AEgIS: tests of gravitation with a beam of H

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AEgIS: a beam of H to test gravity

Tests of gravity require very cold trapped H or a pulsed cold beam of H

Experimental goal: g measurement with 1% accuracy on antihydrogen

(first direct measurement on antimatter)

a) production of a pulsed cold beam of antihydrogen (T~0.1K)

b) measurement of the beam deflection with a Moiré deflectometer
Step i) antihydrogen formation

- Charge exchange reaction:
  \[ \text{Ps}^* + \overline{p} \rightarrow \overline{H}^* + e^- \]

- Principle demonstrated by ATRAP (Cs* → Ps* → H*)

- Advantages:
  - Large cross-section: \[ \sigma \approx a_0 n^4 \]
  - Narrow and well-defined \( \overline{H} \) \( n \)-state distribution
  - \( \overline{H} \) production from \( \overline{p} \) at rest → ultracold \( \overline{H} \)

- pulsed production of \( \overline{H} \)

At \( T(p) = 100 \text{mK}, n(Ps) = 35 \)
\( \nu(H) \approx 45 \text{ m/s} \)
\( T(H) \approx 120 \text{mK} \)
Step ii) beam formation

- Neutral atoms are not sensitive to static electric and magnetic fields
- Electric field gradients exert force on electric dipoles:

\[ E = -\frac{1}{2n^2} + \frac{3}{2} nkF \]
\[ \text{Force} = -\frac{3}{2} nk\nabla F \]

® Rydberg atoms are very sensitive to inhomogeneous electric fields

- Stark deceleration of hydrogen demonstrated

- \( n = 22, 23, 24 \)
- Accelerations of up to \( 2 \times 10^8 \) m/s\(^2\) achieved
- Hydrogen beam at 700 m/s can be stopped in 5 \( \mu \)s over only 1.8 mm

- ongoing work on Zeeman deceleration, Stark deceleration and trapping of H
Step iii) trajectory measurement

- Classical counterpart of the Mach-Zehnder interferometer
  - Decoherence effects reduced
  - “Self-focusing” effect – beam collimation uncritical

- Replace the third grating and detector by position-sensitive detector
  - Transmission increases by ~ factor 3

- Has been successfully used for a gravity measurement with ordinary matter, \( \sigma(g)/g = 2 \times 10^{-4} \)
  - with \( 10^5 \) \( \text{H} \) at 100mK, \( \sigma(g)/g = 1\% \) (expected)

\[ \delta = \frac{gt^2}{a} \]

[Fringe phase and phase shift identical to Mach-Zehnder interferometer!]

challenges (pour fixer les idées):

$10^5 \bar{H}$ at 100mK @ 1 Hz  $\rightarrow 10^4 \bar{H}$ reach target in $10^5$ s

- production rate lower  $\rightarrow$ linear increase in required time
- temperature higher  $\rightarrow$ higher beam divergence

(assumption: all things being equal, systematics under control)

Increase in number of antihydrogen atoms scales with the number of cold (100 mK) antiprotons;

a factor of 100 increase should lead to a factor 10 improvement in sensitivity (although all atoms are produced simultaneously, little risk of pile-up)
Infrastructure today
Layout of the zone
Status of AEGIS apparatus

- **Completed components:**
  - Positron source, rare-gas moderator and trap
  - AD beam line and diagnostics
    - 5-T magnet and trap
    - Laser system
    - 1-T magnet
      - (completed, to be installed October 2011)

- **Main components under design / construction:**
  - Positron accumulator: ordered, delivery March 2012
  - Dilution cryostat: design completed, delivery 2012
  - Moiré deflectometer: prototype being tested in Heidelberg
  - Position-sensitive detector: tests with prototype by summer 2012
  - Antihydrogen detector: design completed, parts ordered, assembly by summer 2012
  - 1-T Penning traps: being designed
Time line

2011: trapping of antiprotons, detector tests
2012: positronium formation & excitation, antihydrogen production
2013: hydrogen beam commissioning & optimization
2014: antihydrogen beam, gravity measurements
2015: antihydrogen beam, gravity + other measurements
2016: improved measurements of gravitational coupling, …
AEgIS will clearly benefit from ELENA...