

BRIEF COMMUNICATIONS

MECHANOLUMINESCENCE

Light from sonication of crystal slurries

Light flashes sparked by acoustic shock waves far outshine those created by manual crushing.

Mechanoluminescence, also known as triboluminescence or fractoluminescence, is light emission induced as a result of mechanical action on a solid^{1–3} — for example, Francis Bacon noted as long ago as 1605 that lumps of sugar emitted light when scraped⁴. Here we elicit mechanoluminescence by a new means, acoustic cavitation, and find intense luminescence and emission lines that are not generated by other mechanisms such as grinding, cleaving, rubbing, scratching, biting or thermal shock.

Acoustic cavitation is the formation, growth and implusive collapse of bubbles in a liquid irradiated with ultrasound⁵. As these bubbles collapse, extreme conditions of thousands of degrees⁶ and hundreds of atmospheres⁷ are generated within the bubble. Intense shock waves are launched outwards from the imploded bubble at velocities exceeding the speed of sound⁸. These shock waves accelerate micrometre-sized particles to high velocities and can create interparticle collisions at roughly half the speed of sound in the liquid (hundreds of metres per second)^{9,10}. Acoustic cavitation may also facilitate interparticle collisions during bubble implosion, or by rapid expansion of a bubble (at tens of metres per second) with particles attached to its surface¹¹.

About 36% of all inorganic and 19% of all organic compounds exhibit mechanoluminescence¹², but there is much we do not know about the phenomenon. When a piezoelectric crystal (such as sucrose or resorcinol) is stressed, polarization of electrical charge is induced. At fracture, the two faces of the crack will have opposite charges; as the faces separate, the local electric field created is sufficient to cause dielectric breakdown of the solid and the intervening gases^{1–3}, producing mechanoluminescence.

On fracture of sucrose in air or under nitrogen gas (N_2), the emission spectra $N_2(C^3\Pi_u - B^3\Pi_g)$ and $N_2^+(B^2\Sigma_u^+ - X^2\Sigma_g^+)$ are seen. When sucrose powder is sonicated in N_2 -sparged dodecane, the emission is the same but its intensity is much greater (Fig. 1a). The mechanoluminescence resulting from sonication is an order of magnitude greater than that from crushing sucrose in dodecane. When sucrose is crushed by hand with a glass rod, the rod moves at tenths of metres per second; however, collisions occur at hundreds of metres per second when a shock wave is launched as a result of acoustic cavitation^{9,10}.

We induced mechanoluminescence from resorcinol under various conditions (see Fig. 1b, which includes the solid-state photo-

luminescence spectrum for comparison). When resorcinol is crushed with a glass rod in air, weak $N_2(C^3\Pi_u - B^3\Pi_g)$ and $N_2^+(B^2\Sigma_u^+ - X^2\Sigma_g^+)$ lines are seen, as well as crystal luminescence; however, when resorcinol is crushed in hexadecane under helium (He) or argon (Ar), only crystal luminescence is observed. In contrast, when a slurry of resorcinol in He- or Ar-sparged hexadecane is sonicated, intense discharge lines of He and Ar gas are created, together with a weaker crystal luminescence. When hexadecane itself, or a hexadecane slurry with hydroquinone (a non-piezoelectric, non-mechanoluminescent

analogue of resorcinol), is sonicated under these conditions as controls, there is no luminescence. Other mechanoluminescent crystals that are sonicated as slurries (for example, *m*-aminophenol; see supplementary information) give an intense gas discharge and crystal luminescence, just like resorcinol.

The intensity of mechanoluminescence is directly proportional to the area of the new surfaces created during fracture¹³. The greater intensity in mechanoluminescence that we observe as a result of cavitation could be due to an increase in the frequency of mechanical action (20 kHz), which increases the rate of fracture, or to a greater intensity of collision; only the latter, however, can explain the very large increase in He or Ar line emission.

We suggest that the mechanoluminescence we observe derives from the following chain of events: acoustic cavitation induces high-velocity collisions between suspended solid particles (primarily resulting from shock waves in the liquid); this causes fracture of the crystallites and induces exceptionally high electric fields due to charge separation at the rapidly separating piezoelectric fracture faces; finally, dielectric breakdown produces an electric discharge, particularly from dissolved gases (for example, He, Ar, N_2) and at the crystal surfaces.

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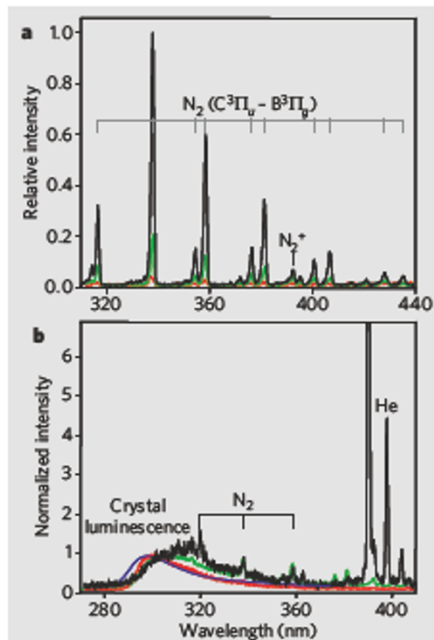


Figure 1 | Mechanoluminescent spectra from sucrose and resorcinol. **a**, Mechanoluminescence of sucrose sonicated in dodecane sparged with N_2 (black trace), crushed in air (green trace), and crushed in N_2 -sparged dodecane (red trace), all at 300 K. The emission spectra consist of the $N_2(C^3\Pi_u - B^3\Pi_g)$ and $N_2^+(B^2\Sigma_u^+ - X^2\Sigma_g^+)$ progressions. The intensity from sonication is an order of magnitude greater than from crushing by hand. **b**, Mechanoluminescence of resorcinol sonicated in hexadecane (black trace), crushed in air (green trace), crushed in He-sparged hexadecane (red trace) and its photoluminescence (blue trace) at 300 K. Strong helium (He) gas discharge is evident, together with crystal luminescence when resorcinol is sonicated in He-sparged hexadecane; N_2 is emitted because of trace N_2 contamination. No He discharge is detected from grinding in the presence of He gas.

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