semipermeable interfaces to send glucose and amino acids in one direction and potential neurotoxins in another, or to field-effect transistors that regulate the passage of charge in an electric circuit. Rectifying solid–solid interfaces could be designed into the atomic structure of the material. At this level, interface engineering would herald a whole new era of 'smart materials'.

Finally, it is interesting to consider the methodological opportunities that are opening up. Just like the famous early animation of the horse's gait (Fig. 2) — where the centuries-old intrigue around the movement sequence of the legs of a galloping horse was resolved once and for all via a time-gated sequence of images[3] — the emergence of *in situ* transmission electron microscopy techniques is set to provide new revelations in materials science. Indeed, much uncertainty exists around various nucleation phenomena. What is needed are clear 'movies' with suitable temporal and spatial resolution that provide new phenomenological insights and atomistic details. One anticipates that these methods will shed light on the mechanisms underpinning complex processes such as solute clustering, precipitation, segregation and growth phenomena. ❐

Simon P. Ringer is at the School of Aerospace, Mechanical and Mechatronic Engineering, and the Australian Centre for Microscopy & Microanalysis, University of Sydney, New South Wales 2006, Australia.
e-mail: simon.ringer@sydney.edu.au

References
1. Zou, L. *et al. Nat. Mater.* **17,** 56–62 (2018).
2. Qu, J. *et al. Adv. Mater.* **29,** 1701888 (2017).
3. Shimamura, A. P. *Hist. Photogr.* **26,** 341–350 (2002).

MATERIAL WITNESS

HOW DOES IT FEEL?

PHILIP BALL

If you were a material, which material would you be? Even if you find the question silly or trivial, you probably won't consider it meaningless. The human impulse to assign affective properties to phenomena and objects seems limitless: think of how we describe people as 'warm' (or even 'hot'), music as 'bright', news as 'heavy'. As far as materials go, some of this is surely down to association — gold implies wealth — or mimicry, as when fur-covered objects seem as comforting and welcoming as our favourite pet.

Is there any systematic way of understanding these links between materiality and affective association? If so, it might be possible to better attune environments to mental well-being, and perhaps even to use objects to communicate emotional states — for example, when circumstances or conditions such as dementia inhibit verbal communication. And you can be sure that marketing specialists and consumer psychologists are alert to the idea, just as currently they look for emotional and other associations of colour and smell.

Some understanding does exist. In particular, Cavanaugh *et al.* studied how people map perceptual dimensions such as temperature, texture and taste onto various emotional states, showing that there are clear and consistent distinctions between the correlates of positive and negative emotions and of high versus low arousal[1]. In a study focusing specifically on materials properties — thermal effusivity, roughness, density, softness, elasticity and opacity — Wilkes *et al.* have now developed a material toolkit, named PhysFeel, for exploring these connections (ref. 2 and S. E. Wilkes *et al.*, manuscript in preparation).

They use sets of 40-mm cubes to systematically vary one of these six properties while keeping others constant: for example, using different metals to vary density, substances from concrete to wax to vary thermal effusivity, and silicone rubbers for elasticity. Participants (29) were asked to handle these cubes and answer questions, and enter discussions, about the emotional associations. Again there was consistency in the results, in ways that suggest metaphorical mimicry: rough cubes were associated with anger, soft and elastic ones with happiness and so on.

On the one hand, the invitation here is to regard such findings as prescriptions for mood-managing desk toys (and there is no harm in that). But in these clear links between materiality and emotional state may be deep clues about the cognitive processes through which we exist and navigate in the world[3]. For one thing, Wilkes and Miodownik[2] caution that "the emotional associations of a material cannot be fully understood in isolation from the cultural totality of the whole material in its context of use."

But one might go further still. According to Donald in 1991[4], "we cannot have a science of mind that disregards material culture as we cannot have an adequate science of material culture that leaves out cognition". One way of interpreting this notion is to say, as Malafouris has[5], that it is a mistake to imagine the mind as some internal mechanism shunted into emotional states by outside (material) stimuli, and to think instead of cognition as a task performed by means of perceptual interaction with materiality. If anything, an appreciation of the somatic aspects of cognition and self-awareness has only increased among cognitive scientists over the decade or two since these ideas were proposed. Perhaps asking what kind of material you are is not such a trivial question after all. ❐

References
1. Cavanaugh, L. A., MacInnis, D. J. & Weiss, A. M. *Cogn. Emot.* **30,** 1430–1445 (2016).
2. Wilkes, S. E. & Miodownik, M. A. *Interdiscipl. Sci. Rev.* (in the press).
3. Renfrew, C. & Scarre, C. (eds) *Cognition and Material Culture: the Archaeology of Symbolic Storage* (McDonald Institute, 1998).
4. Donald, M. *Origins of the Modern Mind: Three Stages in the Evolution of Culture and Cognition* (Harvard Univ. Press, 1991).
5. Malafouris, L. in *Rethinking Materiality: The Engagement of Mind with the Material World* (eds Gosden, C., DeMarais, E. & Renfrew, C.) 53–62 (McDonald Institute, 2004).