Ejected Particles are Always Waves and Never Points

Terry Bollinger
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https://youtu.be/zZ5ww6aYAZ8&lc=Ugw8uujOuXPqgZJGBox4AaABAg

A Comment on The Action Lab post:
What Does an Electron Look Like? (Feb 28, 2023)
https://youtu.be/zZ5ww6aYAZ8
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5:17 “But when we measure where an electron is in a real s-orbital, we find it is here, or here, or here.” No. The correct statement is: “If we hit the electron wave with a probe particle whose wavelength is smaller than the s-orbital, we can collapse the electron s-wave into a new wave whose size is similar to the probe’s wavelength.

Neither entity is ever point-like. If anything, the electron is *more* wave-like after the collapse than before. It can, for example, diffract beautifully from a grating.

When you drew the electrons as points much smaller than the s-orbital, the experiment you inadvertently proposed was to hit some poor, unsuspecting hydrogen atom with extreme x-rays or gamma rays. That is because only such exceedingly energetic photons have wavelengths small relative to sn s-orbital to create such points.

That’s fine in the limited sense that blasting an s-orbital with gamma rays is a doable experiment. However, ignoring the need for such extreme energies leaves students with the wrong impression that point-like electron states are “real” and thus easily accessible at low energies.

They are not. Pushing probe particles to behave even more like exact points is why folks build things like the Large Hadron Collider. That device imparts enough energy — creates small enough probe wavelengths — to get closer to point-like size. However, the energy cost for imparting that degree of “pointiness” to particles such as quarks and gluons is staggering.

Addendum 2023-03-04: An unfortunate conceptual error in many quantum mechanics textbooks and tutorials occurs when they leave students with the impression that after a photon hits an atomic electron, such as an s-orbital electron, the atom ejects the electron as a *particle*. [See Figure 1(a) in the PDF version of this comment.] In this view, the electron proceeds in a straight path until it hits an object that makes its path visible, such as an atom on a screen that then fluoresces.

The source of this error is the overpowering temptation to draw a purely classical straight-line xyz extrapolation of the electron’s path from the atom to wherever it lands on the screen. If you draw such a classical path between that initial ejection point, which for a gamma ray photon may be far smaller than the diameter of the s-orbital, and the atom on which it lands, the result is a line thinner than an atom. Classically interpolating a line between the two well-defined points is deeply tempting and suggests the electron has gone "full particle," revealing its pristine underlying point-like nature. The only apparent weakness in this interpretation is that the origin of the electron at the s-orbital can never be fully point-like since it can only be as small as the wavelength of the gamma ray that struck it. Using increasingly powerful gamma rays partially overcomes this issue since higher energies make the emission point indefinitely smaller. The resulting electron path then expands, at most, to atomic size by the time it reaches the screen atom.

It's all a lie. But do you see where I lied to you?

In my description, I use the phrase "... a fully classical path drawn between... ejection... and impact." Do you see it yet? Why should that path be *classical* instead of, say, quantum... another wave? [See Figure 2(b) in the PDF version of this comment.]

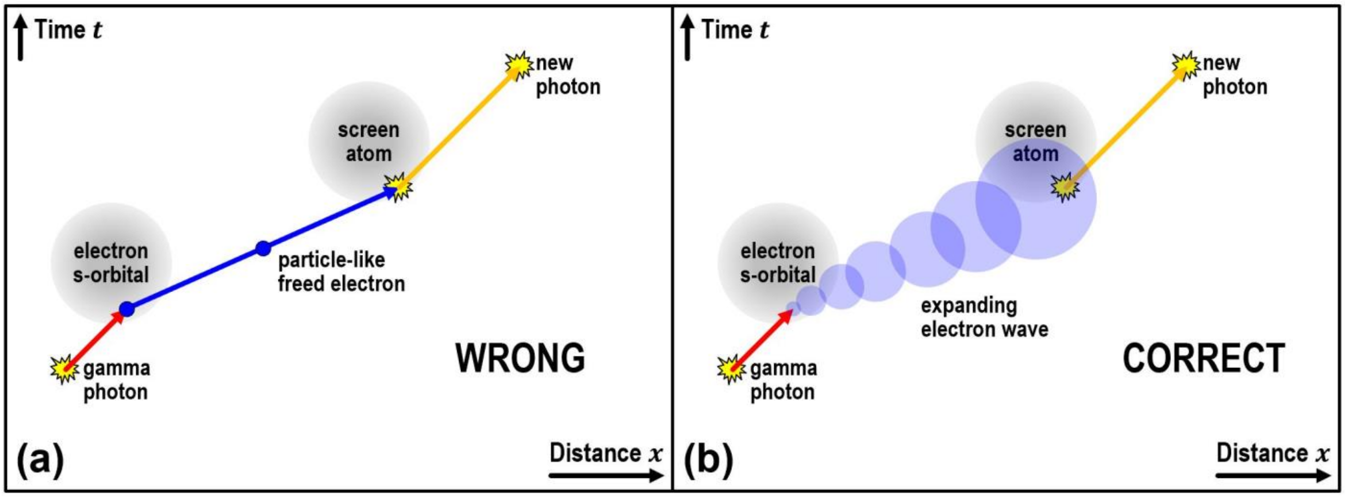

Figure 1. *Electrons expelled from atoms leave as waves, not particles.*

In truth, the electron immediately and vigorously reverts to a wave, both theoretically and experimentally. The electron is as "small as a gamma wavelength" only for one incredibly fleeting moment. Then it becomes a rapidly expanding Schrodinger wave that heads in the general direction of the screen. The electron doesn't become well-localized again until its wave function collapses at some new atom or particle. If that new location ropes the electron into a new orbital, the localization persists, and the electron regains an atomic-scale location, at least for a while. If a metal instead absorbs the electron, it again rapidly loses its location. That's because electrons in conduction bands have wave functions that can extend over the entire human-scale width of a piece of metal.

The wave nature of the electron as it travels between the two locations is easy to prove since inserting the right kind of grating (e.g., a crystal) or potential (e.g., the field lens of an electron microscope) diffracts or refracts the electron wave onto a new path. The existence of such non-particle phenomena along the nominal electron path shows it is *never* theoretically or experimentally sound to extrapolate the electron in a straight line. We mainly do that because, as humans with hardwired xyzt coordinates in our neural architectures, we sincerely want anything that forms a well-defined bundle to travel like rock, not a wave.

Some readers may now say, "Hey, what about cloud and bubble chambers? Those devices show emitted electrons and charged particles moving in well-defined lines and curves!"

Yes, and guess what: Such electrons and particles *also stop diffracting like waves* as they do in vacuums. It's a different experiment! Every time an election bumps an atom along the path of the electron in a particle or bubble chamber, it imparts a tiny bit of momentum to that atom. And guess what? Momentum has a wavelength! The tiny bump may only extract a small amount of energy from the passing electron. Still, the fact that this small amount of energy has a well-defined momentum wavelength means that the bumped atom "sees" the electron and recollapses its wave function to the scale of that tiny momentum transfer. An electron passing through dense ordinary matter *does* behave in a particle-like fashion, but only because it is undergoing almost continual minute momentum exchanges that leave a record of its passing and thus restart another short stint of compact-wave, almost-particle-like behavior.

Your next thought may be: "Wait... doesn't it take a human to collapse a wave function or at least some kind of sentient observer?" There were brilliant folks who sincerely proposed that idea. But other folks like Richard Feynman — a dear friend of the fellow who *did* suggest the need for conscious involvement, but those two were constantly bickering in a remarkably constructive, good-friends way about such things — were much more careful about the sequencing of such events.

For example, in the 1963 audio version of the Feynman Lectures on Physics, Volume III, Section 3-4 *Identical particles,* paragraph 1, Feynman notes that "... if there is a physical situation in which it is impossible to tell which way [a quantum event] happened, it *always* interferes; it *never* fails." By "impossible to tell," he means it left no momentum or energy signature to reveal its path, and by "interferes," he means "behaves like a wave."

The point is simple: Particles never exist as anything smaller than the last momentum exchange event that bound them within some wavelength-defined region. In the case of atoms, that boundary can persist for a very long time. That's a good thing since it's why we exist! For everything else, it's waves, waves, and more waves. We like to impose our very classical, very-un-wave interpolations of motion between events to comfort us into thinking that the deeper parts of the universe behave "just like" our classical world.

Please don't fall for it! The deeper reality underneath is far more exciting and unexpected, a genuine joy to behold once you realize how odd it is.

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