The ingredients of a scalar U(1) gauge theory

Photons couple to some external, conserved matter current whose microscopic origin we do not know.

Charged scalar matter couples to a gauge boson that for some reason has no dynamical degrees of freedom.

$$\mathscr{L}_{\mathrm{U}(1)} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - A_\mu \frac{i}{2}\left(\varphi\partial^\mu\varphi^* - \varphi^*\partial^\mu\varphi - i\varphi\varphi^* A^\mu\right) - \frac{1}{2}(\partial_\mu\varphi)(\partial^\mu\varphi^*)$$

A **complete U(1) gauge theory** describes the internal structure of matter with its conserved electric Noether current **and** how it interacts via dynamical gauge bosons.

We now understand: the redundancy $A_\mu \to A_\mu + \partial_\mu\alpha$ combined with the local transformation $\varphi \to e^{i\alpha(x)}\varphi,\ \varphi^* \to e^{-i\alpha(x)}\varphi^*$ gives rise to U(1) gauge theory.

Note that the **red term** is unphysical (self-interacting photons) and not observed in Nature. This is an indication that this model of matter (complex scalar field) is inappropriate.

The ingredients of a fermionic U(1) gauge theory

Photons couple to some external, conserved matter current whose microscopic origin we do not know.

Charged fermionic matter couples to a gauge boson that for some reason has no dynamical degrees of freedom.

$$\mathscr{L}_{\mathrm{U}(1)} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - A_\mu\overline{\psi}\gamma^\mu\psi - i\overline{\psi}\gamma^\mu\partial_\mu\psi$$

A **complete U(1) gauge theory** describes the internal structure of matter with its conserved electric Noether current **and** how it interacts via dynamical gauge bosons.

We now understand: the redundancy $A_\mu \to A_\mu + \partial_\mu\alpha$ combined with the local transformation $\psi \to e^{i\alpha(x)}\psi,\ \overline{\psi} \to e^{-i\alpha(x)}\overline{\psi}$ gives rise to U(1) gauge theory.

Note that the current is still bilinear in the matter field, and A_μ no longer appears.
This is an indication that this model of matter (complex fermionic field) is appropriate.

file: gauge-theory-visualization-v2.odp, last edited Sep 26, 2018, jb