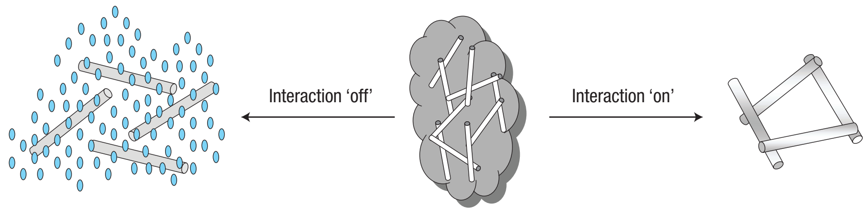

Figure 2 A schematic representation of the polymer nanocomposite. In the ‘on’ state, interactions are formed between the cellulose nanofibres, which maximize stress transfer between the fibres and, as a result, the tensile modulus increases. These fibre–fibre interactions are removed by the addition of a biomedically relevant chemical that competitively forms hydrogen bonds with the fibres, and the system is switched to the ‘off’ state. Reprinted with permission from ref. 1.

far from that desired for the brain. The second potential limitation is the swelling behaviour of the composite: An inward flow of cerebrospinal fluid is critical to modulating the cellulose fibre interactions and, in the current design, it seems as though swelling of at least 30% by volume is necessary to reach the softest state. In the confined space of the brain or spinal cord, this large volume change could have damaging repercussions.

An interesting advantage of this material is the specificity of the stimulus (water) that causes the change in stiffness. Theoretically, as the ‘modulating element’ is determined by the chemistry of the fibre–fibre and fibre–solvent competition, it should be possible to carefully engineer fibre side-chains and the solvent system so that the change in mechanical properties can be triggered by very specific stimuli such as ambient ions or protein or enzyme levels. For instance, one can imagine fibre–fibre interactions being engineered to occur via specific peptide or protein interactions that are then disrupted competitively by specific levels of proteinases.

This material is of particular importance because of its responsiveness to biocompatible, water-based triggers. So, for certain biological applications, the natural world may still offer exciting ways to create adaptive materials. Or, if you are a sea cucumber and know where to look, one potential recipe for true invincibility has just been uncovered.

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MATERIAL MECHANICS

An angle on sticky films

The interplay of various mechanical forces leads to characteristic shapes of torn adhesive films. Analysis of these shapes provides potential for new approaches to material characterization.

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It is a phenomenon that all of us have encountered at some point in our lives: the annoying tendency of adhesive tape to not peel properly. Instead of the whole piece peeling nicely in rectangular fashion, a triangular section all too often narrows and detaches (Fig. 1). On page 386 of this issue, Eugenio Hamm *et al.* analyse this phenomenon, and show that the well-defined angle at the apex of the detached triangular piece is a function of the properties of the film[1]. Moreover, this angle is shown to not only be exhibited by adhesive tape — it seems to be a general property of adhered films, which can also be seen in situations such as tearing wallpaper or peeling a tomato. The derived relationships between material properties and the apex angle provide the potential for new methods of material properties characterization.

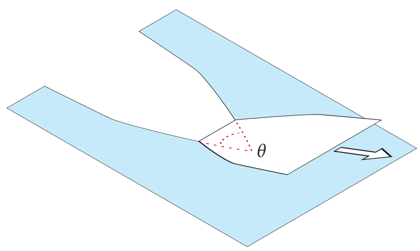

Figure 1 The geometry of a torn piece of film. The apex angle, θ, is related to the properties of the film.

The work of Hamm *et al.* relates the angle at the apex of the torn piece of adhesive film to three parameters of the film on a substrate: the ‘strength’ of the glue, otherwise known as the work of adhesion; the energy required to tear the film; and the stiffness of the film when bent. These three properties can be measured independently and thus the theoretically derived relation between them and the apex angle is experimentally checked. To relate the parameters, a straightforward analysis — based on the energetics of peeling and simple fracture — is presented.

The analysis results in a simple expression for the apex angle. The angle is found to increase with both the stiffness of the film and the work of adhesion, and it decreases with increasing force required to tear the film. The two former terms are both proportional to the width of the torn piece, whereas the tearing force is independent of the width. If all materials parameters remain the same except the film thickness, it is found that the resulting apex angle increases with increasing film thickness — a result that is very hard to guess without the analysis.

A striking feature of this work is that none of the individual elements of the model are new in themselves, but the unifying picture that emerges in which the tearing angle can be viewed as another material parameter characterizing adhered thin films is an innovative understanding. The merit of theoretical analysis cannot be emphasized enough here: a purely statistical analysis without the analytical model would be likely to yield quite poor correlations between the parameters, and the underlying laws would not have been found. Commercial adhesive film of different thicknesses are often made of different materials and therefore have different mechanical properties in addition to the explicit thickness dependence. For this reason a simple trend of the apex angle with thickness is more difficult to observe.

The type of analysis used by Hamm *et al.* in approaching this problem is analytical, in that it doesn't rely on pure computational power but instead reduces the question to a tractable geometric problem. In this sense, it resists the current trend in the domain of theoretical mechanics of materials towards pure computational power, seen in approaches such as finite element analysis and papers quoting huge compliance matrices.

The late P. G. de Gennes described, in the epilogue of his Dirac Lectures[2], the birth of an 'impressionist style' of theoretical physics. Relating it to the visual arts, he compared the impact of computational physics on theoretical physics with the introduction of photography on artistic painting. In the arts, the response to photography was the development of an impressionist style. And so, in response to computational physics, a theoretical physicist may develop an alternative style: an 'impression' focused on a complex phenomenon. The 'impression' that ultimately has to emerge is not necessarily reductionist in all aspects, but rather a sketch of parameter interdependencies and scaling laws that are characteristic for the problem at hand.

The problem of peeling adhesive tape is ideally suited for an impressionist approach, as Hamm *et al.* have treated it: numerical analysis is largely avoided and the focus is rather on the interplay between the parameters. Impressionist need not mean, however, that the outcome is blurry and useless. Hamm *et al.* have avoided the use of scaling laws and chose to use a semi-empirical approach, which provides potential for material characterization based on geometric observation rather than direct mechanical measurements.

The work of Hamm *et al.* adds to a growing range of new, somewhat unexpected, applications of the theory of elasticity. Other examples include the phenomenon of wrinkling[3,4], which also has potential for material characterization. The use of the elasticity of confined DNA[5] as a means to stretch DNA in microchannels[6] — aimed at developing cheap sequencing devices — is also related. This list is obviously not exhaustive but is certainly indicative of the success of the impressionist style of theoretical physics and its sometimes unexpected applications.

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MATERIAL WITNESS

Shrouded in mystery

Radiocarbon dating has revolutionized the study of archaeological specimens, but it remains something of an art. Fluctuations in the ^{14}C content of the atmosphere over time make calibration against other dating techniques necessary, and the spectre of contamination with recent organic matter always hovers.

There is probably no single instance in which these inherent ambiguities in the technique's precision have been more widely publicized than its application to the Shroud of Turin in 1988. That investigation, described the following year (P. E. Damon *et al. Nature* **337,** 611–615; 1989) famously revealed the shroud's linen to be of medieval origin, most probably early fourteenth century, suggesting that this celebrated relic of the Catholic Church is a fake and not the true burial shroud of Jesus.

Whatever the science might say, there is now a groundswell of dissent that is finding a voice in prominent media outlets. One objection is that the dating was distorted either by recent fungal growth on the material or by smoke or scorching from a fire in 1532 that is known to have damaged the shroud, burning holes that were later patched.

These issues were in fact addressed at the time of the initial report by one of the investigators, the late Teddy Hall of Oxford University (*Archaeometry* **31,** 92–95; 1989). Hall pointed out that if the linen was truly 2,000 years old, it would have to be contaminated with as much as 40 percent of modern carbon to give the date measured. Moreover, the data did not vary between samples washed to different degrees. And tests on other samples of cloth gave unchanged dates for various degrees of scorching.

Another view is that the small sample removed from the shroud for dating came from a section that had been repaired in the Middle Ages with an almost invisible weave. The claim is not entirely *ad hoc* – circumstantial and technical arguments can be advanced in its favour (R. N. Rogers, *Thermochim. Acta* **425,** 189–194; 2005). It's certainly regrettable that only one small part of the shroud was studied.

Other critics challenge the radiocarbon study with historical evidence. Hall echoed the standard view that the shroud first appears in the records in 1353. But it is now claimed that an identical shroud is depicted in a late twelfth-century manuscript from Hungary, and that an alleged burial shroud imprinted with the image of Christ can be traced at least to the sixth century.

It's fair to say that, despite the seemingly definitive tests in 1988, the status of the Shroud of Turin is murkier than ever. Not least, the nature of the image and how it was fixed on the cloth remain deeply puzzling. All of this calls for further testing, but that's unlikely to be permitted any time soon. Of course, the two attributes central to the shroud's alleged religious significance — that it wrapped the body of Jesus, and is of supernatural origin — are precisely those neither science nor history can ever prove.

Philip Ball