1. **Exotic Contributions to $g - 2$.** (Problem 6.3 of the book) Any particle that couples to the electron can produce a correction to the electron-photon form factors and, in particular, a correction to $g - 2$. Because the electron $g - 2$ agrees with QED to high accuracy, these corrections allow us to constrain the properties of hypothetical new particles.

(a) The unified theory of weak and electromagnetic interactions contains a scalar particle $h$ called the Higgs boson, which couples to the electron according to

$$H_{\text{int}} = \int d^3x \frac{\lambda}{\sqrt{2}} h \bar{\psi} \psi.$$  \hspace{1cm} (1)

Compute the contribution of a virtual Higgs boson to the electron $g - 2$, in terms of $\lambda$ and the mass $m_h$ of the Higgs boson.

(b) QED accounts extremely well for the electron’s anomalous magnetic moment. If $a = (g - 2)/2$,

$$|a_{\text{exp}} - a_{\text{QED}}| < 1 \times 10^{-10}. \hspace{1cm} (2)$$

What limits does this place on $\lambda$ and $m_h$? In the simplest version of the electroweak theory, $\lambda = 3 \times 10^{-6}$ and $m_h > 95$ GeV. Show that these values are not excluded. The coupling of the Higgs boson to the muon is larger by a factor $(m_\mu/m_e)$: $\lambda = 6 \times 10^{-4}$. Thus, although our experimental knowledge of the muon anomalous magnetic moment is not as precise,

$$|a_{\text{exp}} - a_{\text{QED}}| < 3 \times 10^{-8}, \hspace{1cm} (3)$$

one can still obtain a stronger limit on $m_h$. Is it strong enough?

(c) **(Optional)** Some more complex versions of this theory contain a pseudoscalar particle called the axion, which couples to the electron according to

$$H_{\text{int}} = \int d^3x \frac{i\lambda}{\sqrt{2}} a \bar{\psi} \gamma^5 \psi.$$  \hspace{1cm} (4)

The axion may be as light as the electron, or lighter, and may couple more strongly than the Higgs boson. Compute the contribution of a virtual axion to the $g - 2$ of the electron, and work out the excluded valued of $\lambda$ and $m_a$. 

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**HW #10, due Nov 12**