Time-reversing a laser: What it means and why it's important.

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Over a decade ago an overlooked symmetry of Maxwell's equations coupled to matter was recognized, a relationship between a laser at threshold and a perfectly absorbing resonator. The threshold condition for lasing is the point at which gain balances loss, and the system self-organizes to oscillate coherently at a specific frequency in the highest Q electromagnetic mode. At this special point the system supports a purely outgoing solution of the Maxwell wave equation at a real frequency but with negligible amplitude, heralding the turn-on of a steady-state source of coherent radiation. Time-reversing this threshold lasing equation maps the laser system to another physical realizable electromagnetic system, one in which the time-reflected lasing mode is incident on an identical resonator, except that absorption loss replaces gain, and the purely incoming wave is perfectly trapped by interference and eventually absorbed without scattering. This mapping implies that under very general conditions, any complex structure can be made to absorb perfectly at a specific frequency, if a specific *adapted* input wavefront is imposed and the loss is appropriately tuned, a phenomenon now known as Coherent Perfect Absorption (CPA). While CPA was proposed for classical electromagnetic waves, the effect occurs for all of the linear classical wave equations of physics, and has nonlinear generalizations as well. Moreover, while CPA describes perfect capture and transduction of waves, the theory pointed the way to an even more general theory of reflectionless scattering of appropriate adapted wavefronts ("reflectionless scattering modes", RSMs). This theory applies to quantum waves as well, and provides a new framework to explore the control and routing of waves via interference in guided and even open geometries. I will review a few dramatic experimental and technologically interesting applications of CPA and RSM.