Goulielmakis and colleagues[1] characterized the coherence, and thus the entanglement, of Kr^+ and the lost electron. In their experiments, the intense, ultrashort pump pulse ensures significant overlap of the two quantum states of the removed electron that correlate with two different pathways in the ion's subsystem (Fig. 1b), resulting in a low electron–ion entanglement, a high coherence of the hole's wave packet and high visibility of the interference fringes. The ability to probe decoherence is a very important aspect of the experiment.

The authors' experiment is reminiscent of a two-colour coherent-control scheme[2]. In such schemes, population of a final state is controlled by the relative phase between the two colours of light needed to promote a system from two intermediate states ($J = 1/2, 3/2$) to a final state. One might thus conclude that Goulielmakis *et al.* could have made their measurements without resorting to attosecond pulses — two 'phase-locked' colours, with controlled phase φ between them, would have been enough. From this perspective, the use of a time-delayed attosecond probe can be viewed merely as a convenient way to achieve this goal. Indeed, both colours needed to promote the system to the final $3d^{-1}$ state are naturally present in the ultrashort probe pulse used by Goulielmakis *et al.*, and the relative phase between them changes with the pump–probe delay. Are attosecond probe pulses really needed?

The answer is generally yes, if one deals with open systems. In the authors' study, conducted in the gas phase, decoherence arises only during the preparation of the hole wave packet and does not evolve afterwards. But a notable strength of Goulielmakis and colleagues' technique is that it can also be used in condensed phases (such as liquids and solids). Here, decoherence may quickly evolve during the time delay between the pump and the probe pulses, and so direct time-domain measurements, such as in the experiment[1], become indispensable — a two-colour coherent-control scheme operating with long pulses may not catch ultrafast changes in electron coherence.

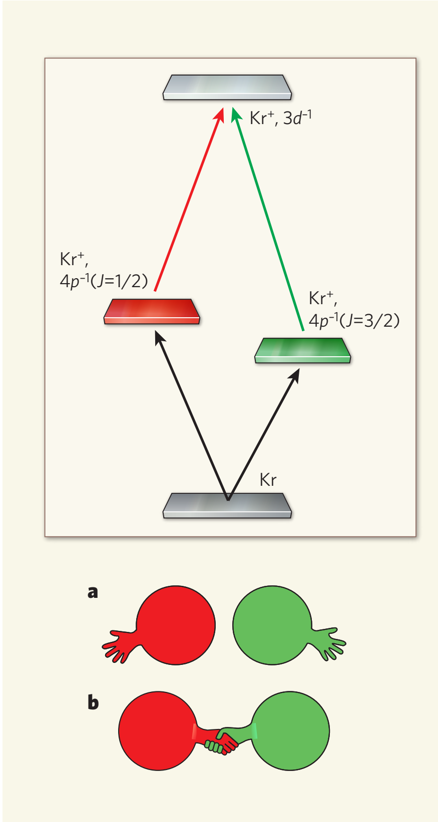


Figure 1 | The first attosecond probe experiments. Goulielmakis *et al.*[1] report a technique for observing electron motion in real time. They irradiated krypton atoms (Kr) with a 'pump' pulse of infrared light lasting a few femtoseconds, liberating electrons to generate Kr^+ ions in a superposition of two states, $4p^{-1}(J = 1/2)$ and $4p^{-1}(J = 3/2)$, where J is total angular momentum. Black arrows indicate the two ionization pathways. The authors then irradiated the ions with attosecond 'probe' pulses of extreme-ultraviolet light, exciting them to a higher-energy $3d^{-1}$ state; red and green arrows indicate the two possible excitation pathways. The complete system constitutes an entangled electron–ion pair. **a**, The different excitation pathways taken by the ion to reach the $3d^{-1}$ state may cause the liberated electrons to adopt orthogonal quantum states. The spheres represent two states of the same electron, in which the red sphere correlates with the $J = 1/2$ state of Kr^+, and the green sphere correlates with the $J = 3/2$ state. The 'hands' on the spheres don't touch, indicating that the states don't overlap. **b**, In Goulielmakis and colleagues' experiments, strong overlap of the two quantum states (indicated by the held hands of the spheres) lowers entanglement and allows the two possible excitation pathways of the ion to interfere. By measuring the interference, the authors tracked the motion of the hole (the absence of the liberated electron) in Kr^+ in real time, characterizing its coherence and the degree of electron–ion entanglement.

Subfemtosecond hole migration across many ångströms has been predicted to occur in large molecules[3,4]. Such motion may have important implications[5] for subsequent, femtosecond-scale nuclear dynamics in these molecules. Thus, early-stage hole dynamics may be connected[5] to the concept of charge-directed reactivity[6] — the idea that molecular bonds break in places to which a hole has migrated. This idea assumes coherence of the hole wave packet when it is prepared. The technique of attosecond transient absorption spectroscopy, introduced by Goulielmakis and colleagues[1], is well suited to check this key assumption.

The coupling of hole motion to other electronic and vibrational modes in molecules, which is responsible for charge-directed

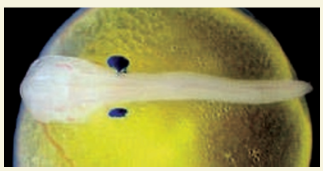
NEUROANATOMY

From fin to forelimb

The vertebrate invasion of land was made possible in part by evolution of the tetrapod forelimb from the fish pectoral fin. But what changes occurred in neural control during this transition?

Robert Baker and colleagues have tackled this question using a thorough application of comparative neuroanatomy (L.-H. Ma *et al. Nature Commun.* **1,** 49, doi:10.1038/ncomms1045; 2010). Their study centred on the developmental biology of several species of ray-finned fish, which are by far the largest group of extant fish. But it also included lobe-finned fish (a lineage that led to tetrapods) and cartilaginous fish such as sharks.

Motor-neuron innervation in tetrapods (forelimb) and fish (pectoral fin) arises from the spinal cord. But for ray- and lobe-finned fish, there is evidence that these nerves also originate in the hindbrain. In following up that evidence, the authors looked at the gross anatomy of the developing pectoral fin buds of various ray-finned fish. They found that they all have a similar organization of the buds themselves, of the myotomes that give rise to muscles, and of the neuroepithelium that generates pectoral motor neurons. Using dye-labelled fin buds (pictured



here in a species called the plainfin midshipman fish, attached to its egg yolk), the authors also demonstrated that the motor neurons project from both the hindbrain and the spinal cord.

Studies with transgenic zebrafish, containing a fluorescently tagged enhancer that reports the activity of the developmental gene *hoxb4a* in motor neurons, confirmed the mapping of pectoral-fin neurons. Further work involved injection of the messenger RNA for a photoactive fluorescent protein, kaede, into zebrafish embryos. The labelled neurons could then be followed during development, crucially showing that they develop *in situ* rather than migrating to their final location.

Baker and colleagues' extension of their study to lobe-finned and cartilaginous fish provided evidence that, in these groups too, pectoral-fin motor-neuron control is exercised from the hindbrain as well as the spinal cord. Overall, the authors conclude that this dual contribution is the ancestral condition in vertebrates. As to the functional context, they speculate that the advent of spinal-only motor innervation of the forelimb allowed another notable characteristic of tetrapods compared with fish — their greater freedom of head movement.
Katie Ridd