CO₂ at 13.8 MPa and 40 °C, there was no detectable [BMIM][PF₆] in the extract, indicating that the solubility is less than 10⁻² mol fraction. In contrast, a mixture of CO₂ with a conventional organic liquid results in significant solubility of the liquid in the CO₂-rich phase. The phase behaviour of the ionic liquid–CO₂ system resembles that of a cross-linked polymer–solvent system², even though [BMIM][PF₆] is a low-viscosity, low-molecular-weight liquid. The liquid phase increased in volume by only 10–20% when 8 MPa of CO₂ pressure was applied, perhaps because it is ionic; this corresponds to a more than twofold decrease in the molar volume.

Naphthalene was chosen as our model non-volatile organic solute because it dissolves readily in [BMIM][PF₆] (maximum solubility of 0.30 mol fraction at 40 °C) and in CO₂ (with a solubility of 0.013–0.017 mol fraction at 35 °C and pressures of 12.2–20.4 MPa; ref 10). A mixture of 0.12 mol fraction naphthalene in [BMIM][PF₆] was extracted with CO₂ at 13.8 MPa and 40 °C with recoveries of 94–96% (Fig. 2). This near-quantitative recovery compares favourably with the dissolution of a similar amount of pure solid naphthalene into CO₂, using the same extractor and analytical technique, as shown (diamonds).

The liquid does not dissolve in carbon dioxide, so pure product can be recovered.

We synthesized³ the ionic liquid 1-butyl-3-methylimidazolium hexafluorophosphate [BMIM][PF₆], which is stable in the presence of either oxygen or water. Our primary objective was to show that CO₂ could be used to extract naphthalene, our low-volatility model solute, from an ionic liquid, but it was important to show that the CO₂-rich phase is not significantly contaminated by the ionic liquid, as would be expected during contact of CO₂ with any conventional organic solvent. We therefore investigated the phase behaviour of [BMIM][PF₆] with CO₂, as well as with naphthalene, and finally that of the [BMIM][PF₆]–CO₂–naphthalene ternary.

CO₂ at 13.8 MPa and 40 °C could not be found at pressures up to 40 MPa, the highest pressure accessible with our equipment. The composition of the CO₂-rich phase is essentially pure CO₂. After extracting the ionic liquid with 55 g of CO₂, the pure product can be recovered.

Long-distance transport of pollen into the Arctic

Airborne particulates can be carried over long distances, but for significant quantities of particulates larger than a few micrometres in diameter to be transported more than a few kilometres usually requires a means of injecting the material high into the atmosphere, such as a volcanic eruption, forest fire or desert windstorm. But an unusual event occurred in the Canadian Arctic last year, in which significant amounts of pine and spruce pollen (30–55 μm long) were transported roughly 3,000 km.

On the night of 5 June 1998 and the following morning, local hunters noticed an unusual concentration of pollen at the edges of ponds on Arctic Ocean ice near Repulse Bay, Northwest Territories, Canada (Fig. 1). Similar deposits were also reported in Pelly Bay, northwest of Repulse Bay, but not in other Arctic communities. The material is a remarkably pure pollen concentrate containing 92% jack pine (Pinus banksiana) and 8% white spruce (Picea glauca). An examination of more than 1,500 pollen grains revealed no pollen from alder (the most common exotic pollen in the eastern Arctic)⁴ or other taxa, no large organic debris and no charcoal. The pollen is in excellent condition, most of it having unbroken walls and intact cytoplasm, unlike the ‘yellow rain’ reported in south-
east Asia in the late 1970s and early 1980s, which proved to be bee faeces.

Pine pollen is known to traverse great distances, and is often found as a component of both pollen rain and stratigraphic pollen assemblages well beyond the tree line. Spruce pollen, being much larger, does not transport as readily but can nevertheless form a significant proportion of the tundra pollen assemblage. Typically, boreal forest pollen deposit in the high Arctic at a rate of less than 1 grain per species per cm² per year. The influx rate in Repulse Bay during this event was not measured, but must have been of the order of hundreds of grains per cm² in only a few hours.

The timing of the deposit and its geographic coverage indicate that the event was the result of an unusually strong low-pressure system that developed over Repulse Bay on 5 June. A three-dimensional back-trajectory analysis indicates that winds arriving at Repulse Bay on 6 June would have been near ground level in central Quebec on 1 June. Pine, spruce and alder may all be in flower at this time of year, depending on weather conditions. High surface winds (up to 24 km h⁻¹) lofted the pollen into the air, and this pollen-laden air mass travelled at approximately the 850 hPa level (~1,300 m) northeast over Labrador, north over the Labrador Sea, and west over southeastern Baffin Island, arriving at Repulse Bay late on 5 June and in the morning of 6 June. The wind speed dropped to less than 20 km h⁻¹, allowing the pollen to settle out. This event lasted an unusually long time (turbulence in the airflow causes most grains to remain airborne for less than a day) and covered a remarkable distance (nearly 3,000 km).

That lifetime residents of the area have never seen anything similar demonstrates the rarity of this type of pollen transport event. As stratigraphic pollen data often integrate several decades in a single sample, however, such rare events may account for some of the variability often seen in the records of high Arctic regions. Similar rare transport events may account for some of the noise in ice-core records of pollen, dust, charcoal and other particulates and aerosols.

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Cause and effect in evolution

The need to see ‘purpose’ in evolution, or at least some internal drive to help the blind processes of random variation and natural selection, is remarkably resilient. Recent manifestations in the scientific literature imagine evolved mechanisms that actively promote further evolution or that facilitate rapid response to changed conditions. For example, Rutherford and Lindquist (and the authors of related commentaries) suggest that the heat-shock protein Hsp90, by stabilizing developmental pathways, fosters the accumulation of hidden variants that can be exposed by environmental challenges and subsequently fixed by selection.

This is interpreted as “an explicit molecular mechanism that assists the process of evolutionary change” (or even “a way of saving up mutations for a rainy day”). Similarly, it is widely believed that organisms increase mutation rates under stressful conditions to improve their chances of hitting on appropriate adaptations.

Such interpretations seem to call for the evolution of properties that anticipate future needs. But selection lacks foresight, and no one has described a plausible way to provide it. In principle, group selection might produce results that seem to escape this limitation. For example, increased mutation rates may indeed allow populations to adapt more quickly to changed conditions, even though they harm most individuals. The evolutionary problem is that such group benefits are usually weaker than individual costs, in a well-defined sense that makes group selection effective only under very restrictive conditions. So, in general, we need explanations that are based on individual fitness differences.

From this perspective, the obvious function of Hsp90 is to prevent abnormalities of the kinds that appear when it is compromised. Up to a few per cent of adults heterozygous for a mutation that inactivates Hsp90 display significant morphological abnormality, so clearly there is selection to maintain its function. Likewise, increased mutation under stress might plausibly arise from trade-offs affecting individual fitness: stressed cells may simply be unable to maintain normal DNA repair without sacrificing other vital functions.

In the natural world, only living things (and their artefacts) have ‘purposes’, and natural selection is the ultimate source of all such ‘purposeful’ design. When speaking of the function or purpose of some feature of an organism, we are therefore referring to the selective advantages that brought the feature into being and that maintain it in the face of recurrent damaging mutations. It is especially important, in any discussion of evolutionary processes, to observe the distinction between function or purpose on the one hand, and effect or consequence on the other. This is not a semantic quibble. Cosmic rays affect evolution by causing mutations, but we would not claim that they exist for that purpose. Similarly, developmental buffering and variable mutation rates may influence the course of evolution, but this does not mean that they evolved to that end.

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