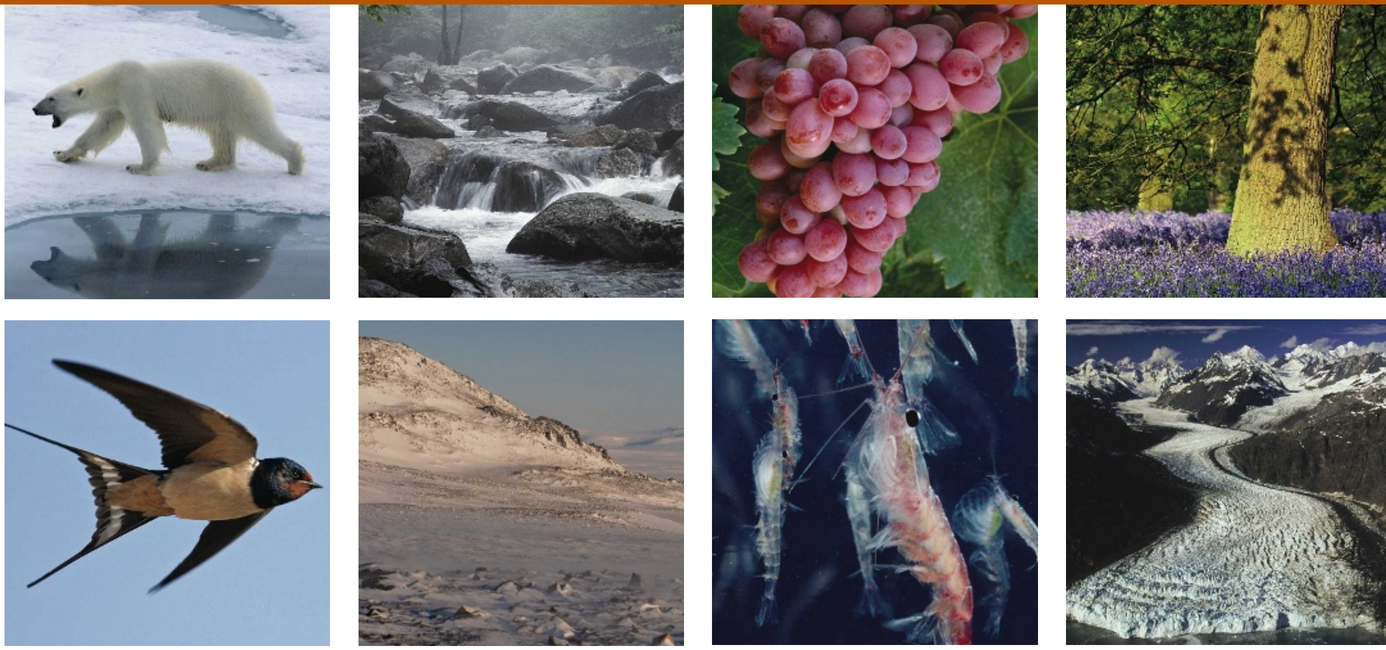

Figure 1 | Going through the changes. The literature sampled by Rosenzweig *et al.*[1] in analysing the possible impacts of climate change covered a diversity of phenomena in a diversity of biological and physical systems. Examples are perturbation of polar bear behaviour; timing of peak stream flow, of grape harvests, and of spring flowering and bird migration; and variation in the freeze–thaw pattern in tundra, in krill stocks and in glacier 'wastage'.

TOP ROW, LEFT TO RIGHT: T. JACOBSEN/ARCTICPHOTO.COM; P. SCHERMEISTER/NATL GEOGR./GETTY IMAGES; E. YOUNG/CORBIS; P. HAYS/STILL PICT

BOTTOM ROW: R. TIDMAN/NHPA; BRYAN & CHERRY ALEXANDER PHOTOGRAPHY; F. NICKLIN/MINDEN PICTURES/GETTY IMAGES; J. HYDE/ARCTICPHOTO.

require an 'end-to-end'[9] modelling system that includes explicit representations of all of the main processes (climatic and non-climatic) that contribute to the variability of the system under study, and can simulate the response to greenhouse-gas increases as well as other factors that can cause changes in the observed impact. Such a tool can then be used to estimate how different external influences contribute to observed changes in systems relative to each other, much as models of the climate system are used to study the relative contributions of greenhouse gases, aerosols and natural climate variability to observed changes in surface air temperature and other basic climate variables[3]. Few such modelling systems are available, in part due to the difficulty of representing the relevant processes within climate models.

Likewise, only a few end-to-end attribution studies have been carried out[1,2]. They are limited to cases where the affected system and its interaction with climate are either relatively well understood[10] or reasonably described empirically[11]. We need more of them. End-to-end studies will help in interpreting the results of less direct approaches to attribution. Moreover, they can also be used to evaluate and adjust projections of future impacts based on changes that have already been observed; that will be essential in formulating strategies to adapt to the consequences of climate change, and to assess their uncertainties, much as has been done with projections of future temperature change[12]. The ultimate goal is to provide probabilistic projections of future effects — that is, estimates of the probability that some outcome will or will not occur — and so allow decisions about adaptive measures to be based on a firmer footing. ■

Francis Zwiers is in the Climate Research Division, Environment Canada, 4905 Dufferin Street, Toronto, Ontario M3H 5T4, Canada.
Gabriele Hegerl is in the School of Geosciences, University of Edinburgh, Edinburgh EH9 3JW, UK.
e-mails: francis.zwiers@ec.gc.ca; gabi.hegerl@ed.ac.uk

1. Rosenzweig, C. *et al. Nature* **453,** 353–357 (2008).
2. Rosenzweig, C. *et al.* in *Climate Change 2007: Impacts, Adaptation and Vulnerability* (eds Parry, M. L. *et al.*) 79–131 (Cambridge Univ. Press, 2007).
3. Hegerl, G. C. *et al.* in *Climate Change 2007: The Physical Science Basis* (eds Solomon, S. D. *et al.*) 663–745 (Cambridge Univ. Press, 2007).
4. Easterling, D. R. *et al.* Science, **289,** 2068–2074 (2000).
5. Zhang, X. *et al. Nature* **448,** 461–465 (2007).
6. Min, S.-K., Zhang, X. & Zwiers, F. *Science* **320,** 518–520 (2008).
7. Parker, D. E., Legg, T. P. & Folland, C. K. *Int. J. Clim.* **12,** 317–342 (1992).
8. Rutishauser, T., Luterbacher, J., Jeanneret, F., Pfister, C. & Wanner, H. *J. Geophys. Res.* **112,** G04016 (2007).
9. Stone, D. A. & Allen, M. R. *Climatic Change* **71,** 303–318 (2005).
10. Barnett, T. P. *et al. Science* **319,** 1080–1083 (2008).
11. Gillett, N. P., Weaver, A. J., Zwiers, F. W. & Flannigan, M. D. *Geophys. Res. Lett.* **31,** L18211, doi:10.1029/2004GL020876 (2004).
12. Meehl, G. A. *et al.* in *Climate Change 2007: The Physical Science Basis* (eds Solomon, S. D. *et al.*) 747–845 (Cambridge Univ. Press, 2007).

SOLID-STATE PHYSICS

Polaritronics in view

Benoît Deveaud-Plédran

Polaritons are an odd cross-breed of a particle, half-matter, half-light. They could offer an abundant crop of new and improved optoelectronic devices — a promise already being fulfilled.

When I first encountered the idea of a polariton, while reading the doctoral work of John Hopfield[1], its beauty stunned me. These mixed 'quasiparticles' are produced in semiconductor materials when the pairing of an electron and its phantom, a hole (this combination in itself a quasiparticle known as an exciton), couples with the photons of a light field. The result is something that is part matter, part light, and inherits qualities of both. Yet for all that they are useful for those who wish to get to grips with the optical properties of semiconductors, I always had a feeling that polaritons were not actually 'real'. I never expected that they would make their way out of the laboratory; still less that they would ever have any practical application.

History is proving me wrong. On page 372 of this issue, Tsintzos *et al.*[2] detail the latest stage of the long march of polaritons to workaday respectability. They describe how they have produced a gallium arsenide diode that emits light directly from polariton states when they break up, at temperatures of up to 235 kelvin — just 60 kelvin or so below room temperature.

This breakthrough is significant, as my initial reservations about polaritons were founded largely on the fact that they can be stable only at very low temperatures and densities — under normal conditions, they tend to disintegrate, transforming themselves spontaneously into run-of-the-mill photons. In a semiconductor laser, or in a light-emitting diode (LED), temperature and density are both high. Light amplification and emission in these contexts are driven not by polariton interactions, but by the behaviour of an electron–hole plasma driven by the current flowing through the diode. It is a simple and robust mode of operation that has remained essentially unaltered in the near-50-year history of such devices, even in the newest vertical-cavity surface-emitting lasers (VCSELs). Over the years, the only factors that have changed are that the size of devices has decreased, and their efficiency has improved.

This story took a new twist in 1991, when a new type of polariton, the cavity polariton[3], came to light. These quasiparticles arise when electrons and holes, in the form of excitons, are confined by the changes in the chemical composition of a substrate to a quantum energy well; simultaneously, photons are localized in the same region using two highly reflecting mirrors. In this way, stable polaritons can be produced. Stable is in this context relative; to a polariton, stability is a lifetime of more than 1 picosecond, a millionth of a millionth of a second.

More pertinently to the case in hand, stability means that cavity polaritons with zero wavevector — a quantity related to their momentum — are naturally the energetic ground state of the cavity system. This ground state will emit light precisely perpendicular to the surface of the confining sample. Subsequent studies have attested that these cavity polaritons have quite a number of useful properties. First, they have large de Broglie wavelengths of around 1 micrometre, meaning that their quantum wavefunctions are large enough to be manipulated easily, making them appealing for applications in quantum optics. Second, they might be stable at room temperature, with obvious advantages. Finally, they are good bosons, meaning that they can be parametrically amplified[4] (that is, split up or joined together in units of different energy, a useful technique for signal amplification), and that many of them can pile up in a given quantum state, eventually leading to the formation of the state of matter known as a Bose–Einstein condensate[5].

A number of patents have been filed on the strength of these admirable qualities. These home in on possible uses for cavity polaritons in, for instance, single-photon emitters, lasers, light-emitting diodes, photodetectors and optical switches. But at least two questions need to be addressed before such applications become reality: whether polaritons can indeed be made to operate at a sensible temperature; and whether they can be activated directly by electrical means.

Polaritons have already been confined in micrometre-sized cavities[6]. Tsintzos and colleagues' advance[2] builds on that, and fits in with a body of work[7–9] published in recent months. Two of these papers describe the construction of VCSEL-like cavities whose mirrors are of good enough quality to induce either electroluminescence[7] or the emission of laser light[8] in the polariton-coupling regime. Both these experiments were performed at temperatures of around 10 kelvin. A third[9] details the realization of a polariton LED that works at up to 100 kelvin.

The new polariton LED that operates at 235 kelvin is thus a step further towards fulfilling the promise of room-temperature, electrically driven polariton devices. The nigh-on simultaneous advances in the field[2,6–8], on the back of the parametric amplification[4] and Bose–Einstein condensation[5] of cavity polaritons, represent in my view the first glimpses of a grand new vista — of an expansive field that one might term 'polaritronics'. It should not be long before real, practical device applications begin to fill that panorama. ■

Benoît Deveaud-Plédran is in the Laboratory of Quantum Optoelectronics, Ecole Polytechnique Fédérale de Lausanne, Station 3, 1015 Lausanne, Switzerland.
e-mail: benoit.deveaud-pledran@epfl.ch

1. Hopfield, J. J. *Phys. Rev.* **112,** 1555–1567 (1958).
2. Tsintzos, S. I., Pelekanos, N. T., Konstantinidis, G., Hatzopoulos, Z. & Savvidis, P. G. *Nature* **453,** 372–375 (2008).
3. Weisbuch, C., Nishioka, M., Ishikawa, A. & Arakawa, Y. *Phys. Rev. Lett.* **69,** 3314–3317 (1992).
4. Saba, M. *et al. Nature* **414,** 731–735 (2001).
5. Kasprzak, J. *et al. Nature* **443,** 409–414 (2006).
6. El Daïf, O. *et al. Appl. Phys. Lett.* **88,** 061105 (2006).
7. Khalifa, A. A., Love, A. P. D., Krizhanovskii, D. N., Skolnick, M. S. & Roberts, J. S. *Appl. Phys. Lett.* **92,** 061107 (2008).
8. Bajoni, D. *et al. Phys. Rev. Lett.* **100,** 047401 (2008).
9. Bajoni, D. *et al. Phys. Rev. B.* **77,** 113303 (2008).

PLANT BIOLOGY

In their neighbour's shadow

Jiří Friml and Michael Sauer

They can't move away from shade, so plants resort to a molecular solution to find a place in the sun. The action they take is quite radical, and involves a reprogramming of their development.

To survive, organisms must adapt to their ever-changing environment. Animals rely mainly on behavioural adaptive responses such as fighting or fleeing. But being stationary, plants must adjust their shape and metabolism accordingly. Plant hormones play an essential part in these adaptive responses, affecting various physiological and developmental processes. The hormone almost universally involved in plant adaptation is auxin. It exerts its effect at several developmental levels ranging from cell elongation and formation of the embryonic axis to fruit ripening[1]. Reporting in *Cell*, two teams — Tao *et al.*[2] and Stepanova *et al.*[3] — identify an enzyme that catalyses the first step in the biosynthesis of auxin, a step that occurs in response to changes in both ambient light and another plant hormone, ethylene.

A plant's repertoire of developmental tricks is extraordinarily broad: permanent stem-cell populations ensure growth throughout life; post-embryonic development allows new organs, such as leaves and flowers, to be generated; and differential growth enables developing plants to seek light, and roots to seek water. So even if plants have to compete — for example, for sunlight with their neighbours — they do so by modulating their own growth rather than by directly preventing that of others. Indeed, a reduction in the quality of light causes shade-avoidance syndrome, a physiological response leading to stem elongation, fewer branches and earlier flowering.

All of these processes are mediated by plant hormones, which, like animal hormones, do not necessarily act at the location at which they are synthesized. But unlike animals, plants lack a cardiovascular system, making effective distribution of hormones problematic. Consequently, the production of plant hormones is not as localized as that of their animal counterparts, and their effect typically depends on the activation of several hormonal pathways and crosstalk between them. Individual hormonal pathways in plants have been generally well characterized at a molecular level, but research into hormone crosstalk is still in its infancy.

For auxin, spatial differences in its concentration (forming auxin gradients) are crucial for specific developmental responses[1]. Local manipulation of cellular auxin levels — for example, by applying auxin in droplets or by locally activating its synthesis — confirmed[4,5] that an increase in the level of this hormone triggers developmental programmes. So a central question in plant biology is how auxin gradients are generated. There are several answers. One is that specialized auxin-transport