1. Due Wednesday, February 24 (2021).

   First, finish the textbook problem **10.2** — calculate to one-loop order the infinite parts of all the counterterms of the pseudoscalar Yukawa theory.

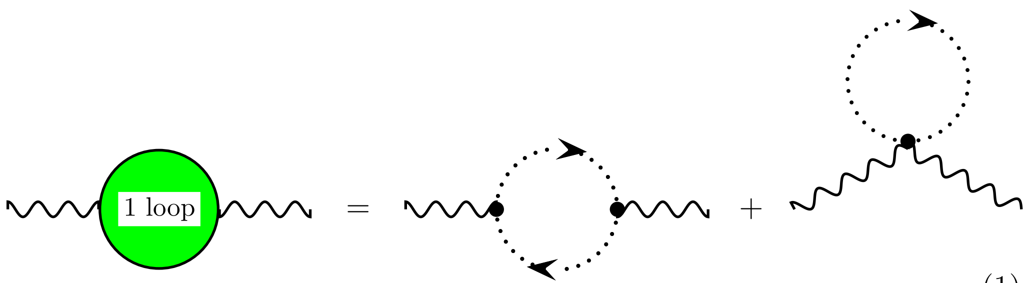
   Hint: the infinite part of the four-scalar amplitude $iV(k_1, \ldots, k_4)$ does not depend on the scalar's momenta, so you may calculate it for any particular $k_1, \ldots, k_4$ you like, on-shell of off-shell. I suggest you take $k_1 = k_2 = k_3 = k_4 = 0$, so in any one-loop diagram all the propagators in the loop have the same momentum q — which makes evaluating such a diagram much simpler.

   Likewise, the infinite part of the one-scalar-two-fermions amplitude $\Gamma^5(p', p)$ does not depend on the momenta p, p', or $k = p' - p$, so you may calculate it for any p and p' you like, on-shell or off shell. Again, letting $p = p' = 0$ makes for a much simpler calculation of the one-loop diagram(s).

2. Due Tuesday, March 2 (2021).

   Next, consider the electric charge renormalization in the scalar QED — the theory of a EM field A^μ interacting with a charged scalar field Φ. At the one-loop level, there are two Feynman diagrams contributing to the 1PI two-photon amplitude, namely

$i\Sigma^{\mu\nu}_{1\,\text{loop}}$ =



(1)

   (a) Evaluate the two diagrams using dimensional regularization and verify that the net amplitude has form

$$\Sigma^{\mu\nu}_{1\,\text{loop}}(k) \;=\; \left(k^2 g^{\mu\nu} \,-\, k^\mu k^\nu\right) \times \Pi_{1\,\text{loop}}(k^2) \tag{2}$$

   (b) Calculate the $\Pi^{1\,\text{loop}}(k^2)$ due to two diagrams (1), add the δ_3 counter-term's contribution, then determine the $\delta_3^{\mathrm{order}\,\alpha^1}$ coefficient — including its finite part, — and write down the *combined* $\Pi^{\mathrm{net}}_{\mathrm{order}\,\alpha^1}$ as a function of k^2.

(c) Consider the effective coupling $\alpha_{\mathrm{eff}}(k^2)$ of the scalar QED at high off-shell momenta, $k^2 \gg m^2$. Show that at the one-loop level,

$$\frac{1}{\alpha_{\mathrm{eff}}(k^2)} = \frac{1}{\alpha(0)} - \frac{1}{12\pi}\left(\log\frac{-k^2}{m^2} - \frac{8}{3}\right) + O(\alpha). \tag{3}$$

3. Due Tuesday March 2.

Finally, a big reading assignment: my notes on diagrammatic proof of the Ward–Takahashi identities. Please go *carefully* through the algebra, and make sure you understand the diagrammatic proof of the identities.

Update 2/20, 11:45 PM: I have just finished reorganizing my notes on the Ward–Takahashi identities, which ended in two new sets: notes on WT identities and the current conservation will be used in my lectures on 2/24–26/2021, while notes on diagrammatic pfoof of the WT indentities is your reading assignment. In terms of my old notes — which were linked to the earlier version of this homework — your reading assignment is the first $20\frac{1}{2}$ pages.