Sound attenuation by sculpture

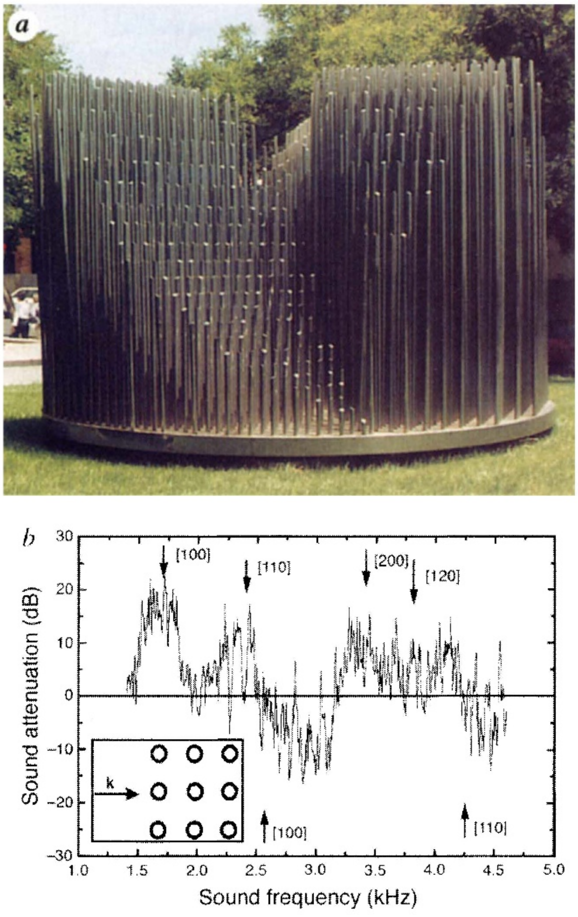
SIR — It is generally accepted that sculptures or *objets d'art* are useless from the scientific point of view. We would like to show here an example of a certain type of sculpture that is of scientific relevance, and which can be related to the recent discovery of the so-called photonic band-gap materials and their generalization to other classical waves[1,2].

Theory predicts that a periodic distribution of wave scatterers, distributed in three-dimensional space, would induce severe attenuation of wave propagation in some spectral regions. The crucial parameters that allow the appearance of gaps are the ratio between the wave velocity in the scatterer and in the host, and also the volume fraction occupied by the scatterers[3]. For elastic or acoustic waves, the density ratio is also important. Experiments are mostly restricted to electromagnetic waves in the microwave region and gaps will appear in a region of wavelengths that corresponds to the periodicity of the scatterers and their geometric size. We are unaware of any experiments on band-gap materials for acoustic waves where band gaps would appear in structures with a periodicity of between a few centimetres and one metre.

These types of structures are well known in modern art and are classified as a form of 'minimalism'. We report here on sound attenuation experiments performed on one of these sculptures (*a* in the figure). The sculpture, by Eusebio Sempere, is exhibited at the Juan March Foundation in Madrid. It consists of a periodic distribution of hollow stainless-steel cylinders, with a diameter of 2.9 cm, simple cubic symmetry and a unit cell of 10 cm. The cylinders are fixed on a circular, 4-m-diameter platform that can rotate around a vertical axis. We have measured sound attenuation in outdoor conditions for sound-wave vectors perpendicular to the cylinders' vertical axis.

The transmission characteristics in decibels vary as a function of the sound frequency (*b* in the figure) with the **k** vector along (100). Similar attenuation spectra have been obtained for other vectors perpendicular to (001), $\mathbf{k}_\perp$. All the spectra have a large noise induced by the sound reflections from nearby buildings. Several maxima (sound attenuation) and minima (sound reinforcement) are present and their frequencies do not depend on $\mathbf{k}_\perp$. The agreement between these features and theoretical maximum and minimum attenuation due to interference of the different crystal planes of the sculpture is fairly good, even though the sculpture does not have an ideal external shape for experimental purposes.

The Bragg attenuation peak at 1,670 Hz (which corresponds to [100] destructive interference) shows a ratio between the full width at half maximum and the peak energy position of 0.18. This value is similar to that obtained in photonic band experiments for a two-dimensional system[4]. The sculpture corresponds to a Cermet topology with a volume fraction occupied by the scatterers of 0.066 and a velocity ratio of 17.9. These values are close to those for which the calculations predict the appearance of a band gap for the propagation of sound waves in a two-dimensional periodic structure[3]. Therefore, the sound attenuation peak at 1,670 Hz could be ascribed to the formation of the first gap in this sculpture.



a, Kinematic sculpture by Eusebio Sempere. *b*, Sound attenuation results as a function of the sound frequency. The wave vector is along the (100) direction as shown in the inset. Arrows indicate the calculated maxima and minima due to interference from the different crystal planes of the sculpture.

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Why leaves are sometimes red

SIR — Anthocyanins are present in leaves of autumn foliage and rapidly developing shoots in tropical trees, but their function has never been satisfactorily explained. In addition, leaf undersurfaces of many tropical rainforest understory herbs are also red because of the presence of anthocyanins. We have examined leaves of two such taxa and report that anthocyanins intercept quanta otherwise absorbed by chlorophyll *b*, thereby protecting leaves from photoinhibition. We thus confirm what may be a general explanation for anthocyanin function in leaves.

The strong association of undersurface coloration with forest understory and the uniformity of anthocyanins suggest that they are selectively advantageous to plants in extreme shade. The hypotheses of increasing leaf temperature or protecting against damage by ultraviolet-B radiation have been discounted[1,2], and no mechanism has yet been discovered by which they could backscatter radiation and increase light-capture efficiency in the red wavelengths[1]. We have thus examined the hypothesis of photoprotection by anthocyanins in these plants.

Anthocyanins *in vivo* should capture wavelengths otherwise absorbed by chlorophyll *b*, which has a longer wavelength absorbance in the Soret band. Chlorophyll *b* is especially associated with the light-harvesting complex of photosystem II, the principal site of photoinhibition and photodamage in the chloroplast[3]. In understory shade, photosystem II-enriched plants are more susceptible to photoinhibition and damage in brief flecks of sunlight[4]. Anthocyanins should absorb at wavelengths otherwise absorbed by chlorophyll *b*, diminish photoinhibition and increase maximum photosynthesis. Anthocyanins may also allow higher chlorophyll concentrations, possibly correlated with changes in photosystem components and function.