



European Summer Campus 2010



"Metamaterials"

Strasbourg, France, June 27 – July 5, 2010



Auxetic Metamaterials

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Acknowledgements

- Co-workers:
 - Brian Ellul
 - Daphne Attard
 - Ruben Gatt
- \$\$\$\$
 - University of Malta
 - Malta Council for Science & Technology
 - Malta Government Scholarship Scheme
- Organisers of Metamaterials European Summer School



The Maltese Islands

- 126 sq. miles
- ~400,000 people



Blue Lagoon



St. Thomas' Bay



Golden bay



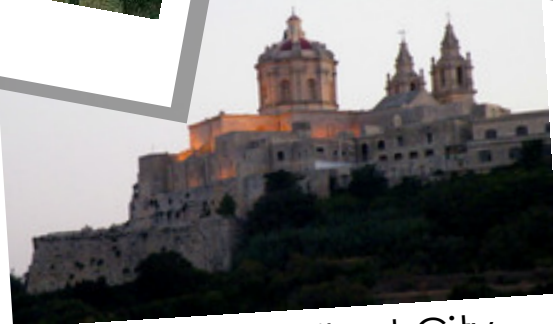
History



Mnajdra Temples



Valletta City



Mdina – The Silent City



St. John's Co-cathedral



University of Malta ... since 1592

- Founded as Collegium Melitense by Papal Decree in 1592
- Public university since 1768 by Grand Master Pinto de Fonseca



1780





The University now ...

- Msida
- ~10,000 students
- The 'home' of the auxetics group



Siggiewi – My home town



Introduction to auxetics

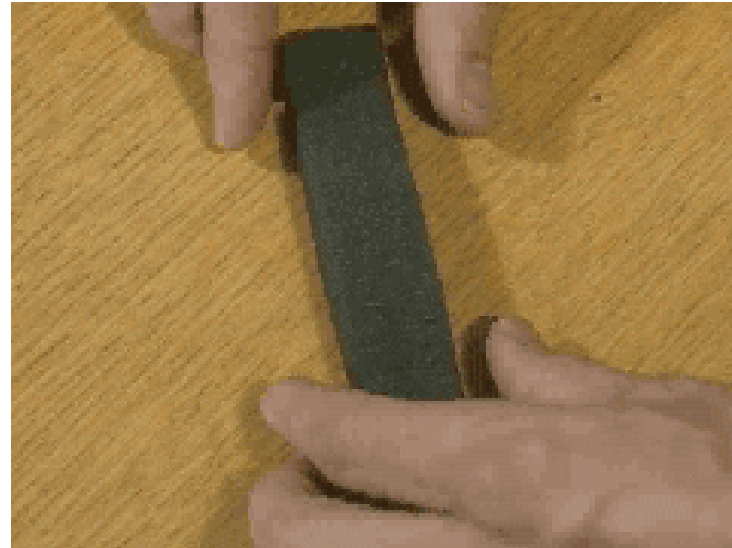
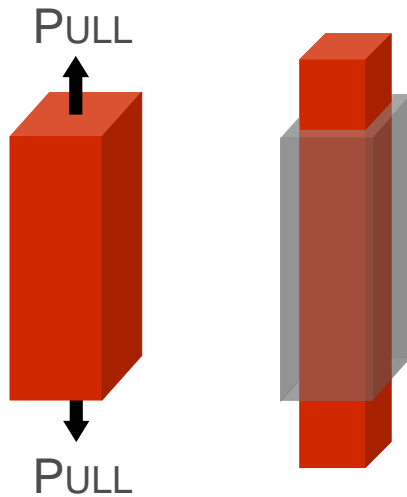




Poisson's ratios

$$\text{Poisson's ratio, } \nu = -\frac{\text{lateral strain}}{\text{axial strain}}$$

$$\text{strain} = \frac{\text{extension}}{\text{original length}}$$



+ve Poisson's ratio \rightarrow materials get thinner when stretched



Common values

Material	Poisson's ratio
Rubbers	0.5
Lead	0.45
Aluminium	0.33
Common steels	0.27
Cellular solids e.g polymer foams	0.1 - 0.4
Cork	0.0



But...

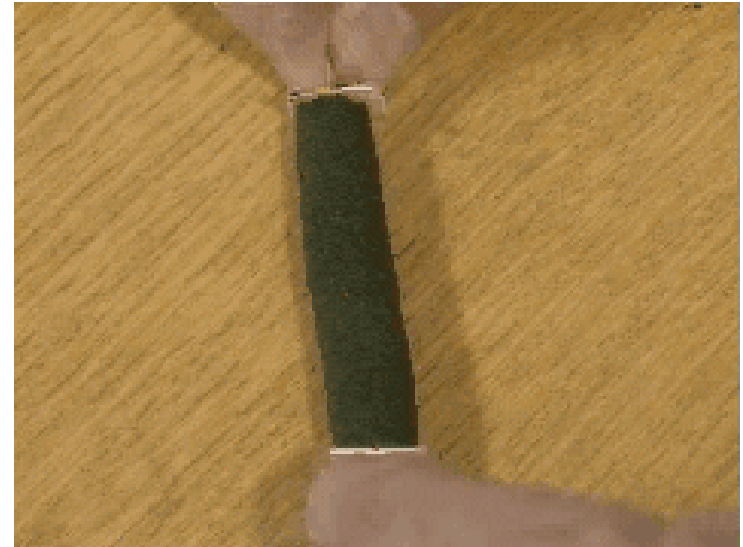
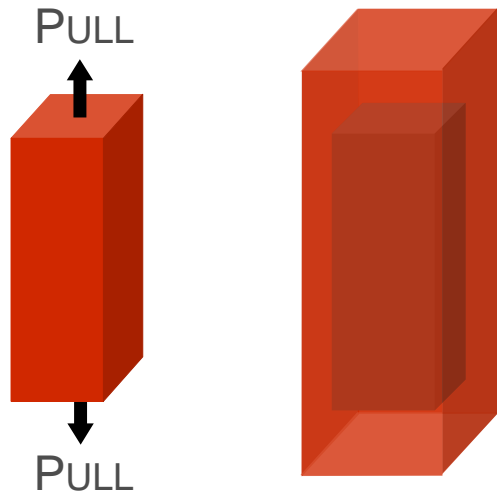
- ... Poisson's ratios can also be negative

$$-1 \leq \nu \leq 0.5$$

... from the classical theory of elasticity (for isotropic materials)



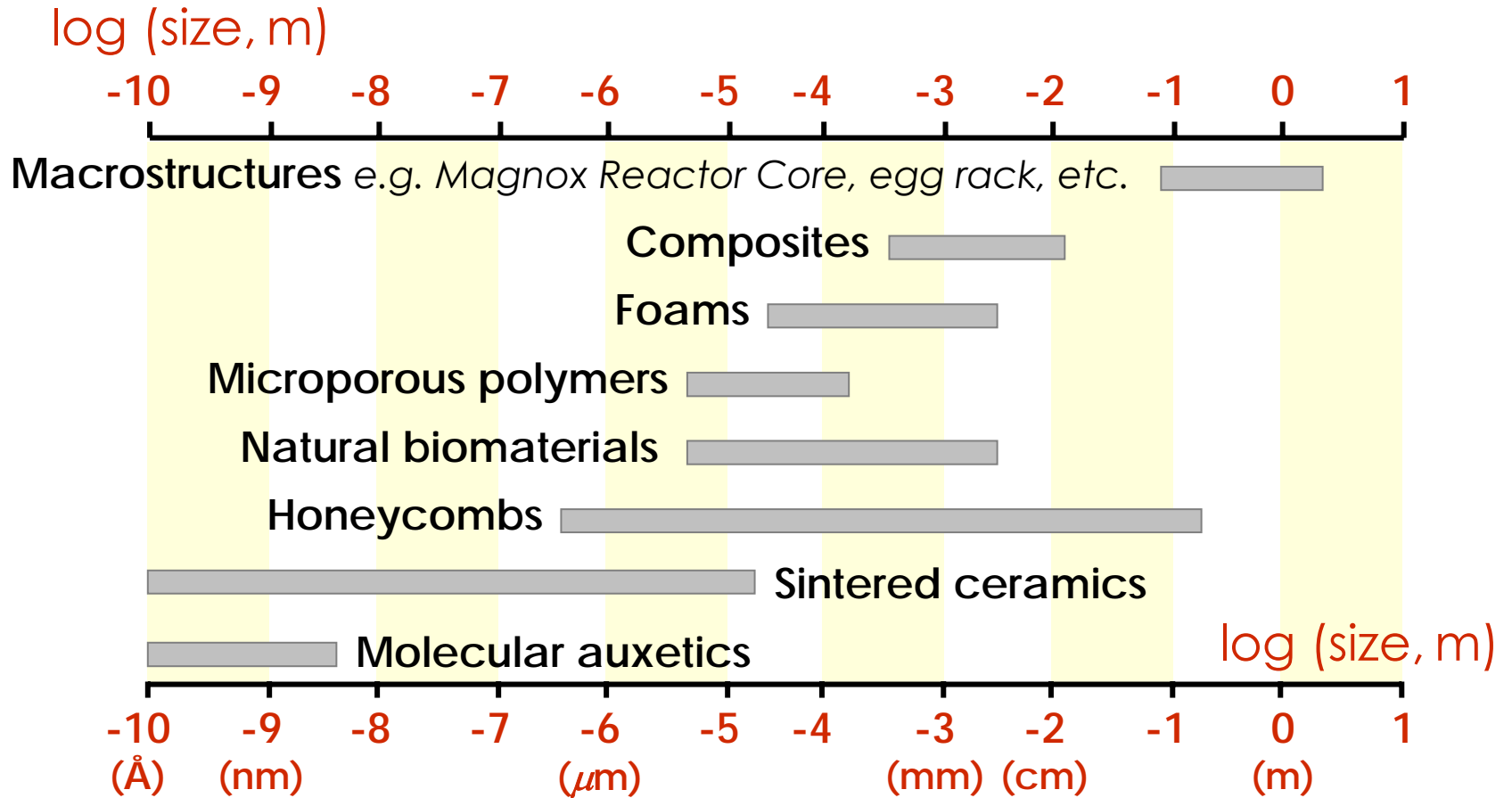
Auxetics



-ve Poisson's ratio \rightarrow materials
get fatter when stretched

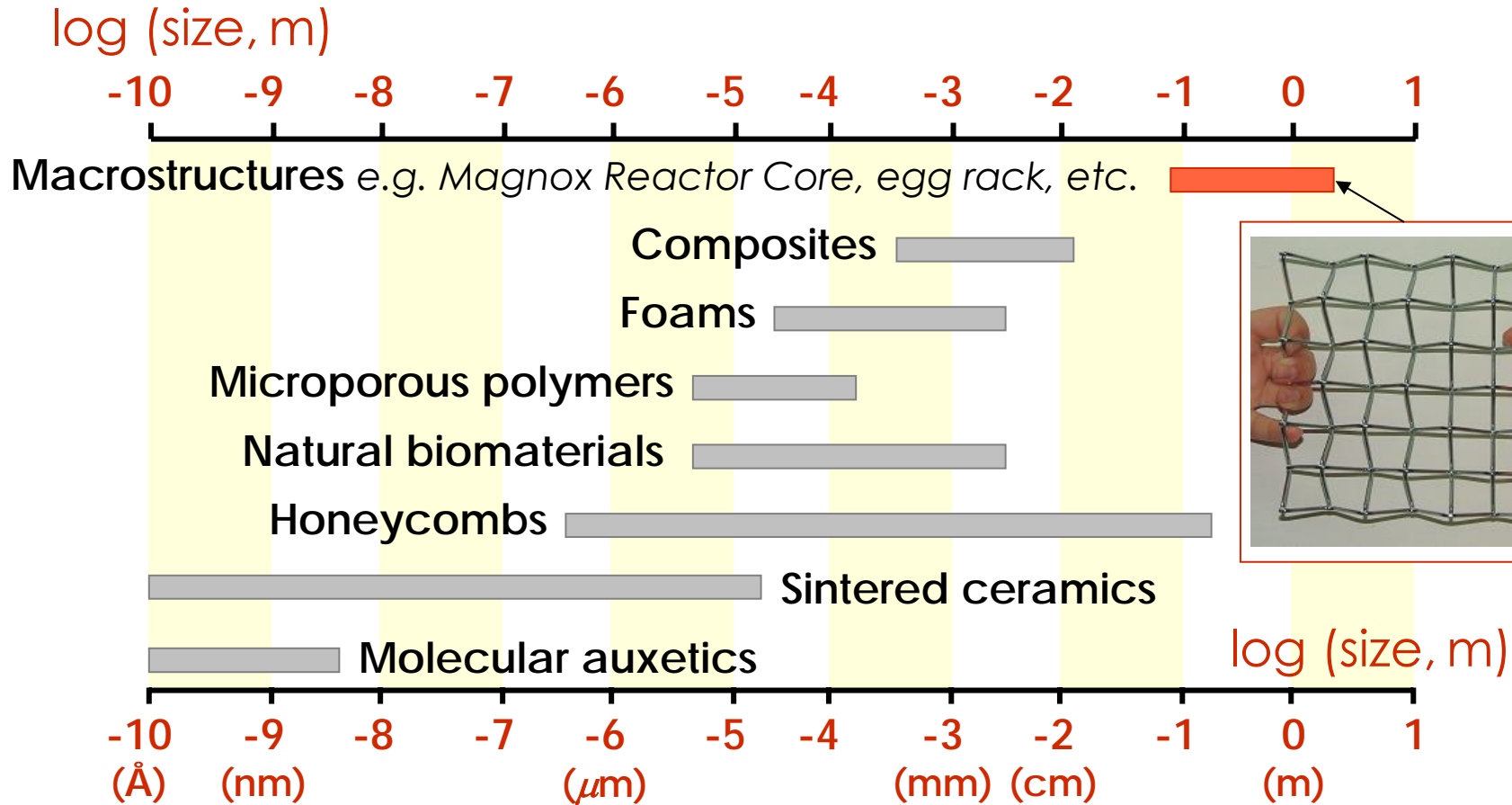


Length scale



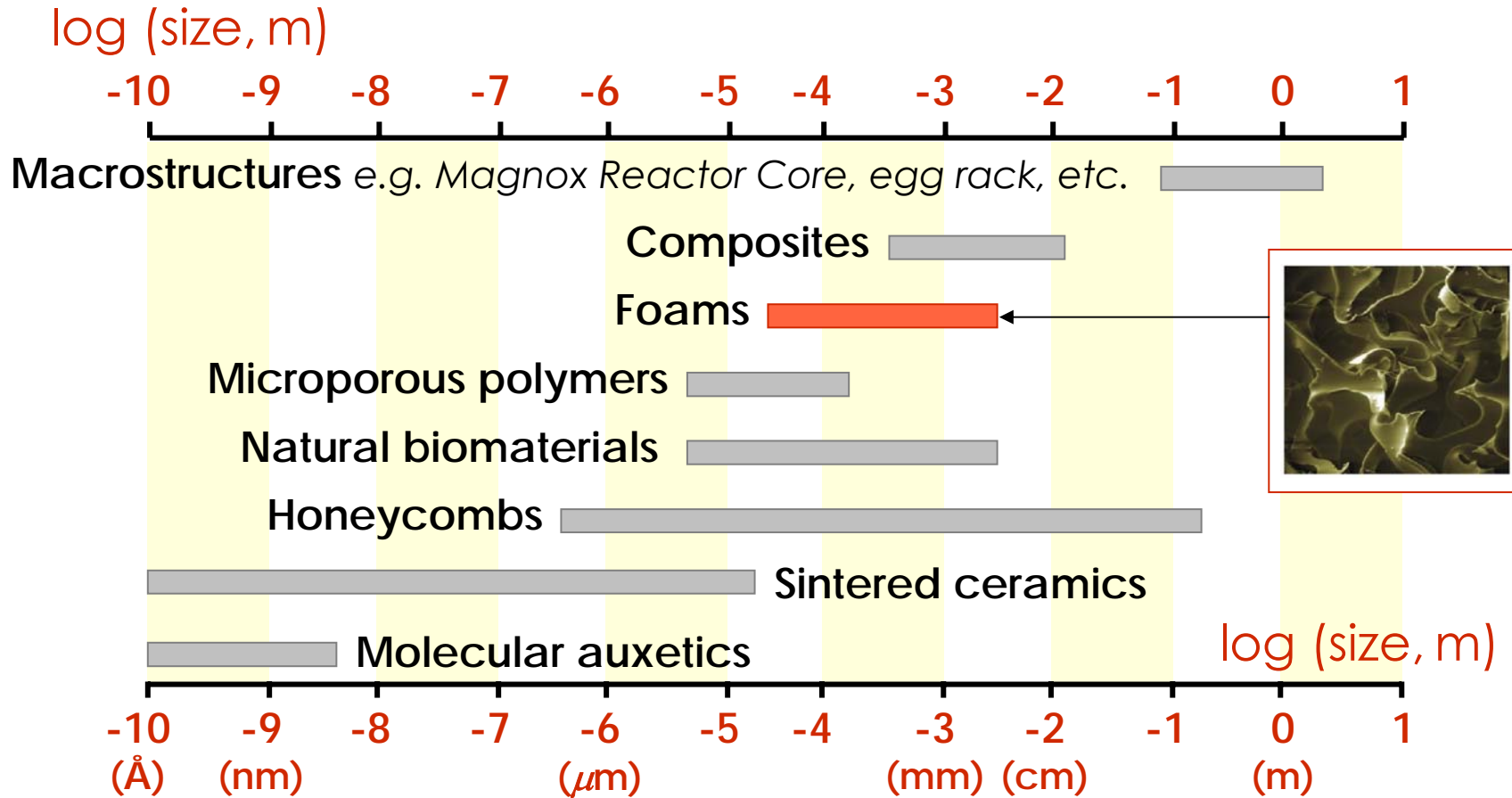


Length scale



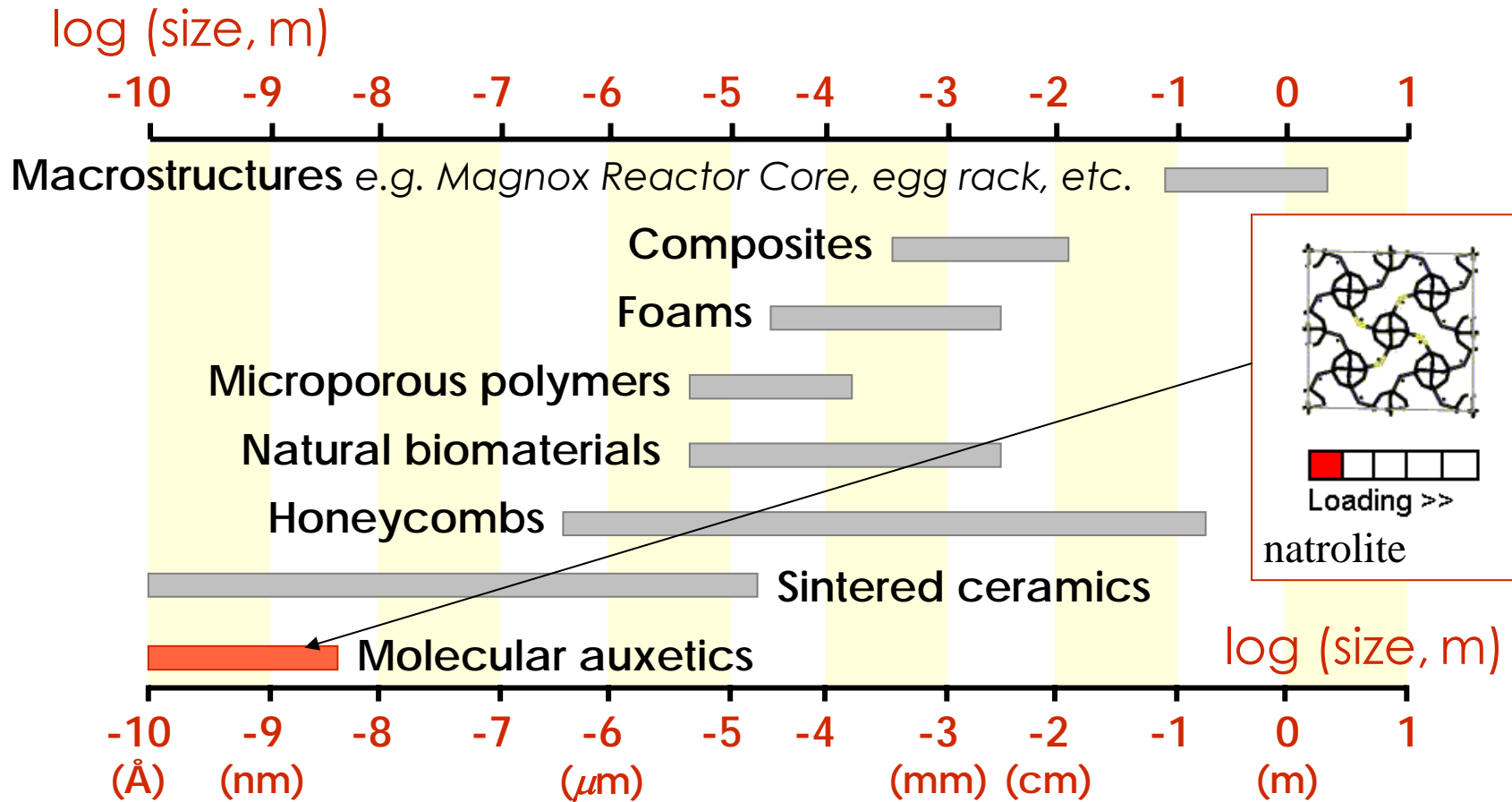


Length scale





Length scale





What gives rise to auxeticity

- Correct co-operation between:
 - The material's internal structure (**geometry**)
 - The way the internal structure deforms when loaded (deformation mechanism)



Auxetic mechanisms (1)

Re-entrant honeycombs

$$\begin{aligned}v_{12} &= \frac{1}{v_{21}} = -\tan(\theta) \frac{X_1}{X_2} \\ &= -\tan(\theta) \frac{l \sin(\theta)}{h - l \cos(\theta)}\end{aligned}$$

Auxetic: $0^\circ < \theta < 90^\circ$

Conventional: $90^\circ < \theta < 180^\circ$

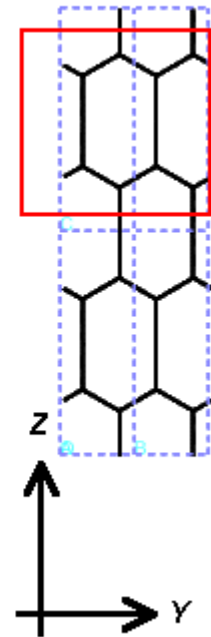
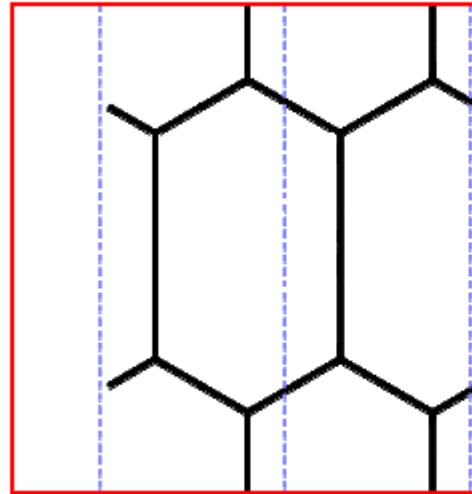




Auxetic mechanisms (2)

Dilating mechanisms

σ_z



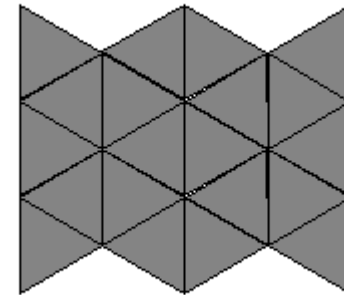


Auxetic mechanisms (3)

Rotating Rigid / Semi-Rigid Units

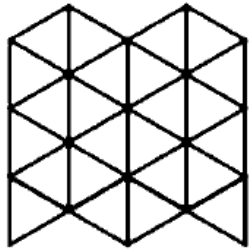
Poisson's ratio will depend on:

- (1) Shape of the rigid unit
- (2) Degree of aperture
- (3) Connectivity
- (4) Extent of rigidity of the unit

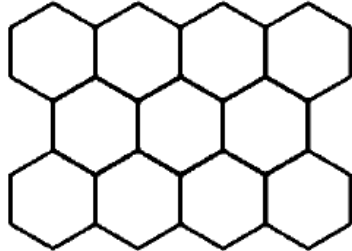




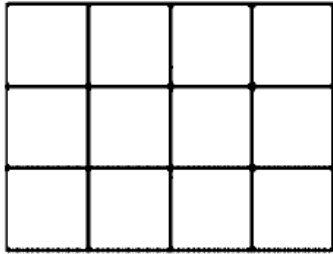
Rotating Quadrilaterals



{3, 6}

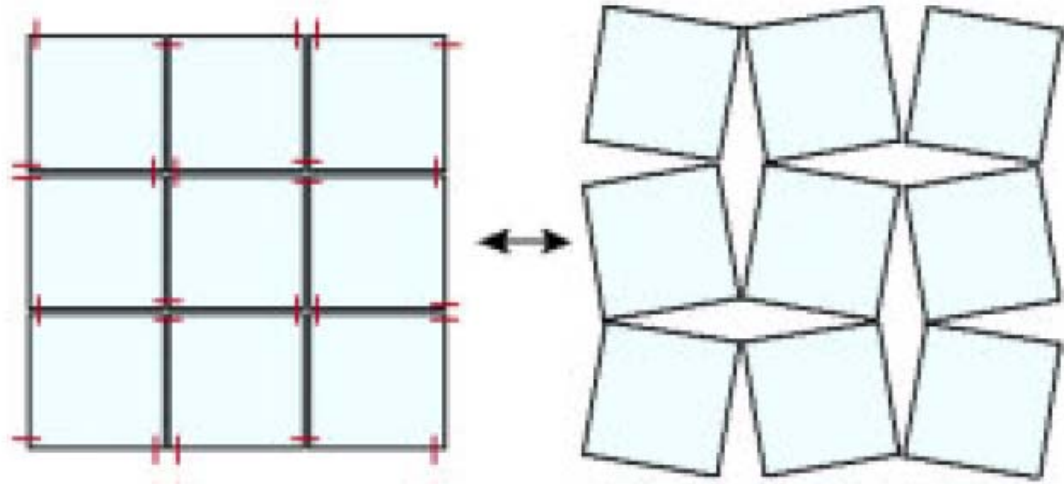
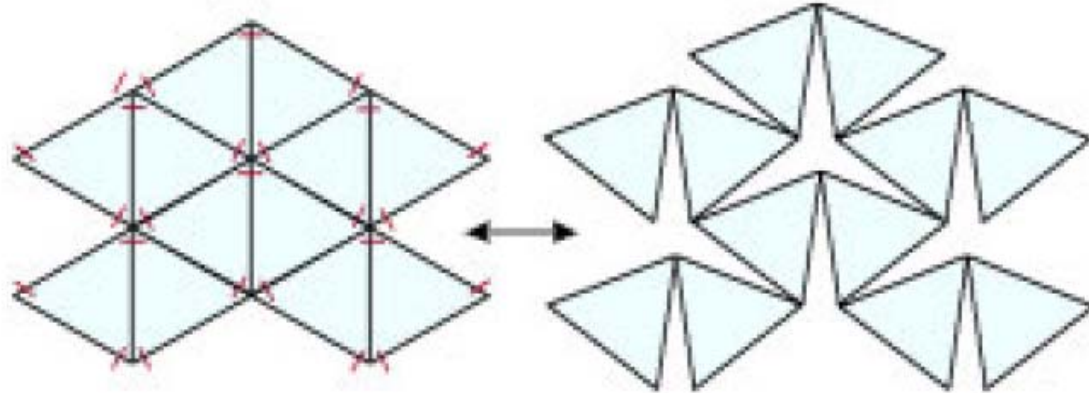


{6, 3}



{4, 4}

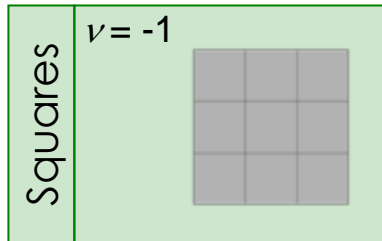
Regular {3, 6}, {4, 4} and {6, 3} tessellated structures.





...more examples

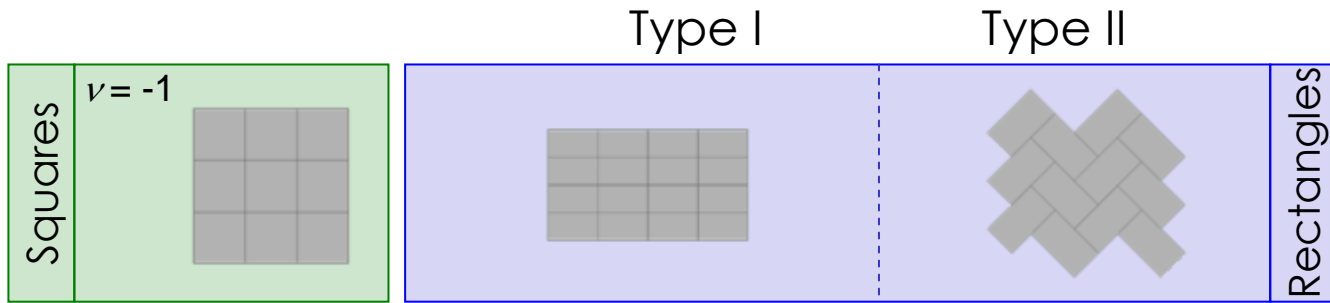
- Rotating rigid units
 - quadrilaterals





...more examples

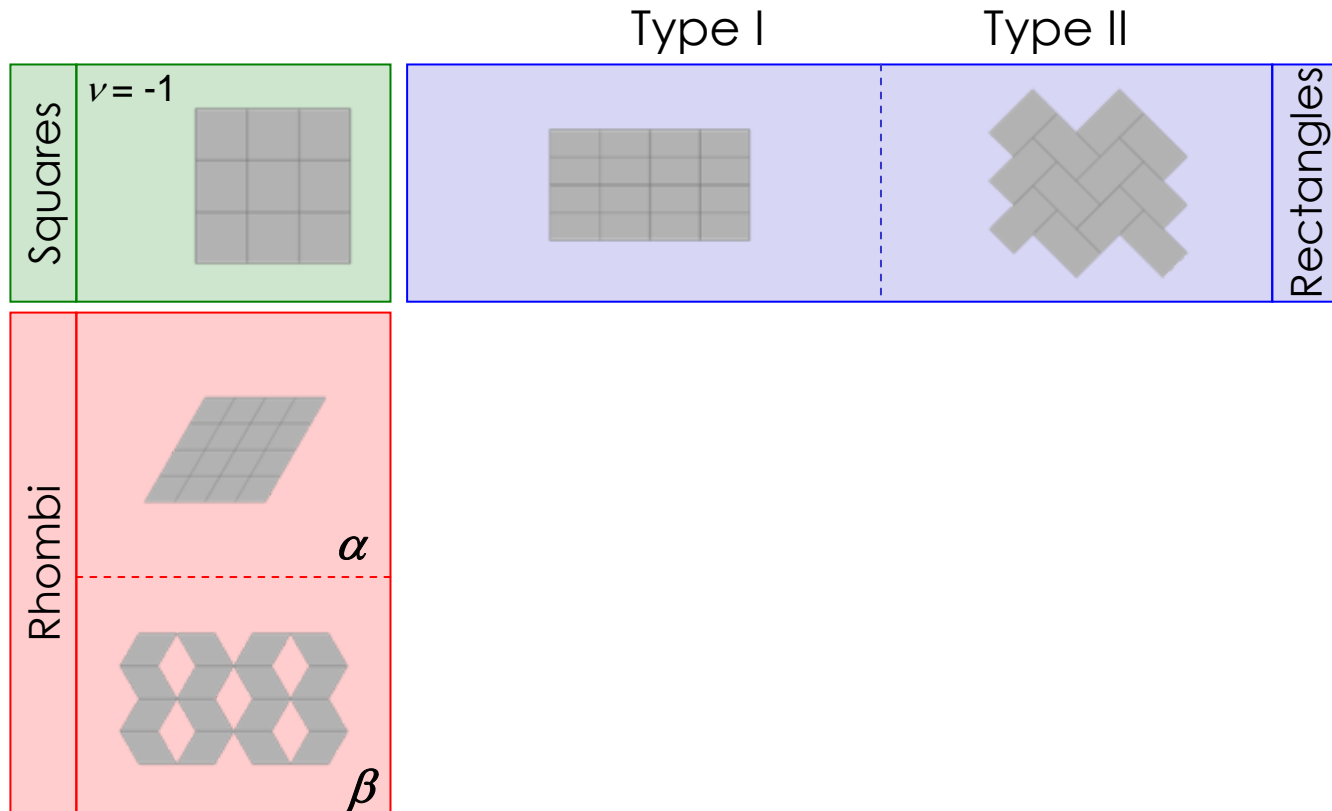
- Rotating rigid units
 - quadrilaterals





...more examples

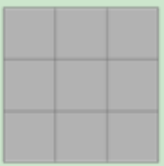
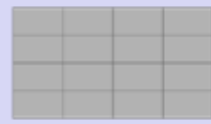



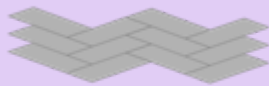



- Rotating rigid units
 - quadrilaterals





...more examples

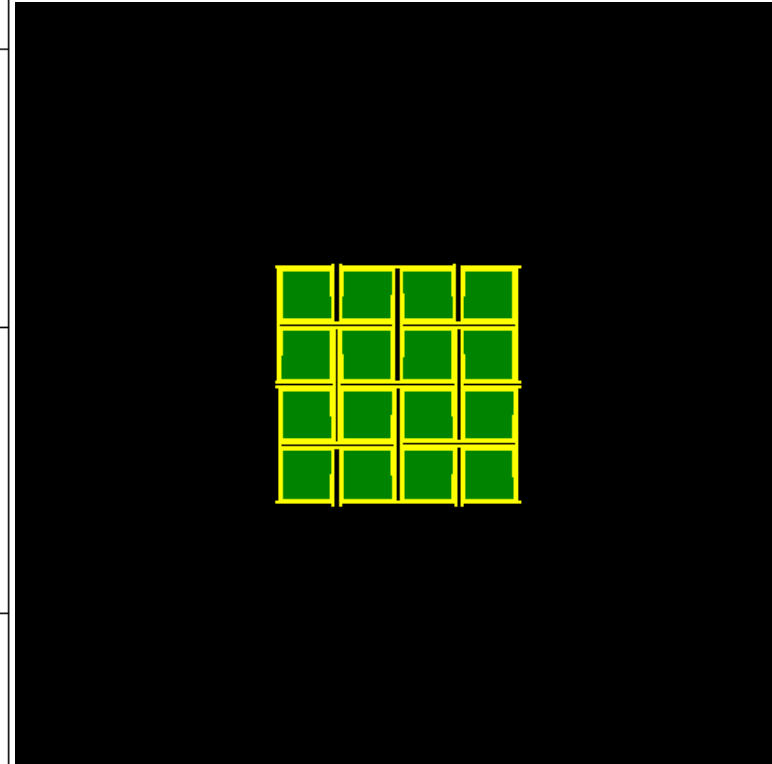
- Rotating rigid units
 - quadrilaterals

		Type I	Type II	
Squares	$v = -1$ 			Rectangles
Rhombi	 α			Parallelograms
	 β			



Others ... The Chirals, Anti-chirals

n	Chiral tessellations	<i>Anti</i> -chiral tessellations
3		
4		
6		SYSTEM CANNOT BE CONSTRUCTED

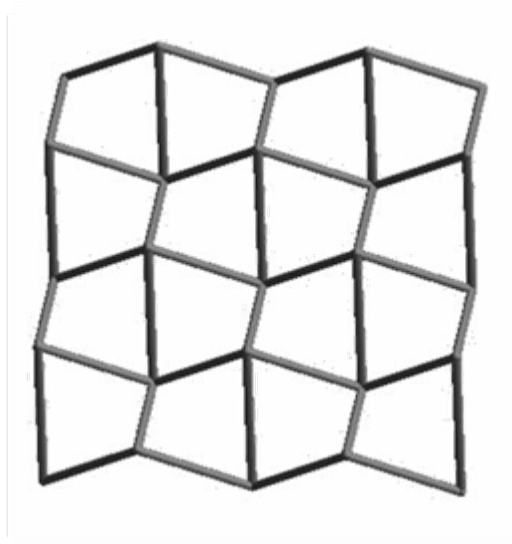


anti-tetrachiral



... and more

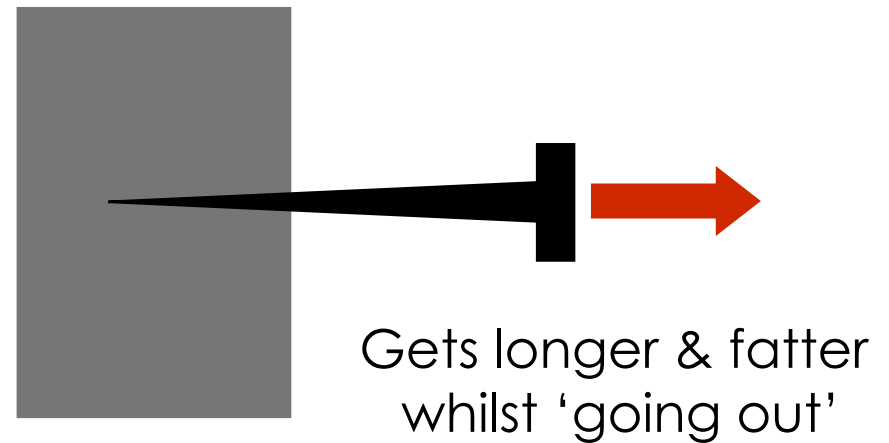
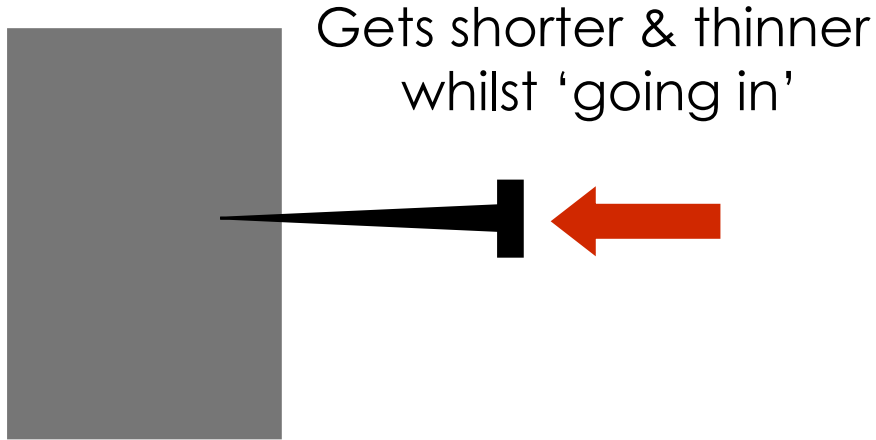
- Egg-rack mechanism





Properties / Applications

- Auxetic nails

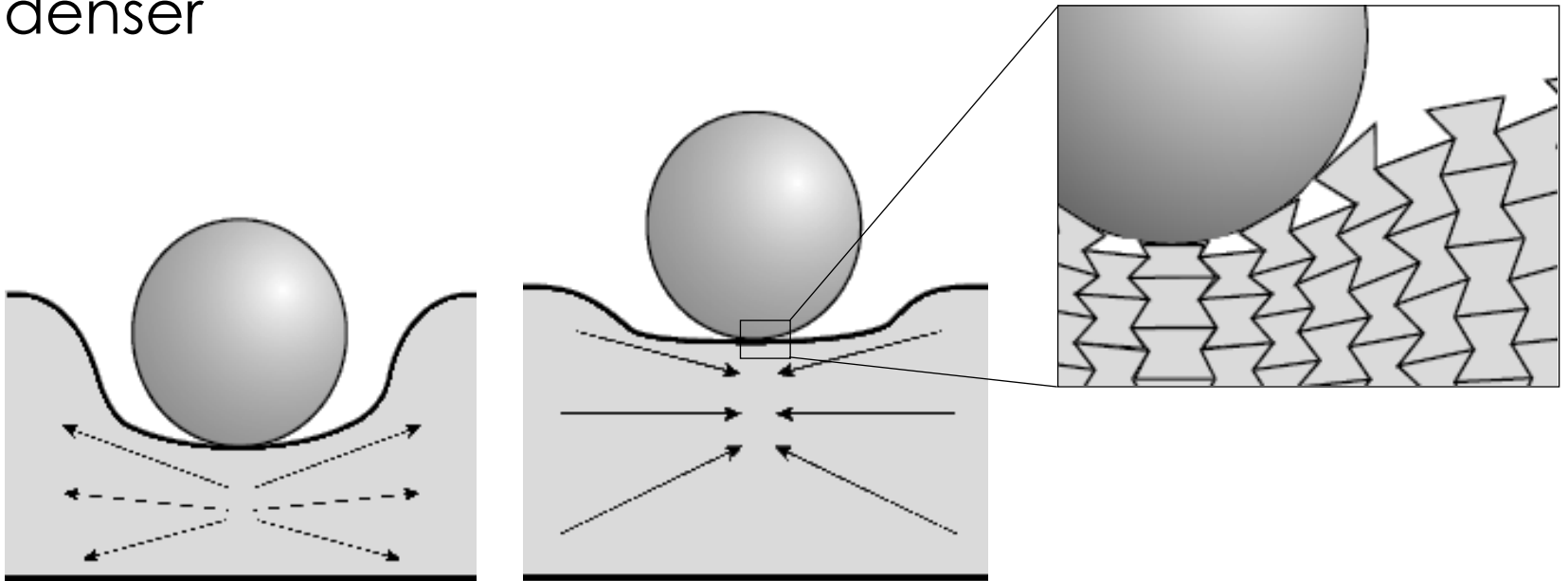




Properties / Applications

Auxetic materials are harder to indent...

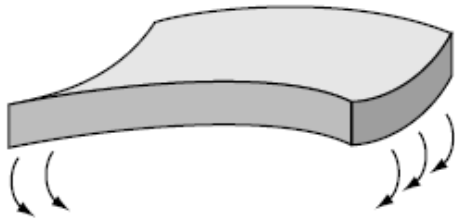
...In auxetics, the material tends to go towards the point of impact to become denser



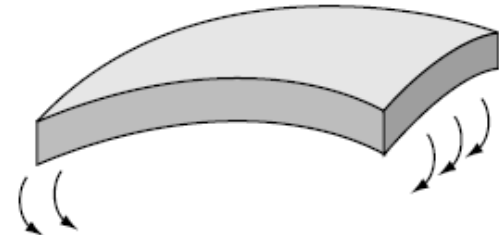


Properties / Applications

Synclastic behaviour...

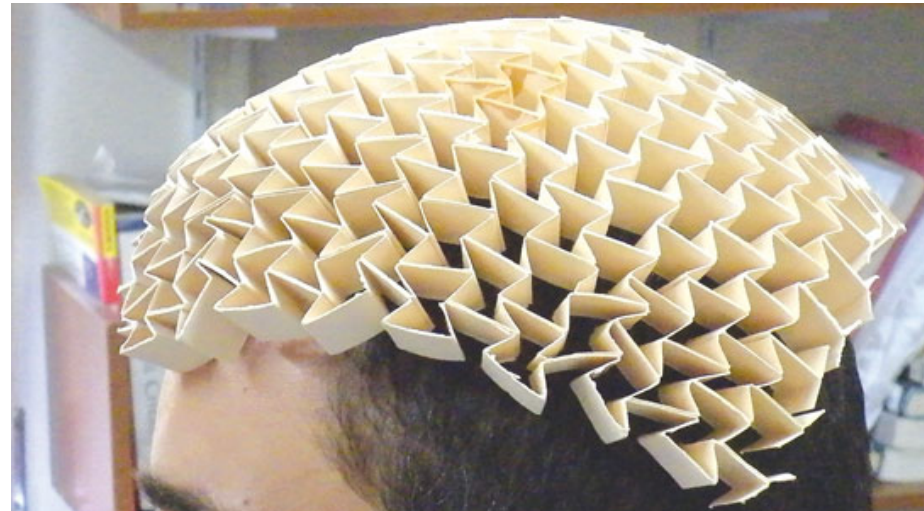


conventional



auxetic

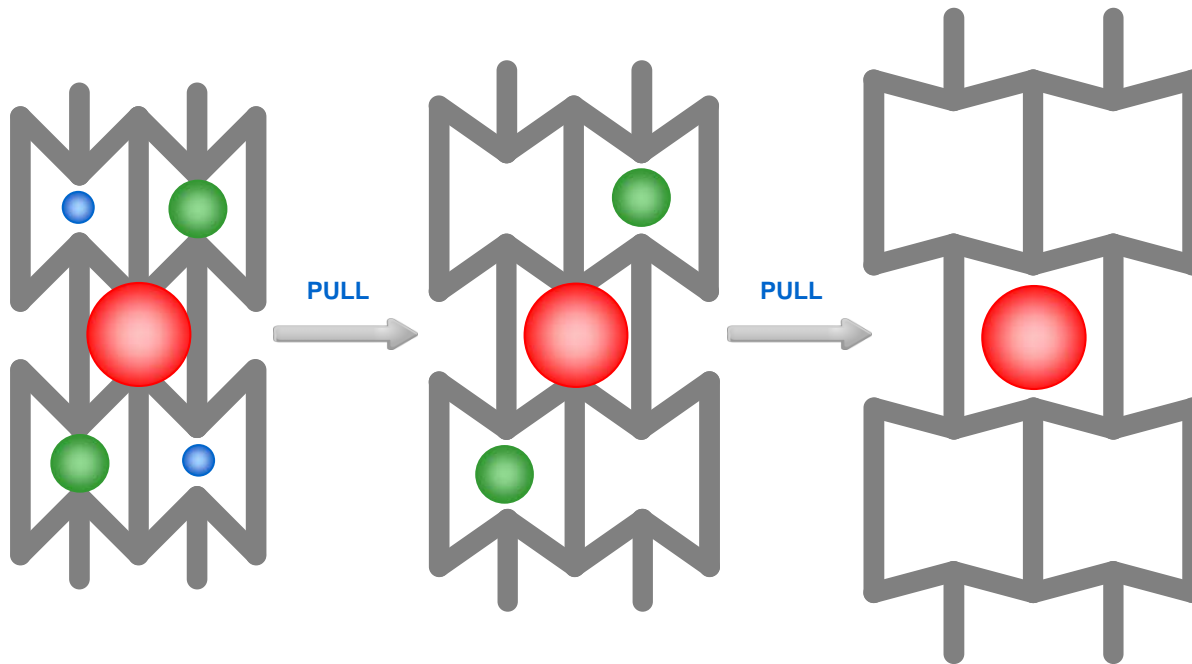
... ability to form dome shaped surfaces

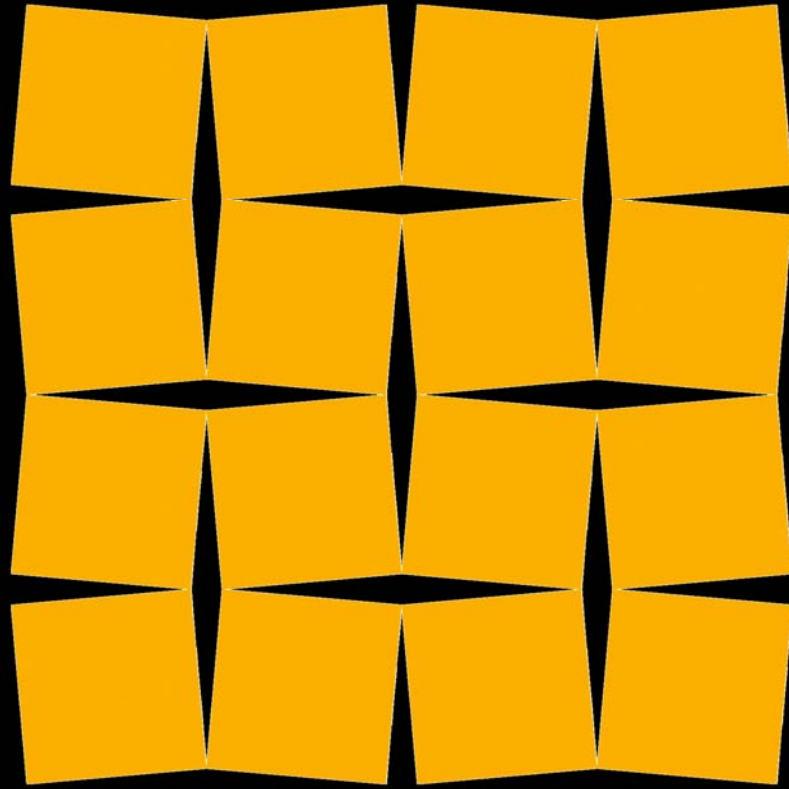




Properties / Applications

- Smart filters

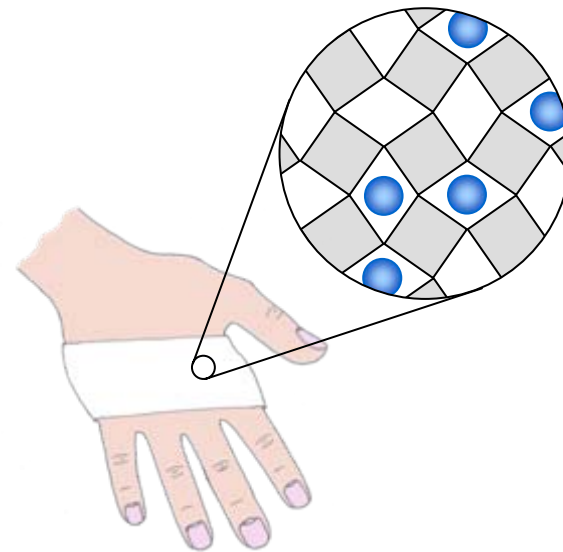
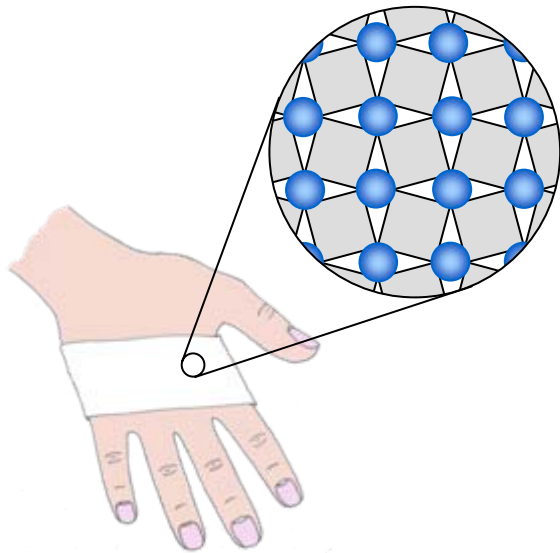






Properties and applications

- Smart dressings





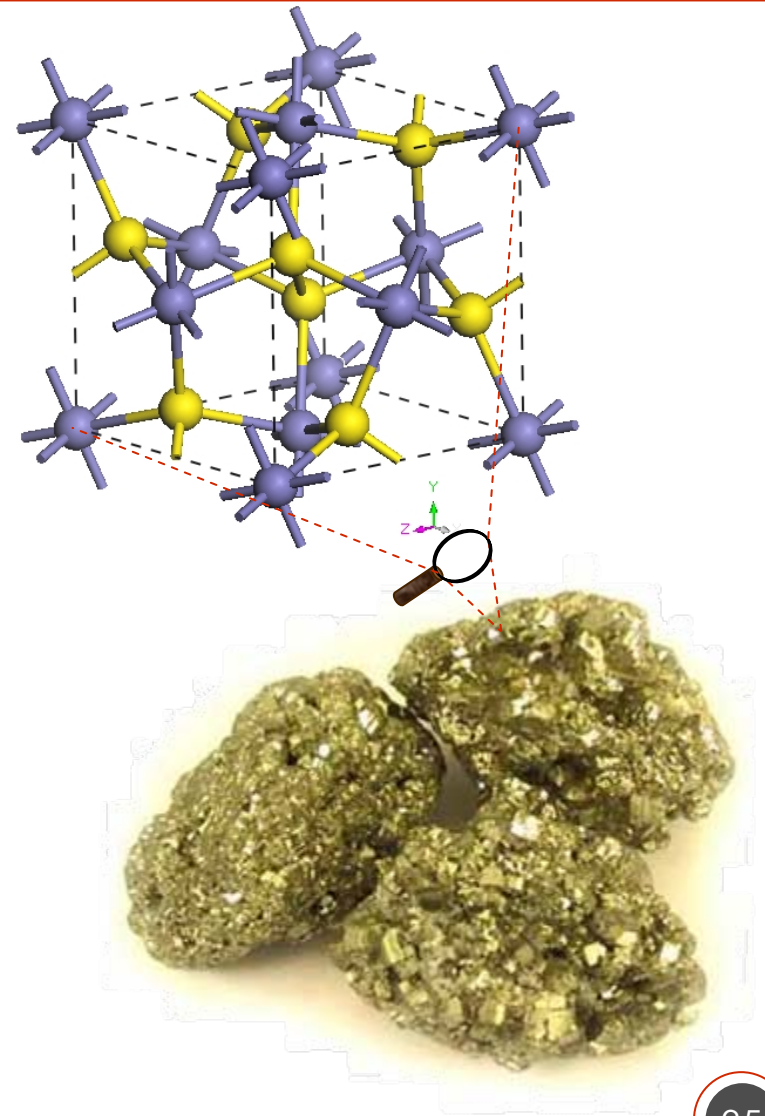
Other Properties

- An increased shear stiffness
- Higher plane fracture toughness



Historical note

- First Report: A negative Poisson's ratio was first reported in single crystals of **iron pyrites** and was attributed to **crystal twinning** [Voigt, 1928].
- This was followed by some isolated reports mostly in the 1970s and 1980s

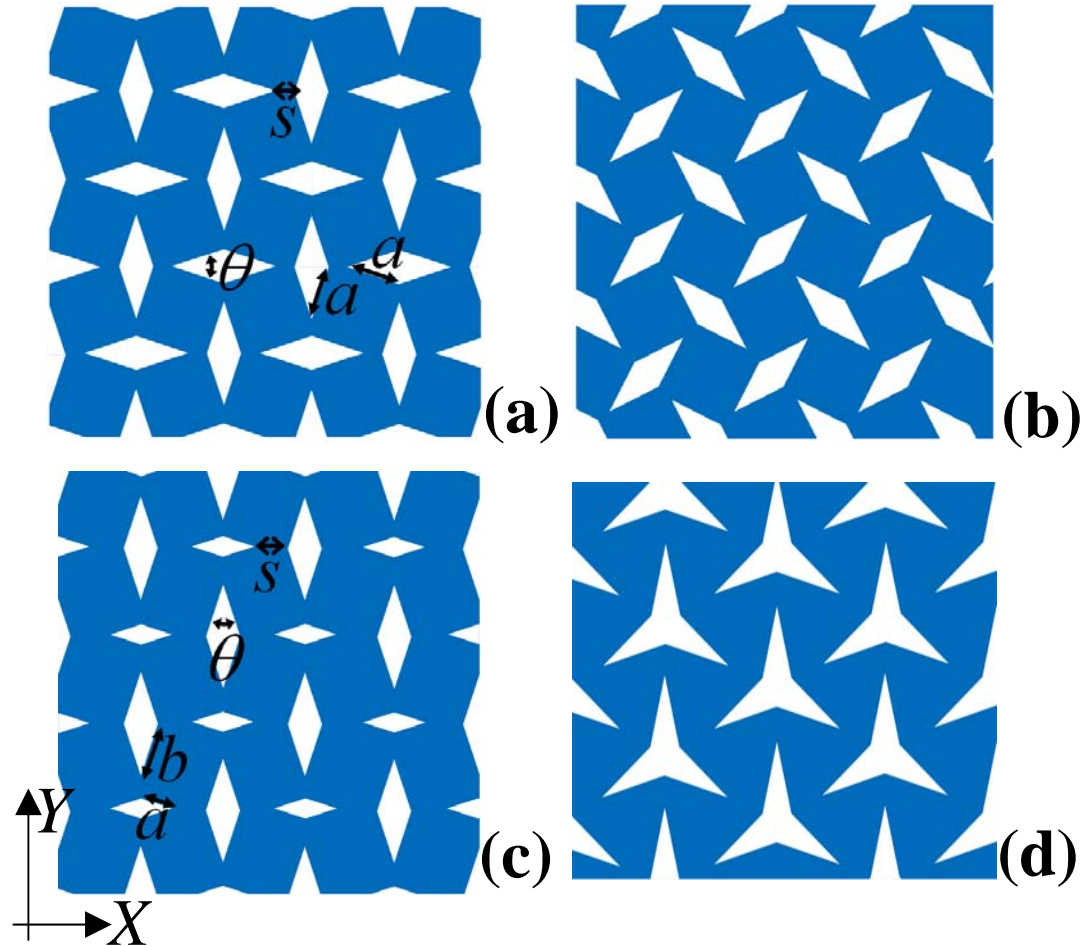


Macro auxetics ... an example





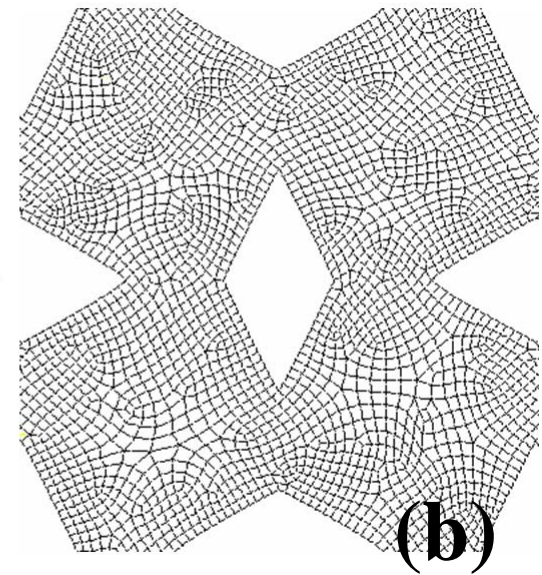
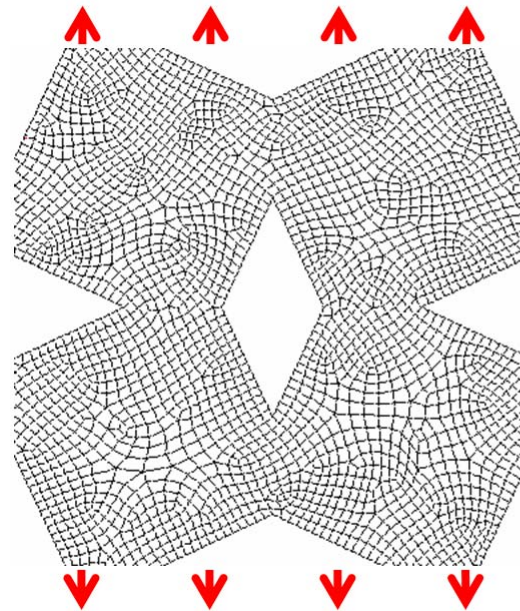
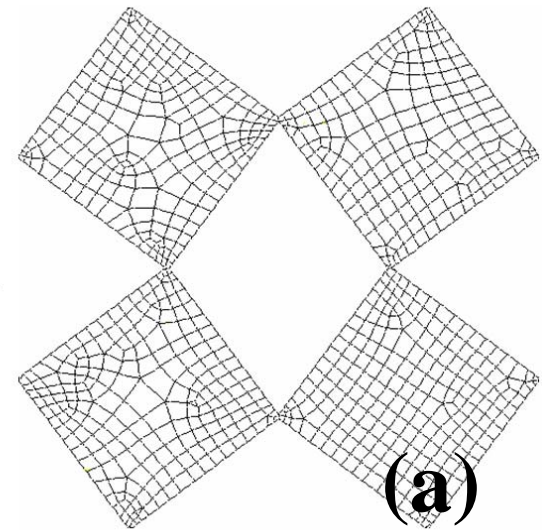
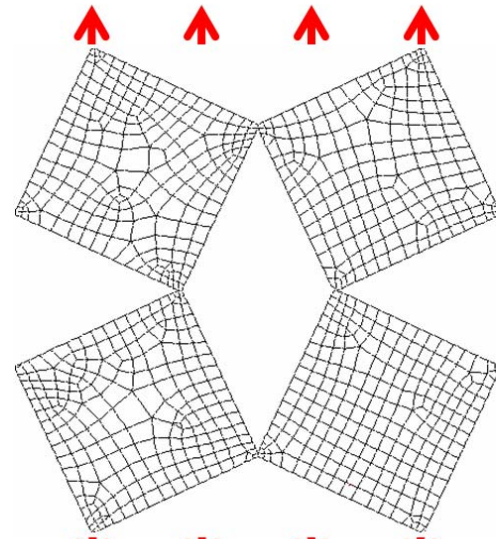
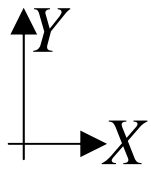
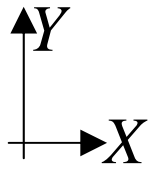
Perforated sheets

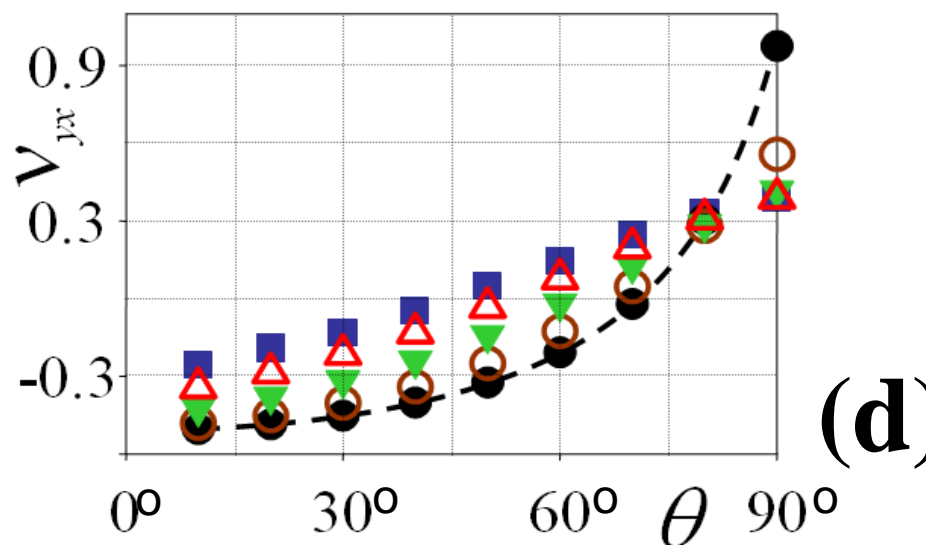
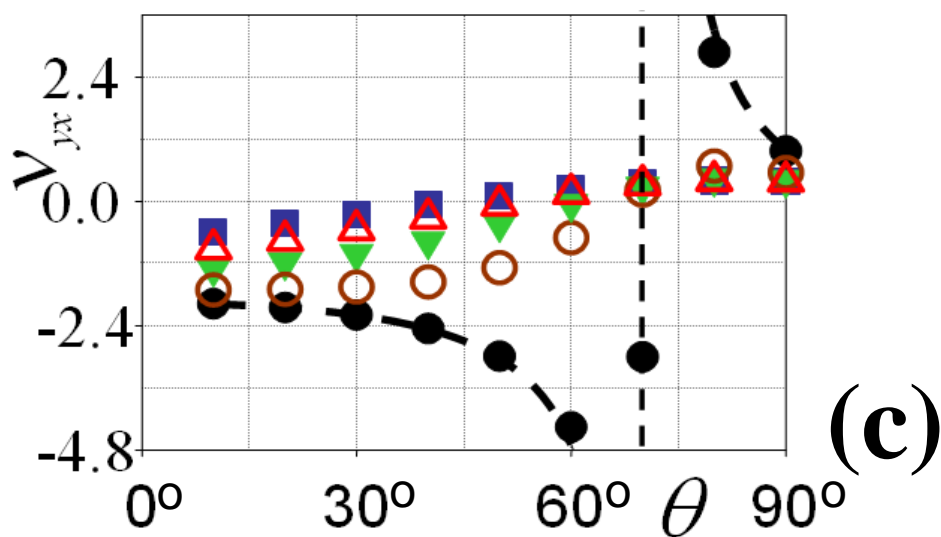
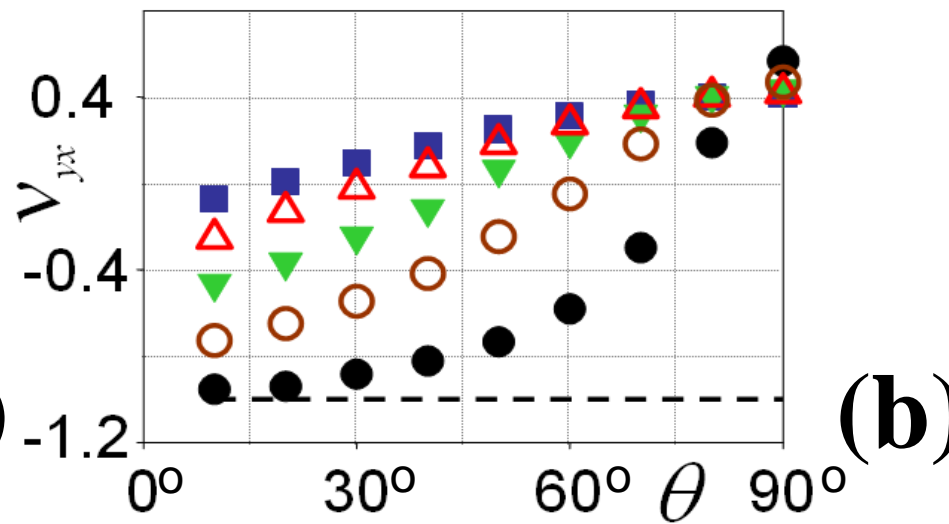
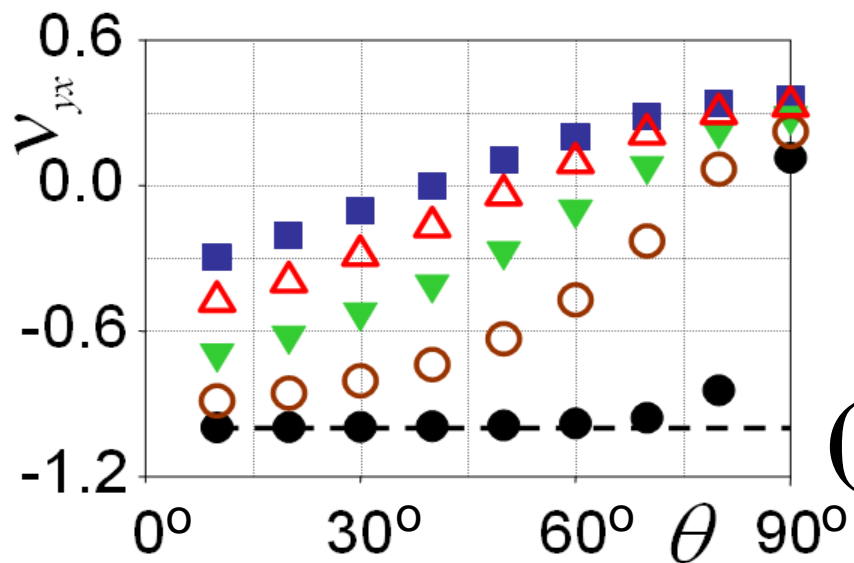




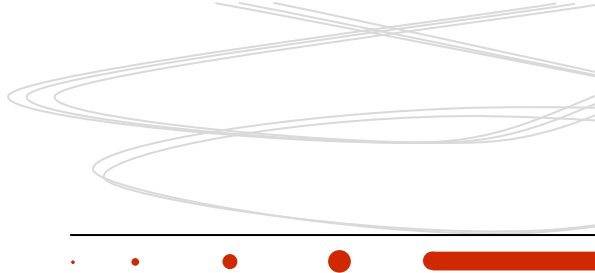
Experiment on Carpet Fabric





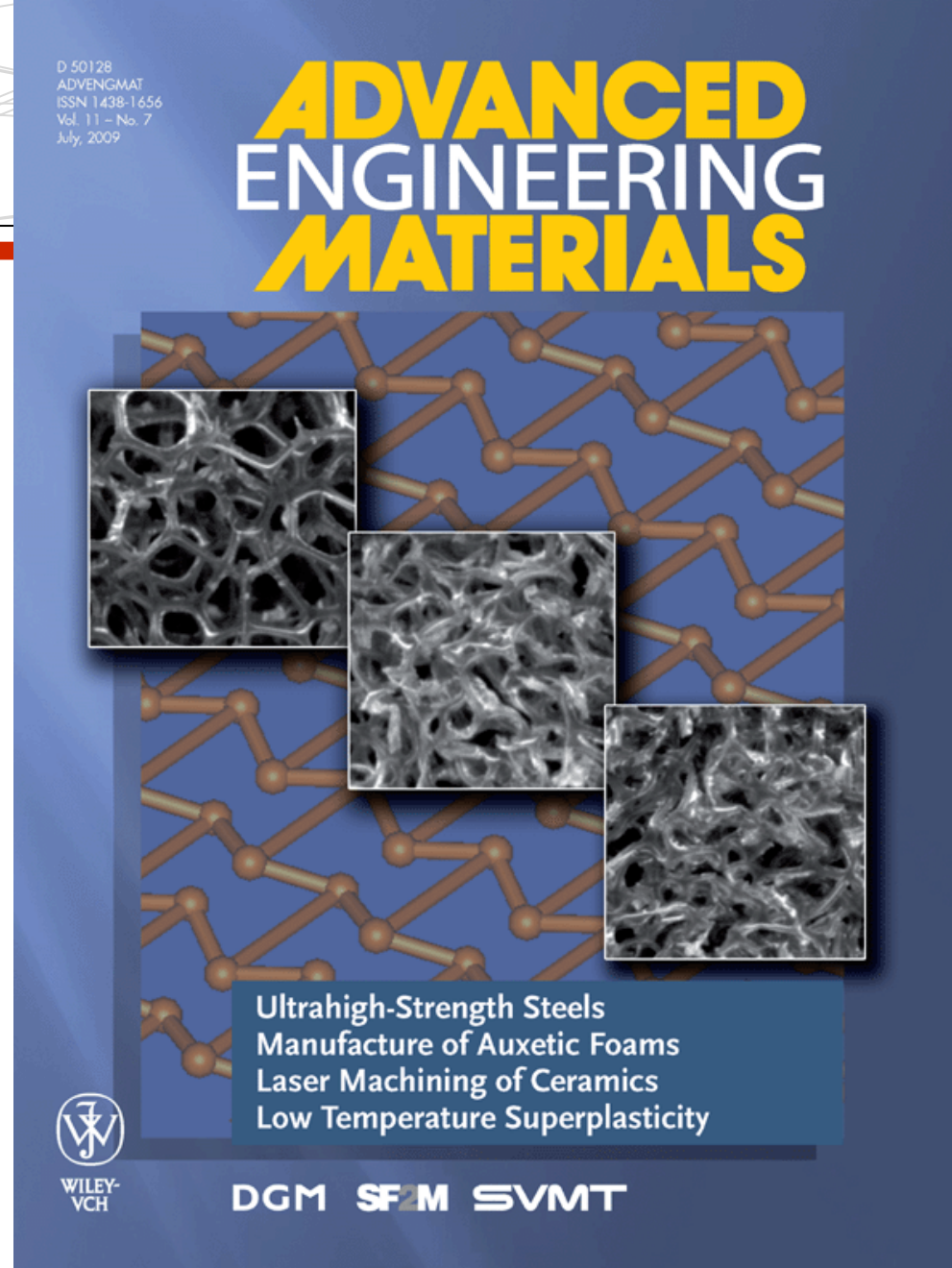


● $s = 0.1$ ○ $s = 1$ ▼ $s = 2$ ▲ $s = 3$ ■ $s = 4$ - - analytical



Microscale Auxetics

... FOAMS





Process

- First manufactured by Rod Lakes, University of Wisconsin, Madison, (R. Lakes, Science, **235** (1987) p. 1038-1040.)
- Produced from commercially available conventional foams through a process involving:
 - Volumetric compression of ~30% in volume
 - Heating to the polymer's softening temperature
 - Cooling whilst remaining under compression



Typical Procedure

Starting from: Reticulated 30 ppi polyester polyurethane

- Cut conventional foam in the shape of a cuboid of size 35 mm x 35 mm x 105 mm long;
- Press sample into a mould of dimensions 25 mm x 25 mm x 75 mm (28.6 % strain along each axis);
- Heat at 200 °C for 10 minutes,
Remove from mould
Stretch
Replace in the mould. x 2
- Cool to room temperature
- Heat for 1 hour at 100 °C

Taken from: Smith, Grima, Evans, Acta Mater. 48 (2000) p.4349-4356.

Technique adapted from: Chan and Evans, J. Mater. Sci., 32 (1997) p. 5945-5953.

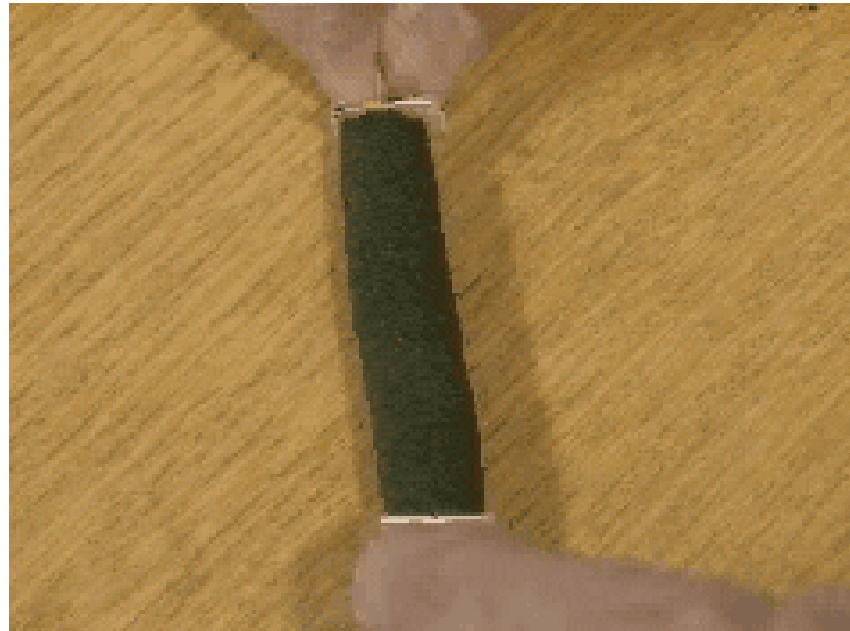


Before ...





... and after





New approach

- Uses solvent instead of heat
- Process involves
 - Wetting foam with appropriate solvent
 - Compressing the foam volumetrically by 30%
 - Allowing the foam to dry well

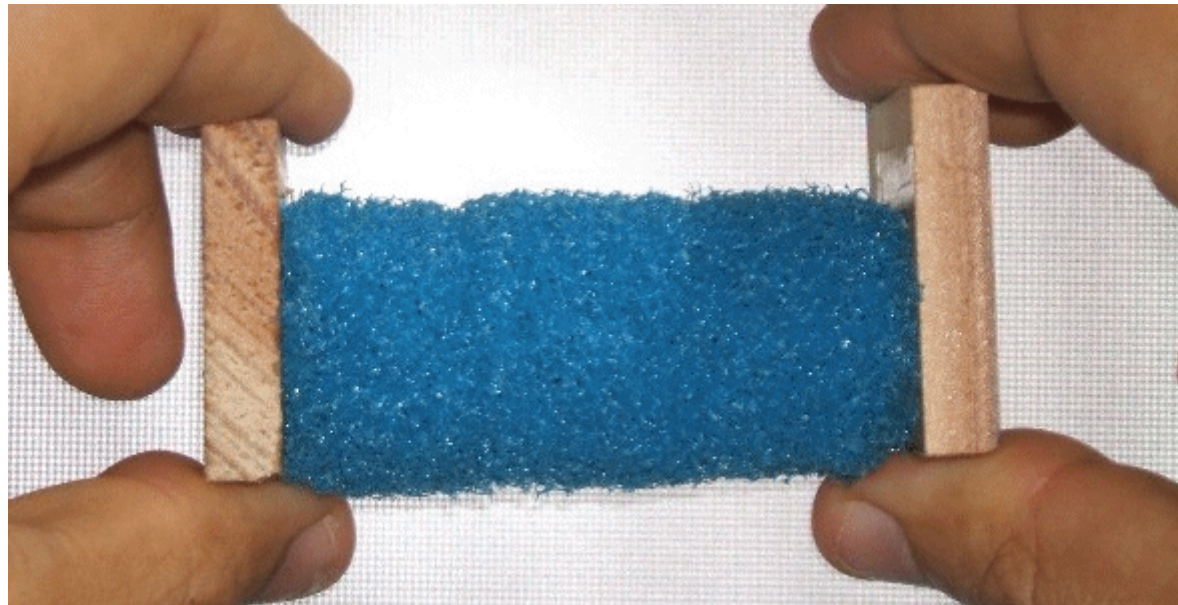


Typical Process

- Starting from: Reticulated 30 ppi polyurethane foam (Dongguan Dihui Foam Sponge, China)
- Cut conventional foam in the shape of a cylinder of diameter 40mm and length 84mm
- Wet the foam with acetone
- Remove excess solvent
- Press sample into a mould of diameter 26 mm and length 55mm (~35 % strain along each axis);
- Allow the sample to dry completely before removing from mould



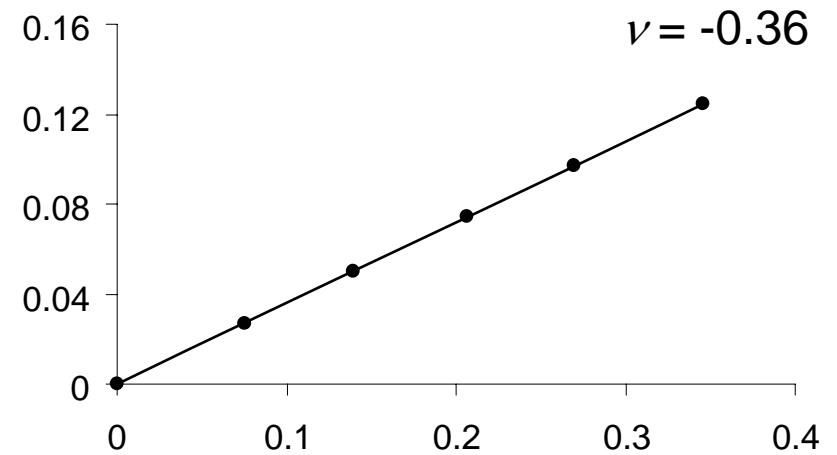
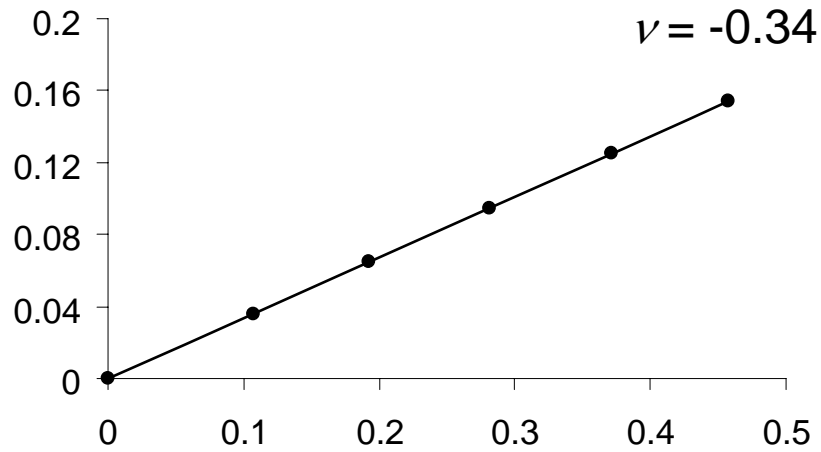
Result

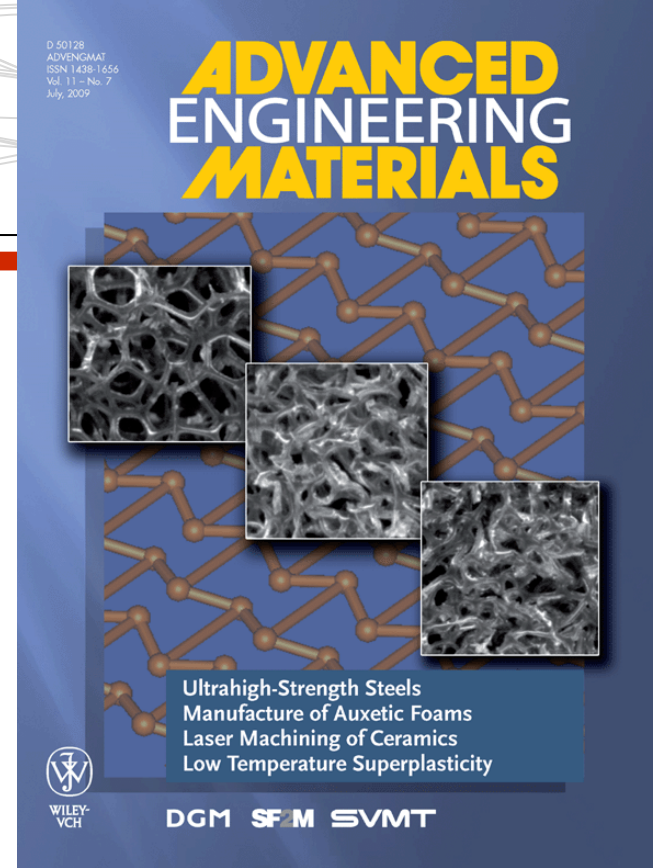
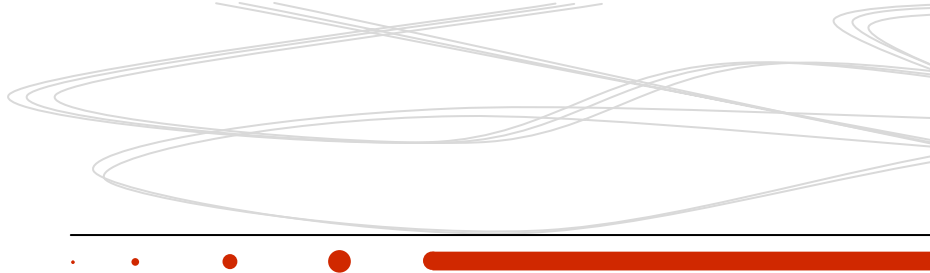


JN Grima, D Attard, R Gatt and RN Cassar, *Adv. Eng. Mater.*, **21** (2009)



Measurements

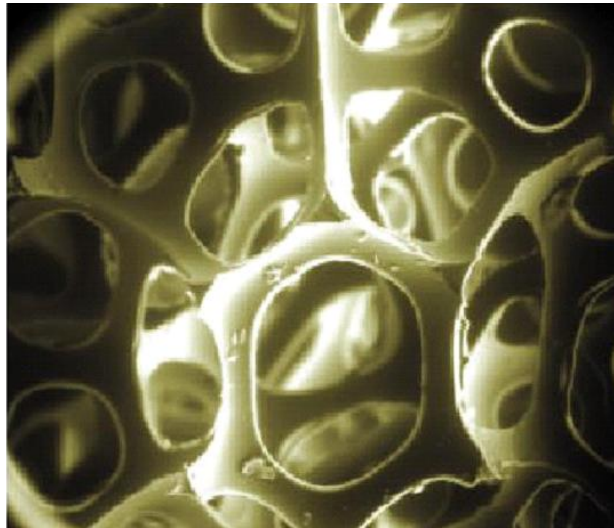




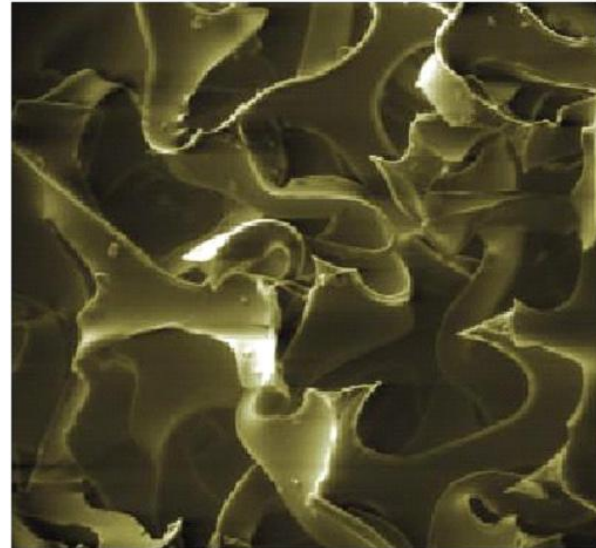
Foams – The Models



Microstructure in auxetic foams



Conventional foam

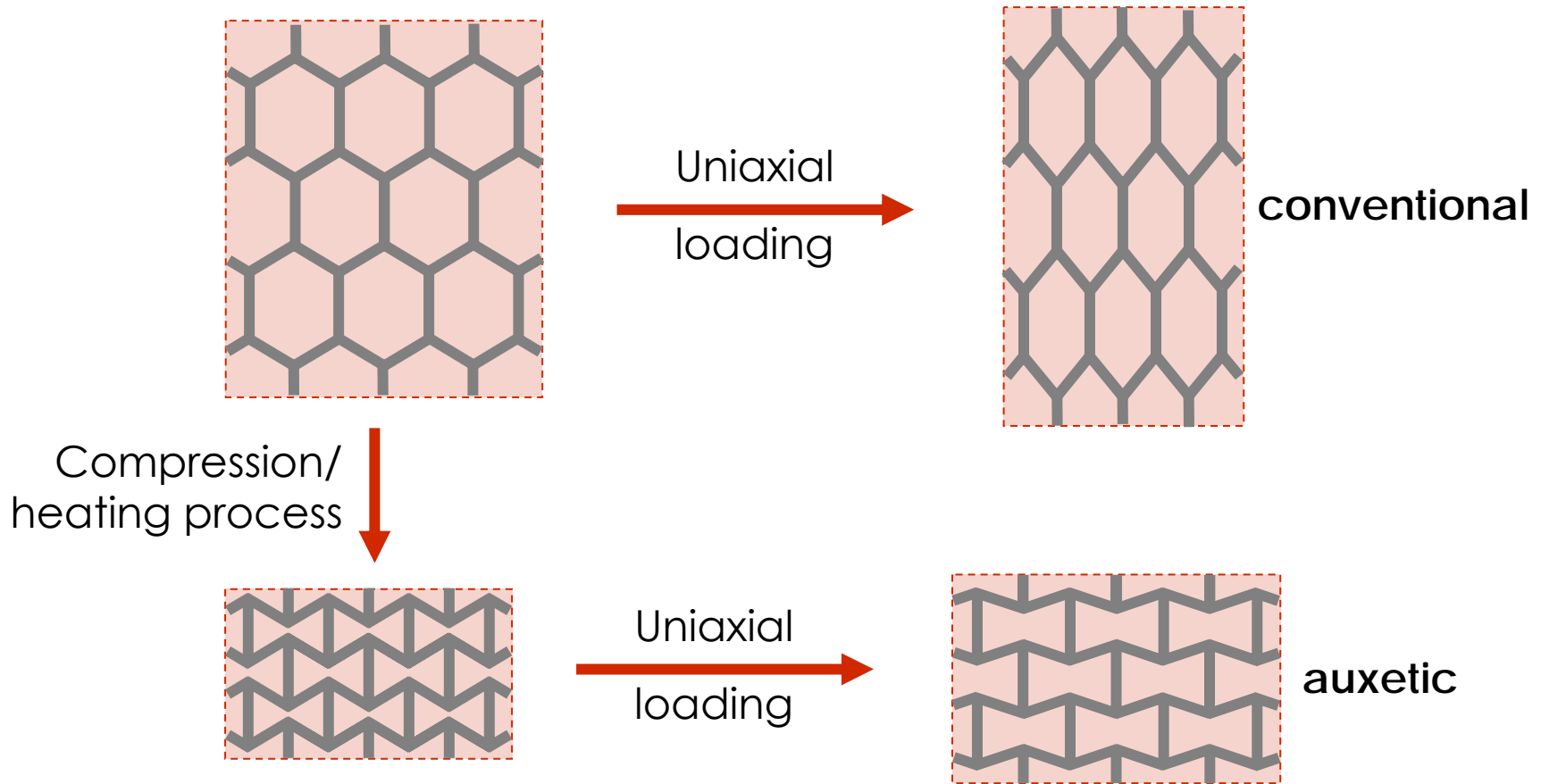


Auxetic foam

JN Grima, A Alderson and KE Evans, *J. Phys. Soc. Jpn*, 74 (2005) 1341.



Re-entrant structures



LJ Gibson and MF Ashby, *Cellular Solids*, Cambridge Uni. Press, 1997.

IG Masters and KE Evans, *Composite Struct*, **35** (1996) 403.

KE Evans, A Alderson and FR Christian, *J. Chem. Soc. Faraday Trans.*, **91** (1995) 2671.

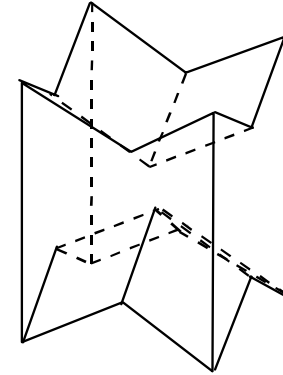
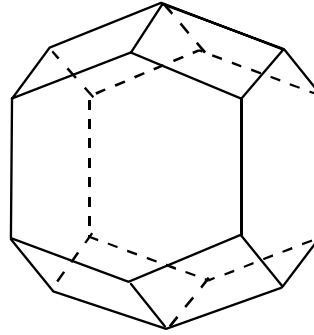


3D Re-entrant structures

conventional

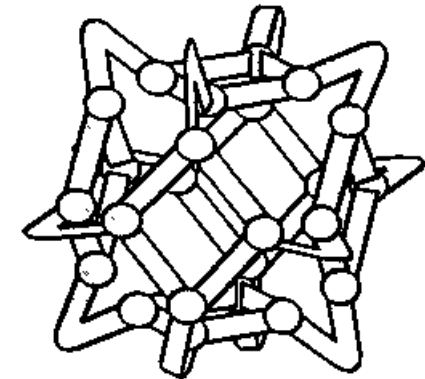
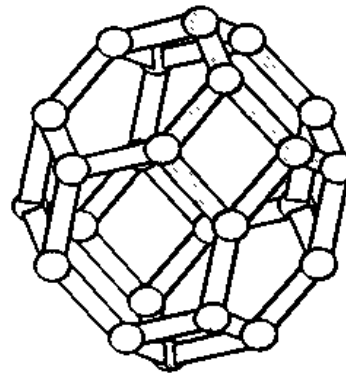
Re-entrant

dodecahedron
foam models



(KE Evans, MA Nkansah and IJ Hutchinson, *Acta Metall. Mater.*, **2** (1994) 1289)

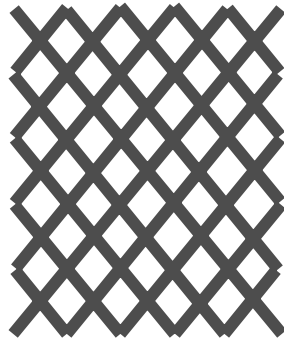
tetrakaidecahedron
foam models



(JB Choi, RS Lakes, *J Compos. Mater.*, **29** (1995) 113.)



Missing rib model



Uniaxial
loading

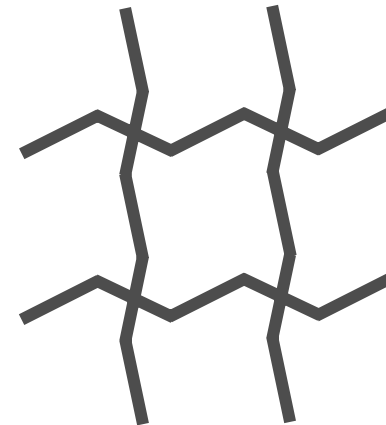


conventional

Compression/
heating process



Uniaxial
loading

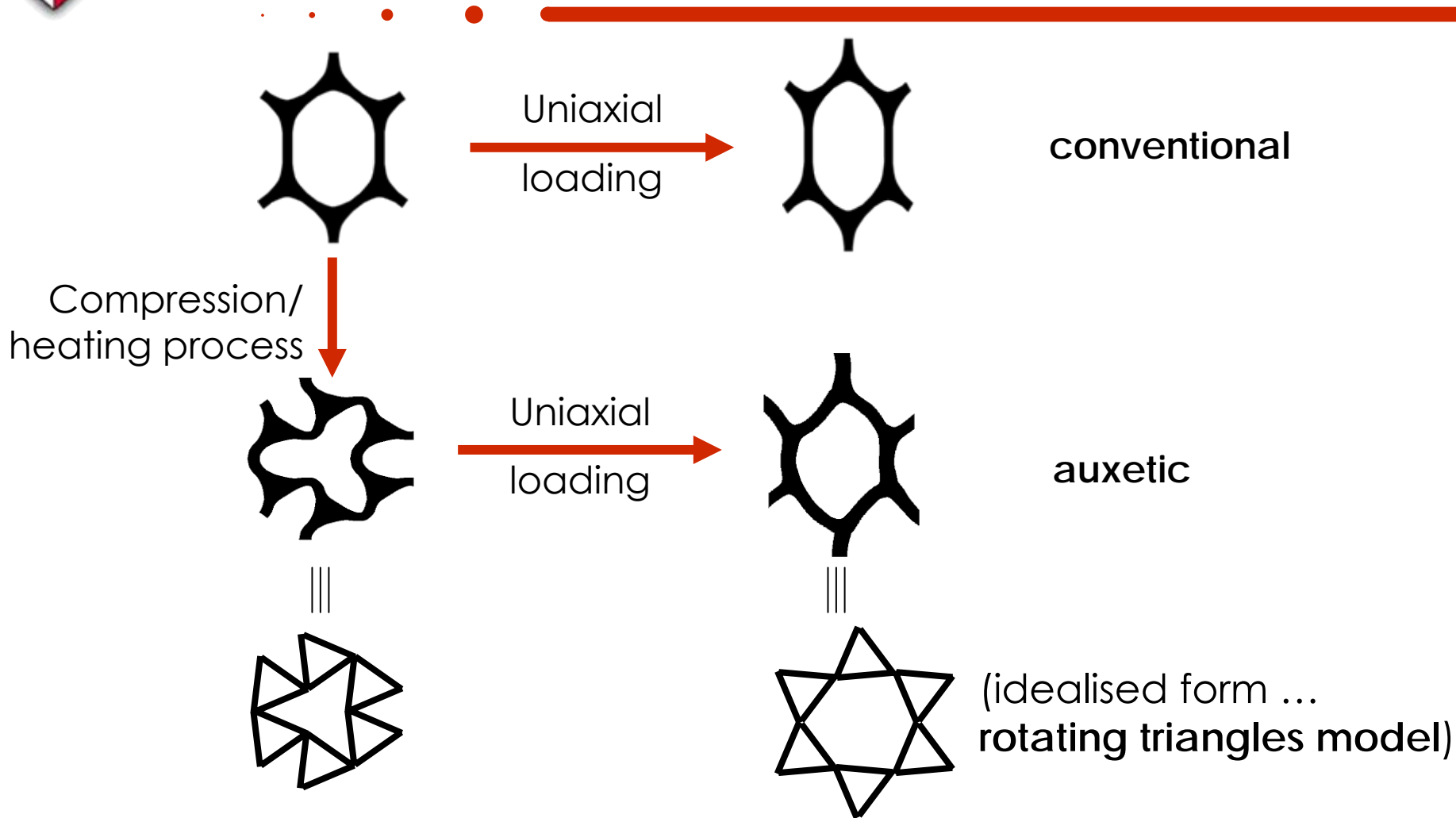


auxetic

CW Smith, JN Grima and KE Evans, *Acta Mater.*, **48** (2000) 4349.



Rotating rigid units



JN Grima, A Alderson and KE Evans, *J. Phys. Soc. Jpn*, **74** (2005) 1341.



Later on ... The evidence

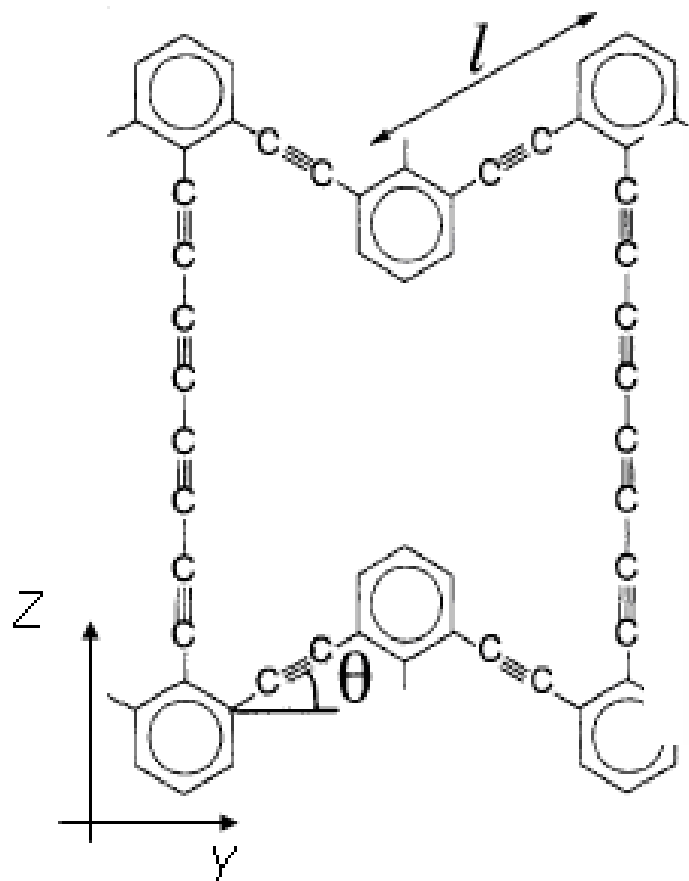
- In situ three-dimensional X-ray microtomography of an auxetic foam under tension, S.A. McDonald, N. Ravirala, P.J. Withers, A. Alderson, Scripta Mater. (2009) p. 232-235 which says:
 - *X-ray microtomography has the potential to unambiguously identify the predominant deformation mechanisms responsible for the auxetic response of polymeric foams. It has been performed in situ on an auxetic polyurethane foam subjected to incremental uniaxial tensile loading. A Poisson's ratio of -0.20 measured from localized microstructural changes observed during the tomographic sequence compares well with the bulk value of -0.21 obtained by videoextensometry. **Evidence obtained by digital image correlation for straightening of bent ribs and rotation of junctions connecting ribs during straining is presented.***

Synthesized 'molecular level' Auxetics: LCPs

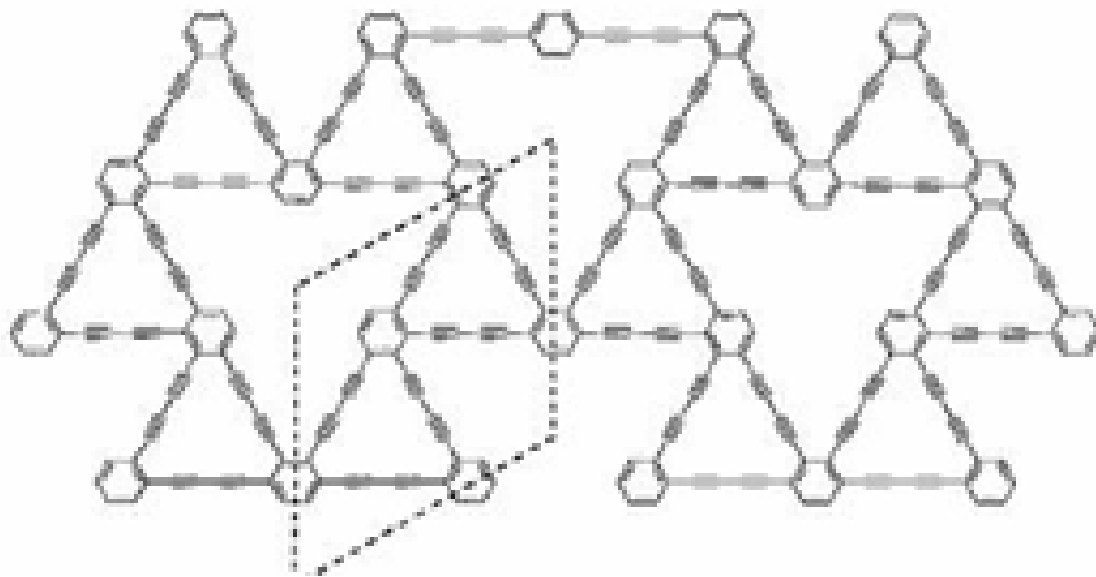




Other possible auxetic polymers



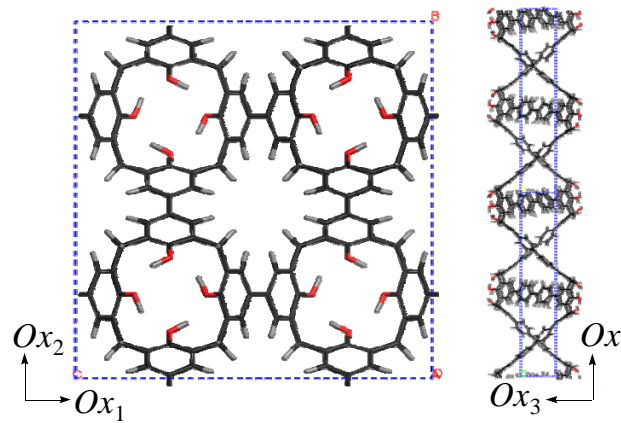
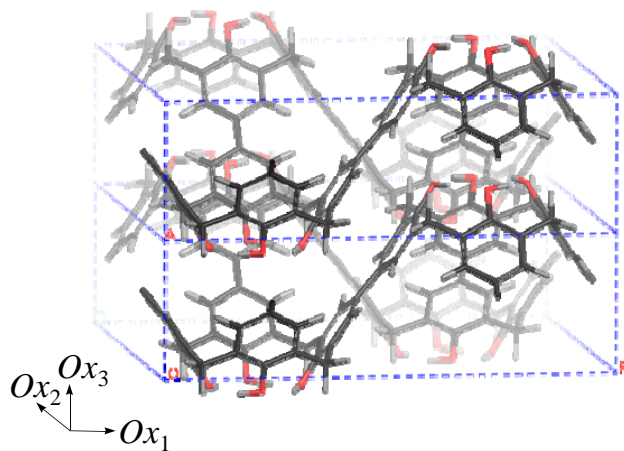
Evans *et al.*, *Nature* (1991)



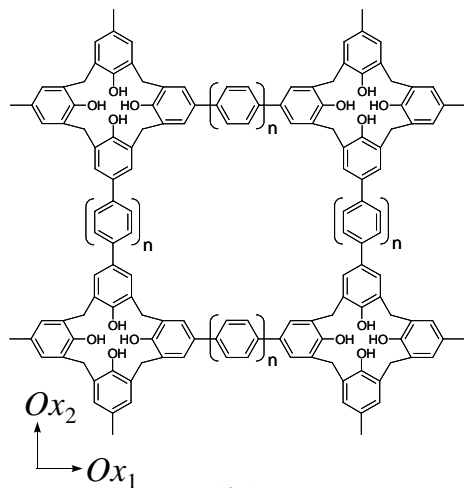
Grima *et al.*, *Chem. Comm.* (2000)



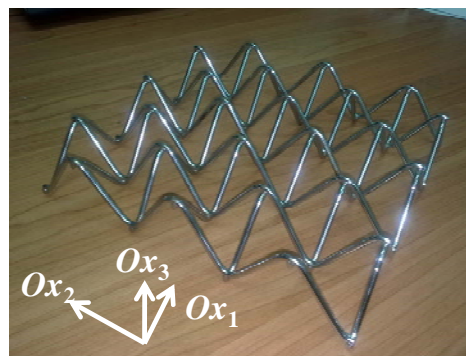
Other possible polymers ...



(a)



(b)



(c)



Auxeticity in Naturally Occurring minerals





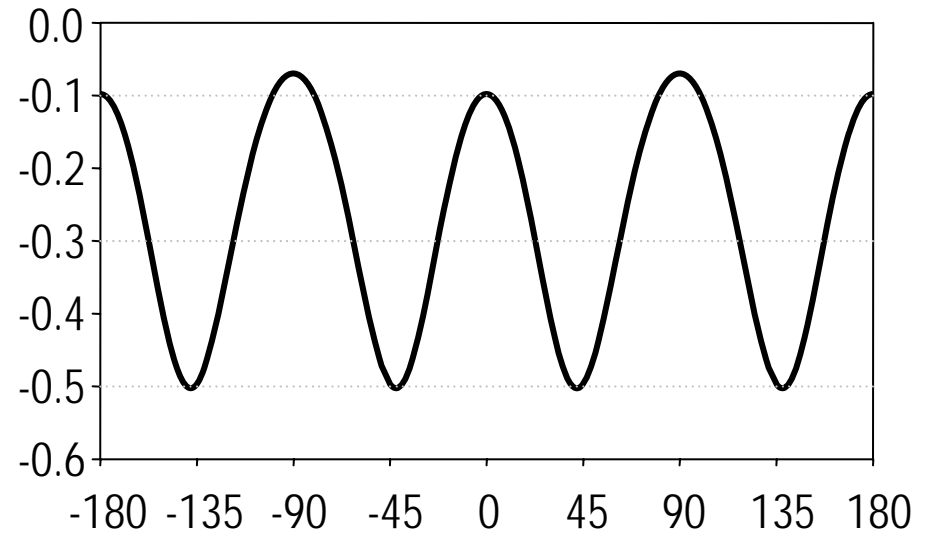
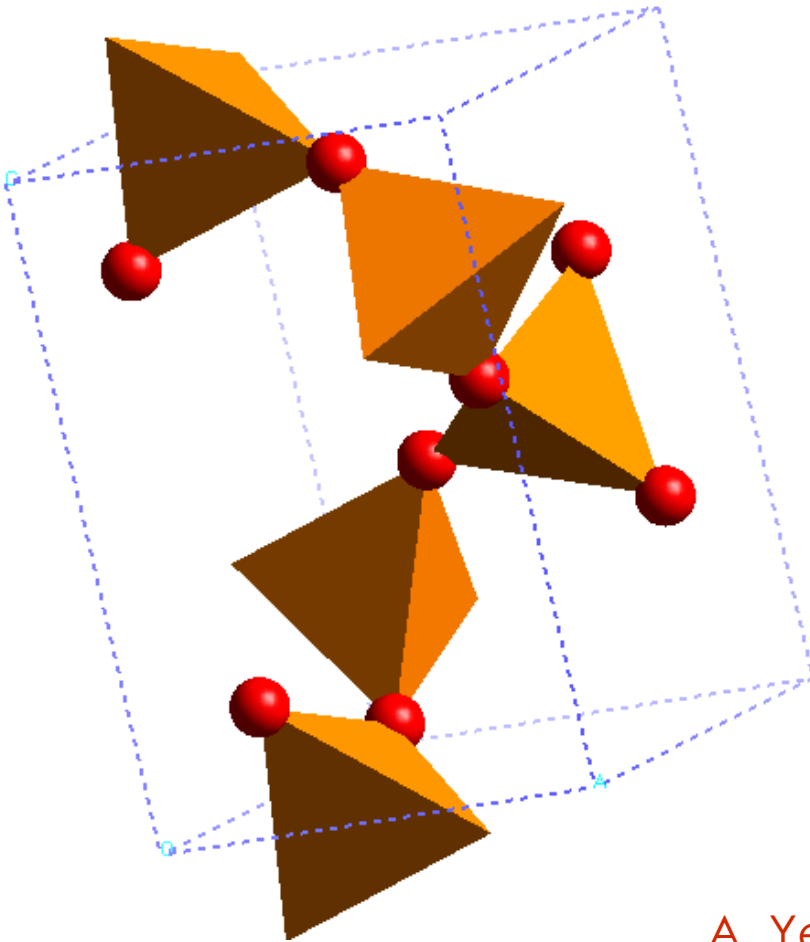
Case Study (i) - Cristobalite

- Meta-stable, crystalline silica
- Has a low temperature phase (**α -cristobalite**) and a high temperature phase (**β -cristobalite**)





α -Cristobalite: mechanical properties



Maximum auxetic behaviour in the (1 0 0) and (0 1 0) planes (yz, xz) at **c. 45°** to the major axes.

A. Yeganeh-Haeri *et al.*, *Science*, **257** (1992) 650

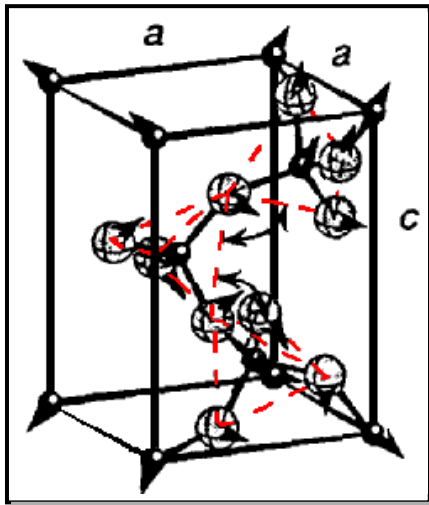


Deformation mechanisms: Rotating tetrahedra

Keskar & Chelikowsky

CTM

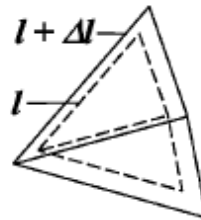
Alderson *et al.*



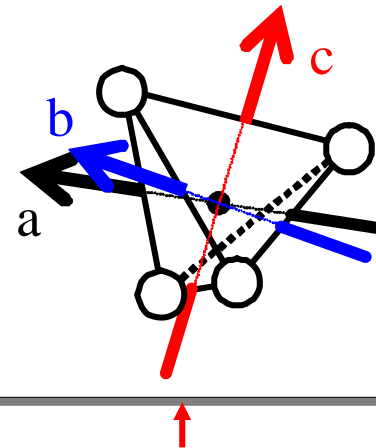
... rotation of SiO_4 tetrahedra

tetrahedra expand / shrink
without changing relative
orientation

DTM



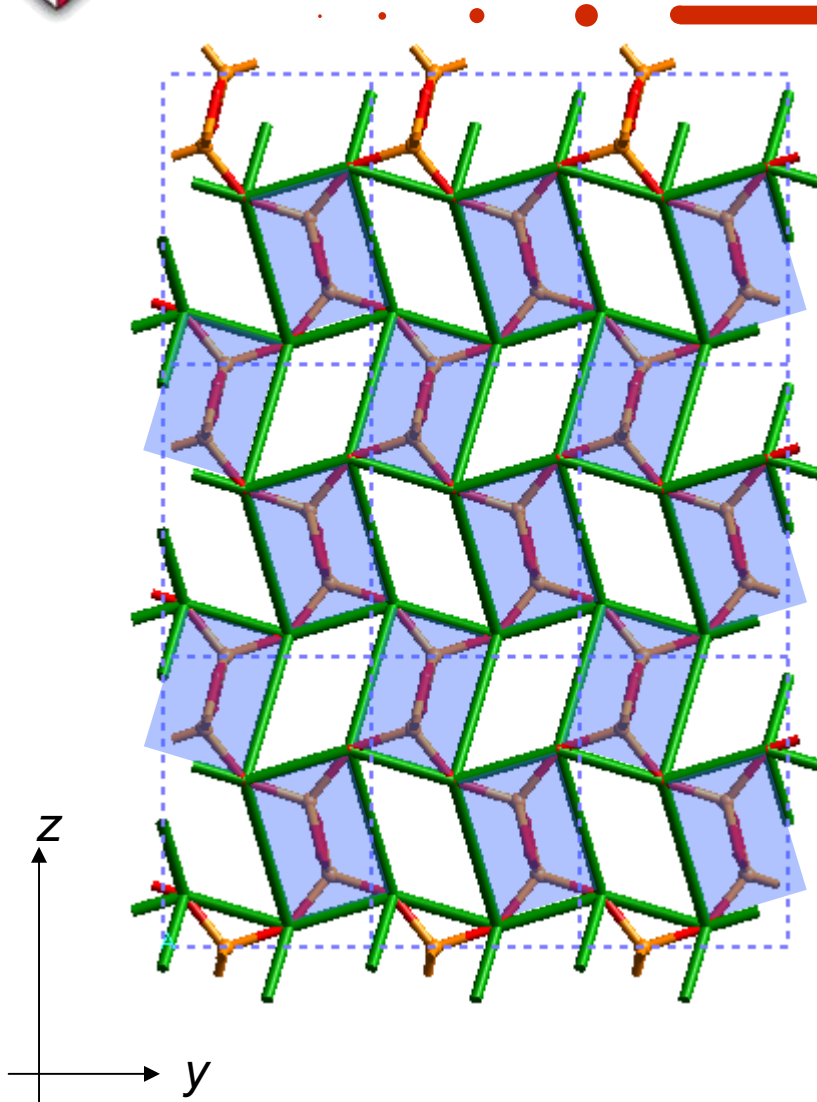
RTM 1 + 2



Tetrahedra rotate relative to
each other @ two distinct
local axis without changing
shape



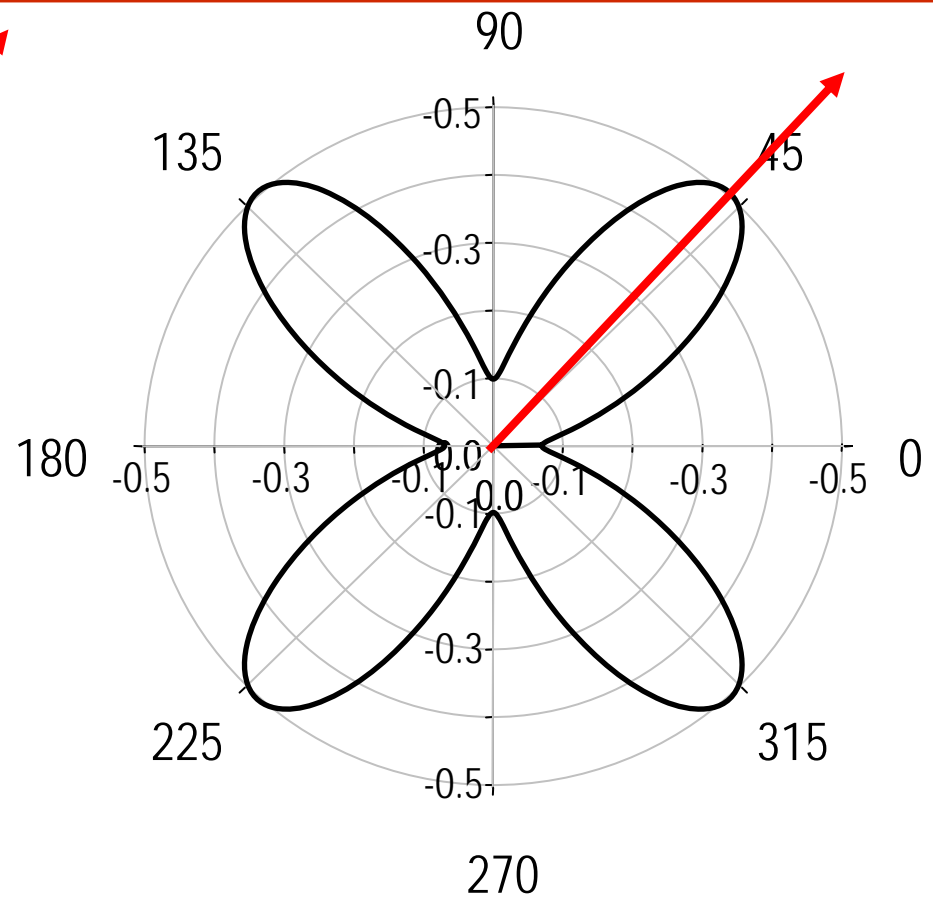
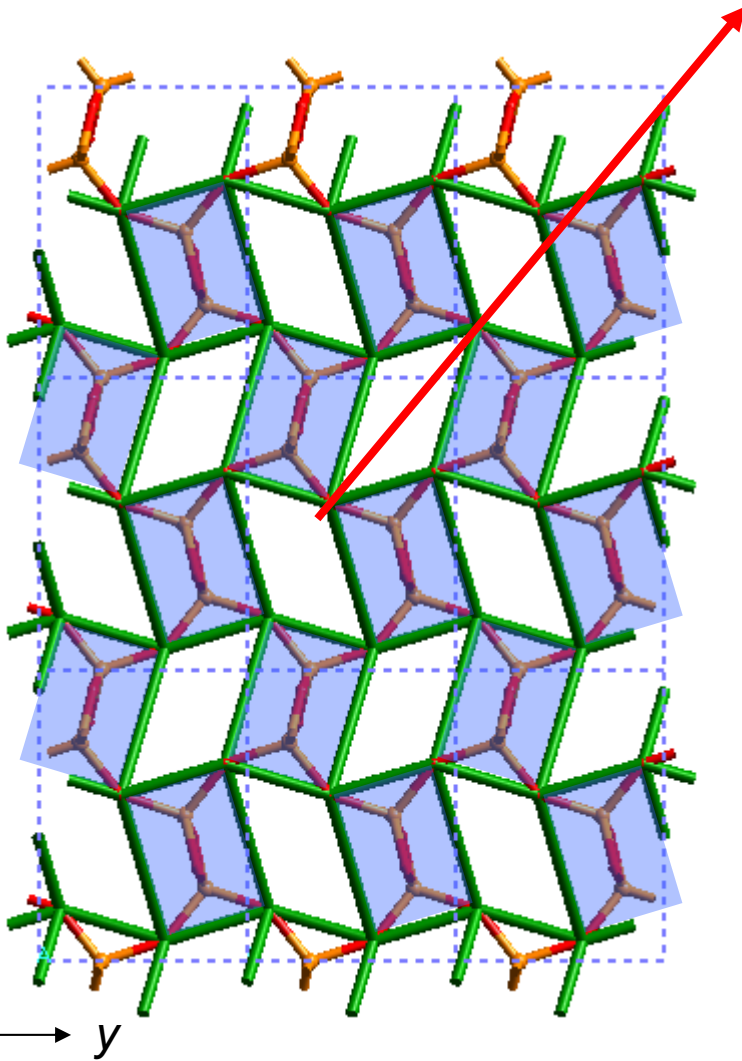
Deformation mechanisms – 2D model



... Rotating rectangles as viewed
in the (100) Plane (yz-plane)



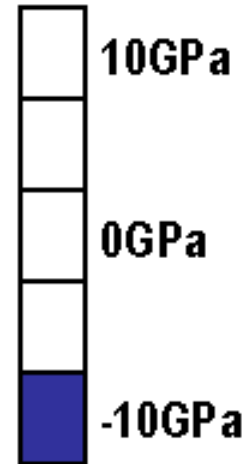
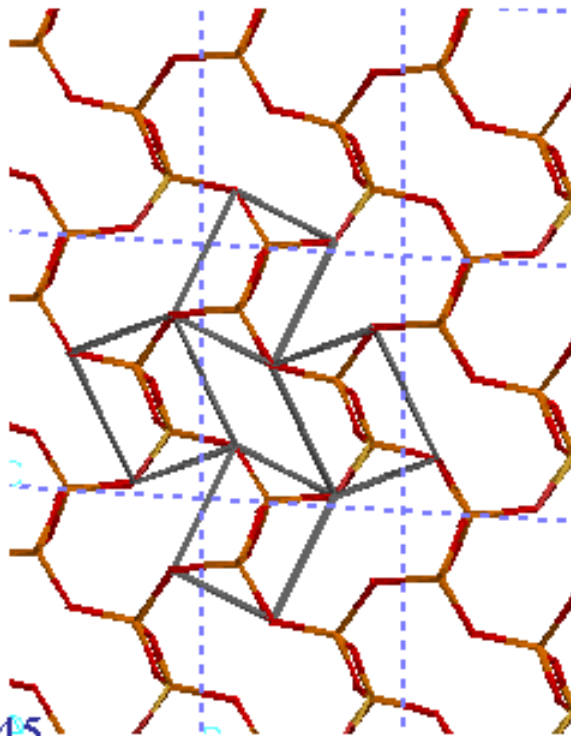
Deformation mechanisms – 2D model



... Rotating rectangles as viewed
in the (100) Plane (yz -plane)



Rotating rectangles model: Molecular Modelling



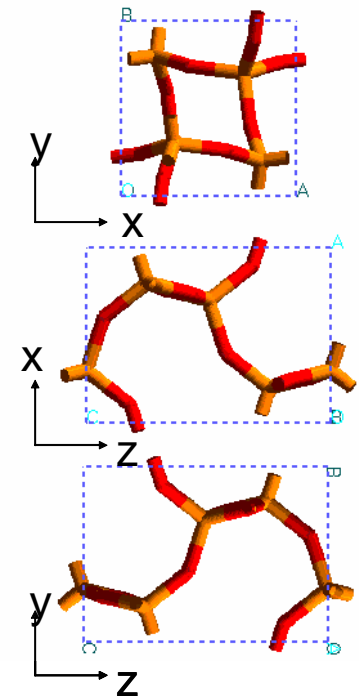
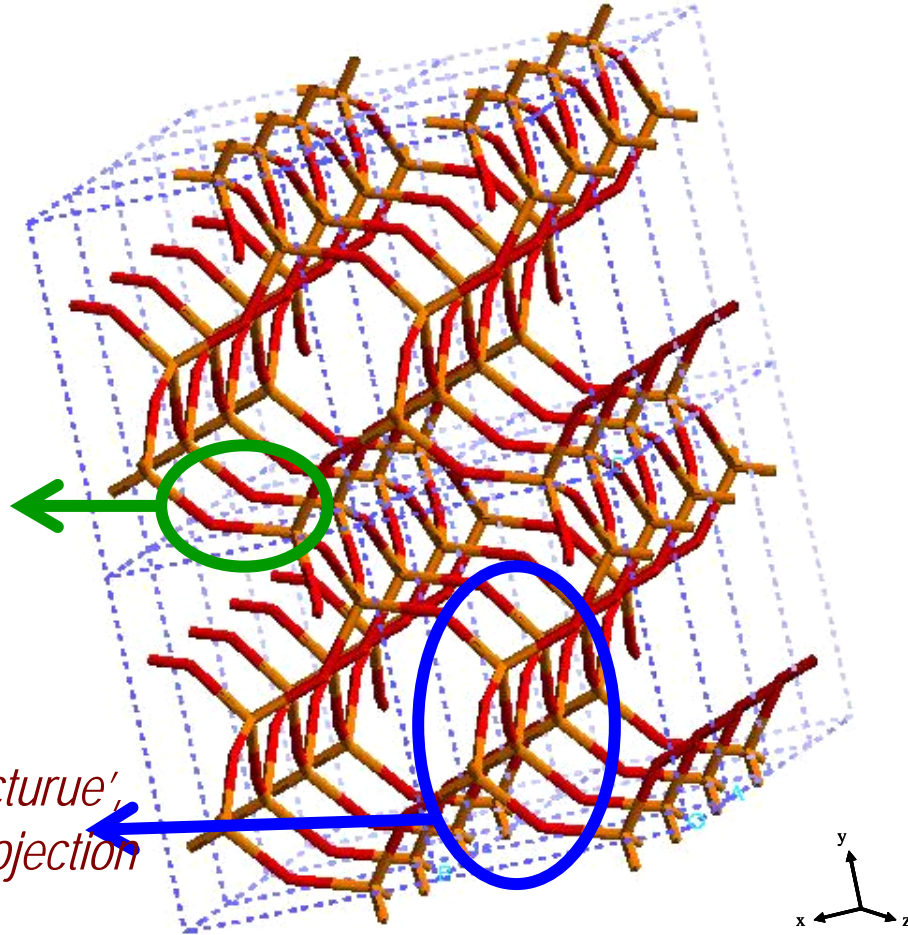
Load in
 σ^z_{45}
direction

*... Rotating Rectangles
mechanism taking place
in the (100) plane*



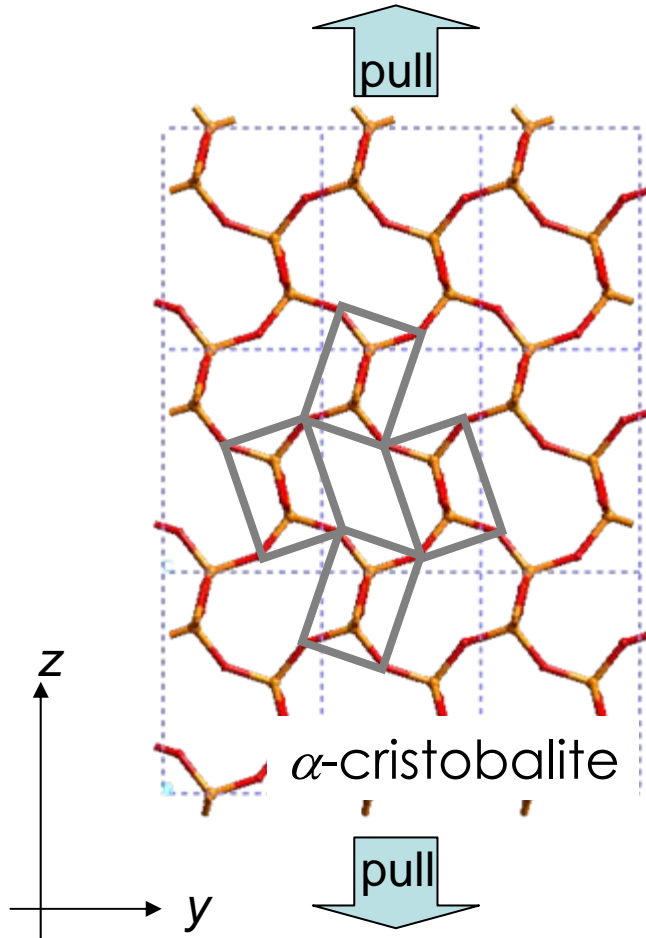
Rotating Rectangles model: Molecular Modelling

*Soft Si - O - Si
bonds representing
the hinges*

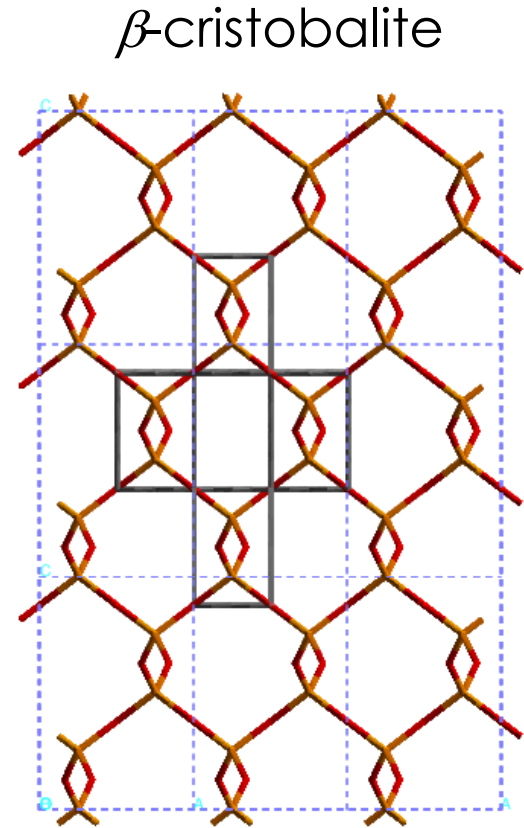




Loss of NPR for the $\alpha \rightarrow \beta$ transition: an explanation

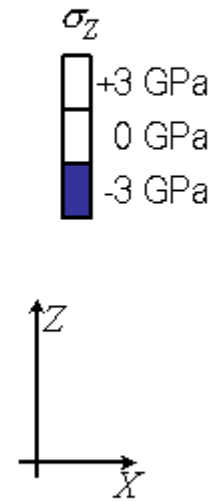
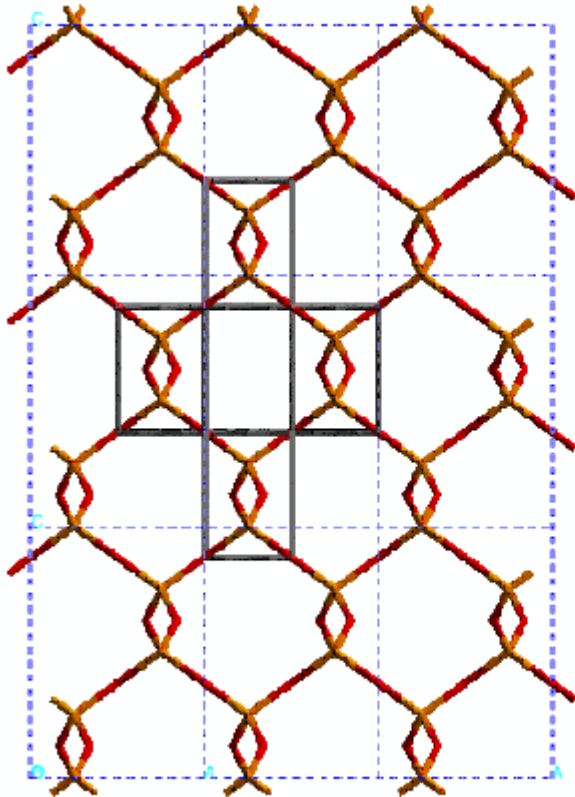


stress-induced
phase transition





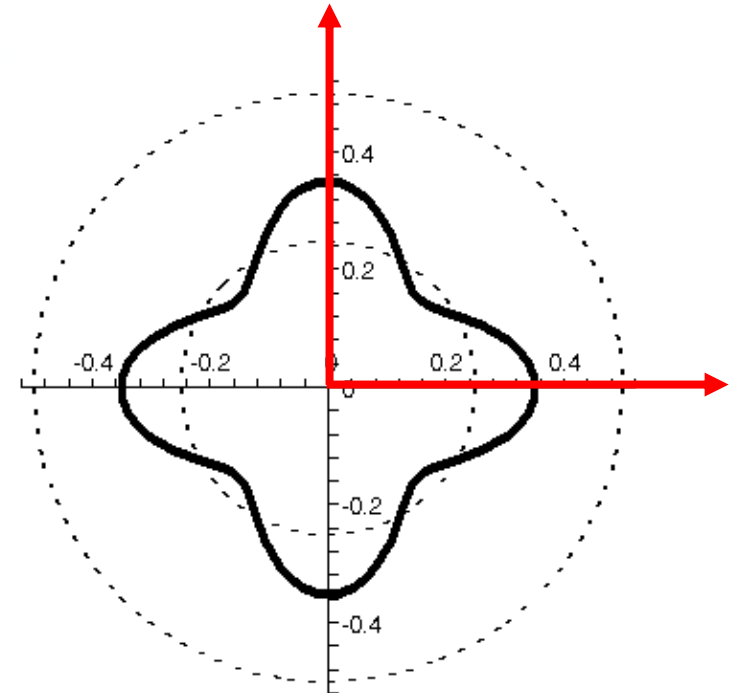
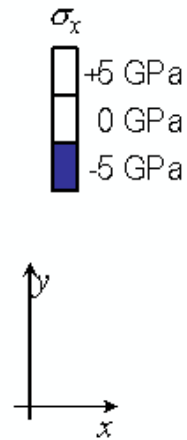
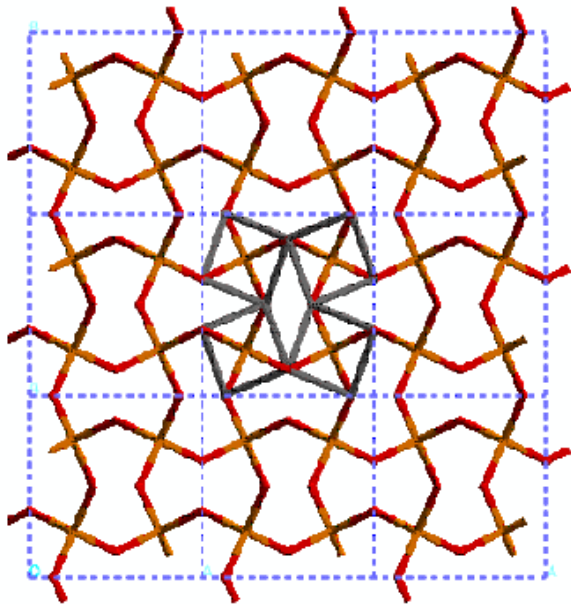
Loss of NPR for the $\alpha \rightarrow \beta$ transition: an explanation



... Conventional behaviour
in β -cristobalite in the
(100) plane



NPR in 'ordered' β -cristobalite – an explanation



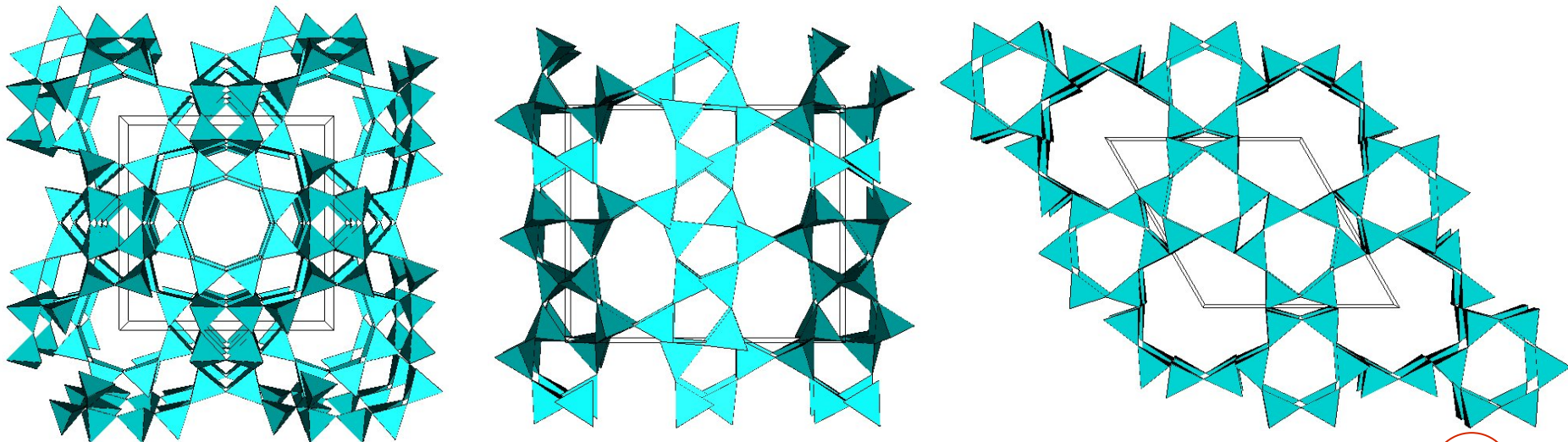
... Rotating squares mechanism taking place in the (001) plane



Case study (ii) - Zeolites

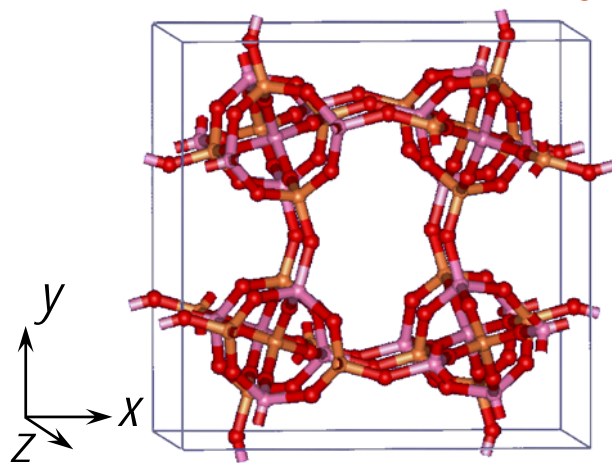
- Why look at zeolites ?

- Zeolites have **highly geometric nanostructures**, i.e. there is the possibility of auxetic behaviour
- Very little experimental data is available on the single crystalline mechanical properties of zeolites





Zeolites ... early studies [1999]



THO (*Thomsonite*)



J.N. Grima et al., Adv. Mater, 12 (2000) p.1912

Force-field	ν_{xy}	ν_{yx}
Burchart ¹	-0.55	-0.55
BKS ²	-0.33	-0.53
Universal ³	-0.33	-0.40
CVFF ⁴	-0.46	-0.46

(1) Burchart, PhD. Thesis, Delft. Univ. Tech, (1992)

(3) Rappe *et al.*, *J. Am. Chem. Soc.* **114** (1992) 10046

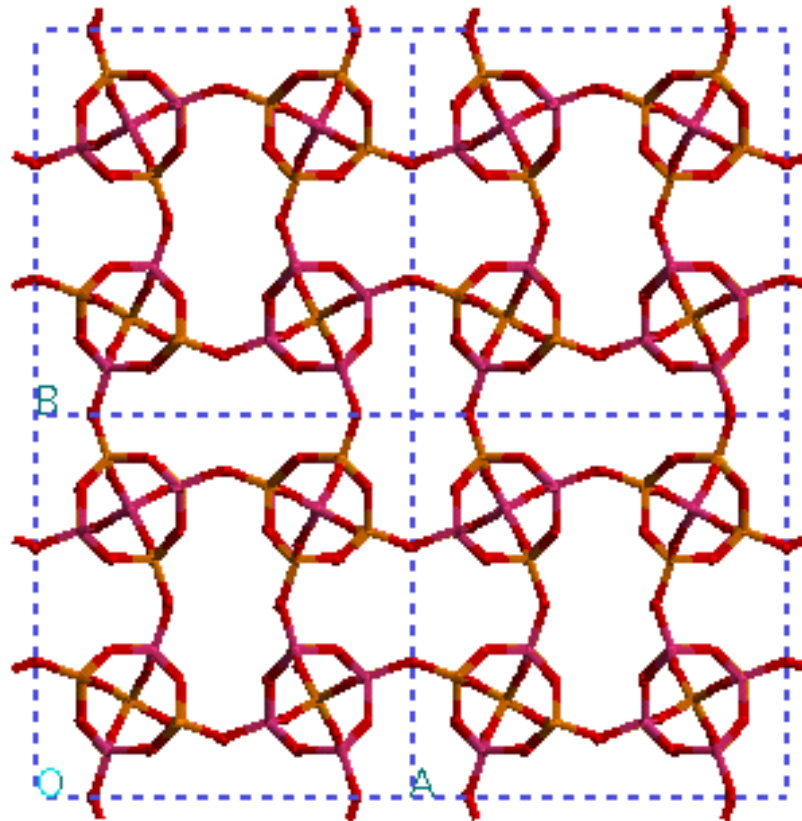
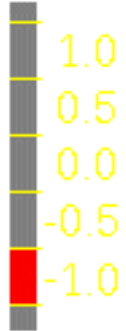
(2) Van Beest *et. al.*, *Phys. Rev. Lett.*, **64** (1990) 1955

(4) Cerius² User Guide, MSI Inc., San Diego, USA (1996)



THO: deformations

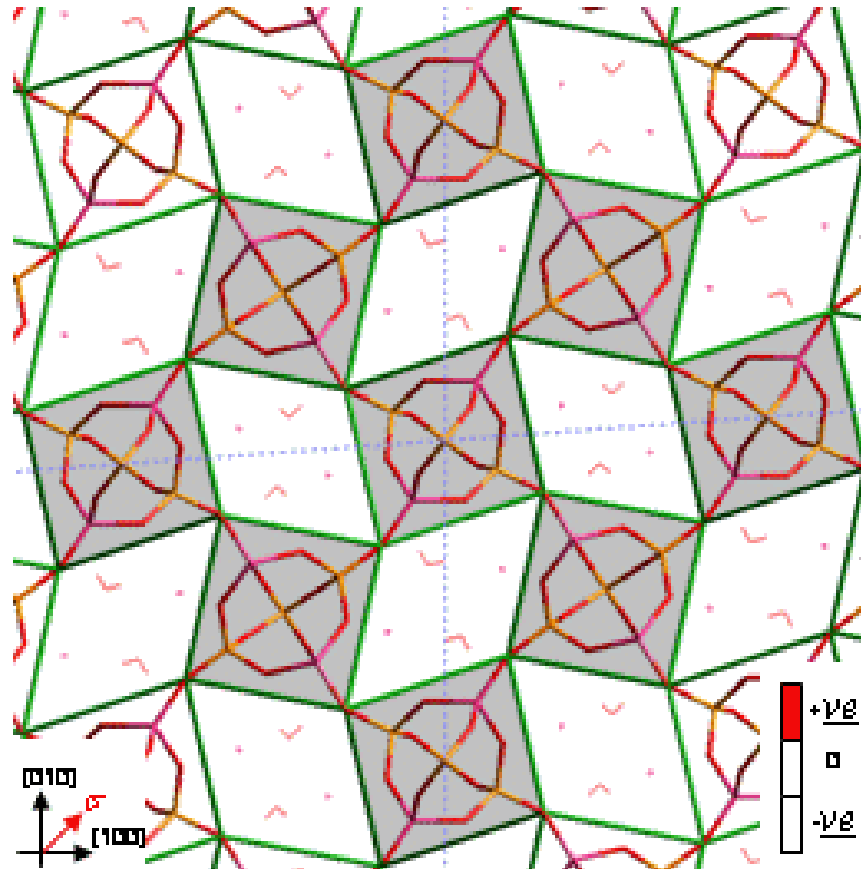
σ_x (GPa)



15.00 Angstroms

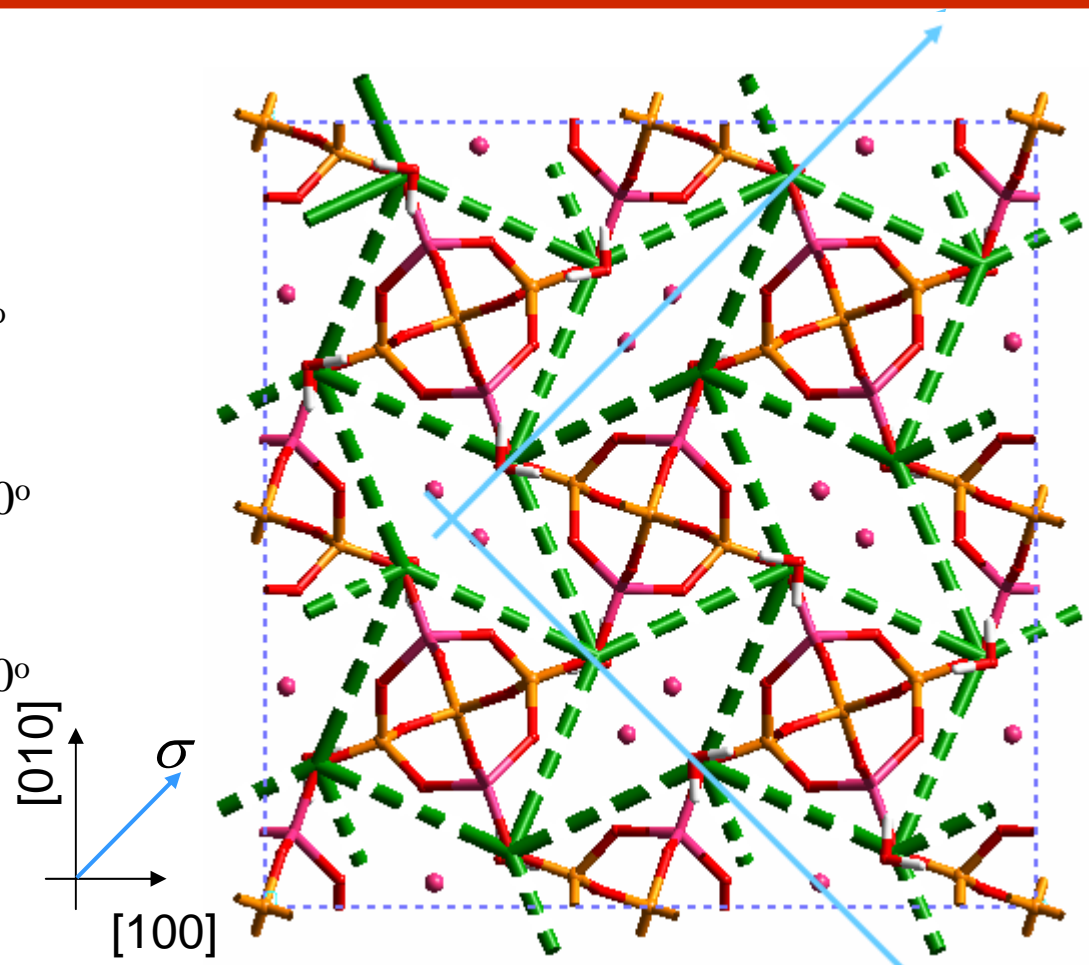
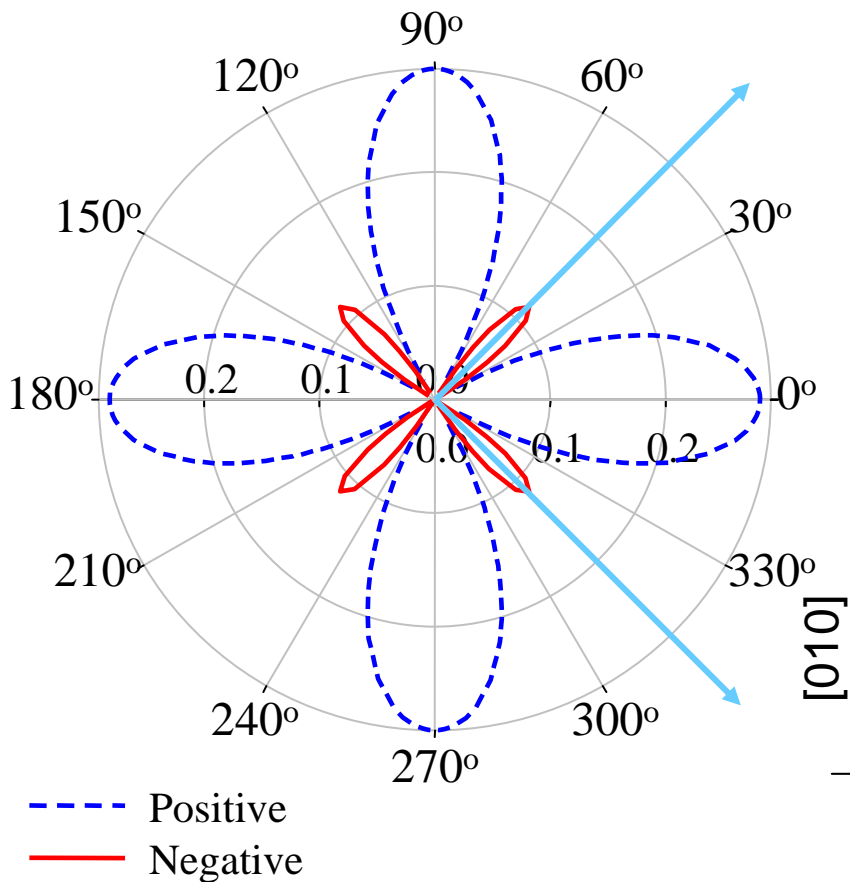


Natrolite (NAT): Deformation





NAT: deformation



C. Sanchez-Valle et al., *J. App. Phys.*, **98** (2005) p.053508

J. N. Grima et al., *J. App. Phys.*, **101** (2007) 086102.



Conclusions ...

- **Auxeticity is a very useful property;**
- There are various types of auxetics ... model structures, polymers, foams, zeolites, etc. etc.
- Can be explained by 'geometry-deformation mechanism' based models;
- Nature can teach us how to 'make' auxetics.

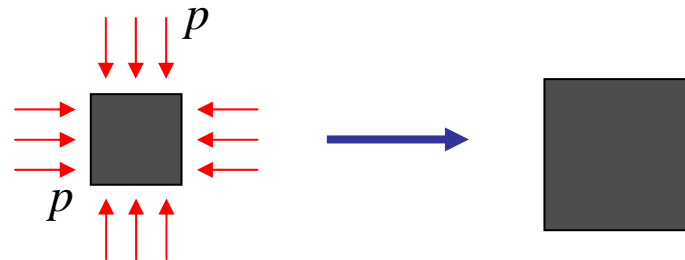


Other thermo-mechanical metamaterials

- Negative Thermal Expansion



- Negative compressibility





Negative Thermal Expansion: NTE

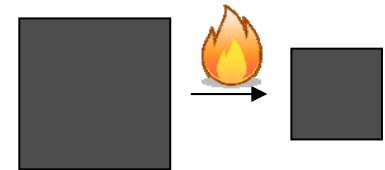
$$\alpha_V = \frac{1}{V} \frac{\partial V}{\partial T}$$

$$\alpha_L = \frac{1}{L} \frac{\partial L}{\partial T}$$

NTE

Cooling ... systems get larger

Heating ... systems get smaller



e.g. water near its freezing point



Applications

- Achieve any pre-desired thermal expansion
- Use as a 'filler' between two expanding strips



- Ensure that gap remains in diffraction gratings / sensors





Problem ...

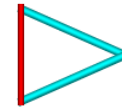
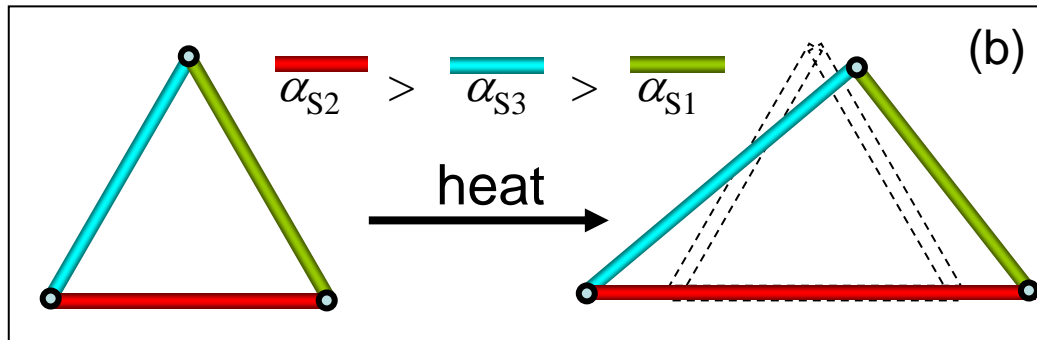
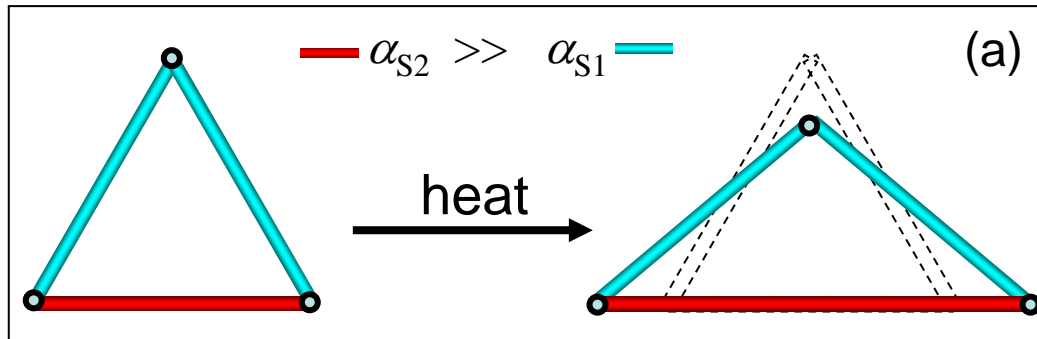
- NTE materials are usually produced on a small scale and are very expensive

Solution ?????



Case Study 1: NTE in triangular systems

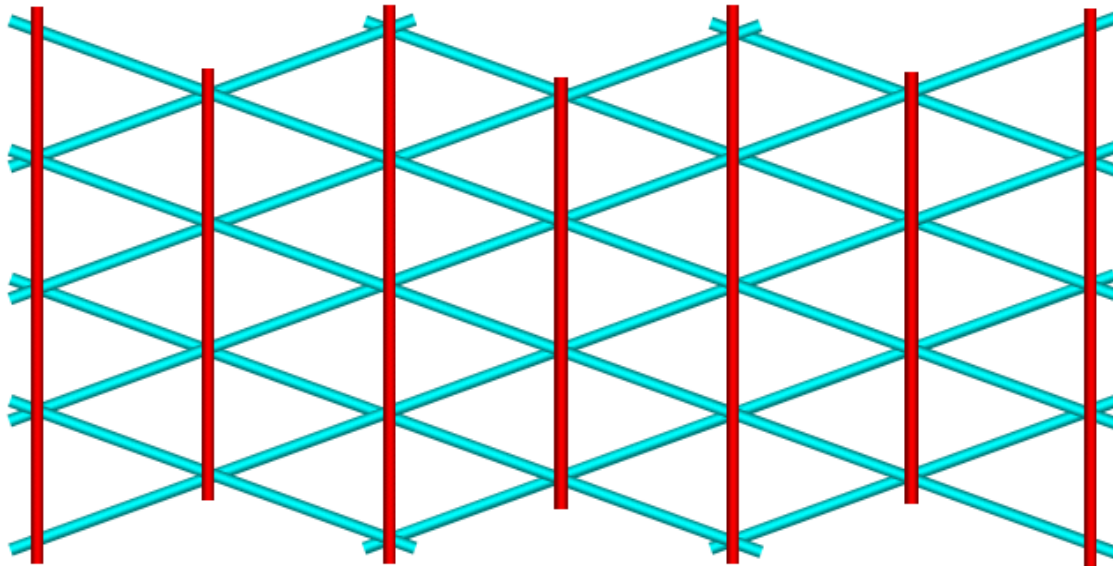
Concept: the flattening of a triangle



- [1] LJ Vandeperre, A Howlett, & WJ Clegg, *Int. Conf. on Modern Materials and Technologies, Florence* (2002).
- [2] LJ Vandeperre & WJ Clegg, *MRS Symposium Proceedings*, **785** (2003) D11.4.
- [3] D Cao, F Bridges, GR Kowah & AP Ramirez, *Phys. Rev. B*, **68** (2003) 014303.
- [4] CW Smith *et al.*, *Auxetic & Related Systems II & III, Poznan* (2005); Exeter (2006)



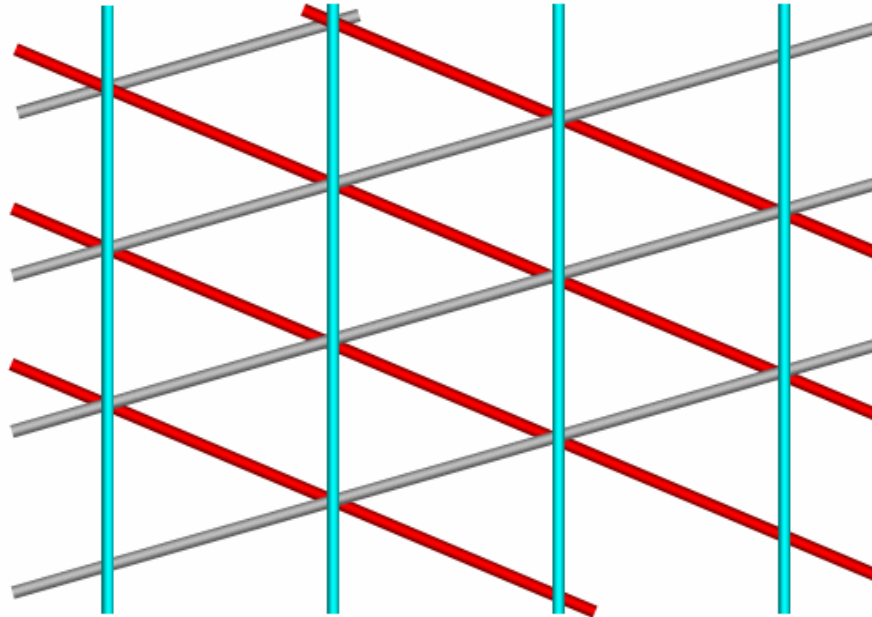
Implementations (1)...





Implementations (2)...

If three sides are made from different materials, the system may shear



J.N. Grima, Proc. Royal Soc. A, (2007)



Model for generalised form

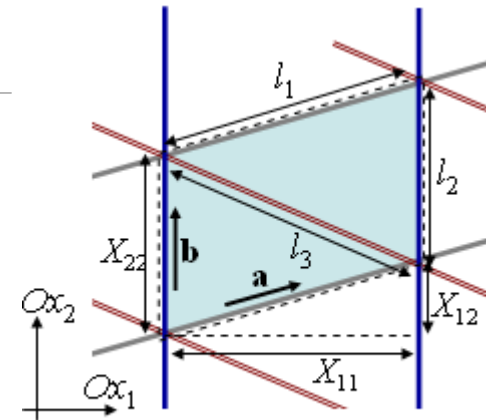
$$\alpha_{11} = \frac{\varepsilon_{11}}{dT} = \left[l_1^2 (l_2^2 + l_3^2) \alpha_{S1} + l_2^2 (l_1^2 + l_3^2) \alpha_{S2} + l_3^2 (l_1^2 + l_2^2) \alpha_{S3} \right] \frac{1}{2l_2^2 X_{11}^2} - \left[2l_2^2 X_{11}^2 \alpha_{S2} + l_1^4 \alpha_{S1} + l_2^4 \alpha_{S2} + l_3^4 \alpha_{S3} \right] \frac{1}{2l_2^2 X_{11}^2}$$

$$\alpha_{22} = \frac{\varepsilon_{22}}{dT} = \alpha_{S2}$$

$$\alpha_{12} = \alpha_{21} = \frac{\varepsilon_{12}}{dT} = \frac{1}{2} \frac{\gamma}{dT} = \frac{l_1^2 (\alpha_{S1} - \alpha_{S2}) - l_3^2 (\alpha_{S3} - \alpha_{S2})}{2X_{11}l_2}$$

$$\alpha(\zeta) = \alpha_{11} \cos^2(\zeta) + 2\alpha_{12} \sin(\zeta) \cos(\zeta) + \alpha_{22} \sin^2(\zeta)$$

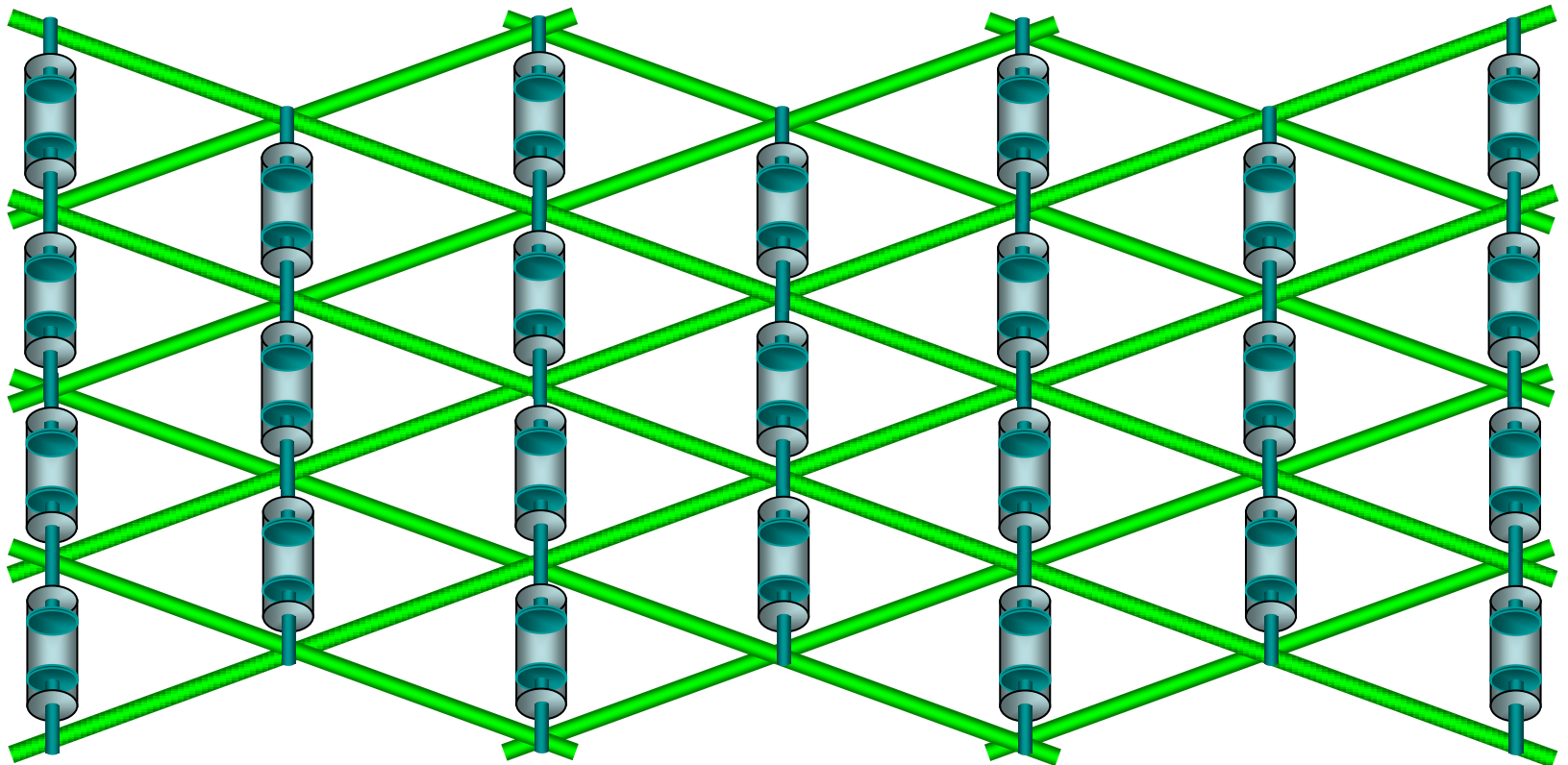
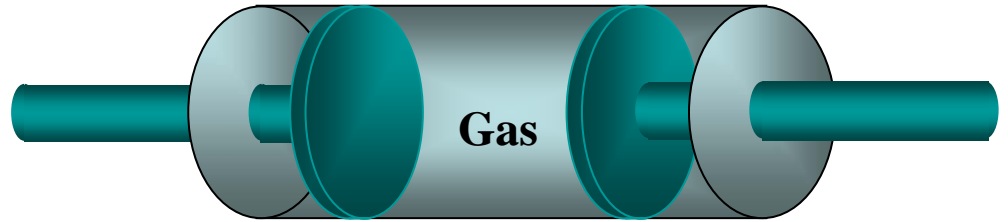
$$\alpha(\zeta)_{\max/\min} = \frac{\alpha_{11} + \alpha_{22}}{2} \pm \sqrt{\left(\frac{\alpha_{11} - \alpha_{22}}{2} \right)^2 + \alpha_{12}^2}$$





Implementation (3) ...

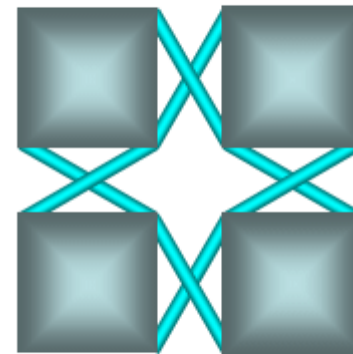
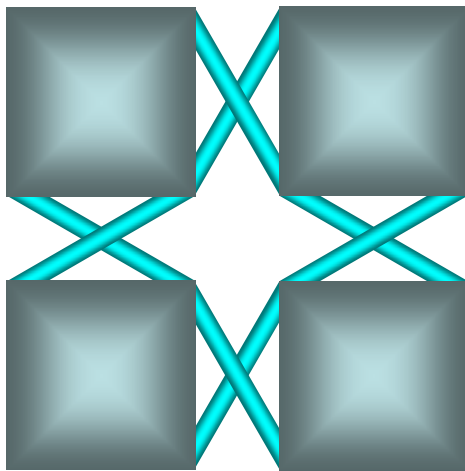
Maximizing the effect
... use of gases





Implementation (4)...

- Clegg & Vandeperre

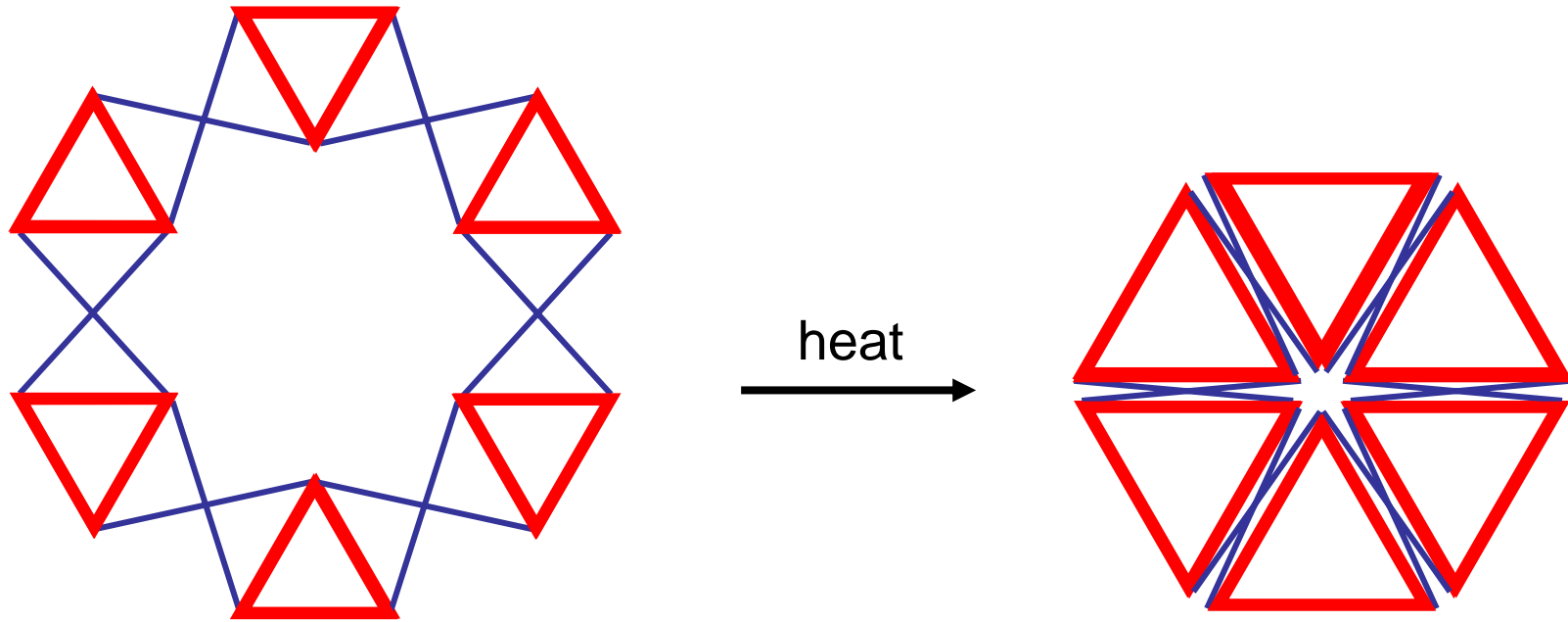


A 2D network which can generate isothermal NTE
(squares can be hexagons or triangles)



Implementation

- Also possible with triangles & hexagons ...





Is this important??? ...New Scientist

29 March 2007

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Cancer therapy: When all else fails Exclusive
People terminally ill with cancer are taking an unlicensed, untested drug called DCA in a desperate bid to survive. Is this the beginning of a damaging trend?

BREAKING NEWS

Triangular strut system 'shrinks' in the heat
Structures that respond to rising temperature by moving in a carefully controlled manner could combat thermal expansion in buildings and devices

14:17 29 March 2007

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MATERIALS
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Volume 10, Number 5
May 2007

The story of the expansion, contraction and thermal expansion incorporating International Mining and Materials

Having a ball
Light metals

ILLUSTRATION: STEVEN POLLITON

• NOW YOU SEE IT – SUPERLENSES MADE FROM METAMATERIALS
• SHRINKING WICKS – NEGATIVE THERMAL EXPANSION • PROFILE OF MINING

Thermal Processing & Surface Engineering

Feeling the heat

The adverse effect of thermal expansion on a range of applications, including bridges and fuel cells, can now be minimised, say scientists at the University of Malta. They have devised a model to help predict the impact of heat on a structure's shape.

Thermal expansion can create anomalous problems, explains lead researcher Dr Joseph Grima, "particularly in situations where a system is required to operate at a wide range of temperatures, when a contact between two or more materials that expand differently from each other – creating unwanted forces – or when thermal expansion results in the closure of gaps that must be present between electrodes in fuel cells (and sensors).

"A significant amount of work has therefore been performed on materials which exhibit anomalous thermal expansion properties, including negative thermal expansion – materials which shrink on heating. We wanted to study systems which can produce similar effects but can also be produced cheaply and on a large scale."

This research follows work carried out by scientists at the University of Cambridge and Exeter, both in the UK. It involves creating a structure from triangles constructed using three rods that are connected to each other by rotating joints. If one side of the triangles is made from a material that responds to rising temperatures more than the other two sides, the structure has been shown to shrink. In one direction when heated, becoming shorter in height (see figure a, below, left).

Any rigid material – metals, alloys, plastics – can be used in the construction of the system, says Grima. "The important thing is to have at least one component that has a different thermal expansion coefficient from the rest."

To enable better control of thermal properties, the triangles can also be created using three different materials at varying lengths (see figure b, below, left), Grima adds. "Through careful control of the materials and dimensions used, the resulting system can be made to exhibit a wide range of thermal expansion coefficients, and thus we can take-make structures for use in practical applications."

The equations he derived can be used to precisely compute and predict the percentage changes in dimensions of the overall structure per degree of temperature change.

By virtue of its rigid framework and use of conventional materials, the team argues that the model is suitable for load-bearing functions and could eventually be mass produced cheaply to any size specification, be it for use in construction or a microscopic system. Further research is now

Grima also works on acoustic materials (negative Poisson's ratio) that expand when stretched instead of getting thinner, and sees potential for combining the two projects. He says, "One of our aims is to produce systems that have both properties, simultaneously negative. This is interesting as acoustic exhibits enhanced physical characteristics ranging from increased extension resistance to improved acoustic damping properties." A possible application is the manufacture of tunable filters with pass axes that get larger on stretching or under heat.

For further information, e-mail: joseph.grima@um.edu.mt

This research was sponsored by the Malta Council for Science and Technology and CHESMA-COMES, an EU Framework 6 project led by Dr Fabrizio Scarpa of the University of Bristol, UK.

Rajul Maitra

Cooling down

Scientists at the University of Oulu, Finland, and the Pennsylvania Polytechnic Institute in the USA claim that carbon nanotubes can be integrated into many electronic products to solve the persistent problem of thermal management. According to researchers, the nanotubes dissipate heat as effectively as copper, but are more flexible, lighter and fit more tightly.

"As devices continue to decrease in dimension, there is a growing need for miniature on-chip thermal management," explains Rajul Maitra, a researcher at Pennsylvania. "When reduced to sub-millimetre sizes, the integrity of traditional cooling materials breaks down. Carbon nanotubes maintain their high strength, low weight and excellent conductivity."

Image courtesy of Rajul Maitra

On the face of it

Shallow ridges on sharks' scales, known as denticles, are the secret to the animals' quick movement through water. Now, researchers from the Fraunhofer Institute in Germany can apply a shark-inspired coating to the complex surfaces of a ship, car or aircraft wing section. After curing with ultraviolet light, the vehicles are imbued with their own aerodynamic shark skin.

Engineers from Brown and Purdue Universities in the USA have found that changing the surface texture of implants can affect the way cells behave on a wide variety of materials. Their recent experiments have focused on the materials used in stents and artificial blood vessels. Currently, about 30% of small diameter blood vessel grafts last more than five years and up to 20% of stents have to be replaced because the artery walls have thickened around them. Concerns have also recently arisen regarding a link between drug-coated stents and clotting. Researchers have now introduced nanoscale bumps on the surface of implant materials, such as titanium and biodegradable polymers (PLGA), to better match the natural texture of endothelium, the thin lining of cells on the inside of healthy blood vessels. By doing so, they found that endothelial cells quickly colonised the foreign surfaces, effectively camouflaging them and preventing specific immune cells from ever seeing the implants.

Bill Clegg, University of Cambridge ... A mathematical tool that makes designing the strut-based structures easier could be useful in a variety of engineering situations, he adds: "Thermal expansion is an enormous problem, particularly when you have layers of different material that expand differently, or when the gaps between electrodes are important, like in fuel cells or oxygen sensors."

<http://www.auxetic.info>



...CORDIS focus Newsletter

Issue number 278 — May 2007

ISSN 1022-6559

CORDIS

http://cordis.europa.eu

focus

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EN



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MEPs approve regulation for innovative therapies

A proposed regulation on marketing innovative therapies and on monitoring patients and products post-authorisation, was approved by the European Parliament (EP) on 25 April 2007.

The regulation provides for a compulsory centralised procedure to authorise the marketing of innovative products, and also for post-authorisation monitoring of patients and products. In the compromise package reached between Members of the European Parliament (MEPs) and the Council of the EU, amendments were included to enhance product safety and make the process easier for small and medium-sized enterprises (SMEs).

Innovative therapies have the potential to cure diseases such as Parkinson's, Alzheimer's and degenerative conditions such as cancer and heart disease. They involve the use of gene therapy, cell therapy and tissue engineering, and it is this aspect of the proposal that led to long discussions on ethics in the run-up to the EP vote.

The new regulation will not affect decisions made by the EU Member States on whether to allow the use of certain types of cells, such as embryonic stem cells. Some MEPs had wanted to include amendments prohibiting the use of these cells, but this position was rejected first by the Committee on the Environment, Public Health and Food Safety, and then by the EP as a whole.



continued on page 2

AROUND EUROPE

Groundbreaking research by Maltese academics hits the headlines

Maltese scientists are celebrating as their groundbreaking work on developing a way of reducing the impact of thermal expansion attracted the interest of the international scientific press.

The respected *New Scientist* magazine, which promotes important scientific discoveries likely to impact society, took up the story as one of its breaking news items on its website, following the publication of the research results in *Proceedings of the Royal Society A*.

This was a cause to celebrate for the smallest EU Member State in terms of both population and area.

The team of scientists from the University of Malta had worked on negative thermal expansion, successfully developing a way of designing structures of any size that shrink when heated. This work follows from earlier research by Drs Bill Clegg and Luc Vandepere from the University of Cambridge, United Kingdom, and by Professor Ken Evans and Dr Chris Smith from the University of Exeter, United Kingdom.

Their work was funded by the Malta Council for Science and Technology (MCST) and the EU-funded 'Chiral smart honeycomb' (Chismacomb) project, led by Dr Fabrizio Scarpa of the University of Bristol, United Kingdom. It could be applied to reduce the

impact of thermal expansion on anything ranging from bridges to microscopic systems.

'The University of Malta is gradually building an infrastructure to conduct world-class research in niche areas of engineering, science and medicine,' said Professor Juanito Camilleri, the rector at the University of Malta.

'Though we do not have a long-standing tradition of institutional research, and despite the very modest funds to sustain such endeavours, our up-and-coming researchers have shown, time and again, through their publications, that they can put us on the international map of scientific and technological innovation,' he added.

The team of scientists studied triangles with at least one side made from a different material to the others, connected by rotating joints. They found that the diverse materials would change volume in response to temperature in a different way. The triangles would actually shrink in one direction when heated.

The researchers then derived equations that describe the behaviour of their triangle-framework system as these are essential to predicting the response to temperature of their structure. So the mathematical model makes it possible to choose exactly how such a structure behaves.

The coordinator of the project, Dr Joseph N. Grima, and his colleagues believe the lattices of the triangles could have all kinds of applications. 'We have shown that it is possible to easily design systems that exhibit a tailor-made response to temperature,' he said. 'These systems could be constructed very cheaply and could be as big as a bridge or on a microscopic scale,' he concluded.

For more information from the University of Malta, for further interviews, please visit: <http://www.uom.edu.mt> <http://www.cordis.europa.eu> EOR: 27407

Austrian budget places research in 'best hands'

'Research is in the best hands, a sufficient budget is there,' said Austrian Science Minister Johannes Hahn in response to a presentation of the 2007 budget by Finance Minister Wilfried Holzer.

The budget for science and research will climb by EUR 420.8 million in 2007 — a rise of more than 13.7% — to EUR 3.501 billion. In 2008, a further increase of EUR 47 million is planned, taking funding up to EUR 3.538 billion. This is the biggest increase since 1991, and was welcomed by Mr Hahn, the Science Council, the Association of Professors, and the Rectors' Conference alike.

Mr Hahn described the budget speech as 'a true declaration about the future of our society.' 'And what is more the future than science and research?', he asked.

Universities are also set to benefit from the new budget — to the tune of over EUR 500 million

over the coming three years. This equates to a 10% funding increase.

The minister pledged that more money will be made available to support students at a later stage — time constraints had meant that only an across-the-board increase in funding was possible for this budget. Mr Hahn indicated that more targeted funding will be made available at a later stage, once discussions on objectives have taken place.

For more information from the Austrian Government, for further information on research activities in Austria, please visit: <http://www.aug.ac.at> <http://www.europa.europa.eu> EOR: 27408



Johannes Hahn

CORDIS focus Newsletter — No 278 — May 2007

23



NPR & NTE

Can a system exhibit both NPR and NTE?

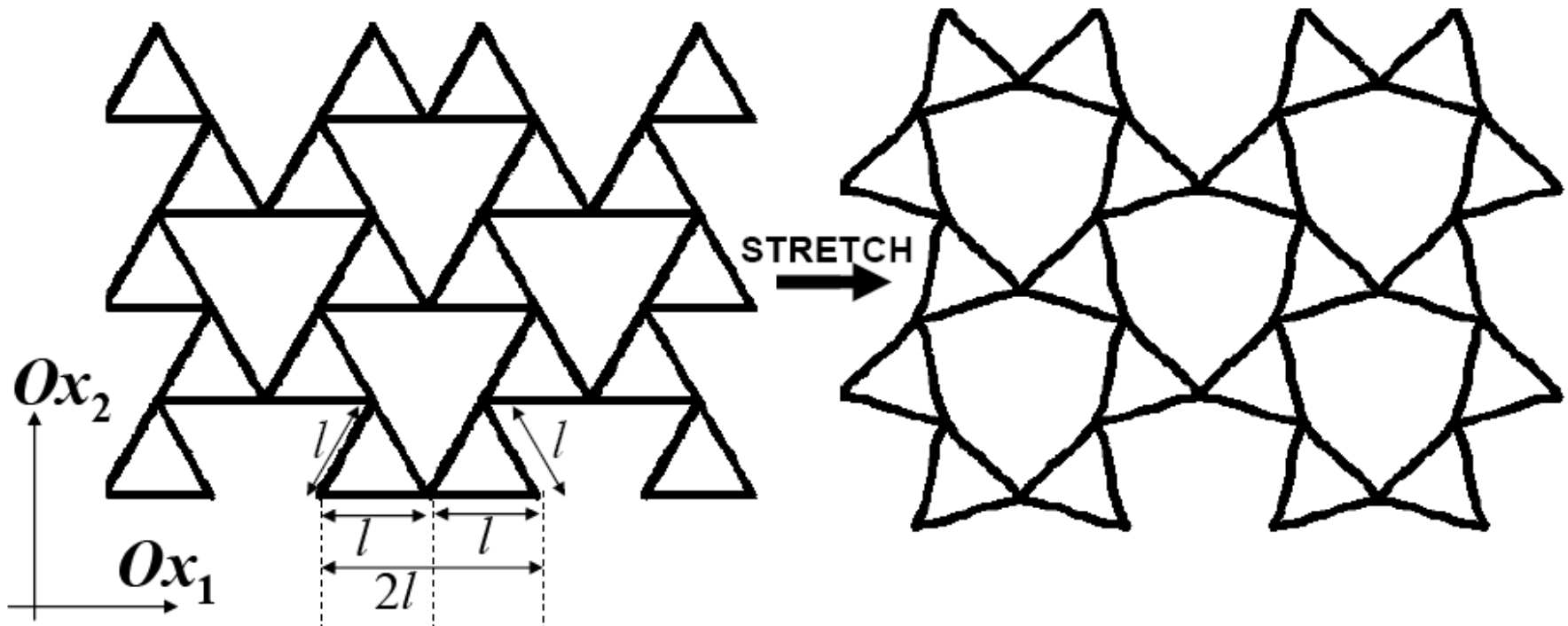
YES

... For example the rotating triangles system



Auxeticity from 'Rotating Triangles' geometry

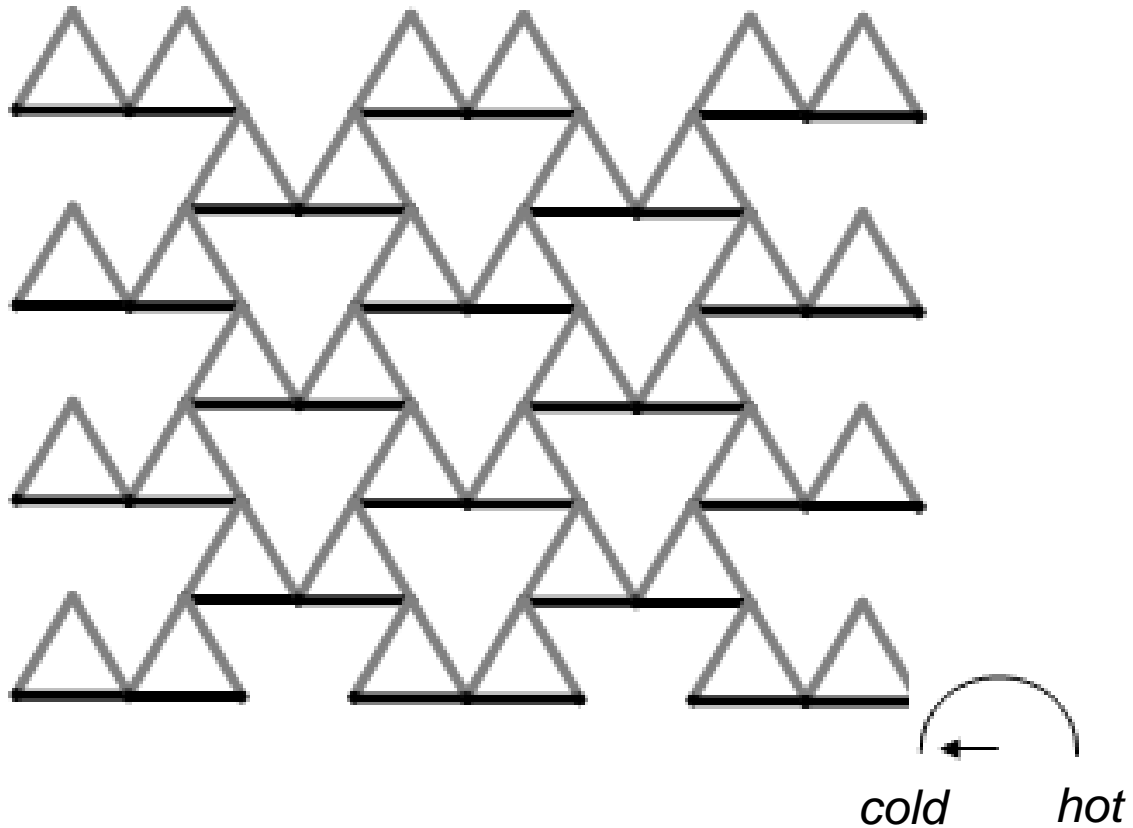
Negative Poisson's ratio



J.N. Grima, et al., *J. Phys. Soc. Jpn.*, **76** (2007) 025001



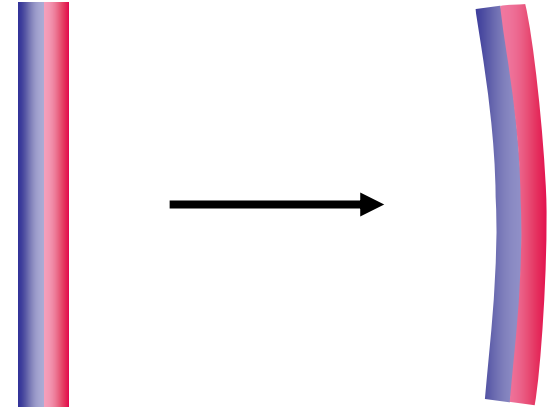
MR & NTE



J.N. Grima, *et al.*, *J. Phys. Soc. Jpn.*, **76** (2007) 025001



Case Study 2: Bi-materials



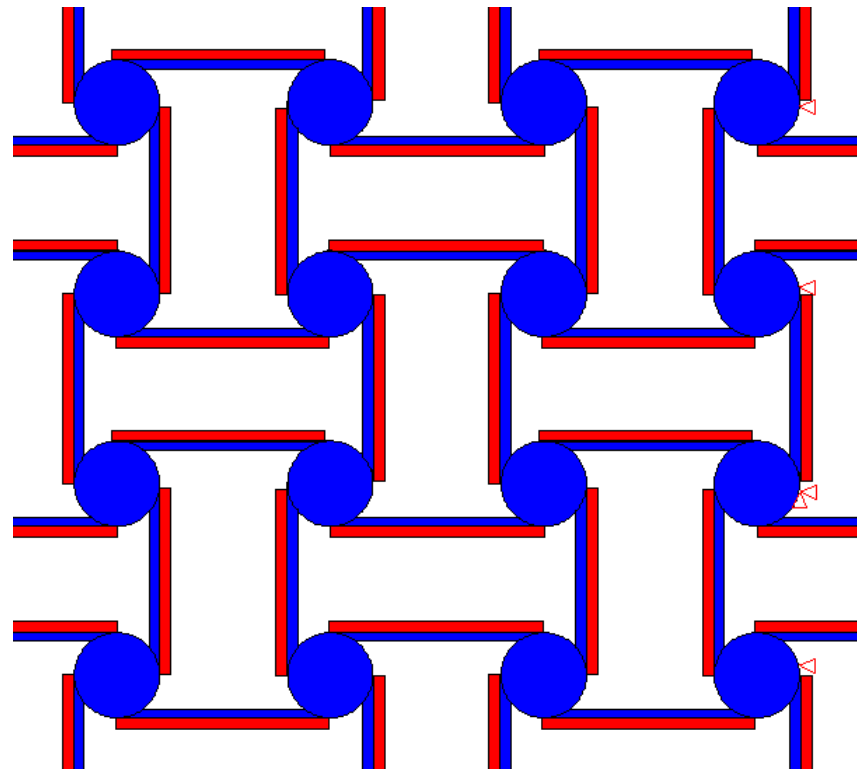
Heating a bi-material with components having different thermal expansion coefficients will cause a curvature

Same thing will apply if they have different moduli, etc.



Implementation ...

- Use with anti-tetrachiral (of other similar systems)

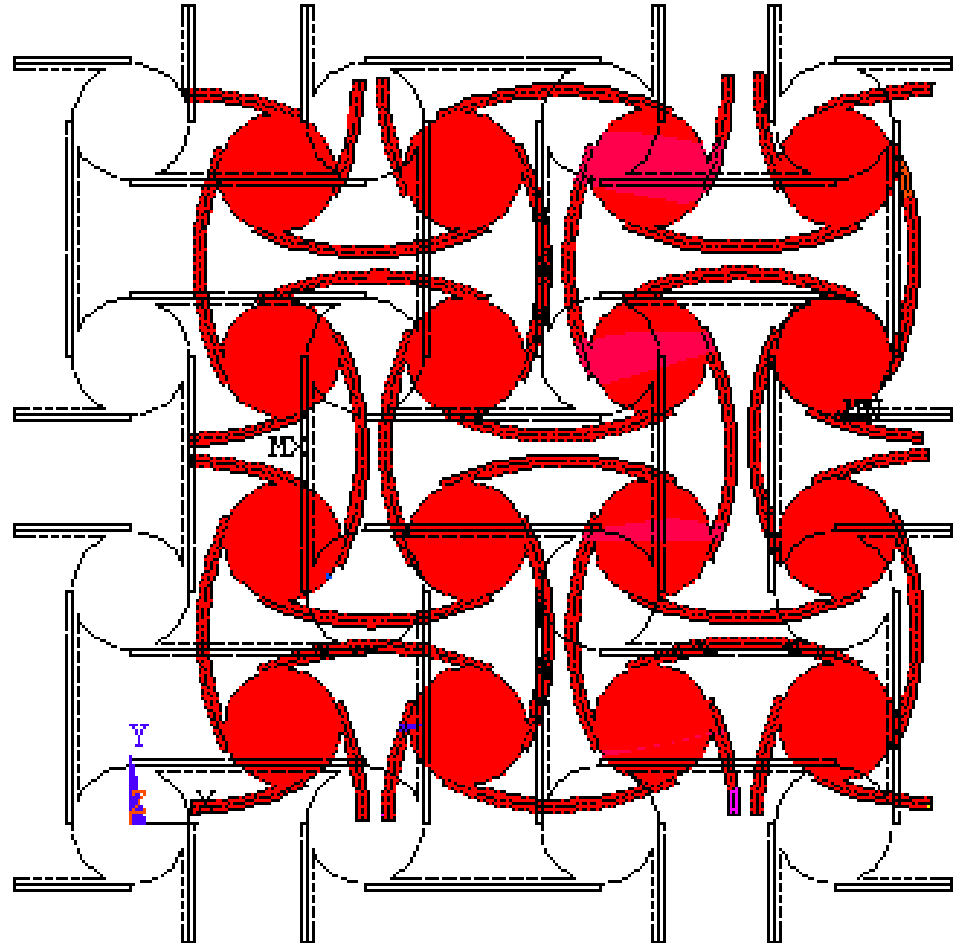




Result ... NTE / NPR

e.g.: NTE (verified with ANSYS)

	Material 1	Material 2
Young's modulus (psi):	1.20×10^5	1.20×10^5
Poisson's ratio:	0.3	0.3
Coefficient of Thermal Expansion:	5×10^{-7}	0.00011

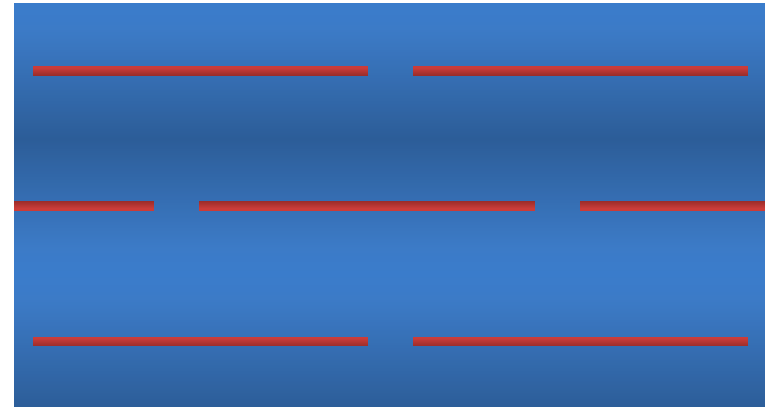




Case Study 3: NTE in composites with Needle-Like inclusions

***i* MA**
engineering & research

(Ing. Michael Attard)

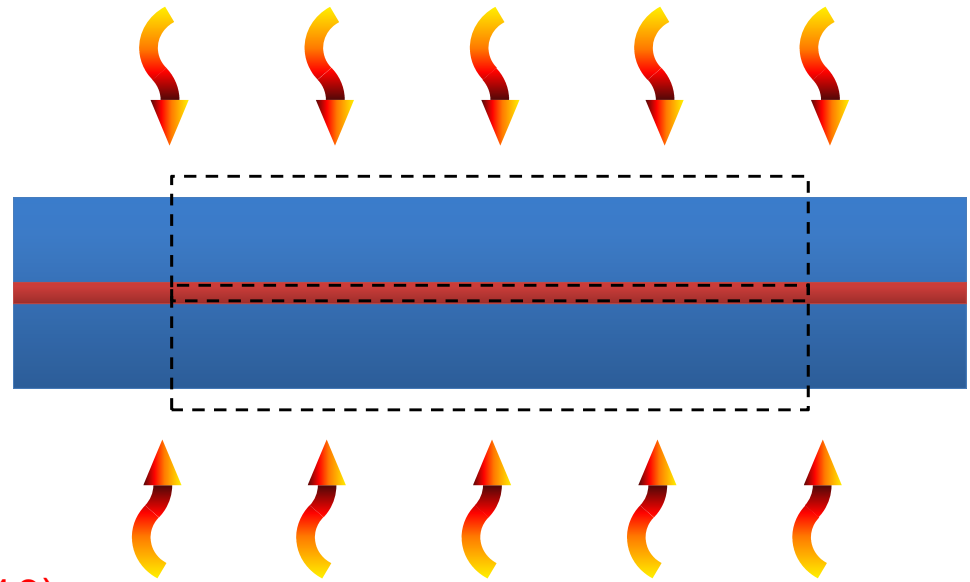




Case Study 3: NTE in composites with Needle-Like inclusions



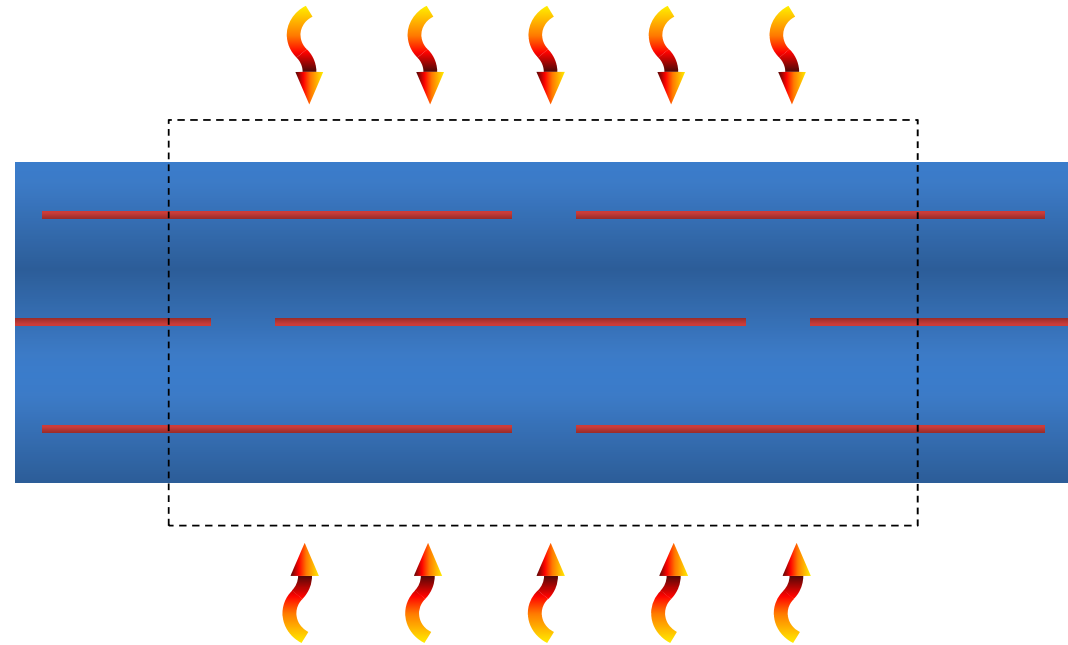
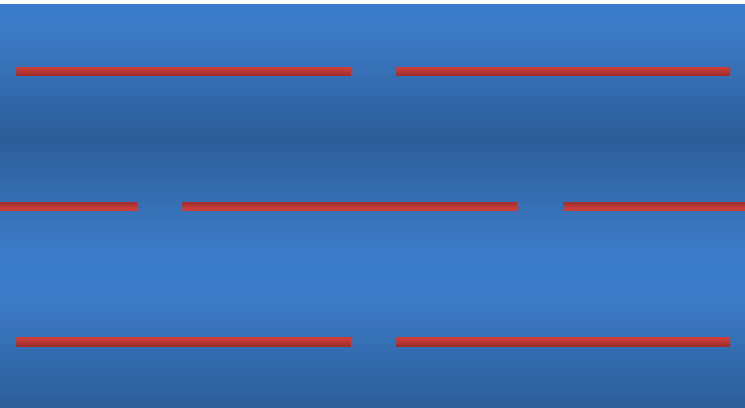
i MA
engineering & research



J.N. Grima *et al.*, *Comp. Sci. Tech.* (2010)

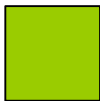
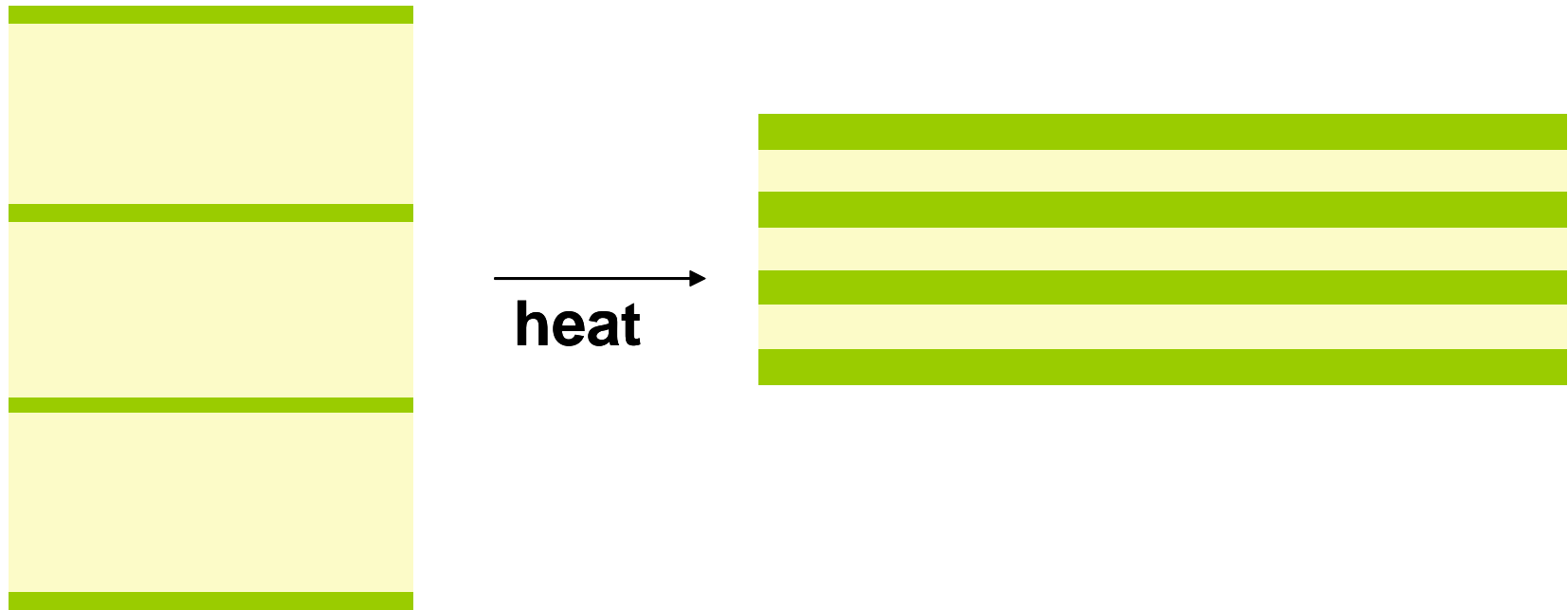


Case Study 3: NTE in composites with Needle-Like inclusions





Alternative 'multi-layered' systems



Material A: Stiff, high CTE



Material B: Soft, high Poisson's ratio, low CTE

J.N. Grima *et al.*, Phys. Stat. Sol. RRL (2010)



Negative compressibility, **NC**

- Compressibility is a measure of the relative volume change of a fluid or solid as a response to a pressure (or mean stress) change.

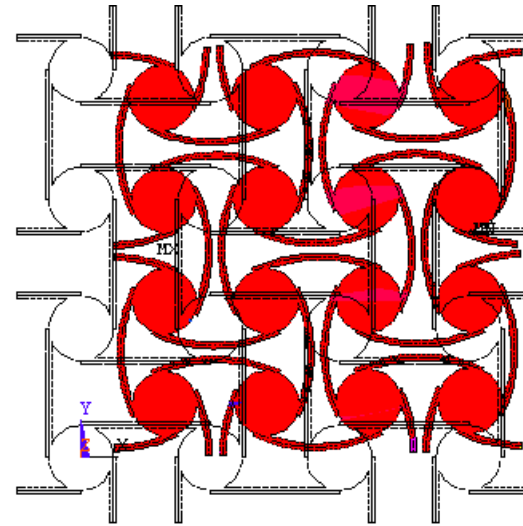
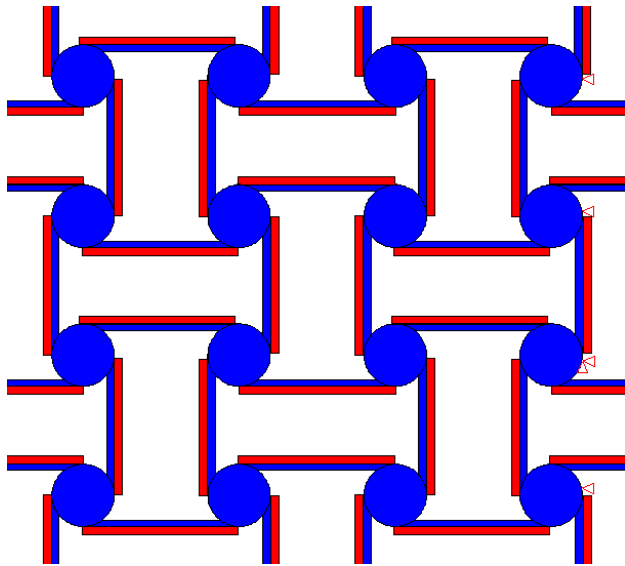
$$\beta = \frac{1}{K} = -\frac{1}{V} \frac{\partial p}{\partial V} \leftarrow \text{Normally negative}$$

- Normally: System gets larger under negative pressure (partial vacuum)
- **Negative compressibility: systems get smaller under negative pressure**



Negative Compressibility

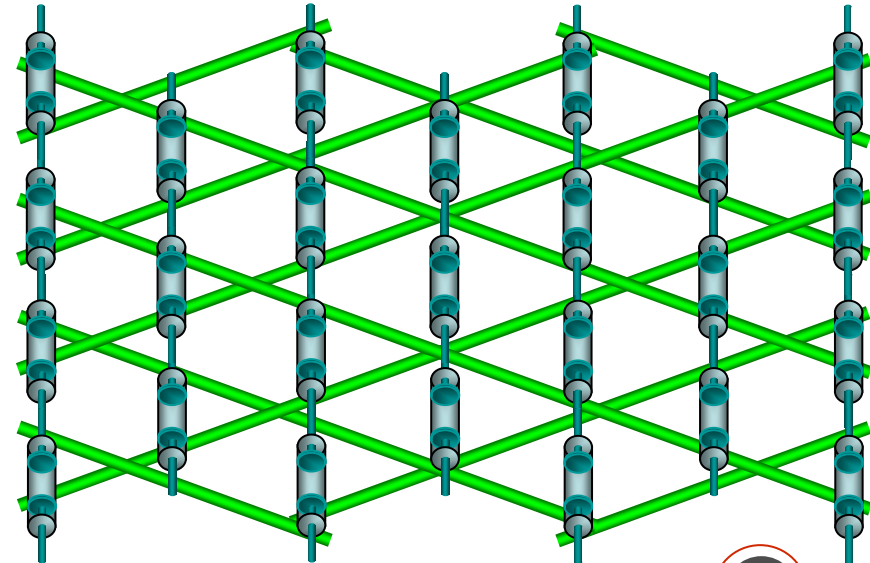
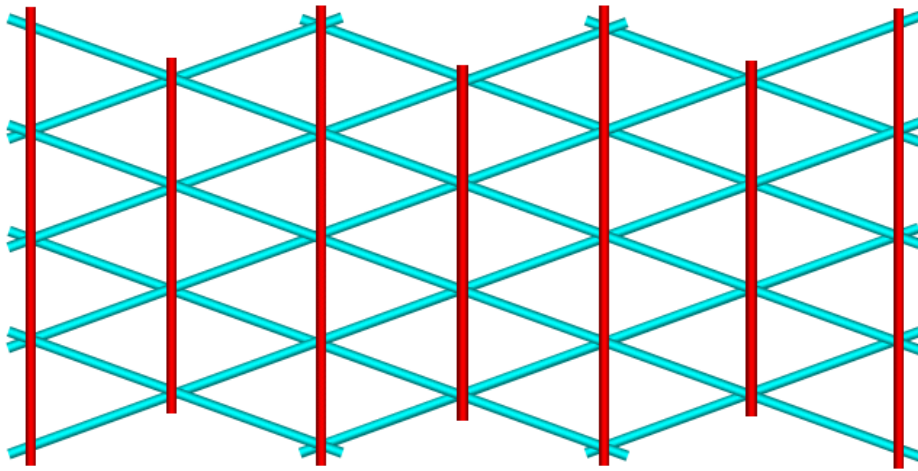
- Bimaterials also bend when subjected to a change in pressure if constituent materials have different Young's moduli and/or Poisson's ratio



R. Gatt & JN Grima, Scripta Mater. (2007)
R. Gatt & JN Grima, Phys. Stat. Sol RRL. (2007)



Also in triangular systems ...



D. Attard et al. *Phys. Stat. Sol. B* (2008)



Conclusions

- There are various thermo-mechanical metamaterials, including auxetic metamaterials, NTE and NC systems
- Some of these systems can be 'constructed; based on very simple models and concepts;
- Thermo-mechanical metamaterials can have some very interesting applications;
- NPR / NTE / NC can co-exist, and when they do, results are very interesting.

Thank you !

www.auxetic.info

