Preparations for Stark-interference type measurements in Francium

Author: Iris Halilovic

For the FrPNC Collaboration

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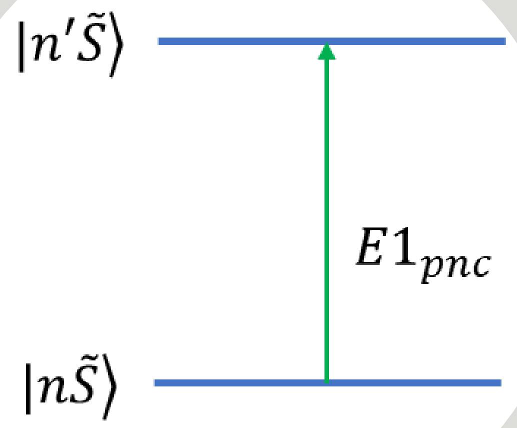
APNC and test of the standard model

- Parity non-conserving (PNC) weak neutral current interaction between atomic electrons and nucleons
- Gives rise to atomic PNC (APNC) effects
- Slight mixing of atomic states of opposite parity
- Consequently, a faint electric dipole transition can be excited between states of the same parity (otherwise forbidden)

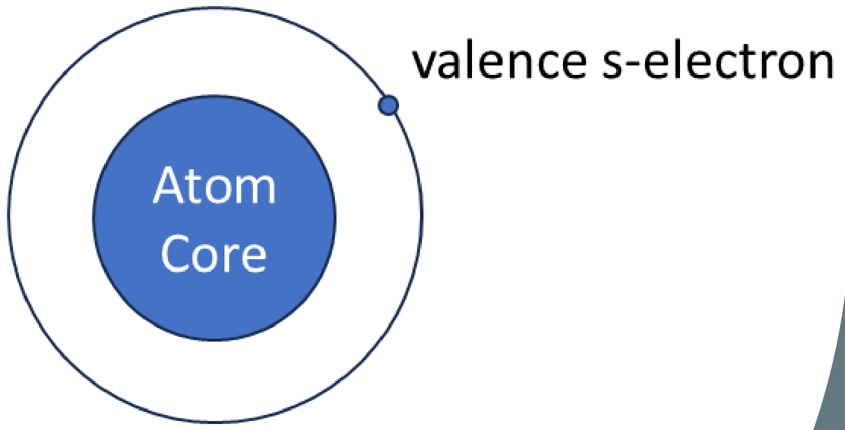
$E1_{pnc}$ transition is a signature of APNC sensitive to the nuclear weak charge Q_W

$$|\tilde{S}\rangle = |S\rangle + \epsilon_{pnc}|P\rangle$$



APNC and test of the standard model

- Extraction of nuclear weak charge depends on atomic theory calculations
- Introduces theoretical uncertainty which varies by atom
- Alkali atoms are structurally simple making high accuracy atomic theory feasible
- Results compared to standard model prediction



$$Q_W = 2\left(\kappa_{1p} Z + \kappa_{1n} N\right)$$

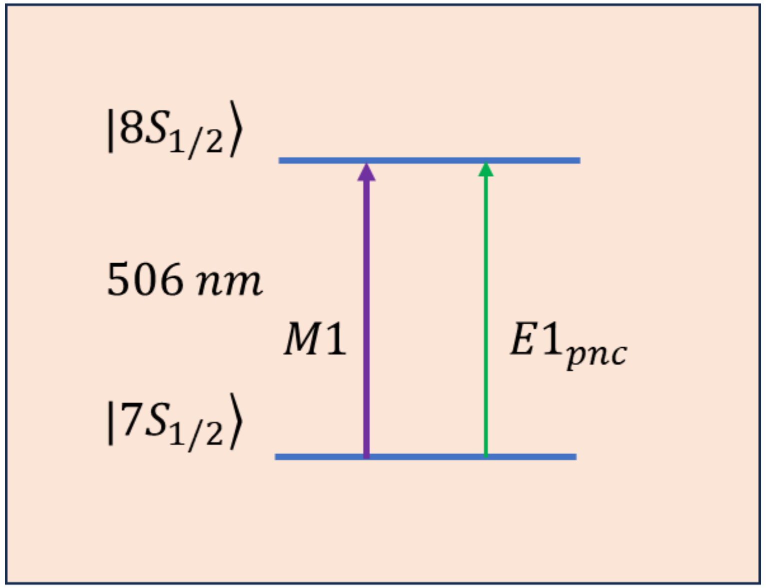
$$\kappa_{1p}^{SM} = \tfrac{1}{2}(1-4(\sin\theta_W)^2)$$
$$\kappa_{1n}^{SM} = -\tfrac{1}{2}$$

$$Q_W^{SM} \approx -N$$

APNC experiments in Francium

- Fr is the heaviest alkali atom
- Sensitive to APNC due to its heavy nucleus $APNC \propto Z^2N$
- Laser spectroscopy of 7S – 8S transition
- In free space E1 strictly forbidden
- M1 arises from relativistic effects and hyperfine interaction – hard to detect $f_{M1} \sim 10^{-13}$
- E1pnc – unobservable on its own $f_{E1_{pnc}} \sim 10^{-21}$

In free space:



Typical oscillator strength of an allowed E1 transition is ~ 1

Amplification of APNC signal by interference

- E1pnc interference with a stronger parity conserving (PC) amplitude
- Amplifies the APNC signal to levels where detection is feasible
- Total observed transition rate is

$$R = |A_{pc} + A_{pnc}|^2$$
$$= |A_{pc}|^2 + 2Re(A_{pc}A_{pnc}^*) + |A_{pnc}|^2$$

- Interference term amplified by

$$|A_{pc}/A_{pnc}|$$

- Changes sign under parity transformation of the system
- Small oscillation in total observed transition rate synchronous with parity reversals

Stark-interference technique

- Prepare the atomic system in an external electric field
- This perturbs the atom, causing mixing of S and P states
- Stark-induced electric dipole amplitude between states of the same parity
- Parity conserving and tunable!

$$E1_{Stark} = \alpha\vec{E}\cdot\vec{\epsilon}\delta_{F,F'}\delta_{m,m'} + i\beta\left(\vec{E}\times\vec{\epsilon}\right)\cdot\langle F'm'|\vec{\sigma}|Fm\rangle$$

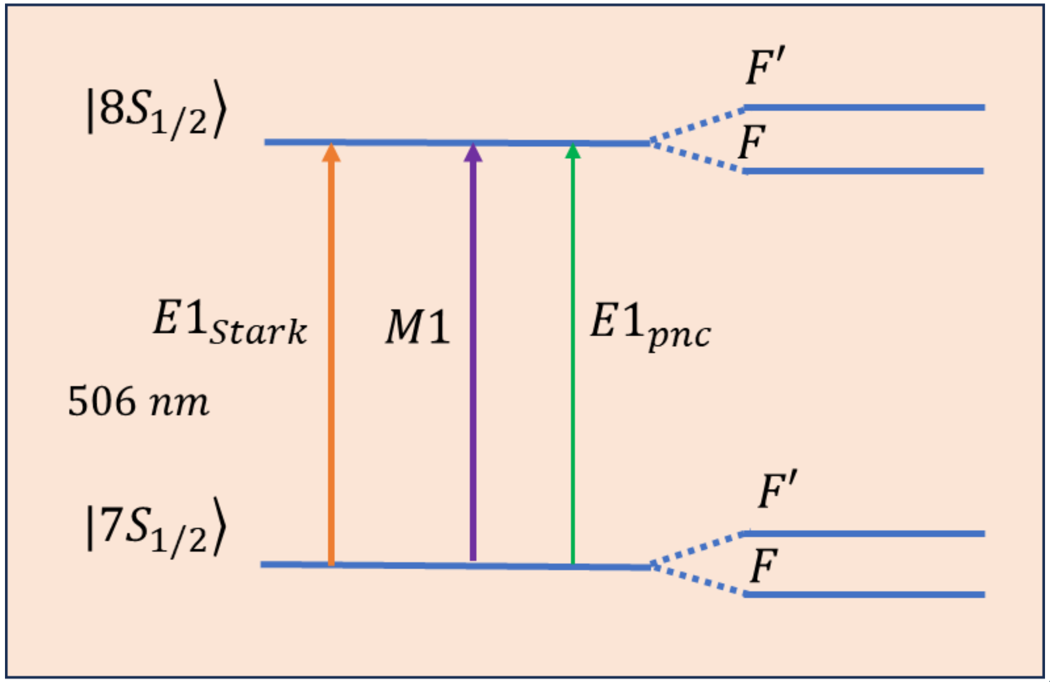
- At a field strength of a few kV/cm,

$$f_{E1_{Stark}} \sim 10^{-10}$$

- And its interference with E1pnc is expected to be 6 orders of magnitude larger than just E1pnc alone

$$|A_{pc}/A_{pnc}| \sim 10^6$$

In an external DC electric field:



$$R_{7S\to 8S} \propto \left|E1_{Stark} + M1 + E1_{pnc}\right|^2$$

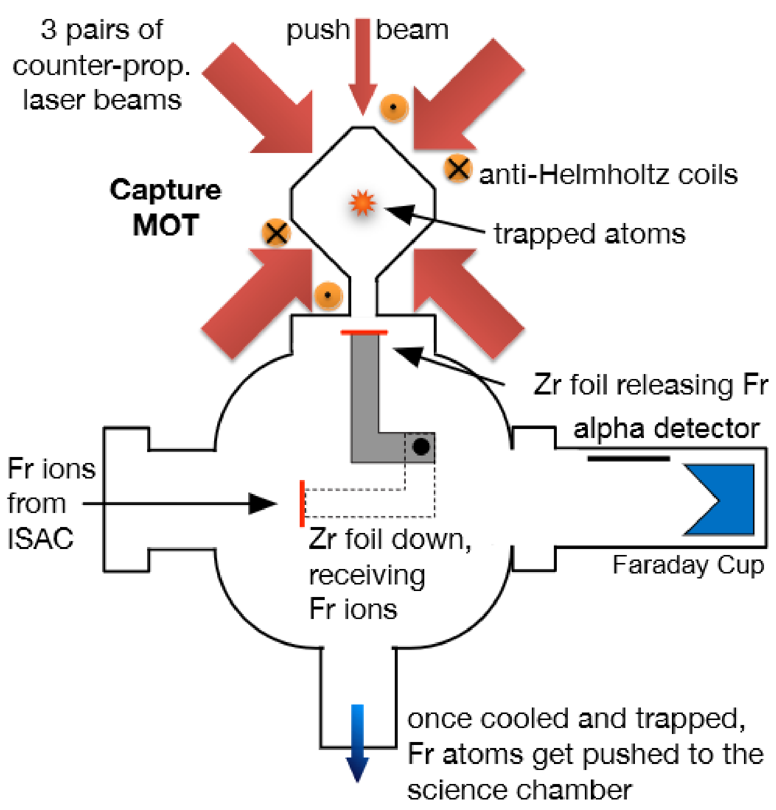
Spectroscopic investigation of the 7S-8S transition

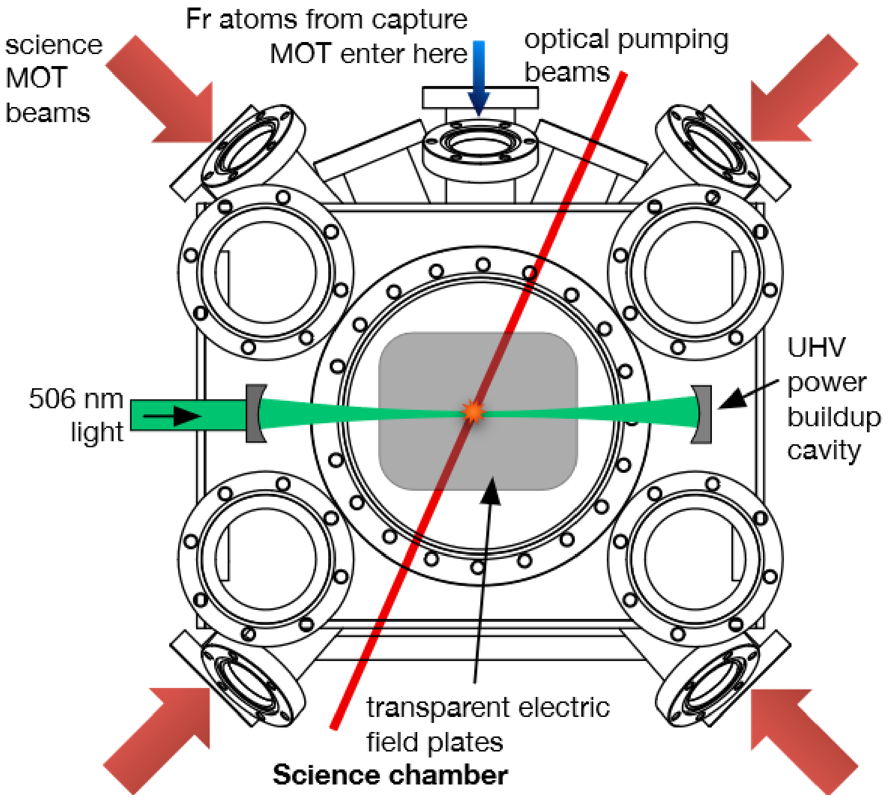
- The total transition is characterized by

$$\alpha, \beta, M1_{rel}, M1_{hf}, \text{and } E1_{pnc}$$

- All of these parameters need to be measured to understand the transition before ultimately measuring APNC in Fr
- These parameters are also important benchmarks for atomic theory in Fr
- Recent detection efficiency improvement and new PBC allowed for better than 10% measurement of the relativistic component of M1
- See Anima Sharma's talk this evening for more details

Magneto-optical traps at the FTF





Measurement of asymmetry under parity reversals

- Under parity transformation, such as reversal of the external electric field, the interference term E1stark-E1pnc changes sign
- Observed change in detected fluorescence synchronous with parity flips
- The asymmetry is

$$\frac{R_+ - R_-}{R_+ + R_-} \propto \frac{Im(E1_{pnc})}{\beta E}$$

- Atoms need to be polarized otherwise interference term vanishes
- A static magnetic field is required to lift the degenergy of the hf magnetic sublevels
- Atoms need to be prepared in a definite state $|Fm_F\rangle$

E1stark-M1 Interference

- Interference terms depend on the geometry and polarization of the system
- E1stark-M1 distinguished from E1stark-E1pnc by its change in sign when direction of the light wavevector is reversed
- It also changes sign with parity reversals and so is expected to be the biggest systematic challenge in measuring APNC
- Study stray and misaligned fields that mimic PNC
- Measurement of fluorescence asymmetry due to E1stark-M1 will follow the same principle as for E1stark-E1pnc
- Implement field plates in the science chamber that can be tilted in-situ
- Implement fast reversal of electric field (first type of parity transformation)

References

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FrPNC Collaboration

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Thank you! / Merci!

Any Questions?