Auxetics - The more you stretch them, the fatter they become

Dr. Joseph N. Grima

IMAGINE yourself stretching an elastic band. The more you stretch it, the thinner it becomes. But does this always have to happen? The answer is no and materials which defy common expectation and become fatter when stretched and narrower when compressed do exist. These materials have a negative Poisson's Ratio (conventional materials have a positive Poisson's ratio) and are referred to as *auxetic* materials. The word *auxetic* was proposed by Professor Kenneth E. Evans of the University of Exeter, UK in 1991 and is derived from the Greek word *auxetos*, meaning "that may be increased" [1]. Researchers at the Department of Chemistry of the University of Malta are involved in various projects in close collaboration with Professor Evans, a collaboration that has proved to be very successful.

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Negative Poisson's ratios were first reported for single crystalline iron pyrites in the first half of the 20th century. This phenomenon was attributed to twinning defects in the pyrites crystals and was regarded as an anomaly. However, apart from this and some other isolated reports of this unusual behaviour, the study of materials with a negative Poisson's ratio only established itself in the late 1980's. Since then, negative Poisson's ratios have been predicted, discovered or deliberately introduced in several classes of naturally occurring and man-made materials including foams [2,3], polymers [1,4-6], metals [7], silicates [8] and zeolites [9,10]. It was found that in all of these cases, this unusual effect can be described in terms of models based on the material's internal structure (geometry) and the way this internal structure responds to applied loads (deformation mechanism). An important feature that has emerged from research in this field is that the Poisson's ratio does not depend on scale. Deformation can take place at the nano- (molecular), micro- or even at the macro- level. The only requirement is the right synergism between the geometry and the deformation mechanism.

To illustrate this synergism between the geometry and the deformation mechanism, one may consider a simple example of a two-dimensional honeycomb structure deforming by hinging of the ribs forming the network. As illustrated in *Figure I*, stretching of the traditional honeycomb will result in the cells getting longer in the loading direction and narrowing along the transverse direction. This results in a positive Poisson's ratio. Auxetic behaviour may be obtained through the hinging deformation mechanism by performing a simple modification in the honeycomb geometry to obtain a re-entrant structure. Stretching of this re-entrant honeycomb will result in the cells getting longer in both the loading and transverse directions with the effect that the structure exhibits a negative Poisson's ratio.

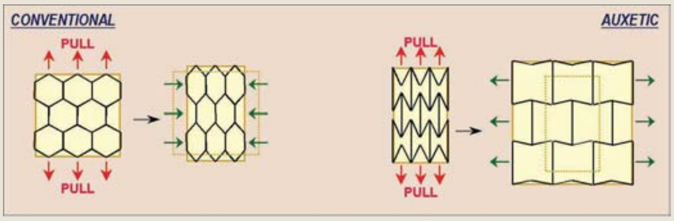


Figure I: The conventional and auxetic forms of a two-dimensional honeycomb structure deforming by hinging of the ribs

The presence of a negative Poisson's ratio should not be treated solely as a scientific curiosity. Materials that get fatter when stretched and thinner when compressed are ideal for making various objects such as screws, nails and even clothes and bullet covers. When an auxetic screw or nail is being pushed inside the material it becomes thinner and hence on going in it encounters less resistance. However, if it is pushed outwards, it expands and jams itself more tightly in its hole. For similar reasons, when an auxetic bullet is fired, the force imparted on the bullet will force it to contract laterally hence encountering less resistance on exiting the barrel. Clothes made from auxetic fabrics would also be much more versatile than conventional clothes. The idea of clothes where ‘one size fits all’ could become more of a reality and packing a suitcase before travelling will become a much simpler task as clothes could be compressed to much smaller volumes when not in use. Furthermore, because the Poisson’s ratio does not depend on scale, the research on auxetic materials can easily be extended to structures built from conventional components that would ‘open up’ when stretched. These 'expandable' structures can be particularly useful for the manufacture of space structures such as large antennas and sun shields that could be launched into space in a closed compact form and then 'opened up' at a later stage in space.

The beneficial effects resulting from this counter-intuitive auxetic behaviour can also be found in applications that go beyond the direct effect of getting fatter when stretched and thinner when compressed. Negative Poisson’s ratios impart various additional enhanced characteristics in the materials’ properties such as an increased resistance to indentation. When a falling object hits a conventional material, the force of the impact compresses it with the result that the material will spread in the directions perpendicular to the direction of impact. In auxetics, the compression caused by the impact has the reverse effect and the material compresses towards the point of impact, and so becomes much denser. This property makes auxetic foams far superior to their conventional counterparts in protective applications.

Auxetics can also withstand twisting or tearing forces (shearing) to a higher degree than conventional materials and are more resistant to fracture. These are particularly desirable qualities in structural components that are particularly prone to fail under shear strain or to fracture (e.g. beams in buildings, sheets used in the manufacture of airplanes or cars, etc.). The resistance to fracture in auxetics is due to the fact that when the material is being pulled apart, it expands hence ‘closing up’ any potential cracks. In conventional materials this does not happen.

Another very interesting feature of auxetic materials is that they exhibit a natural tendency to form double-curved dome-shaped surfaces as opposed to conventional materials that tend to form saddle-shaped surfaces *(see Figure 2)*. This makes auxetic sheets ideal candidates for applications such as airplane noses where a dome-surface is required. Having established that materials with a negative Poisson’s ratios could be so useful in various practical applications, it is understandable that there is an ongoing search for new auxetic materials, ideally ones that occur naturally or else are easy to manufacture. There are various phases in the process of discovering or developing new auxetics, including an investigative phase with the help of modelling. It is at this investigative stage that most of the research on auxetics at the University of Malta is carried out.

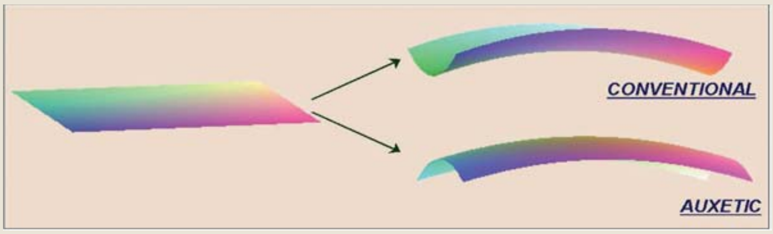
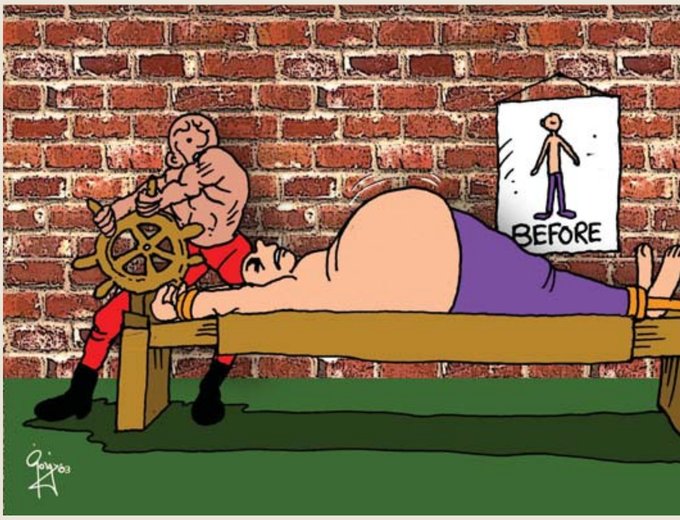


Figure 2: Sheets made from auxetic materials have a natural tendency to form dome-shaped surfaces as opposed to conventional ones that form saddle-shaped surfaces

Modelling offers various advantages over more traditional experimental science. A modelling experiment is usually much less laborious than the real experiment. The costs are also significantly lower as there is no need for expensive dedicated apparatus that is beyond the reach of many academics. Furthermore, it has now become common practice to carry out a modelling-based investigative phase prior to commencing a full-scale practical investigation, as this would test the ideas being put forward and optimise the experimental procedure for optimum final results. All this has been very successfully applied to the design and discovery of new auxetics.

Modelling also makes it possible to attain a better understanding of the underlying principles responsible for auxetic behaviour in naturally occurring auxetics (or in man-made materials where the auxetic behaviour was obtained without an investigative modelling phase). A knowledge of the manner by which nature makes this unusual property possible allows the scientist to design new man-made materials or structures that mimic these naturally occurring auxetics [*e.g.* 10]. An important part of the research on auxetics in Malta is in this direction and is aimed at obtaining a better understanding of the principles behind auxetic behaviour in various classes of materials ranging from polyurethane foams to silicates.



We are also performing simulations to obtain further evidence that some zeolites may exhibit negative Poisson's ratios. The possibility of zeolites with negative Poisson's ratios has some very important commercial repercussions since zeolites are used as molecular sieves, and experimental and theoretical studies have shown that the pore-sizes in auxetic sieves can be altered by application of mechanical stress, thus allowing tuneable selective sieving [11].

Another project is aimed at proposing designs for novel organic polymeric networks that could form the basis of a synthesis and real production of man-made auxetics. Man-made auxetics produced with the help of modelling have the added advantage that they can be pre-designed to some specific set of mechanical properties hence producing tailor-made materials.

So far, our results have been very promising and have proven that the modelling work on auxetics gives good value for money. The modelling work on auxetics has also made it possible for academics at a relatively small university such as the University of Malta to collaborate effectively with leading foreign partners and successfully compete at an international level. Given the new possibilities and opportunities for transnational collaborative efforts, the future for our research on auxetics can only be better than the present.

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