17. No evidence for objectively existing particles.

One of the consequences of the arguments in Part II is that, in addition to showing quantum mechanics does not disagree with our everyday perceptions, they also imply there is no evidence for the objective existence of particles, separate from the wave function, where 'objective' here is taken to mean there is only a single version of the particle, localized to a single, small region. This result is shown by considering all the alleged evidence for particles and observing that all the particle-*like* characteristics of matter can be explained by the properties of the state vectors alone. (The same argument also shows there is no direct evidence for collapse.) The alleged evidence for the concept of particles is based on a relatively few categories of observations.

0. Before listing and refuting the reputed evidence, we note that all the **numerical successes** of quantum mechanics, such as the prediction of the energy levels of hydrogen, come from equations for the wave functions (or state vectors; or fields). There are, in these successes, no equations for the time evolution of the positions and momenta of particles, for example. So in the mathematics at least, none of these 'quantum' successes give any hint that particles exist apart from the wave functions.

1. Experimentally one finds the results of experiments are invariant with respect to place, time, orientation, and so on. Using only this invariance plus linearity, group representation theory mathematically shows that the particle-like properties of **mass, energy, momentum, spin, and charge** can be attributed to the state vectors (Ch. 12). Thus it is not necessary to postulate the existence of particles as possessors or carriers of these attributes.

2. Even though there can be many versions of reality in a state vector, it is not necessary to assume the existence of single-version particles to explain why we **perceive only a single version** of reality. Basic linear, multi-version quantum mechanics, by itself, implies the observer will never perceive more than one version. (Ch. 11)

3. Even though a wave function may be spread out over many grains of film, quantum mechanics predicts we will perceive only one localized grain as exposed. This explains the perceived **localization** of effects from spread-out wave functions. (Ch. 14)

4. An extension of the localization argument shows that quantum mechanics predicts we will perceive a sharply defined, unambiguous **particle-like trajectory** in a cloud chamber from a spread-out wave function. (Ch. 15)

5. Einstein used the **photoelectric effect** to argue that there must be particles of light—photons. That effect, however, plus the related Compton effect can be shown to follow from items 1, 2, and 3 above, plus the results of Ch. 13 in which it is shown that parts of the wave function carry the full properties (energy, momentum, charge) of the wave function. Thus quantum mechanics alone can account for the photoelectric and Compton effects.

6. There are **thermodynamic and chemical** arguments which seem to imply the existence of particles. But they all involve the quantization (or unitization) of matter, and that occurs in pure quantum mechanics—a different wave function for each particle-*like* unit of matter—as well as in (reputed) particle-based physics. Further, the highly successful **classical Newtonian mechanics** can be derived from quantum mechanics (A17.1), so it also does not constitute evidence for particles.

7. Finally, if there are no particles, then one has the added bonus that there is no mystery in understanding the **entangled-state experiments**, including the non-local results of the Bell-Aspect experiment (Ch. 16 and A16.1) and the quantum eraser (A16.2). The properties of the state vectors alone correctly predict all these results perfectly well, with no need to postulate action at a distance, the effect before the cause, and so forth. Further, the uncertainty principle is just a theorem about wave function properties (A17.2), so it, too, loses its mystery if there are no particles.

Use of the term 'particle.'

These seven items constitute all the alleged evidence for particles. But since quantum mechanics alone can account for all these particle-*like* properties of matter, there is no reason to postulate the existence of particles separate from the wave function. It is, however, still convenient to use the term "particle," but now instead of it referring to a single-version, localized, objective piece of matter, it refers to a state vector that may in some cases correspond to multiple versions of reality. The state vector corresponding to an electron will have mass m_e, charge $-e$, and spin ½ for example, while the state vector corresponding to a photon will have mass 0, charge 0, and spin 1.

The same argument would apply to "fields." There is no evidence for objectively existing, single-version fields—electron fields, photon fields—which have effects limited to a single, small, localized region.

Relation to Everett's many-worlds interpretation.

We note that Part II essentially constitutes a defense (except for probability) of the Everett many-worlds interpretation, with several arguments not found in Everett's paper filled in.

The problem with probability.

The observation that basic, linear quantum mechanics can explain so many seemingly puzzling effects does not mean that it alone constitutes a valid interpretation.

Why? Because a linear, unitary theory alone cannot account for probability or the probability law (Ch. 8, Ch. 18). Each version is perceived on every run (in the quantum mechanical mathematics) so there can be no *probability* of perception.

Kets as the fourth mystery.
One more thought. Although we usually use the term 'wave function' here to denote the states of matter, they are technically expressed in the mathematics as sums of kets, $|m,E,p,S,s_z,Q\rangle$ (A6.2, Ch. 12) These are conventionally understood to stand for or represent states of particles. But if there are no objectively existing particles or fields, what does the ket $|m,E,p,S,s_z,Q\rangle$ stand for? This constitutes the fourth mystery of quantum mechanics. We will consider one possible solution in Part IV.

Generality of the result.

The result is quite general in that it uses only four basic mathematical principles.
(A). Linearity of the operators.
(B). Physical states correspond to vectors (rays) in a Hilbert space.
(C). Invariance and group theoretic properties.
(D). The 'local' properties of the linear, Hermitian Hamiltonian.

Any mathematical system that is based on these four principles, no matter how abstract—including the scheme of Part IV, string theory, and so on—will give back our familiar, concrete, particle-like perceptions of the physical world. (Note: This is not precisely true. A fifth principle, the probability law, is needed for explaining the probabilistic results in the entangled state experiments.)

And just to make sure we are on the same page, all our familiar perceptions are explained without invoking collapse, hidden variables, action at a distance, or the existence of 'particles' (where 'particle' here means any 'object' that has only a single version). Only the state vectors exist.