mechanism is switched off, and we therefore usually consider that double ionization can be well described by a sequential model based on the single-active-electron approximation[9]. What Pfeiffer *et al.* found was that the second ionization step takes place much earlier than predicted by the sequential double-ionization model.

What does this really tell us? One might criticize the approximations used in the semi-classical model. First, how can we define the timing of the electron release? It is probably impossible to answer this philosophical question rigorously. The authors trace back the classical electron trajectory and determine the time when the trajectory had zero velocity. This fully classical definition is surely debatable but any alternative would not shift the timing by more than a half cycle. Second, is neglecting the Coulomb potential justified? It has recently been shown[10] that the angular distribution of the electron released by elliptically polarized laser fields is sensitive to the details of the electron-ion interaction, which would cast doubt on the validity of the minute hand of the attoclock. According to Pfeiffer *et al.*, the Coulomb correction is small in the intensity regime they studied and cannot explain the observed timing difference.

Third, is the theory used to calculate the tunnelling rate reliable? Fourth, is there any multi-electron effect during the ionization? Ideally, to answer these questions we would use time-dependent Schrödinger equation (TDSE) simulations. However, TDSE simulations for a multi-electron atom in an elliptically polarized strong field are currently not feasible due to exceedingly large computing time requirements. Very recently, Wang and Eberly[11] studied sequential double ionization with elliptical polarization using a classical-ensemble simulation that fully takes into account electron–electron interactions at all times. Such simulations might shed light on the multi-electron effects, though it is not clear how quantitatively the classical-ensemble model can describe strong-field ionization. Also, there remains uncertainty in the intensity and temporal profile of the pulses used in the experiments. The exploration of these issues will be an exciting prospect, and possibly at the same time sow the seeds of even more controversy. ❐

Kiyoshi Ueda is at the Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan; Kenichi L. Ishikawa is at the Photon Science Center, Graduate School of Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan.
e-mail: ueda@tagen.tohoku.ac.jp; ishiken@atto.t.u-tokyo.ac.jp

References

1. Corkum, P. B. & Krausz, F. *Nature Phys.* **3,** 381–387 (2007).
2. Pfeiffer, A. N., Cirelli, C., Smolarski, M., Dörner, R. & Keller, U. *Nature Phys.* **7,** 428–433 (2011).
3. Eckle, P. *et al. Nature Phys.* **4,** 565–570 (2008).
4. Altucci, C., Velotta, R. & Marangos, J. P. *J. Modern Optics* **57,** 915 (2010).
5. Zewail, A. H. *J. Phys. Chem. A* **104,** 5660–5694 (2000).
6. Goulielmakis, E. *et al. Science* **320,** 1614–1617 (2008).
7. Goulielmakis, E. *et al. Nature* **466,** 739–743 (2010).
8. Schultze, M. *et al. Science* **328,** 1658–1662 (2010).
9. Maharjan, C. *et al. Phys. Rev. A* **72,** 041403 (2005).
10. Popruzhenko, S. V., Paulus, G. G. & Bauer, D. *Phys. Rev. A* **77,** 053409 (2008).
11. Wang, X. & Eberly, J. H. Preprint at http://arxiv.org/abs/1102.0221v1 (2011).

THE PHYSICS OF BLOOMING

Watch it unfold

Their genesis is described with flowery eloquence in the *Geoponica*, a collection of twenty books of agricultural lore compiled during the tenth century: as the goddess Hera was suckling Heracles, drops of milk fell onto the ground and grew into lilies (the milk spilt into the sky became the Milky Way). Over the centuries, lilies — and in particular their blooms — have held mystical appeal, as a symbol of purity or rendered emblematically as the *fleur de lys* in coats of arms and flags. They've received less attention, however, from science, even if the mechanisms of how lilies and other flowers bloom, and thus how they reveal the bright colours of their petals and adopt their characteristic shape, are not fully understood.

Haiyi Liang and L. Mahadevan have taken a close look at the physical process of blooming and present a compact theory for the movements involved (*Proc. Natl Acad. Sci. USA* **108,** 5516–5521; 2011). The metamorphosis from bud to flower takes, depending on the flower, somewhere between a few hours and several days, suggesting that the process is driven by growth, rather than, for example, by flow of water.

© ISTOCKPHOTO.COM / LUBOMIR JENDROL

For the common lily *Lilium Casablanca* (pictured), which Liang and Mahadevan have studied, the process typically spans four and a half days. During that time, pressure builds up inside the bud, as the three inner petals grow inside the three outer sepals that embrace them. A locking mechanism between petals and sepals ensures that the bud remains intact during this period, but once a critical pressure is reached, the flower blooms relatively rapidly, as petals and sepals reverse their curvature and at the same time wrinkle around the edges.

These wrinkles hint at differential growth being part of the blooming process. It had been proposed that the relevant difference in growth rate is between the upper and lower sides of the petals and sepals, and that the midrib has an important role. But by shaving the midrib off petals, Liang and Mahadevan proved that it is not necessary for blooming. Furthermore, they find in their observations and through modelling that growth at the edges alone can induce the shape change.

So it's all about forces and stresses then, rather than mystique and elegance? Not quite, say Liang and Mahadevan. They see their study as "infusing a scientific aesthetic into a thing of beauty", but also expect, more pragmatically, that these findings could inspire new designs for artificial edge-activated bimorphs.

ANDREAS TRABESINGER