Sokolov Effect

Long-Range Interaction of Hydrogen with Metal Surface

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Outline

1 Background
   - Neutral Hydrogen
   - Stark Effect
   - Hydrogen Atom Interferometer
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2 Sokolov Effect
   - Pamir
   - Broken Theories
   - Summary
   - Dysprosium
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3 Conclusions
Energy Levels of Hydrogen

\[
\begin{align*}
2S & \quad \quad \quad 2P \\
1S & 
\end{align*}
\]
Energy Levels of Hydrogen

- Lifetime of 2 P states is \( \sim 1.5 \) ns

\( 1\text{S} \rightarrow 2\text{S} \rightarrow 2\text{P} \)
Energy Levels of Hydrogen

- Lifetime of 2 P states is \( \sim 1.5 \text{ ns} \)
Energy Levels of Hydrogen

- $1S_{1/2}$
- $2S_{1/2}$
- $2P_{1/2}$
- $2P_{3/2}$

- Lifetime of $2P$ states is $\sim 1.5$ ns
- Fine-Structure effects lift degeneracies
Energy Levels of Hydrogen

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Energy Levels of Hydrogen

- Lifetime of 2 P states is $\sim 1.5 \text{ ns}$
- Fine-Structure effects lift degeneracies
- Lamb Shift is on the order of 1 GHz
(Nearly) Degenerate Perturbation Theory

\[ H' = d E_o + \frac{\delta L_S}{2}(|2S_{1/2}><2S_{1/2}| - |2P_{1/2}><2P_{1/2}|) \]
(Nearly) Degenerate Perturbation Theory

\[ H' = dE_o + \frac{\delta_{LS}}{2}(|2S_{1/2}><2S_{1/2}| - |2P_{1/2}><2P_{1/2}|) \]

- \[ H'_{nm} = \begin{pmatrix} \frac{\delta_{LS}}{2} & d_{SP} E_o \\ d_{SP} E_o & -\frac{\delta_{LS}}{2} \end{pmatrix} \]

- Eigenvalues are
\[ \pm \frac{1}{2} \sqrt{\delta_{LS}^2 + 4E_o^2d_{sp}^2} \]
(Nearly) Degenerate Perturbation Theory

\[ H' = d E_o + \frac{\delta_{LS}}{2} (|2S_{1/2}><2S_{1/2}| - |2P_{1/2}><2P_{1/2}|) \]

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- Eigenvalues are
  \[ \pm \frac{1}{2} \sqrt{\delta_{LS}^2 + 4E_o^2 d_{sp}^2} \]

- New eigenstates are superpositions of old eigenstates

\[ \Delta E = \delta_{LS} + 2E_o d_{sp} \]
• Atoms enter and leave E-Field non-adiabatically
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- Atoms leaving field have $2\, P_{1/2}$ component
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- Atoms leaving field have $2P_{1/2}$ component
- Acquired phase depends on energy difference and time in field

$$c(2P_{1/2}) \propto \cos(\sqrt{\delta_{LS}^2 + 4E_o^2 d_{sp}^2} T)$$
Optical Analogue

This set-up is analogous to an optical interferometer
Measurement of Lamb Shift

Pamir

Diagram of experimental setup:

- H₂S
- Measurements labeled 1 to 6
- Electric field indicated by E

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Initial Results

Problems:
- Difficult to assess systematic errors

![Graph](image-url)
Initial Results

Problems:
- Difficult to assess systematic errors
- Non-trivial electric field near entrance and exit slits
Double Interferometer

- Use two interferometers separated by distance 'l'

Diagram showing the setup of the double interferometer with labeled parts 1 to 8.
Double Interferometer

- Use two interferometers separated by distance ‘l’
- Oscillation period of $2P_{1/2}$ intensity depends only on Lamb-Shift and velocity

$$w(\Delta l) = \cos \left[ \frac{\omega}{v} \left(1 - \frac{v^2}{c^2}\right)^{1/2} \Delta l \right]$$

$$+ c \cos \left[ \frac{\omega_1}{v} \left(1 - \frac{v^2}{c^2}\right)^{1/2} \Delta l \right]$$
Double Interferometer

Use two interferometers separated by distance ‘l’

Oscillation period of $2P_{1/2}$

Intensity depends only on Lamb-Shift and velocity


Sokolov Yu L, in Proc. 2nd Int. Conf. on Precision Measurements and Fundamental Constants II (1981)
Now the second electric field is turned off.
First Candidate: Stray Charges

- Effective electric field corresponds to 10-12 V/cm
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- To confirm predictions modify set-up accordingly...
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![Diagram illustrating the setup with labels 1 to 5, 2S, v, U, E, L, E = 0, and D.](image)
First Candidate: Stray Charges

- Effective electric field corresponds to 10-12 V/cm
- To confirm predictions modify set-up accordingly...

- Effective field must be orthogonal to first longitudinal field
Results
Second Candidate: Beam Halo

• Maybe diffraction halo of beam is interacting with metal surface
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- Beam size is 50 μm, slit width is 200 μm
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- Misalign beam to measure halo.
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- Maybe diffraction halo of beam is interacting with metal surface
- Beam size is 50 $\mu$m, slit width is 200 $\mu$m
- Misalign beam to measure halo.

Beam halo is small: 1.4 $\mu$m
Third Candidate: Entanglement?

- B B Kadomtsev proposes the effect is due to the creation of entangled states
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- Magnitude of effect should depend on material properties of conductor
Results

- Left graph: Scale of the effect (%) vs. temperature (T, °C)
- Right graph: Amplitude of interference curve (arbitrary units) vs. length (L, cm)

- Symbols:
  - Circle: Annealed palladium
  - Cross: Cold-hardened palladium
Kadomtsev’s Theory also makes predictions
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The experiment is modified twice more.
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Summary of Results

- All discussed theories have failed to describe experimental results
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- Other proposed candidates (Casimir force, image charges, etc) are not consistent with the magnitude of observed effect
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- All discussed theories have failed to describe experimental results.
- Other proposed candidates (Casimir force, image charges, etc.) are not consistent with the magnitude of observed effect.
- No theories consistent with experimental results have been proposed.
Atomic Dysprosium

Atomic Dysprosium also has nearly degenerate states of opposite parity (3 MHz-GHz)
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Dysprosium may be a sensitive tool for measuring this effect.
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- Near degeneracy of $2S_{1/2}$ and $2P_{1/2}$ states to electric fields makes hydrogen ideal for use in atomic interferometer
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- Level structure of hydrogen and **Stark** Effect
- Near degeneracy of $2S_{1/2}$ and $2P_{1/2}$ states to electric fields makes hydrogen ideal for use in atomic interferometer
- There exists an unexplained interaction between hydrogen atoms and metal surfaces
Yu L Sokolov

Yu L Sokolov, V P Yakovlev, V G Pal’chikov, and Yu A Pchelin

Yu A Kucheryaev, V G Palchikov, Yu A Pchelin, Yu L Sokolov, and V P Yakovlev

Yu L Sokolov, V P Yakovlev

Yu L Sokolov
in *Proc. 2nd Int. Conf. on Precision Measurements and Fundamental Constants II* (1981)

B B Kadomtsev

S T Belyaev