Waves?

by [Lev Tsitrin](#) (March 2025)

They say that "a picture is worth a thousand words" —and if we mean the speed of internalizing information, it is most certainly true: the eye absorbs an image instantly, while reading a thousand words takes a while.

But this does not mean that a picture is more truthful than words. Surprisingly, even in science—an area that unlike (say) politics or law precludes underhanded manipulation of facts (facts being the engine of science, and their adequate explanation, its end goal) —pictures, I would argue, can be deceptive too.

As I thought and read more about waves after [expressing my surprise]() at why anyone would find the notion of "particle-wave duality" surprising and difficult to grasp rather than obvious and commonsense, it dawned on me that the difficulty may stem from the familiar pictures of a wave as a bunch of undulations of electromagnetism or of particles going through space—as shown in, say, Wikipedia's [animation]() of the spread of an electromagnetic wave—or of the water wave [observed in detail]() from the same narrow angle, —pictures that in my view are as deceptive as presenting a bunch of identical boats following each other in a straight line as a picture of a single boat as it moves forward.

Wikipedia's animations imply that the ongoing sequence of undulations is a single wave—but the way I see it, each individual undulation is a separate wave—separate because it is generated independently from undulations that precede and follow it, and has no connection to them whatsoever. The only linkage between them (if this can be called a linkage) is that they all have been produced by the same generator.

The fact that each undulation is a separate wave is well illustrated by speech: just as each written word is composed of letters (i.e. "atoms of writing," so to speak), each word coming out of a mouth is composed of a bunch of consecutive notes ("atoms" of a spoken word?), the tongue constantly generating extremely brief but completely different undulations that form speech. Of course, the tongue is capable of sending out the same, identical undulations continuously—like we see in the pictures of waves—but those would produce an inarticulate sound like "uuuuuu" —hum rather than words. A single "u" coming from a single undulation is a separate wave; the above-quoted "uuuuuu" is a sting of six separate (though identical) undulations (i.e. waves) following each other.

In other words, individual undulations or waves are like kids born to the same parents: they are completely separate individuals (though they can be lumped under the general header of "offspring"). Better yet (because we talk here of inanimate objects), the continuous flow of undulations is like bullets fired from an automatic rifle—each bullet being its own, completely autonomous thing even though it is one of many rounds fired out of the same clip by the same rifle. Each bullet is, needless to say, a separate entity.

A bullet is a perfect analogy to a wave—and this has some very interesting ramifications. Perhaps the most important one renders nonsensical the notion of "wave frequency." An undulation (or wave) has length, height (or "amplitude"), and speed—same characteristics as objects; in that respect, waves are no different from particles at all. "Wave frequency" is a confused misnomer for the "wave trigger's frequency" —the speed with which the device that generates waves can, after firing a wave, go back to the firing configuration again. This device (say, a guitar that produces undulation in air after a string is pulled and released, which we perceive as a note of music) is as separate from the wave it generates as a gun is separate from a bullet. The guitar can shoot sound waves with certain "frequency" —but each of those waves have no "frequency" at all, just like a bullet has no frequency—but a machine gun does. "Wave frequency" is a nonsensical combination of words based on confused conflation of the generator of wave with a wave itself; “frequency” can only relate to the objects that produce and absorb waves, but not to waves themselves.

Incidentally, the fundamental similarity between a wave generator and a gun readily explains the inverse relationship between the length of a wave and the frequency with which the generator can fire the waves (i.e. the higher the frequency the shorter the wave). A larger bullet needs a larger gun to fire it. The larger the gun, the longer the path its gears have to travel to return back to the firing position. The longer the path, the greater the time it takes to be ready to fire the next bullet. Hence, the larger the gun the fewer the number of bullets per minute it can fire: an increase in the size of a bullet reduces the frequency of fire. A miniature gun firing tiny bullets will have far greater frequency of fire than a howitzer. The same is true for waves: the shorter the string a musician pulls, the shorter the path it has to travel to go back to its vertical, “firing” position—hence, greater frequency with which it vibrates.

All this is to say that there is no fundamental difference between moving particles and waves at all (and for that matter, there is a good deal of basic similarity between the devices that set them in motion) —the only difference being that waves are made of the substance in which they move (i.e. molecules of air or water) while particles or objects like bullets are made of external, dense substance. That’s all the difference there is—though this difference in materials admittedly allows for some very different behaviors (waves, for instance, can just go through each other on their merry way; particles can’t).

Now, electromagnetic waves are a different animal entirely. To me, the subject is full of deep mystery, as exemplified by the mind-boggling action of the magnets, repelling or attracting each other through a space in between, depending on how you turn them. To add to that “action-at-a-distance” mystery (or as a part of it), we are told that electromagnetic waves propagate through vacuum—by self-regenerating, father and farther into space, their initial electromagnetic impulse at the mindboggling speed of light. Clearly, charges—those mysterious things that attract and repel each other at a distance—operate very differently from the objects that, with no mystery involved, just hit each other head-on.

And yet, there are commonalities. Both kind are generated by some external intrusion—a rock thrown into the water in the case of mechanical waves or, in case of electromagnetic ones, electrons forcibly dislodged from their position during, say, a chemical reaction that pushes electrons from one atomic orbit to another, producing heat and light (like when turning a knob in a gas stove), or by introduction of external electromagnetism (like when flipping a light switch).

A rock sinking deeper in a pond displaces water on its way to the bottom; as the rock moves down, water flows to the sides to give it room, and rushes back in after it passed, the molecules bumping against each other head-on and rebounding, and pushing their neighbors farther away, pushing the resulting undulation farther and farther away. I guess radio waves get generated in a similar way—once a wire is attached to the opposite poles of a battery, its electrons get pushed—just like a rock—along the wire by the forces of repulsion from a negative pole of the battery, and of attraction to the positive pole due to the mystical (to me) force that acts on charges. On their way along the wire, those forcibly displaced negatively-charged electrons kick sidewise the electrons near which they pass, and they in turn generate electromagnetic ways. But unlike waves generated by a rock thrown into water that, being made of water, are confined to the pond, electromagnetic waves are not confined to the wire. They flow outside, continuing through vacuum at the speed of light, doing what mechanical waves that are made of the material they travel in, cannot do.

Vacuum is, by definition, made of nothing—but is it "nothing" through which electromagnetic waves traverse the universe? In a sense of being devoid of objects or particles, the answer is "yes" —interstellar space is overwhelmingly empty. But as to electromagnetism, this is not true at all: Wikipedia informs us of the cosmic background radiation that fills the entire Universe since shortly after the Big Bang. It may of course be irrelevant to the spread of electromagnetic waves (which may, like mechanical waves, travel through each other), or it may not be; but clearly, this cosmic radiation is fundamental to the Universe, and may play part in its workings, rather than being just a historical testimony to the Big Bang that now (so to speak) gathers dust in the archives of the history of Creation. (I even wonder whether it plays a role in the (to me) mysterious behavior of magnets—what if those all-pervading pulses that, needless to say, directly touch the surface of the magnets, organize in further layers around magnets' sides, and forcibly hit the facing edges of magnets when the same poles are facing each other, producing repulsion, or hit the opposing edges when one magnet is turned around, causing magnets to rush towards each other?)

And, applying my initial contention that each individual undulation is its own, separately-generated, independent wave, the source that emits it getting slower as the length of the waves it shoots increases, and emitting shorter waves with greater frequency (which really means shooting out more waves within a given period of time), makes for a natural explanation of photoelectric effect in which electrons are knocked out of a metal plate by light, the shorter the wavelength the greater the "energy"? ("Energy," to me, is one of those human conventions that I find hard to grasp, there being no tangible—i.e. mechanically visualize-able—picture of it. In the case of the photoelectric effect, is "energy" measured by the number of electrons knocked out during a certain period? Or is this number combined with the height of their jump?) In any event, just as in the case of a machine gun where the smaller the bullet the faster the gun can shoot, thus hitting more targets (though each is hit with a weaker force), why would it be surprising that the shorter the wave length and the more waves per second are shot at the metal plate, more electrons are hit and knocked out? What's there to wonder at?

This goes counter to Wikipedia's description, "The frequency ν_o is the threshold frequency [at which light starts knocking out electrons] for the given material. Above that frequency, the maximum kinetic energy of the photoelectrons … rise linearly with the frequency, and have no dependence on the number of photons and the intensity of the impinging monochromatic light." Since I equate "frequency" with "the number of photons," the attempt to play off the increase in frequency against the increase in the number of photons doesn't make any sense to me. To my mind, increase of "frequency" is tantamount to the "increase in the number of photons" hitting the plate—which, in turn, causes increased emission of electrons.

(Given that I do not understand what exactly is being measured in evaluating the "kinetic energy" of ejected electrons, I wonder whether it is possible to experimentally count the number of ejected electrons and—separately—the height of their jump. I'd expect the former to go up as the wavelength goes down—and (by analogy with mechanical waves), the latter to go down as the wavelength goes up. In other words, the greater "energy" of progressively shorter waves is a result of greater number of progressively weaker hits—though each hit is sufficiently strong to lift an electron out of the plate. Another question is whether multiple waves can "hit" the same electron, giving it greater speed after it has already been ejected, and gets airborne? (Given the mysterious "action at a distance" that underpins electromagnetics, this does not require precise collision, and is therefore not inconceivable). And, following the same logic—can the longer waves that are unable to eject electrons at least interact with electrons after the shorter waves knocked them out of metal, and sent them flying—or do the electrons and those longer waves just ignore each other?)

Bottom line—once we are no longer confused by misleading visual representations of waves, and adjust our dictionary to no longer conflate waves with generators of waves, and stop ascribing to waves "frequency" which they do not possess, a wave looks so much more like a particle (or charge). So why be surprised that it acts like one? What's the big deal about "particle-wave" (and one should add, "charge-wave") "duality"?

In fact, is there a "duality"? Mechanical waves are made of particles. Electromagnetic waves seem to be pulsing charges. Mechanisms that generate them are, in their most general principle of operation, identical. So perhaps not only is there no "duality" —but, in the final analysis, there are no "waves"?

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