What role remains for quanta in quantum field theory?

Doreen Fraser
Department of Philosophy, University of Waterloo
Affiliate, Perimeter Institute for Theoretical Physics
dlfraser@uwaterloo.ca

Seven Pines Symposium XVIII
May 2014

Quanta interpretation of QFT

The Fock representation for a free system (of mass m) in Minkowski space supports a *quanta* interpretation

- Eigenvectors of total number op N have appropriate relativistic energies for n particle states
- $|0\rangle$ invariant under unitary representation of Poincaré group ("looks the same to all observers" [in inertial motion])

Quanta interpretation of QFT

Further questions (to be bracketed):

- To what extent do quanta possess particulate properties? (e.g., localizable, bear labels)
- What happens in other circumstances? (e.g., accelerating observers, non-stationary spacetimes)

A quanta interpretation is not available for interacting systems

The quanta interpretation underwritten by the Fock representation for a free system is not extendable to interacting systems.

Mathematical representations for interacting systems cannot be interpreted as directly describing quanta.

Possible way out?

The only known method of interpreting a QFT in terms of particlelike entities is the quanta interpretation that naturally arises from the Fock representation for a free system. One response would be to find another way of interpreting interacting fields in terms of particlelike entities, one that does not require a Fock-type Hilbert space representation. But this is a program, not a solution, and even at that a program without an obvious starting point. ("Fate of particles," p.857)

What role remains for quanta in quantum field theory?

Mathematical representations for interacting systems cannot be interpreted as directly describing quanta.

According to QFT, quanta are not fundamental entities. What less-than-fundamental status could quanta have?

Motivations for retaining a non-fundamental quanta interpretation

(a) Phenomenological: cloud or bubble chamber photographs of particle scattering or decay; detections by particle detectors

Motivations for retaining a non-fundamental quanta interpretation

(a) Phenomenological: cloud or bubble chamber photographs of particle scattering or decay; detections by particle detectors

(b) Theoretical:
(i) Atomic hypothesis

Norton: "a thesis of ontological reduction asserts that thermal systems just are systems of many molecules, spins, radiation modes, and so on. ... While the ontological thesis is quite amibitious, the evidence in its favour is so massive that, now, no one who doubts it is or should be taken seriously." ("Infinite idealizations," 2012)

Healey: "while talk of fundamental fields and Weinberg's elementary particles as bundles of energy play an essential heuristic role in applications of the Standard Model, the decompositional strategy has indeed 'probably run its course' here." ("Physical composition," 2013)

Motivations for retaining a non-fundamental quanta interpretation

(a) Phenomenological: cloud or bubble chamber photographs of particle scattering or decay; detections by particle detectors

(b) Theoretical:
(i) Atomic hypothesis

(ii) Standard Model

Motivations for retaining a non-fundamental quanta interpretation

(a) Phenomenological: cloud or bubble chamber photographs of particle scattering or decay; detections by particle detectors

(b) Theoretical:

(i) Atomic hypothesis

(ii) Standard Model

(iii) Spontaneous symmetry breaking (e.g., Higgs mechanism)

Non-fundamental quanta interpretations

Option 1: Retreat to instrumentalism

Davies (1984), "Particles do not exist"

> *There are quantum states and there are particle detectors. Quantum field theory enables us to predict probabilistically how a particular detector will respond to that state. That is all. That is all there can ever be in physics, because physics is about the observations and measurements that we can make in the world. We can't talk meaningfully about whether such-and-such a state contains particles except in the context of a specified particle detector measurement. (p.69)*

Non-fundamental quanta interpretations

Option 2: Exploit scattering theory

Asymptotically (as $|t| \to \infty$), the interacting system approaches a free system

Non-fundamental quanta interpretations

Option 2: Exploit scattering theory
Asymptotically (as $|t| \to \infty$), the interacting system approaches a free system

Approximation or idealization?

Non-fundamental quanta interpretations

Option 2: Approximation or idealization?

Norton (2012):

An *approximation* is an inexact description of a target system. It is propositional.

An *idealization* is a real or fictitious system [=free system], distinct from the target system [=interacting system], some of whose properties provide an inexact description of some aspects of the target system.

Non-fundamental quanta interpretations

Option 2: Approximation or idealization?

Norton (2012):

An *approximation* is an inexact description of a target system. It is propositional.

An *idealization* is a real or fictitious system [=free system], distinct from the target system [=interacting system], some of whose properties provide an inexact description of some aspects of the target system.

Quanta are an idealization (cf. Teller (1995))

Non-fundamental quanta interpretations

Option 3: Quanta are emergent

Analogue: quasi-particles in CMP
Wallace (2001), "Emergence of particles from bosonic quantum field theory"

Non-fundamental quanta interpretations

Option 4: Quanta are intuitive pictures that accompany the mathematical formalism. These intuitive pictures can be heuristically useful without being representative of the world (even approximately)

Analogue: Maxwell's ether models of electromagnetism

> *The substance here treated of...is not even a hypothetical fluid which is introduced to explain actual phenomena. It is merely a collection of imaginary properties which may be employed for establishing certain theorems in pure mathematics in a way more intelligible to many minds and more applicable to physical problems than that in which algebraic symbols alone are used. (Maxwell [1856] 1890, 160)*

Peskin and Schroeder: "adds to our reserves of knowledge a completely new source of intuition about how field theory expectation values should behave"