Potential Fields in QFT

Robert D. Klauber www.quantumfieldtheory.info June 15, 2024

Volume 1 QED

For the vast majority of the theory and problems in QFT, there is no external potential field (no external forces acting on particles). In those cases, what we consider classically to be a potential field is, on the QFT level, a collection of virtual particles being exchanged between the real particles in macroscopic objects.

See, for example, the end of Chap. 8 in Vol. 1 of *SFQFT*, Sect. 8.10, pgs 243-246.

However, there are cases where we consider what, in QFT lingo is called an "external field", and that is essentially a potential field, as understood classically, but represented in QFT as a fixed source (not a particle, *per se*) that emits and absorbs virtual photons.

See, in above reference, from the bottom of pg. 415 to top of pg. 416 (sub-section titled "Changes to Feynman Rules for External Fields") and the Appendix of Chap. 16 (titled *Deriving Feynman Rules for Static, External (Potential) Fields*), pg. 430 to 431a.

Wholeness Chart. Potential Fields in QFT

Model Employed	**How Often Used**	**Potential Field in QFT?**	**Result**	**See *SFQFT***
Particles interacting with one another	~98% of the time	No	Macroscopic potential field	Sect. 8.10, pgs 243-246 graphically; most of book generally
Particle interacting with external field	~2% of the time	Yes	Macroscopic potential field	bottom pg. 415 to top pg. 416 and Chap. 16 Appendix, pgs. 430-431a

Volume 2 The Higgs Potential

The above focused on a potential as affecting a particle, where the potential is external to the particle. This could occur, in QFT math, two ways.

One as an interaction between particles, where one particle feels the effect of the other via a virtual particle exchange. (First row below column titles in above chart.) Each particle moves under the interaction with the other.

The second way is interaction with an external field. This is also mediated by a virtual particle emitted from the external field. The external field is considered stationary.

There is a third way we talk about potential, and that is found in Vol. 2, Chap 6 (and further chapters).

Classically, this can be thought of like a trampoline. The gravity potential pulls in downward, more in the middle than the sides. This is an external potential. But as the trampoline stretches, potential energy builds up within the trampoline itself. Like in a spring. The trampoline, like a stretched spring, in its tendency to move back to equilibrium with gravity, can cause something on it (like a human gymnast) to move. Potential energy changing to kinetic energy.

So, a classical field can have potential energy stored inside it (like stretching in this example). It can also react to an external potential (like the gravity potential field in this examples).

In QFT, the Higgs field can be considered to have its own internal potential energy. It will naturally tend toward the lowest potential energy state, like the trampoline tending to return to the unstretched state, or a ball rolling into the center of a bowl.

This is actually modeled as potential energy density, since we are working with a field, and thus, energy densities (potential, kinetic, etc.) at each point in space for the field. This is what we mean by the Higgs potential.