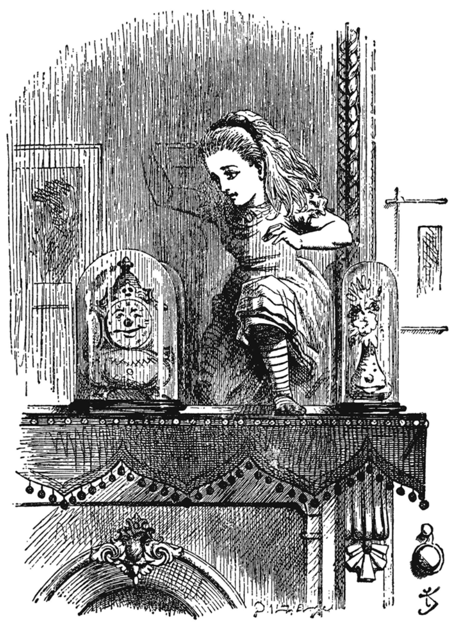
Through the laser mirror

On the 60th anniversary of the first functioning laser, we imagine a research landscape without it.

Sixty years ago, this month — on 16 May 1960 — Theodore Maiman returned from work and told his wife that his "experiment worked today"(https://go.nature.com/2VrT16M). Little did he know that the stimulated emission from ruby he had observed (Maiman, T. H. *Nature* **187**, 493–494; 1960) would be remembered as the first working laser and go on to spark a technology that has become a firm part of our daily lives. Today, lasers can be found in optical drives and they are crucial to the fibre optics underlying the broadband internet that allows us to stream films or scientific conferences. And, of course, they also permeate modern scientific research.

Lasers form the basis of countless scientific methods and of entire fields of research: without them, nonlinear optics, precision metrology, atomic physics, fluorescence imaging and ultrafast spectroscopy would certainly not exist as we know them. But what if Maiman's experiment had never worked? What might a researcher — let's call her Alice — encounter if she suddenly found herself in a strange research landscape where no lasers (or their microwave precursors) existed?



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Although a laser is an optical device, optics itself would mostly be affected in areas where nonlinear effects or short pulses are required. Nonlinear optics would not be the large and varied field of research that it is now, but would be restricted by the field strengths that continuous, incoherent high-power sources can provide. Other areas, like plasmonics and metamaterials, which are primarily concerned with linear optical properties, do not rely on laser sources. Indeed, it can be beneficial to move to longer wavelengths when structures become very complicated and difficult to fabricate, as is already the case in some fields.

Without nonlinear optics, quantum optics could not rely on spontaneous parametric downconversion to generate single photons and entangled pairs, but would have to employ other sources like quantum dots, which can be driven electrically and whose emission can be manipulated and utilized with surface acoustic waves, rather than directly by optical means. Alternatively, moving to microwave sources for quantum information tasks would eliminate the need for optical-to-electronic. In fact, a lot of the research on quantum technologies already uses superconducting qubits, which operate at microwave frequencies, although the ultralow temperatures they require present challenges of their own.

Without femtosecond — not to speak of attosecond — pulses, the time-resolved spectroscopy that is widely used to study the dynamics of atoms, molecules and charge carriers today could only be performed at large-scale facilities like synchrotrons, which restricts the available pulse lengths and wavelengths and comes with access limitations that do not apply to table-top sources. Yes, carrier dynamics can often be inferred from transport measurements with the help of theoretical models, but there would be no experimental confirmation of the results. Experimental condensed-matter physics would then likely focus on electron densities and band effects instead. Spin dynamics would remain in reach with the help of neutron and X-ray scattering, and methods like electron paramagnetic resonance might be more widely used. More generally, magnetic effects are naturally linked to microwave frequencies and could still be explored by electromagnetic means.

In atomic physics, laser trapping and laser cooling are so prevalent that one may wonder if it would still be possible without these tools. Although using lasers to both cool and trap atoms may be a particularly elegant solution, some atoms can also be trapped magnetically. Unlike the interference patterns that form optical lattices, the physical dimensions of the magnets place tight constraints on the physics that can be studied in this way. If a few decades of research had been invested, nanomagnets or clever metamaterial designs may well have allowed the field to progress, but the cooling of individual atoms may remain out of reach, and there would instead be a greater focus on condensates and low-temperature physics.

Not all research in atomic physics requires atoms to be trapped. For example, atomic clocks would work just the same and could replace optical clocks in a world where the direct interface of microwaves and electronics would be more widely exploited — despite their lower precision. Similarly, fusion research would continue to use magnetic fields to confine the plasma.

One big observation that certainly would not have been possible without lasers is the observation of gravitational waves using LIGO's interferometer with its 4-km-long arms. Interference over such long distances without the extraordinary coherence lengths of laser light is simply not possible.

Of course, it is impossible to predict which direction areas of physics that currently rely on the use of lasers may have taken without it. After all, science often builds on inventive solutions that are not at all obvious, but allow research to continue under less-than-ideal circumstances. But back here in the real world, lasers have given us experimental access to the ultrafast timescales of electronic processes, allowed us to study matter at the level of individual atoms, and contributed to our understanding of the cosmos. The 60th anniversary of Maiman's experiment is an apt time to pause for a moment and celebrate the device whose exceptional coherence properties and short pulses underlie so many scientific and technological achievements. ❐

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