Lab Tests of Dark Energy

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Dark Energy Couplings to the Standard Model

$$\mathcal{L} = -\frac{1}{2}(\partial\phi)^2 - V(\phi) + \mathcal{L}_{sm} + \mathcal{L}_{int}$$

photons

$$\mathcal{L}_{int} \ni \frac{1}{4M}\partial_\mu\phi A_\nu \widetilde{F}^{\mu\nu}$$

fermions

$$\mathcal{L}_{int} \ni \frac{1}{M}\partial_\mu\phi\bar{\nu}\gamma^\mu(1-\gamma_5)\nu$$

"Quintessence and the rest of the world," Carroll, PRL 81, 3067 (1998)

"Neutrinos…, and dark energy," Ando et al, PRD 80, 123522 (2009)

Dark Energy Coupling to Electromagnetism

Varying ϕ creates an anomalous charge density or current

$$\vec{\nabla} \cdot \vec{E} - \rho/\epsilon_0 = -\frac{1}{Mc}\vec{\nabla}\phi \cdot \vec{B}$$

$$\vec{\nabla} \times \vec{B} - \mu_0\epsilon_0\frac{\partial \vec{E}}{\partial t} - \mu_0\vec{J} = \frac{1}{Mc^3}(\dot{\phi}\vec{B} + \vec{\nabla}\phi \times \vec{E})$$

Magnetized bodies create an anomalous electric field
Charged bodies create an anomalous magnetic field

Dark Energy Coupling to Electromagnetism

Cosmic solution:

$$\dot{\phi}/Mc^2 \sim H$$

$$\nabla\phi/Mc^2 \sim Hv/c^2$$

$$\hbar H \sim 10^{-42}\mathrm{GeV}$$

Local solution:

$$\nabla\delta\phi/Mc^2 \sim \epsilon_Q a_g/c^2$$

$$\epsilon_Q = 2V'/V''Mc^2$$

$$\hbar\epsilon_Q a_g/c^2 \sim 10^{-32}\mathrm{GeV}$$

Dark Energy Coupling to Electromagnetism

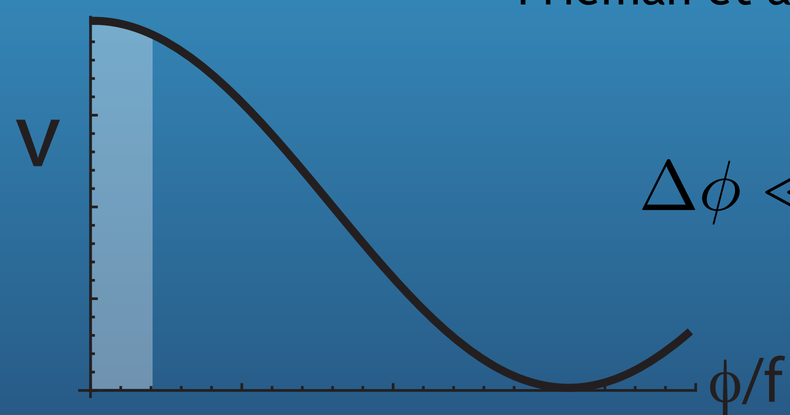
Cosmic Birefringence: $\Delta\theta = \Delta\phi/2Mc^2$

$$-1.41^\circ < \Delta\theta < 0.91^\circ \ (95\%\mathrm{CL})$$

Komatsu et al (WMAP7), ApJS 192, 18 (2011)

Field Evolution: $V = \mu^4(1 + \cos(\phi/f))$

Frieman et al, PRL 75, 2077 (1995)

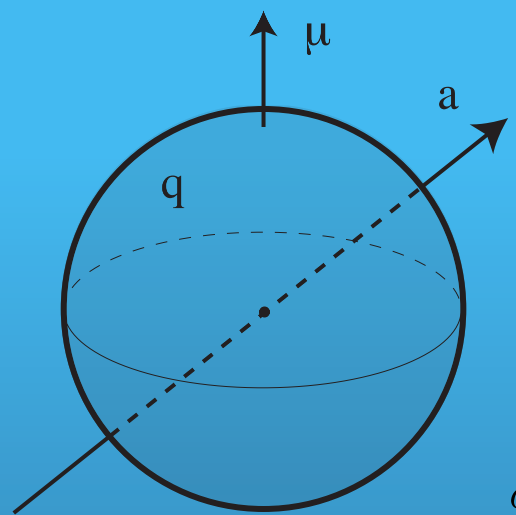


$$\Delta\phi \ll M_P, \ \epsilon_Q \lesssim 10$$

Dark Energy Coupling to Electromagnetism

$$\vec{\nabla} \cdot \vec{E} - \rho/\epsilon_0 = -\frac{\epsilon_Q}{c}\vec{a}_g \cdot \vec{B}$$

$$\vec{\nabla} \times \vec{B} - \mu_0\epsilon_0\frac{\partial \vec{E}}{\partial t} - \mu_0\vec{J} = \frac{\epsilon_Q}{c^2}\vec{a}_g \times \vec{E}$$



proton as charged, magnetized sphere

spin-flip in the local field

$$\vec{E} = \frac{qr}{4\pi\epsilon_0 R^3}\hat{r}$$

$$\vec{B} = \frac{2}{3}\mu_0\vec{M}$$

$$\delta\vec{B} = \frac{\mu_0 q\epsilon_Q}{20\pi Rc}\left(5\vec{a}_g + \frac{r^2}{R^2}((\vec{a}_g\cdot\hat{r})\hat{r} - 2\vec{a}_g)\right)$$

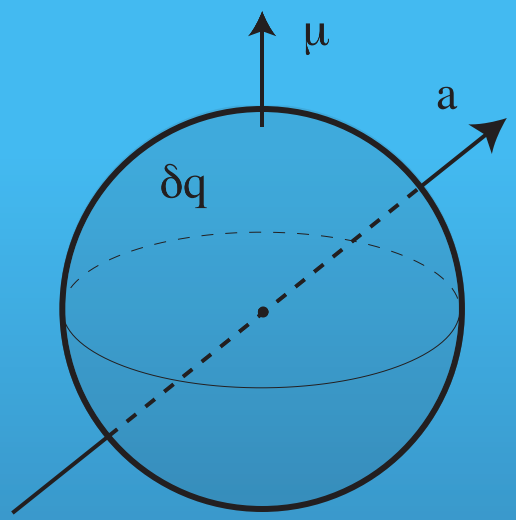
$$\vec{\tau} = \frac{2\mu_0 q\epsilon_Q}{5\pi Rc}\vec{\mu}\times\vec{a}_g$$

$$\Delta\mathcal{E} = \frac{2\mu_0 q\epsilon_Q}{5\pi Rc}\mu a_g \simeq 10^{-34}\epsilon_Q\mathrm{GeV}$$

Within grasp of experiments?

Brown et al, PRL 105, 151604 (2010)

See also: Flambaum et al, PRD 80, 105021 (2009)



$$\vec{B} = \frac{2}{3}\mu_0 \vec{M}$$

neutron as magnetized sphere

charge due to the local field

$$\delta q = \frac{2\epsilon_Q}{3c^3}\vec{a}_g \cdot \vec{\mu}$$

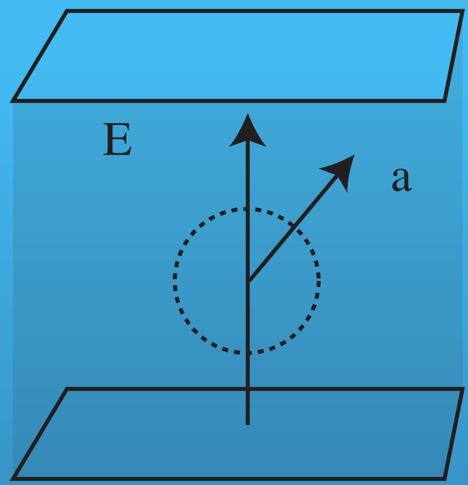
$$\simeq 10^{-32} e$$

$$q_N = -0.4(\pm 1.1) \times 10^{-21} e$$

Baumann et al, PRD 37, 3107 (1988)

Spinning superconducting shell?

Precession of a drag-free gyro: Ω is too small



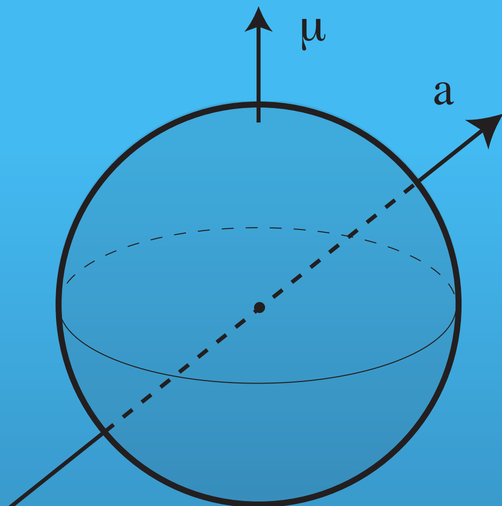
macroscopic slab electric field

magnetic field due to the local field

$$\delta\vec{B} = -\frac{\epsilon_Q}{2c^3}\vec{r}\times(\vec{a}_g\times\vec{E})$$

$$\simeq 10^{-25}\epsilon_Q\left(\frac{\Delta\Phi}{\mathrm{V}}\right)T$$

Huge voltage required;
Turn on field, Faraday’s law!



$$\vec{B} = \frac{2}{3}\mu_0\vec{M}$$

macroscopic magnetized sphere

voltage due to the local field

$$\Delta V = \frac{\epsilon_Q R^2}{5c}\vec{a}_g \cdot \vec{B}$$

$$\simeq 0.3\epsilon_Q \left(\frac{B}{T}\right)\left(\frac{R}{0.1m}\right)^2 nV$$

Within grasp of experiments?

See also: Bailey & Kostelecky, PRD 70, 076006 (2004)

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