron–boron alloy magnet placed near the output window of the NC. The variation of the field strength was achieved by axial displacement of the magnet system and was monitored by a calibrated magnetometer ‘Teslameter HT201’. In spite of a strong spatial gradient of the field produced by the permanent magnet, the variation of $B$-field inside the interaction region is negligible as compared to the amplitude of $B$ [22]. The right inset of figure 1(b) shows the photograph of the K NC where one can see interference fringes formed by light reflection from the inner surfaces of the windows because of variable thickness $L$ of the vapour column across the aperture.

The SR measurements (geometry of the reflected laser beams presented in the left inset) were performed for $L \approx 350 \text{ nm}$. Although the decrease of $L$ improves the spatial resolution (which is very important when using high-gradient field permanent magnets), it simultaneously results in a broadening of the SR spectral linewidth; therefore $L = 350 \text{ nm}$ appears as the optimal thickness. This additional broadening is a result of atom-wall collisions: the reduction of the thickness $L$ between the windows shortens the flight time of atoms toward the surface, determined as $t = L/v_c$ ($v_c$ is the projection of the thermal velocity perpendicular to the window plane), thus making atom-wall collisions more frequent and leading to additional broadening. To form a frequency reference, a part of the laser radiation was branched to an auxiliary SA setup formed in a 1.4 cm long K cell.

3. **Theoretical considerations**

In this section, we give the outline of our theoretical model, additional details on the calculations of dSR spectrum are found in [2, 23]. The problem of calculating the spectrum of alkaline vapours confined in a NC when a longitudinal $B$-field is applied can be split in two points: the calculation of the transition probabilities and frequencies [24], and the calculation of the line profile inherent to the NC properties [25–27].

3.1. **Transition probabilities and frequencies under magnetic field**

The starting point for spectroscopic analysis of alkali vapours under longitudinal magnetic field is to write down the Hamiltonian of the system $H_0$, as the sum of the hyperfine structure Hamiltonian $H_0$ modified by the magnetic interaction, such that

$$H_m = H_0 + \frac{\mu_B}{\hbar} \mathbf{B} \cdot (g_e \mathbf{L}_e + g_S \mathbf{S}_e + g_I \mathbf{I}_e),$$

where $\mathbf{L}_e$, $\mathbf{S}_e$, and $\mathbf{I}_e$ are respectively the projection of the orbital, electron spin and nucleus spin momentum along $z$, chosen as the quantisation axis; $g_{e,S,I}$ are the associated Landé factors (for the sign convention, see [28]). Details of the construction of the Hamiltonian in the base $\{F, m_F\}$ can be found in [24]. The transitions probabilities $W_{eg}$ are proportional to the square of the dipole moment $\mu_{eg}$ between the states $|e\rangle$ and $|g\rangle$

$$W_{eg} \propto \sum_{F,E'F'} c_{E'E} a(F'_{eg}, m_{e}; F_{gE}, m_{g}; q) c_{E'E},$$

with the coefficients $c_{E'E}$ given by the eigenvectors of diagonalized $H_m$ matrix and $a(F_{eg}, m_{e}; F_{gE}, m_{g}; q)$ are the unperturbed transfer coefficients, defined as

$$a(F_{eg}, m_{e}; F_{gE}, m_{g}; q) = \frac{(-1)^{1+I+L+E+P_{T}}}{{\sqrt{2L + 1}} \sqrt{2F_e + 1}} \sqrt{2F_g + 1}$$

$$\times \left\{ F_e 1 F_g \left\{ F_e 1 F_g \left\{ F_e 1 F_g \left\{ F_e 1 F_g \right\} \right\} \right\},$$

where the parentheses and the curly brackets denote the 3- and 6-j coefficients, respectively; $q = 0, \pm 1$ is associated to the polarisation of excitation such that $q = 0$ for a $\pi$-polarised laser field, $q = \pm 1$ for a $\sigma^\pm$-polarised laser field.

3.2. **Line profile**

The transition lineshape of atoms confined in thin cells having a gap between their windows of the order of the laser wavelength has been deeply studied in [25–27]. The resonant contribution to the reflected signal reads (in intensity)

$$S_v \approx 2 \frac{t_{w\text{w}}}{\mu_B} \Re \{ r_v [1 - \exp(-2ikL)] \} \times \left[ I_b - r_v I_f \exp(2ikL) \right] E_{in},$$

where $t_{w\text{w}}$, $r_w$ are respectively transmission and reflection coefficients, $Q = 1 - r_v^2 \exp(2ikL)$ is the quality factor associated to the NC of thickness $L$ and $E_{in}$ is the incident electric field amplitude; $I_f$ and $I_b$ are integrals of the polarisation due to direct and backscattered laser radiation

$$I_f = \frac{ik}{2e_0} \int_0^L P_0(z) dz, \quad I_b = \frac{ik}{2e_0} \int_0^L P_0(z) \exp(2ikz) dz.$$
vapour with the laser radiation, and the matrix \( \propto + \) homogeneous relaxation processes; \( \{a, b\} = ab + ba \) is the anticommutator.

where \( H \) is the Hamiltonian describing the interaction of the vapour with the laser radiation, and the matrix \( I' \) accounts for homogeneous relaxation processes; \( \{a, b\} = ab + ba \) is the anticommutator.

4. Results and discussion

4.1. Circular polarisation analysis

On figure 2(a), the red curves show dSR experimental spectra in the case of \( \sigma^- \) circularly-polarised laser radiation for five different values of the applied longitudinal magnetic field, from bottom to top: 470, 500, 690, 720 and 780 G. The complementary study with a \( \sigma^+ \) circularly-polarised excitation for the \( B \)-field values of 530, 590, 680 and 800 G is shown on figure 2(b). The spectra are recorded for a reservoir temperature \( T_R \approx 150 \, ^\circ \text{C} \), a laser power \( P_L \approx 0.1 \, \text{mW} \), and atomic transitions linewidth \( \approx 80 \, \text{MHz} \) full width at half maximum.

It is worth to note that the dSR amplitudes are proportional to the relative probabilities presented in figure 3. As it is seen from figure 2(a), there are two groups formed by transitions \( I' \rightarrow J' \) and \( \Theta' \rightarrow \varnothing' \) and all these eight transitions whose diagram is shown in the inset of figure 3(a) are well seen. The same remark holds for transitions \( 1 \rightarrow 8 \) and \( 16 \rightarrow 29 \) from figure 2(b) (transition diagram shown in the inset of figure 3(b)). Note that for a given group, the amplitudes of the transitions are equal to each other with the frequency intervals between them being nearly equidistant. These peculiarities as well as the strict number of atomic transitions which remain the same with increasing magnetic field are evidences of the establishment of Pashen–Back regime. Transitions labelled \( \Theta' \) and \( \Theta \) are the so-called ‘guiding’ transitions (GT) [20, 29]; their probability as well as their frequency shift slope remain the same \( (s = \pm 1.4 \, \text{MHz G}^{-1}) \) in the whole range of applied \( B \)-fields.

The lower (black) curves show SA spectra for \( B = 0 \). As shown in [30], the existence of crossover lines makes the SA technique useless for a spectroscopic analysis for \( B \gg 100 \, \text{G} \). The blue curves show the calculated dSR spectra of \( ^{39}\text{K} \) and \( ^{41}\text{K} \) isotopes with the linewidth of 80–100 MHz for \( \sigma^- \) (figure 2(a)) and \( \sigma^+ \) (figure 2(b)) polarised laser radiations. As it is seen, there is a very good agreement between the experiment and the theory. Although there is only 6.73% of \( ^{41}\text{K} \) isotope in natural K, a much better agreement with the experiment is realised when \( ^{41}\text{K} \) levels are also included into theoretical considerations; particularly the peaks shown by the arrows in figure 2(b) are caused by the influence of \( ^{41}\text{K} \) isotope. A very good agreement between the experiment and the theory can be seen for both polarisations and all applied magnetic fields.

It is important to note that at a relatively small magnetic field \( B \sim 400 \, \text{G} \) the two groups are already well formed and separated which is, as mentioned earlier, a consequence of the small value of \( B_0(\text{K}) = 165 \, \text{G} \). In order to detect similar well formed groups for \( ^{87}\text{Rb} \) atoms, one must apply a much stronger magnetic field of \( B \sim 6 \, \text{kG} \) since \( B_0(\text{Rb}) / B_0(\text{K}) \sim 15 \) [3, 16]. It is also interesting to note that the total number of atomic transitions for both circularly-polarised laser excitations is 44 when \( B \sim B_0(\text{K}) \sim 150 \, \text{G} \), while for \( B \gg B_0(\text{K}) \) only 16 transitions remain: this is the manifestation of the HPB regime.
Figure 3 shows the transition probabilities versus magnetic field for (a) $1'\rightarrow 4'$ and $5'\rightarrow 8'$ transitions versus $B$-field for a $\sigma^-$-polarised excitation. (b) Evolution of the probabilities of $1-4$ and $5-\mathfrak{g}$ transitions versus $B$-field for a $\sigma^+$-polarised excitation. The insets show the corresponding atomic transitions diagrams of $^{39}$K D$_2$ line in the HPB regime, expressed in the basis $|n, mj\rangle$ (uncoupled basis). Selection rules for the transitions are $\Delta mj = \pm 1, \Delta mI = 0$ for $\sigma^\pm$-polarised light. For simplicity, only the transitions that remain in the spectrum for strong magnetic field are presented.

Figure 4. Calculated magnetic field dependence of the frequency shifts of $^{39}$K D$_2$ line, for the transitions $1-4$ and $5-\mathfrak{g}$ ($\sigma^+$ excitation) and for the transitions $1'-4'$ and $\mathfrak{g}'-8'$ ($\sigma^-$ excitation). The guiding transitions $\mathfrak{g}$ and $\mathfrak{g}'$ are indicated.

Figure 5. K D$_2$ line, for $\pi$-polarised radiation recorded and calculated for $B = 300, 380, 480, 680$ G. The red and blue traces show respectively the experimental and theoretical dSR spectra of $^{39}$K and $^{41}$K atoms, with a linewidth $\sim 120$ MHz, NC’s thickness $L = 350$ nm, $P_t = 0.1$ mW, and $T_R \sim 150$ °C. The lower curve is the SA spectrum that serves as a frequency reference. The transitions $\mathfrak{g}$ and $\mathfrak{g}'$ are IFFA transitions (see the text). The dashed lines show the frequency position of the atomic transitions and are drawn for convenience.

Figure 3 shows the transition probabilities versus magnetic field for (a) $1'-4'$ and $\mathfrak{g}'-8'$ transitions ($\sigma^-$ excitation) and for (b) $1-4$ and $5-\mathfrak{g}$ transitions ($\sigma^+$ excitation); for labelling, see the transition diagrams in insets. As we see, the transition probabilities inside the groups $1-4$ and $1'-4'$ for $B \gg 165$ G tend asymptotically to the same value (0.0625); the same remark can be made for the groups $5-\mathfrak{g}$ and $\mathfrak{g}'-8'$ which probabilities tend to the one of the GT $\mathfrak{g}$ and $\mathfrak{g}'$ (0.185). The later remarks are another peculiarities of the HPB regime.

The calculated magnetic field dependence of the transition frequency shifts under circularly-polarised excitation is presented on figure 4. The frequency slope of transitions $5-\mathfrak{g}$ tends asymptotically to the same value of the GT transition $\mathfrak{g}$ ($\sigma^+ = +1.4$ MHz G$^{-1}$), while the frequency slope of transitions $\mathfrak{g}'-8$ transitions tends to the one of the GT transition $\mathfrak{g}'$ ($\sigma^- = -1.4$ MHz G$^{-1}$). Note that having a frequency reference (for example, the transition $F_g = 2 \rightarrow F_g = 1, 2, 3$), the magnetic field can be determined from the frequency shift of the transition labelled 1 using the respective curve shown in figure 4 in a wide range of $B$-fields with $350$ nm spatial resolution [3] (for magnetic fields $>10$ G, the...
transition labelled 1 is not overlapped with any other transition).

4.2. Linear polarisation analysis

To achieve a linear ($\pi$) polarisation excitation of the K vapour, the experimental setup presented on figure 1(b) is slightly modified: the B-field is directed along the laser electric field $E (\| B_{laser})$, the $\lambda/4$ plate is removed and two permanent magnets are used to set the $B\| E$ configuration.

In figure 5, the red curves represent dSR experimental spectra obtained for $B = 300, 380, 480, 680 \text{ G}$, with $T_R \sim 150 \text{ }^\circ\text{C}$ and a $\pi$-polarised laser radiation having a power $P_L = 0.1 \text{ mW}$. The blue lines show the theoretical calculations with the corresponding experimental parameters. As we see there are eight well resolved transitions, labelled 1–8, having amplitudes that tend asymptotically to the same value (see figure 6(a)). Note that, in this case, the transition line-width is a bit larger ($\sim 120 \text{ MHz}$) which is caused by inhomogeneities of the transverse magnetic field across the laser beam diameter of 1 mm. The magnetic field dependence of their transition frequencies is presented on figure 6(b).

The transitions 2 and 6 are IFFA transitions (see the text).

Figure 6. Calculated probabilities (a) and frequency shifts (b) of $^{39}\text{K} \text{D}_2$ line $F_r = 1, 2 \rightarrow F_e = 0, 1, 2, 3$ transitions versus magnetic field for $\pi$-polarised laser radiation. For readability, (c) shows the evolution of the transitions probabilities in the range 0–50 G. Figure (d) represents the transition diagram (in the uncoupled basis $|m_I, m_F\rangle$) for the HPB regime. Selection rules for the transitions are $\Delta m_J = 0, \Delta m_I = 0$. The transitions 2 and 6 are IFFA transitions (see the text).
The peculiarities of the atomic transitions behaviour of K in the
HF regime is different in the case $D_1$ and $D_2$ lines: (i) as
discussed earlier there are two groups of eight transitions
together with $\sigma^+$ and $\sigma^-$ circularly-polarised light for the
$D_2$ line and each of these groups contains one GT. Meanwhile,
in the case of $D_1$ line there are two groups of only four
transitions, one for each circularly-polarised light, and the GT
are absent. (ii) In the case of $\pi$-polarised laser radiation, the
spectrum of K $D_2$ is composed by eight atomic transitions,
including two IFFA transitions, meanwhile the one of the $D_1$
line counts two GT and two IFFA transitions.

Investigation of the modification of the transition frequencies and probabilities for K $D_1$ line using absorption
spectroscopy from a NC was reported in [20]. The small
number of atomic transitions (four for each circular polarisation)
and the narrowing of the spectra due to the Dicke effect at $L = \lambda/2 = 385 \text{ nm}$ [33] were the reasons that the
resolution of the recorded spectra was sufficient enough.
However, due to a larger number of atomic transitions (eight)
formed by circularly-polarised laser radiation, absorption
spectra of K $D_2$ line in NC are strongly broadened. For this
reason, we illustrate on figure 7 the advantage of the dSR-
technique over the conventional absorption one. In this figure,
the upper blue trace shows the absorption spectrum of K $D_2$
line obtained from a NC with $L = 350 \text{ nm}$ and $\sigma^+$ laser
excitation and a magnetic field set as $B \sim 600 \text{ G}$. Although
the eight absorption peaks are slightly resolved, they have big
pedestals which overlap with one another, causing strong
distortions in amplitudes. In order to get the correct ones, one
needs to perform a not trivial fitting due to a special
absorption profile inherent to the NC. Meanwhile, the middle
curve shows the corresponding dSR spectrum, where eight
atomic transitions are completely resolved. Thus, for K $D_2$
line selective reflection technique is strongly preferable.

As mentioned earlier, a remarkable property of K atoms
is that the HPB regime occurs at very small magnetic field as
compared to widely used Rb and Cs atoms, and magneto-
optical studies using the HPB regime can be realised with a
much smaller magnetic field. Particularly, in [14], a complete
HPB regime was achieved for the $^{133}$Cs $D_2$ line for a
magnetic field $B = 27 \text{ kG}$. Using an additional laser and
optical pumping process of the ground-state sublevel a high
polarisation of nuclear momentum was achieved. Similar
results could be obtained with K atomic vapour for ten
times smaller magnetic field $B \sim 2.5 \text{ kG}$, because

$$B_0^{(41K)} / B_0^{(133Cs)} \sim 10.$$  

Let us note that the energy-level structure for the isotope
$^{41}$K is very similar to that of $^{39}$K, while the hyperfine splitting
for the ground and excited levels are smaller [34, 35]. Parti-
cularly, the hyperfine splitting of the ground $4S_{1/2}$ level is
254 MHz, which is 1.8 times smaller than the one of $^{39}$K. This
means that the constant $B_0^{(41K)} \sim 90 \text{ G}$ and the HPB regime
is achieved at smaller magnetic field. In addition, the structure
of $^{41}$K spectrum in strong longitudinal magnetic field is the
same as $^{39}$K: two groups of eight transitions are recorded
for circularly-polarised excitation, each of these groups con-
taining one GT. In the case of $\pi$-polarised radiation, one can
count eight transitions from which two are IFFA transitions.

Transitions of $^{41}$K follow the same behaviour than the ones of
$^{39}$K (see figures 3 and 6(a)), while equivalent probabilities are
reached at a smaller magnetic field strength.

5. Conclusion

We have demonstrated that, despite a large Doppler width
of atomic transitions of potassium, SR of laser radiation from a
K atomic vapour confined in a NC with a 350 nm gap
thickness allows to realise close to Doppler-free spectroscopy.
Narrow linewidth and linearity of the signal response with
respect to transition probabilities [1] allow us to detect, in an
external longitudinal magnetic field, separately two groups
each of them composed by eight transitions and formed either
by $\sigma^+$- or $\sigma^-$-polarised light.

We have also showed that the dSR-method provided much
better spectral resolution ($\sim$80 MHz) than that based on the
absorption spectrum realised in NC with a thickness $L \sim \lambda/2$,
since narrow linewidth of the transitions allows one to avoid
overlapping of the nearly located atomic transitions; here, the
frequency separation between transitions is $\sim 100 \text{ MHz}$.
The theoretical model describes the experiments very well. The experimental results along with calculated magnetic field dependence of the frequency shifts and the probabilities for 1→4 (1′→4′) and 5−→ (5′→8′) transitions under \( \sigma^+ \) (\( \sigma^- \)) laser radiation, as well as the one for transitions 1–8 transitions observed in the case of \( \pi \)–polarised laser excitation and the detection of two IFFA transitions give the complete picture of potassium \( D_2 \) line atomic transitions behaviour in magnetic field.

The implementation of this recently developed setup based on narrowband laser diodes, strong permanent magnets, and dSR-method using NC allows one to study the behaviour of any individual atomic transition of \( ^{39}\text{K} \) atoms as well as of \( ^{23}\text{Na}, ^{85}\text{Rb}, ^{87}\text{Rb}, ^{133}\text{Cs} \) \( D_1 \) and \( D_2 \) lines. Particularly, the NC-based dSR-method could be a very convenient tool for the study of \( ^{23}\text{Na} \) atomic vapour, since the atomic transitions are masked under a huge Doppler width of \( \sim 1.5 \) GHz in conventional spectroscopic experiments.

It should be noted that a recently developed fabrication process of a glass NC [36], much simpler than the one using sapphire materials, will make the NC-based dSR-technique widely available for researchers.

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