building larger hydrogen-bonded clusters on substrates and perturbing the motion of the heavy-atom skeleton, which drives proton transfer, in a controlled and anisotropic manner. In particular, one can speculate whether concerted many-body tunnelling can also occur in water clusters larger than hexamers (involving even more than six protons) or whether chirality could be transferred between individual clusters. Although it remains to be seen whether correlated proton motion occurs and can be exploited at higher temperatures, the level of controlled collective proton tunnelling achieved by Meng *et al.*[1] opens up many exciting avenues in condensed-phase hydrogen-bonded networks, and it may even be a first step towards a more general approach to simultaneously manipulating several quantum particles in real space. ❐

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ACOUSTICS

Stretchy string theory

What's the physical mechanism behind the distinctive sound of a banjo? David Politzer — probably better known for his work on quantum chromodynamics than his passion for banjos — may not be the first to ponder this question, but he certainly provides a valuable clue towards answering it (*Acta Acust. united Ac.* **101,** 1–4; 2015).

A banjo, or indeed any instrument in the banjo family (including the kora of West Africa, the tar of Persia and the shamisen of Japan), has strings tightened along a neck and over a bridge that is attached to a drumhead. In contrast to a guitar, the strings of a banjo are fixed at the instrument's rim by means of an adjustable tailpiece, resulting in a 'floating bridge' (pictured). Sound is produced through the combined vibration of the strings and the drum.

A vibrating string with fixed ends undergoes expansions. In basic physics textbooks, these length changes are usually ignored because they are of second order in the vibrational amplitude. Although second-order stretching does contribute to a banjo's timbre, it is not a distinguishing characteristic — all plucked string instruments share this feature. Oscillation of the bridge, however, introduces a string stretch that is first order in the motion of the bridge (perpendicular to the string). This causes linear changes in the string's tension while vibrating, making the string's oscillation itself a nonlinear process. Modulated tensions affect partials — the Fourier components of a tone — because a string's frequency is proportional to the square root of its tension.

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Politzer argues that this type of nonlinear frequency modulation is very likely the key mechanism behind banjo timbre. Several observations support the author's 'string theory'. The instrument's tonality should be amplitude-dependent; and indeed, when played loud, a banjo sounds more 'banjo-like' (often described as metallic) than when plucked softly. The main piece of evidence is the role of the angle the strings make when passing the bridge — the so-called break angle. It is common banjo lore that increasing the break angle enhances 'sound metallicity'. Politzer's model shows that if stretching is not taken into account, there is no dependence of timbre on break angle.

We're still some way off from a full understanding of banjo sound. A complete description would have to incorporate the stretching of the strings, the forces on the bridge and the dynamics of the drumhead. But Politzer's insight will no doubt be useful for many banjo players, who are notorious for tinkering with their instruments in search of the perfect sound.

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