An experimental determination of quantum defects of ng and nh series for $^{85}\text{Rb}$

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**Motivation**
- Calculations of the Stark effect
- Ionic dipole and quadrupole polarizabilities of atoms (clock applications, etc)

**Previous Experimental Values**

<table>
<thead>
<tr>
<th></th>
<th>$\delta_g$</th>
<th>$\delta_h$</th>
<th>$\alpha_d\ (a_0^3)$</th>
<th>$\alpha_q\ (a_0^5)$</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Han (2006)</td>
<td>0.00400(9)</td>
<td>N/A</td>
<td>8.9 &lt; $\alpha_d$ &lt; 9.3</td>
<td>0 &lt; $\alpha_q$ &lt; 43</td>
<td>Two photon MW spectroscopy</td>
</tr>
<tr>
<td>Afrousheh (2006)</td>
<td>0.00405(6)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Electric-field induced resonant energy transfer</td>
</tr>
<tr>
<td>Johnson (2011)</td>
<td>0.00402(8)</td>
<td>0.0015(2)</td>
<td>8.5 &lt; $\alpha_d$ &lt; 9.7</td>
<td>0 &lt; $\alpha_q$ &lt; 55</td>
<td>MW spectroscopy</td>
</tr>
</tbody>
</table>
Experimental Setup

**Energy level diagram**

- **480nm LASER Pulse**
- **Microwave Pulse**
- **Field Ionization Pulse**

**Timing Diagram**

- **B Field off**
- **4ms**
- **500ns**
Experiment Overview

Measure **(zero field)** d->g and d->h energy intervals using microwave spectroscopy

\[ E_{n\ell j} = -\frac{1}{2(n - \delta_{n\ell j})^2} \]

quantum defect

Determine quantum defects of g and h

Adiabatic core polarization theory

Determine the polarizabilities of Rb+ ionic core

**Challenges**

1. As \( l \) increases, the intervals between \( l \) states decreases
2. As \( l \) increases, the Stark shift due to small stray fields become a significant problem
3. In our setup (and in many other), the electric field cannot be nulled in all directions
The Transition

-> Identify and use the low field parameter which depends on the static field $E_s$, not its square $E_s^2$ to obtain zero field energy intervals
Simple Minded Approach

Frequency vs. Applied Bias (in one direction only)

\[ \Delta W \propto E_s^2 \]
A Better Approach

Frequency vs. Signal Amplitude

\[
\Omega = \frac{\langle (n + 1)d|\mu E_{mw}|nf\rangle \langle nf|\mu E_S|ng\rangle}{W_{ng} - W_{nf}}
\]

![Graph showing frequency vs. signal amplitude with various microwave frequencies and signal amplitudes. The graph displays multiple curves representing different signal amplitudes such as 0.61 V, 0.56 V, 0.51 V, 0.46 V, and 0.34 V. The x-axis is labeled as Microwave Frequency (GHz), and the y-axis is labeled as 28g Signal (arb. units).]
Dipole and Quadrupole Polarizabilities

\[ W_{\text{pol},nl} = -\frac{\alpha_d}{2} \langle 1/r_{nl}^4 \rangle - \frac{\alpha_q}{2} \langle 1/r_{nl}^6 \rangle \]

\[ \frac{\delta_{nl}}{n^3} = \frac{\alpha_d}{2} \langle 1/r_{nl}^4 \rangle + \frac{\alpha_q}{2} \langle 1/r_{nl}^6 \rangle \]

\[ 2 \frac{\delta_{nl}}{n^3 \langle 1/r_{nl}^4 \rangle} = \alpha_d + \alpha_q \frac{\langle 1/r_{nl}^6 \rangle}{\langle 1/r_{nl}^4 \rangle} \]
## Results and Comparison

\[ \delta_g = 0.0039741(16) \]
\[ \delta_h = 0.0014066(57) \]

<table>
<thead>
<tr>
<th></th>
<th>( \alpha_d ) ((a_0^3))</th>
<th>( \alpha_q ) ((a_0^5))</th>
</tr>
</thead>
<tbody>
<tr>
<td>This work</td>
<td>9.12(2)</td>
<td>14(3)</td>
</tr>
<tr>
<td>Other works</td>
<td>8.9 &lt; ( \alpha_d ) &lt; 9.3 ((\text{Exp})[12])</td>
<td>0 &lt; ( \alpha_q ) &lt; 43 ((\text{Exp})[12])</td>
</tr>
<tr>
<td></td>
<td>8.5 &lt; ( \alpha_d ) &lt; 9.7 ((\text{Exp})[13])</td>
<td>0 &lt; ( \alpha_q ) &lt; 55 ((\text{Exp})[13])</td>
</tr>
<tr>
<td></td>
<td>8.98 ((\text{Exp})[14])</td>
<td>35.4 ((\text{Th})[11])</td>
</tr>
<tr>
<td></td>
<td>9.1 ((\text{Th})[11])</td>
<td>38.37 ((\text{Th})[30])</td>
</tr>
<tr>
<td></td>
<td>9.11 ((\text{Th})[31])</td>
<td>35.41 ((\text{Th})[29])</td>
</tr>
<tr>
<td></td>
<td>9.076 ((\text{Th})[29])</td>
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Conclusion

• A new experimental technique was adopted to measure zero-field frequency of d->g and d->h transitions for $^{85}\text{Rb}$

• From the data, ng and nh series quantum defects of $^{85}\text{Rb}$ was extracted

• From the quantum defects, the ionic dipole and quadrupole polarizabilities of $^{85}\text{Rb}$ was determined

• The values agree well with the previous measurements, and have less uncertainty

Acknowledgement

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Microwave spectroscopy of the cold rubidium $(n+1)\, d_{5/2} \rightarrow ng$ and $nh$ transitions

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