Quantum Wave Packets Have Momentum

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Email Excerpt

Here's a statement you'll find in some form in almost any quantum mechanics textbook:

> *The wave function is a mathematical abstraction that describes all that is knowable about the location and momentum of a particle. It is not a physical entity.*

A caution: While it's correct that plane waves are, in a limited sense, "pure information" without physical attributes, this is not true for wave packets. Wave packets always have momentum directly detectable through the elastic (coherent) rebound of the wave packet from a reflective surface. The reflection inverts the waveform, but it never collapses it. Collapse corresponds instead to the experimentally wholly different absorption processes (e.g., a photon exciting an atom) followed by incoherent reemission (cooling).

Consequently, every wave packet has at least one finite, non-information property — momentum — that impacts the classical world without revealing the particle's location in that packet, provided that the wave packet reflects coherently.

Wave function momentum gets a bit confusing because while it's true that one plane wave contains no measurable momentum when it reflects from a surface coherently, the integral of all plane waves in a wave packet necessarily has momentum equal to that of the particle associated with the wave packet. The correct statement is that each plane wave deposits infinitesimal momentum, normalized to give the particle's exact momentum after integration.

To my knowledge, Feynman never specifically addressed the need to integrate normalized infinitesimal momentum transfers in his QED model. Consequently, folks who attempt to use QED to model Maxwell's exceptionally well-verified pre-quantum prediction of electromagnetic pressure invariably end up very confused. Most instead end up using Maxwell's non-quantized model instead. For a single photon, using Maxwell's smoothly evolving electromagnetic field to predict momentum transfers (light pressure) is identical to saying wave functions have momentum since, for individual photons, that smoothly evolving electromagnetic field is their wave function.

You might be surprised how deep this thread goes. Here's an example:

A critical concept missing from math and physics is that "pure information" is the asymptotic limit of momentum transfers that grow too small to show up in classical experiments. Plane waves are a perfect example, and, notably, these cannot exist in the physical universe due to requiring infinite space and time to form. The tricky part is that even the faintest, least classically detectable infinitesimal momenta remain incredibly and disproportionately impactful on the quantum side. In particular, asymptotically small momenta are the physics definition of information and thus the source of "observations" of quantum wave functions. Mathematics becomes the asymptotic *limit* of such processes.