European Summer Campus 2010

Campus Europe International été 2010

"Metamaterials"

Strasbourg, France, June 27 – July 5, 2010

Auxetic Metamaterials

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University of Malta

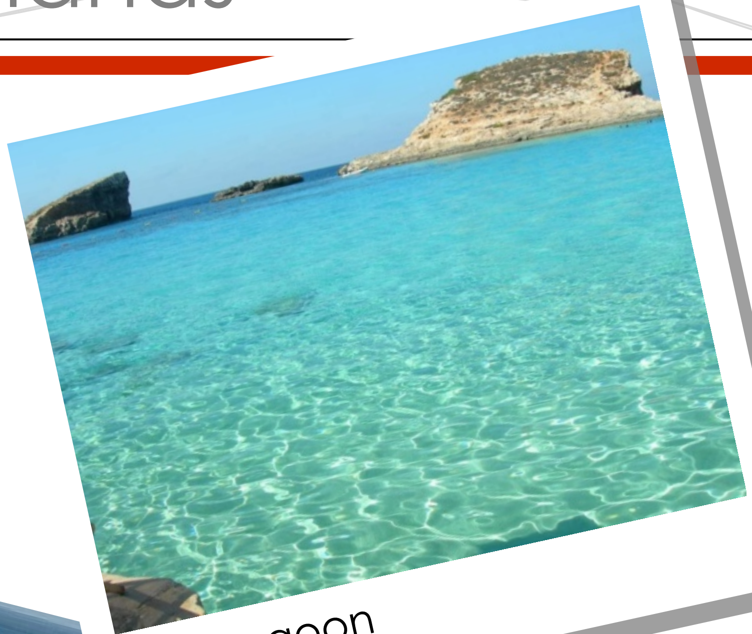
http://www.auxetic.info

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


SAGGIO
DI
ARITMETICA UNIVERSALE
DEDICATO
A SUA ALTEZZA SERENISSIMA
F. EMMANUELE DE ROHAN
Gran-Maestro della Sagra Religione Gerosolimitana, e dell' Ordine di Sant' Antonio di Vienna,
PRINCIPE
di MALTA, e Gozo, e Sig. del Real Dominio di Tripoli ec.
IN MALTA MDCCLXXX.
Nella Stamperia del Palazzo di S. A. S. Per Mallia suo Stampatore
Con Licenza de' Superiori.

1780

The University now …

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

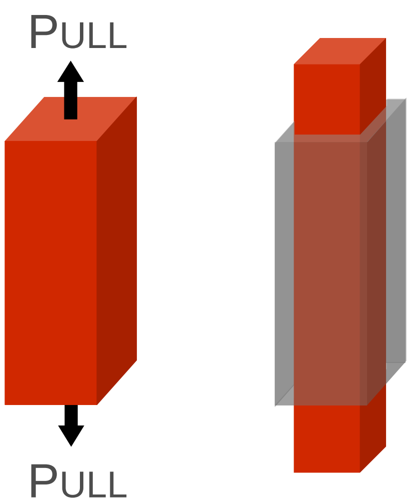
Siggiewi – My home town

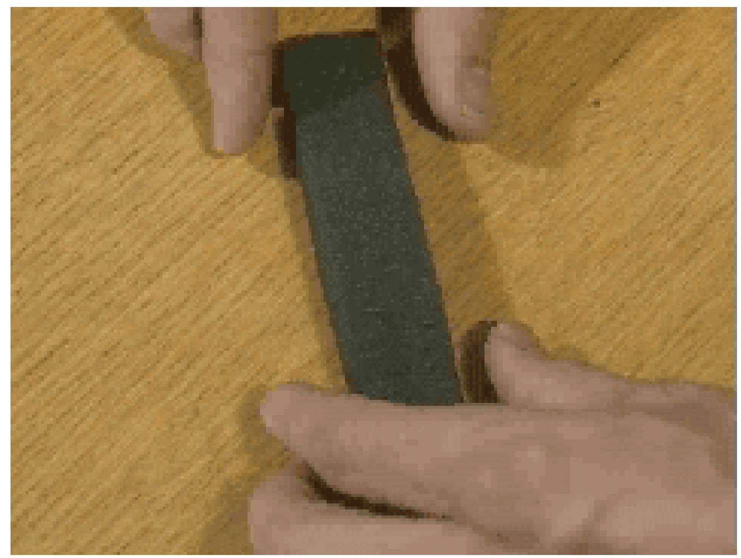
Introduction to auxetics

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 → 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

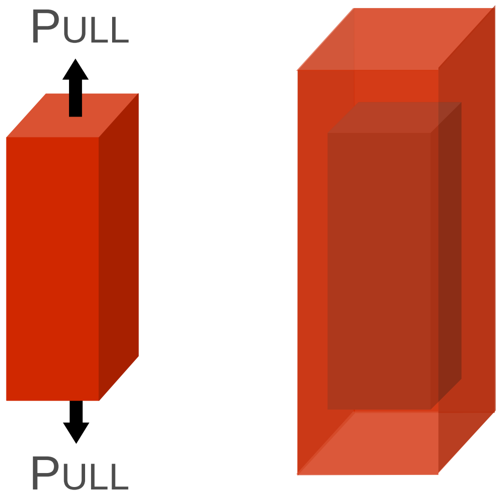
But…

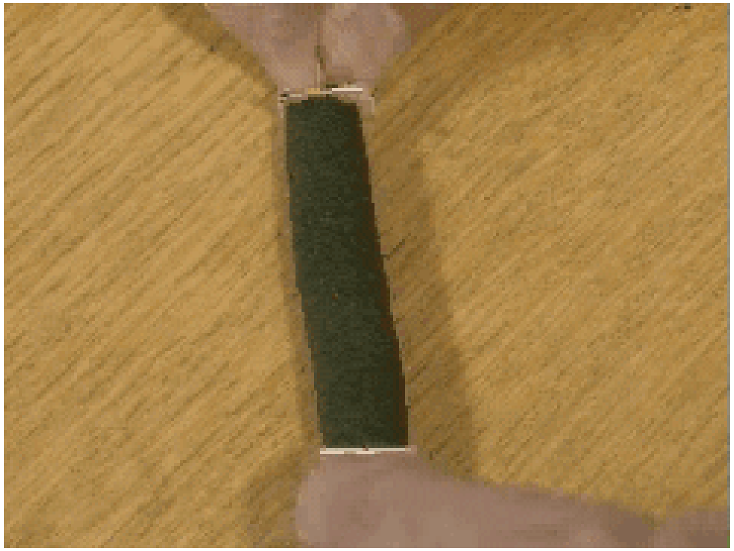
- … Poisson's ratios can also be negative

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

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

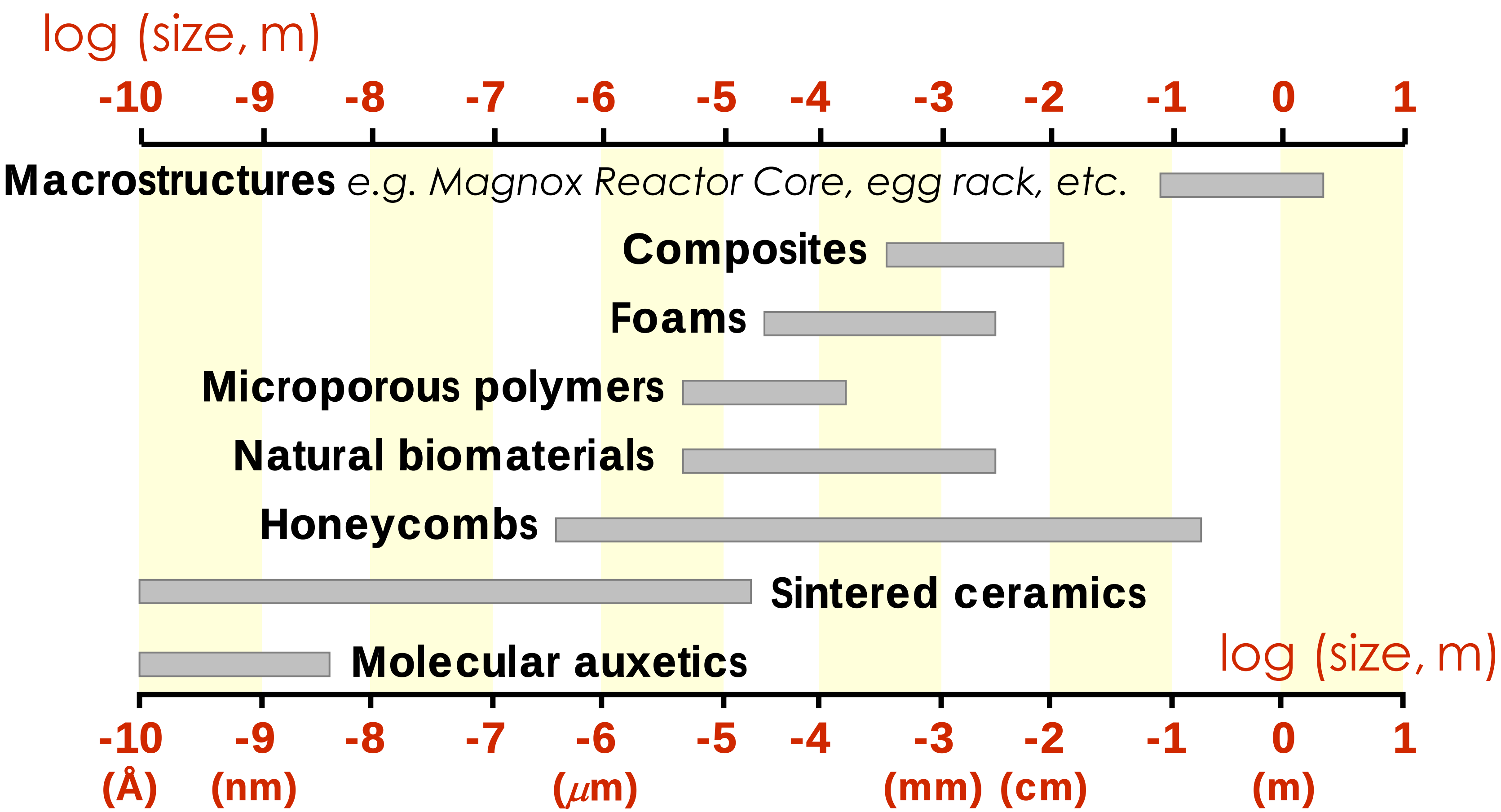
Auxetics



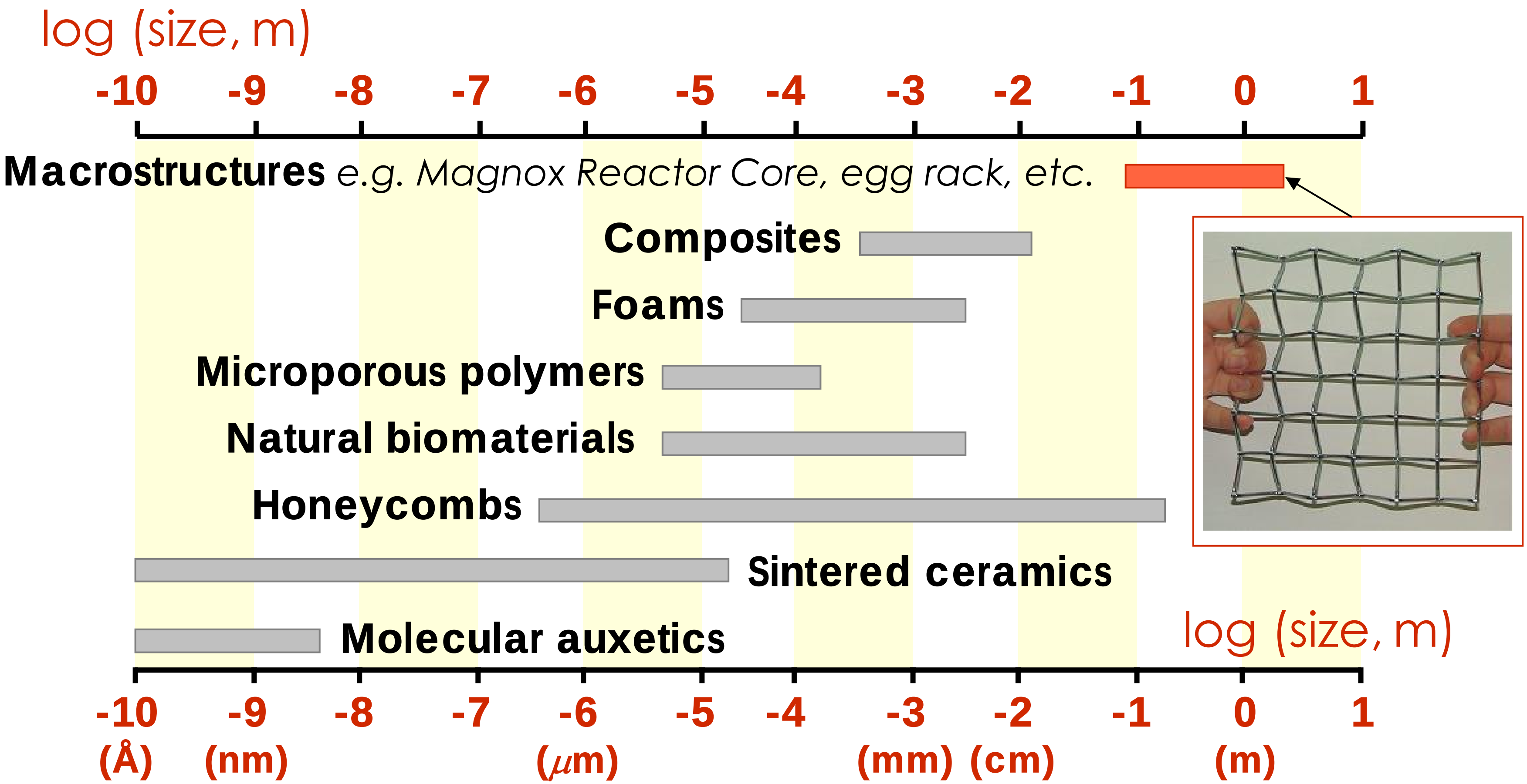


-ve Poisson's ratio → materials get fatter when stretched

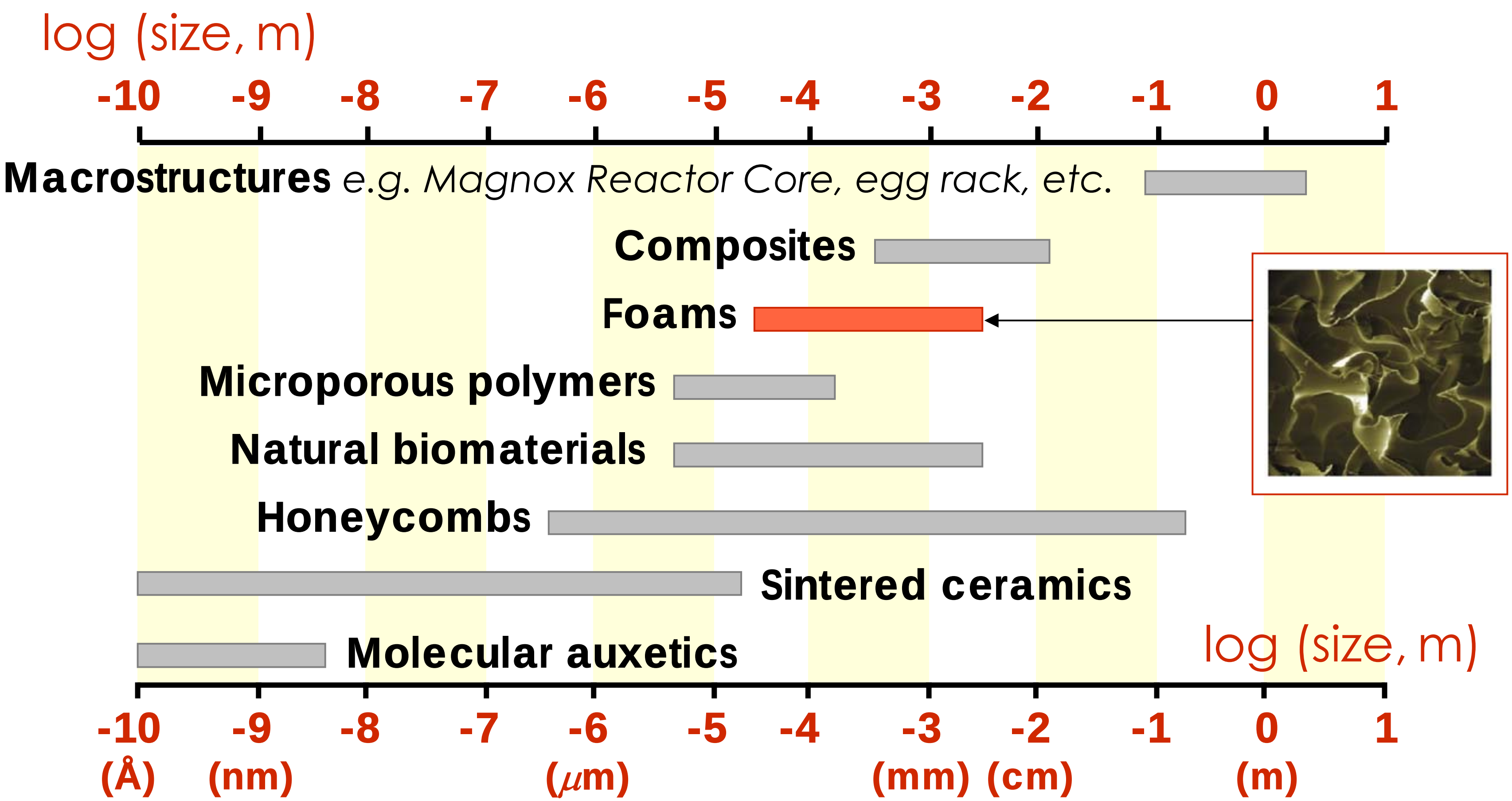
Length scale



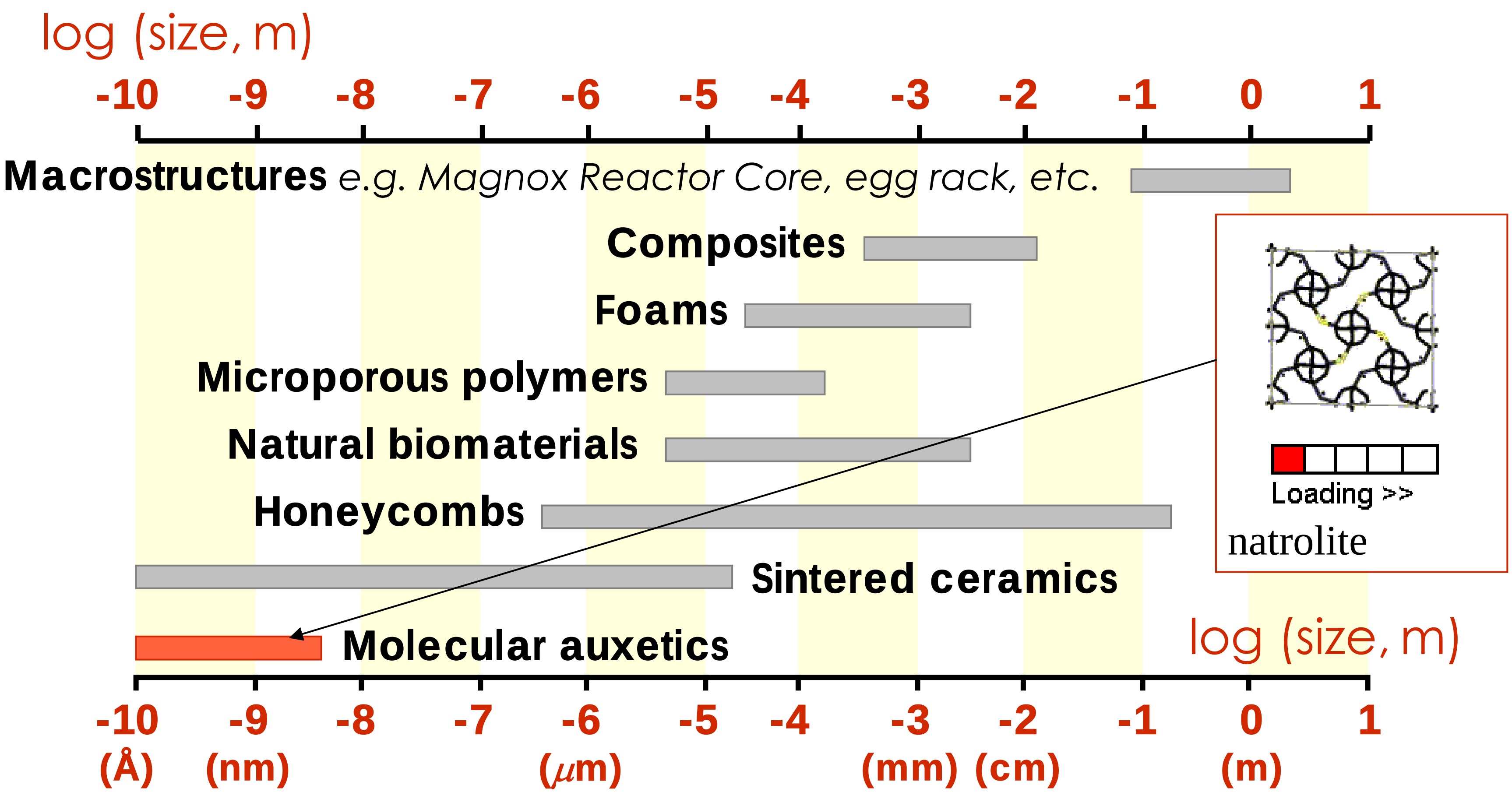
Length scale



Length scale



Length scale



What gives rise to auxeticity

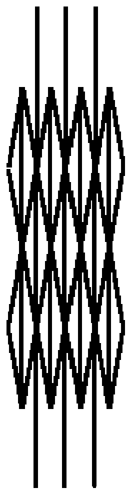
- Correct co-operation between:
  - The material's internal structure (**geometry**)
  - The way the internal structure deforms when loaded (deformation mechanism)

Auxetic mechanisms (1)

Re-entrant honeycombs

$$\nu_{12} = \frac{1}{\nu_{21}} = -\tan(\theta)\frac{X_1}{X_2}$$

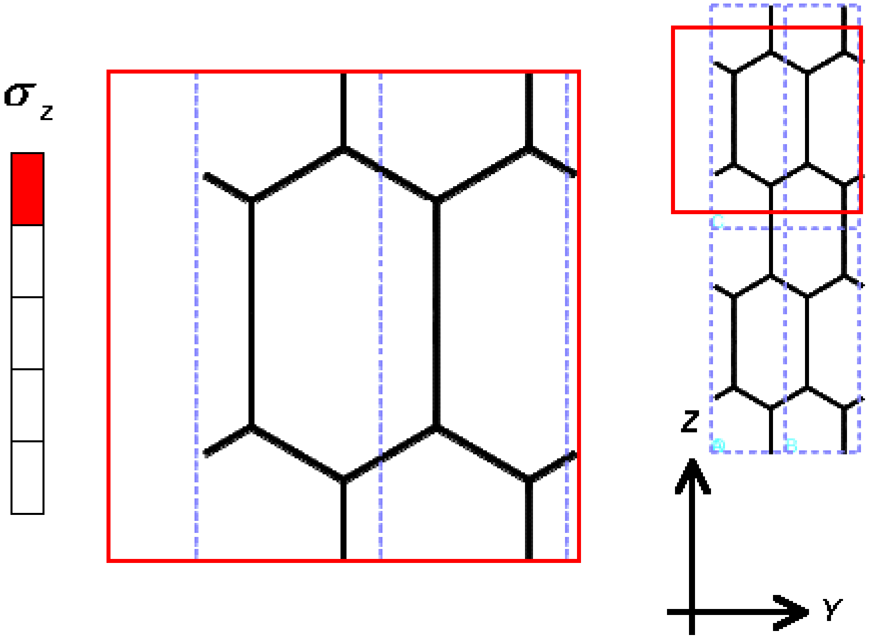
$$= -\tan(\theta)\frac{l\sin(\theta)}{h - l\cos(\theta)}$$



Auxetic: 0º < θ < 90º

Conventional: 90º < θ < 180º

Dilating mechanisms



Rotating Rigid / Semi-Rigid Units

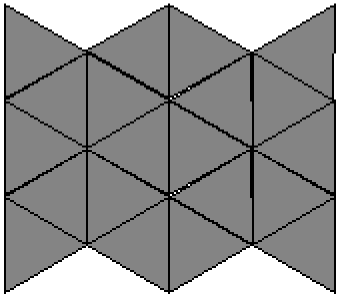
Poisson's ratio will depend on:

(1) Shape of the rigid unit

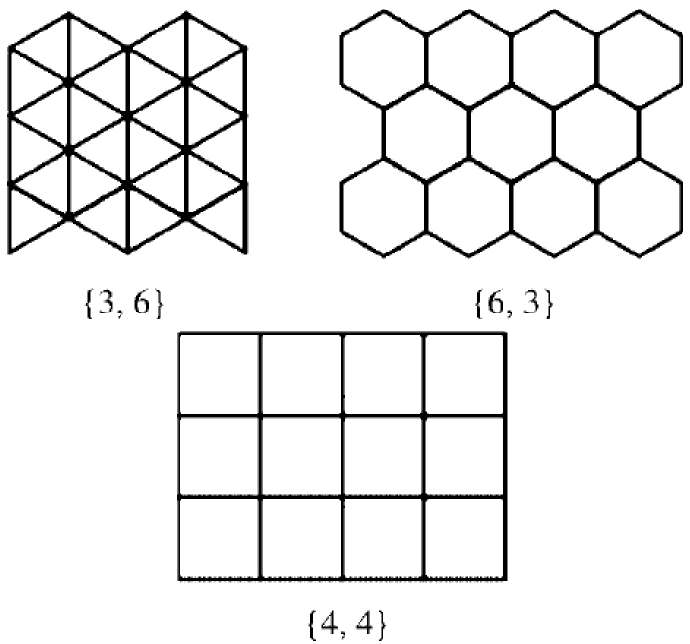
(2) Degree of aperture

(3) Connectivity

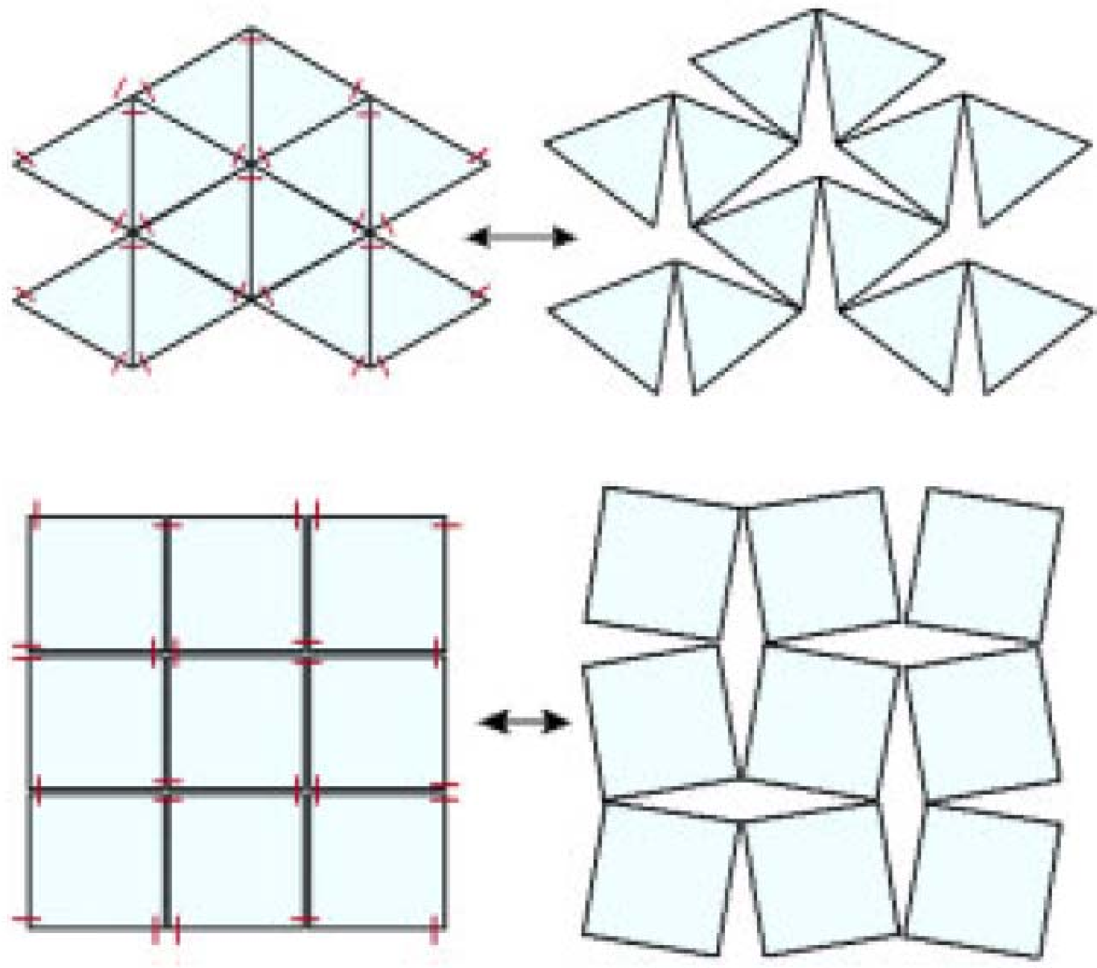
(4) Extent of rigidity of the unit



Rotating Quadrilaterals

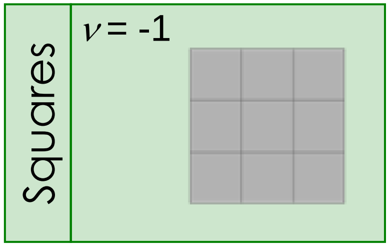


Regular {3, 6}, {4, 4} and {6, 3} tessellated structures.



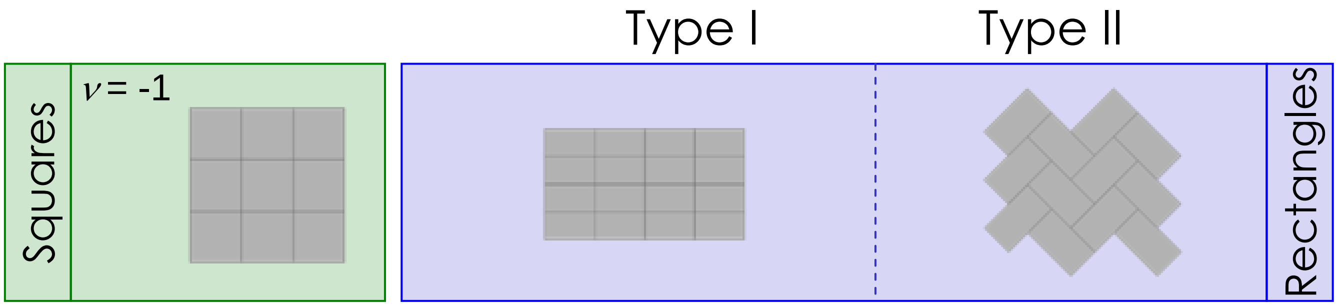
...more examples

- Rotating rigid units
  - quadrilaterals



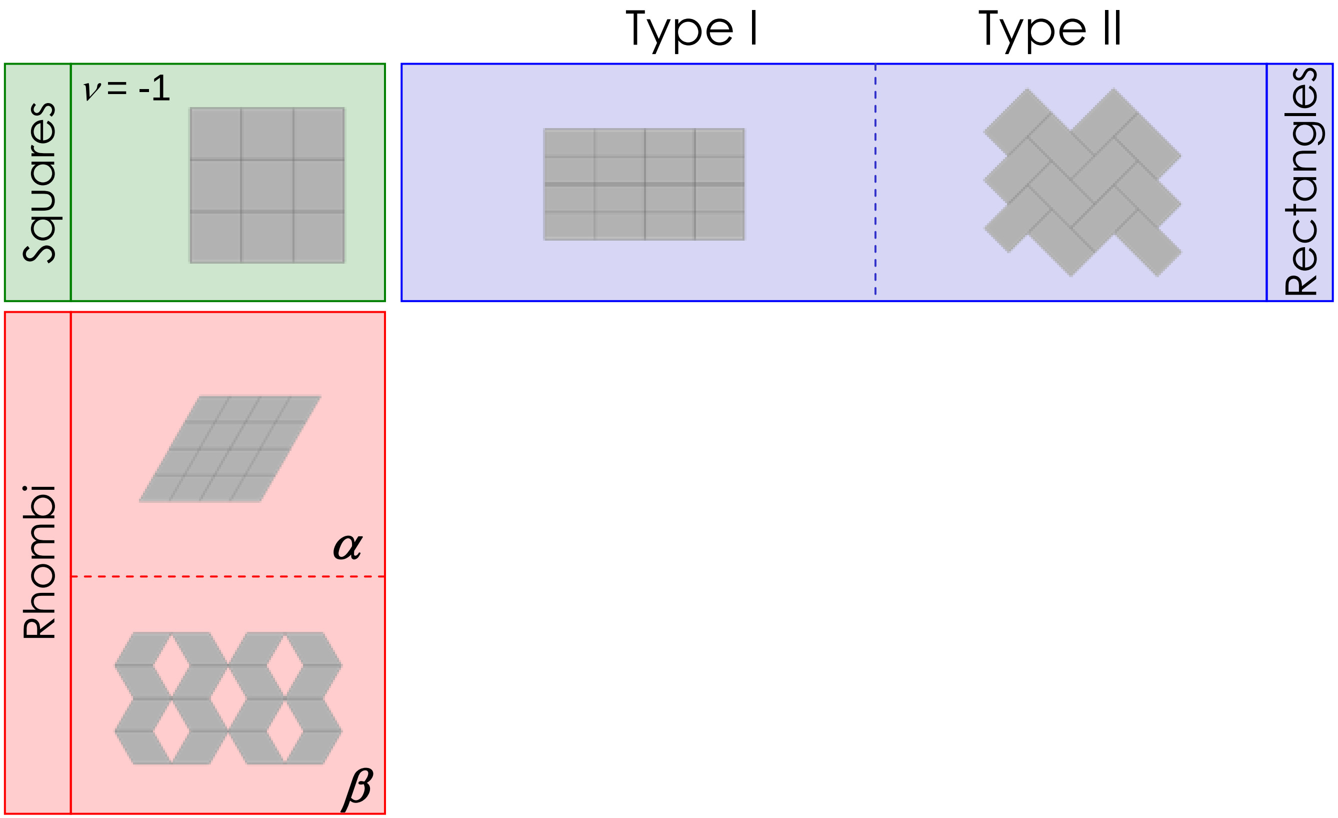
...more examples

- Rotating rigid units
  - quadrilaterals



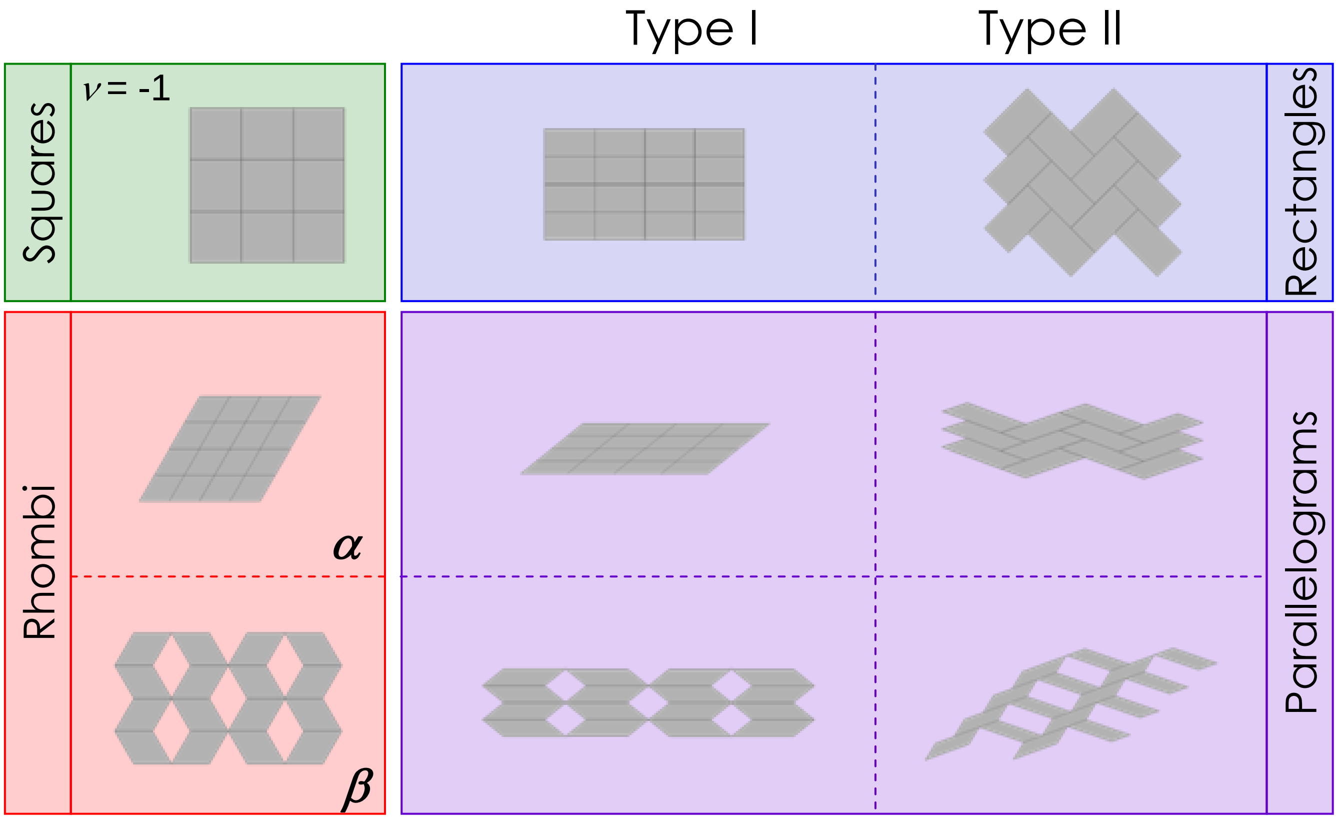
...more examples

- Rotating rigid units
  - quadrilaterals

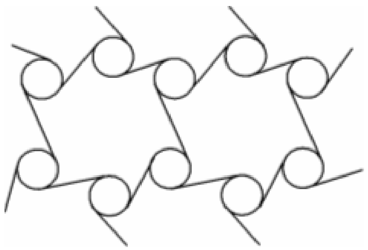
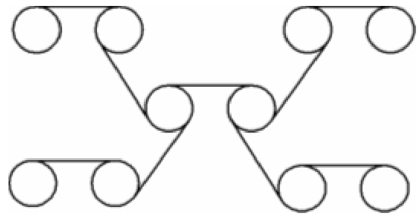
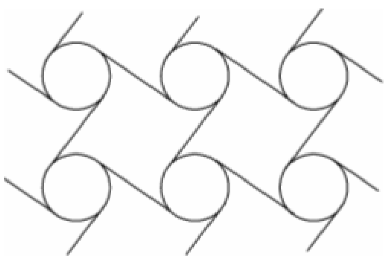
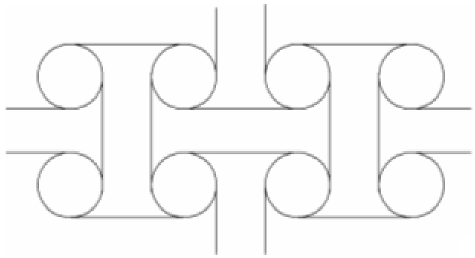
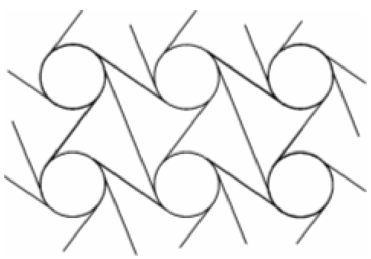


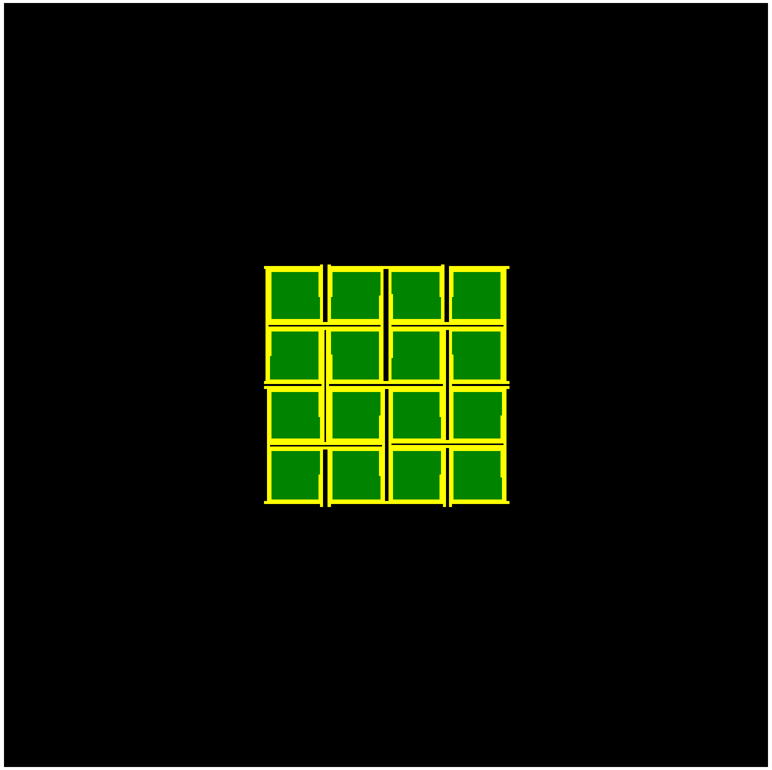
...more examples

- Rotating rigid units
  - quadrilaterals



Others … The Chirals, Anti-chirals

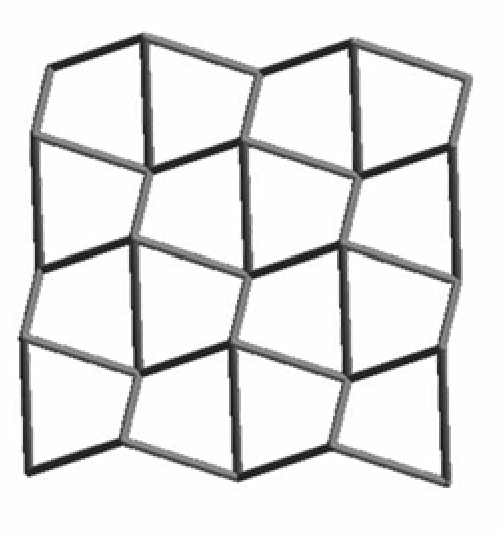
n	Chiral tessellations	*Anti*-chiral tessellations
3		
4		
6		SYSTEM CANNOT BE CONSTRUCTED



anti-tetrachiral

… and more

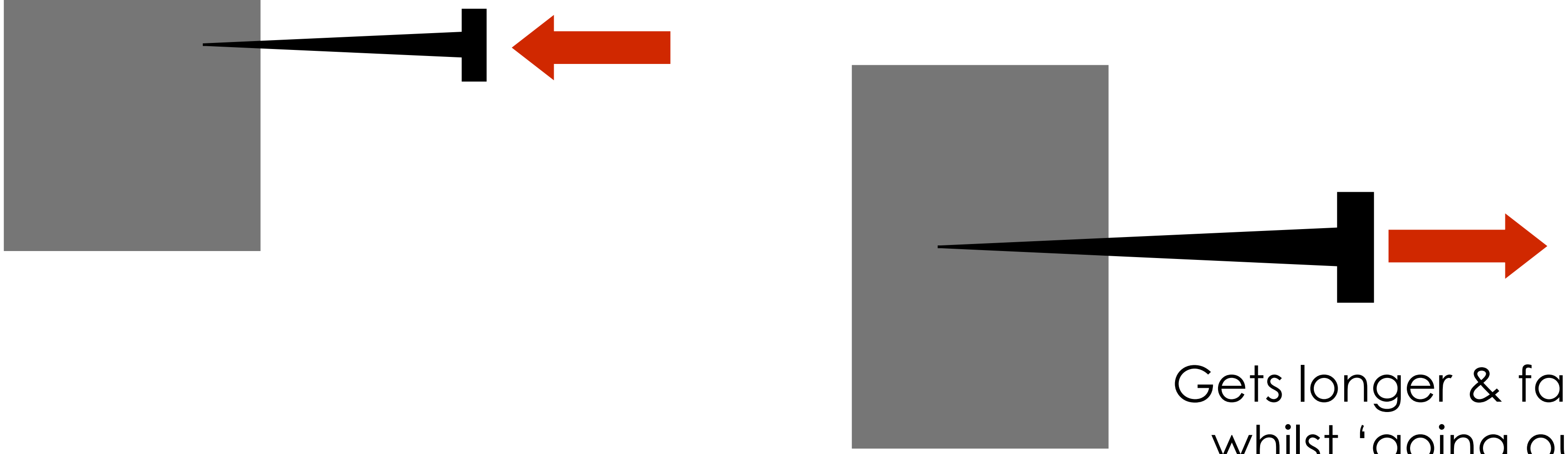
- Egg-rack mechanism



Properties / Applications

- Auxetic nails

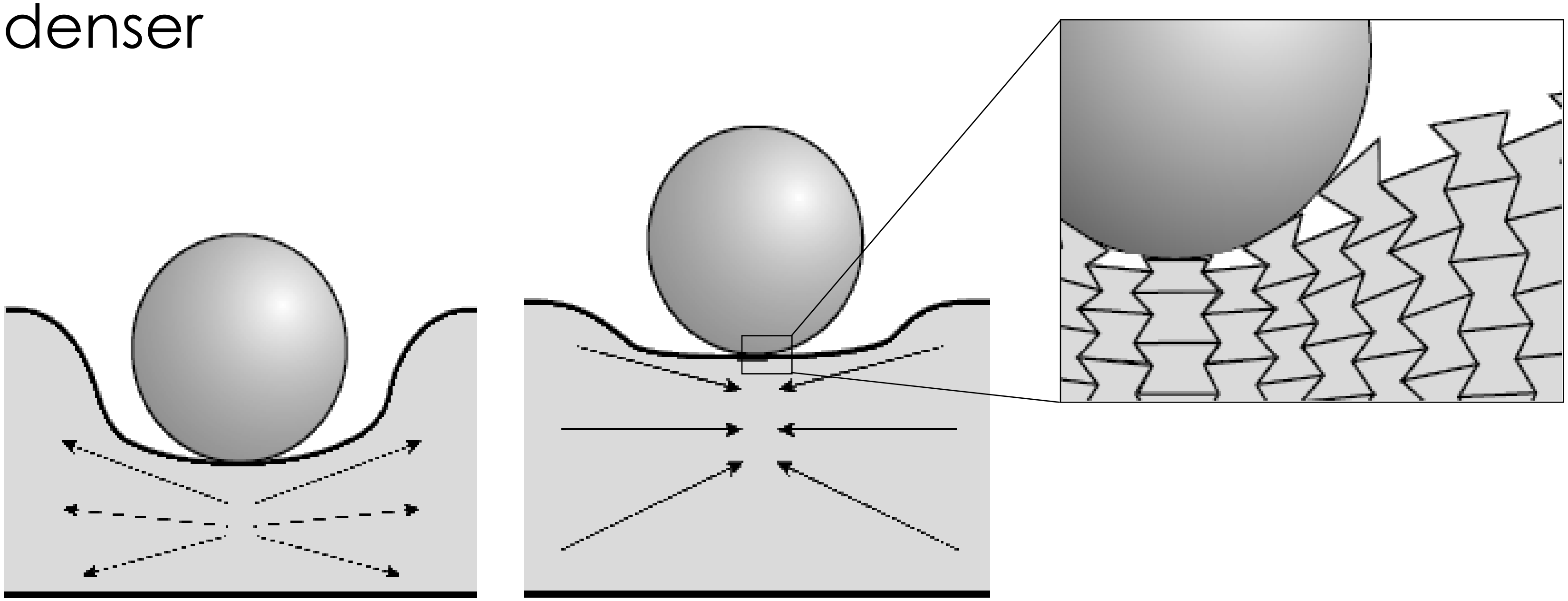
Gets shorter & thinner
whilst 'going in'



Gets longer & fatter
whilst 'going out'

Auxetic materials are harder to indent...

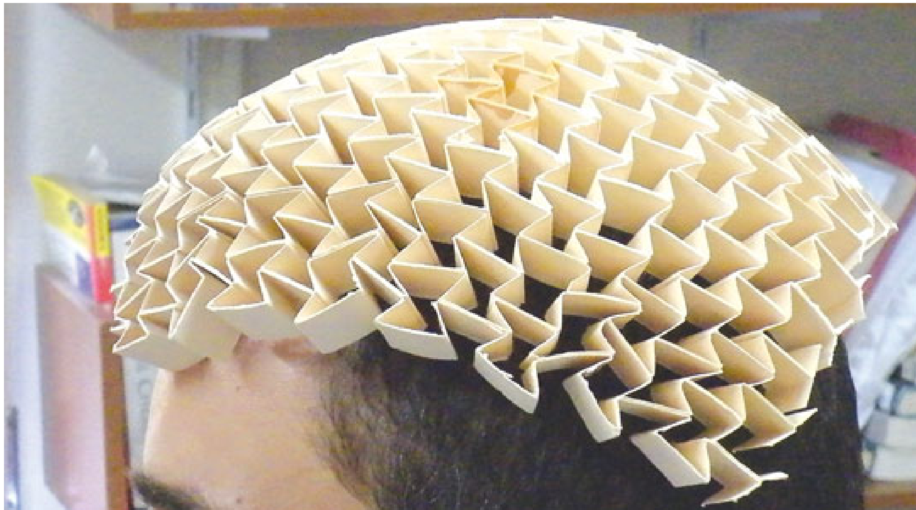
...In auxetics, the material tends to go towards the point of impact to become denser



Properties / Applications

Synclastic behaviour...

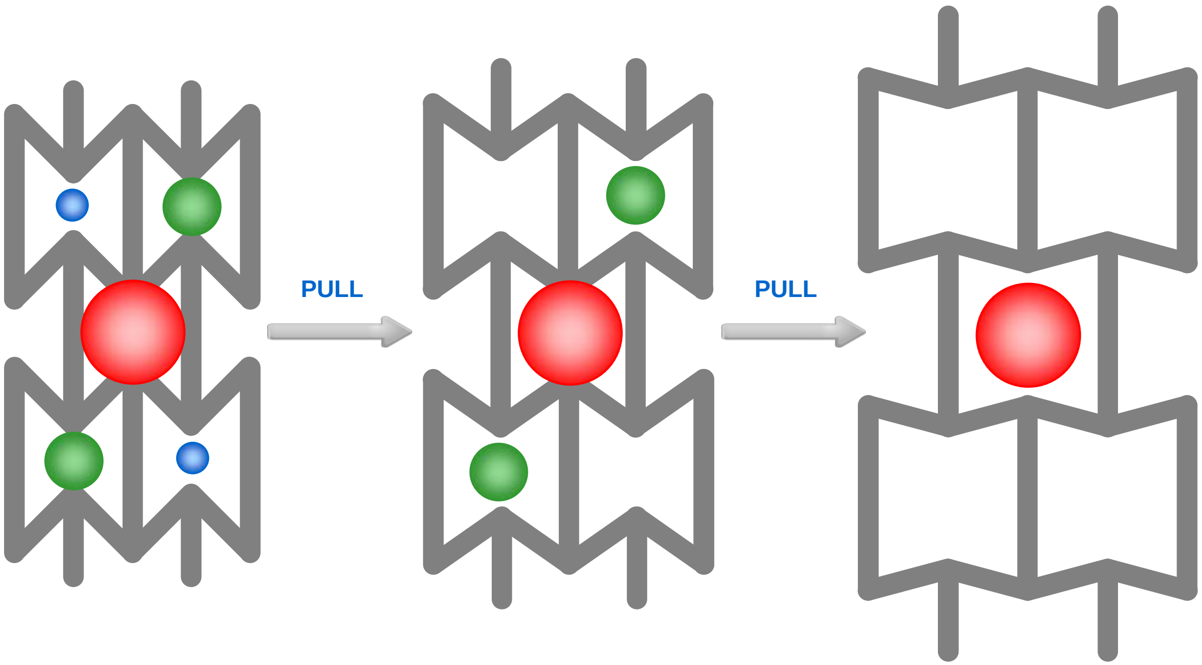
... ability to form dome shaped surfaces

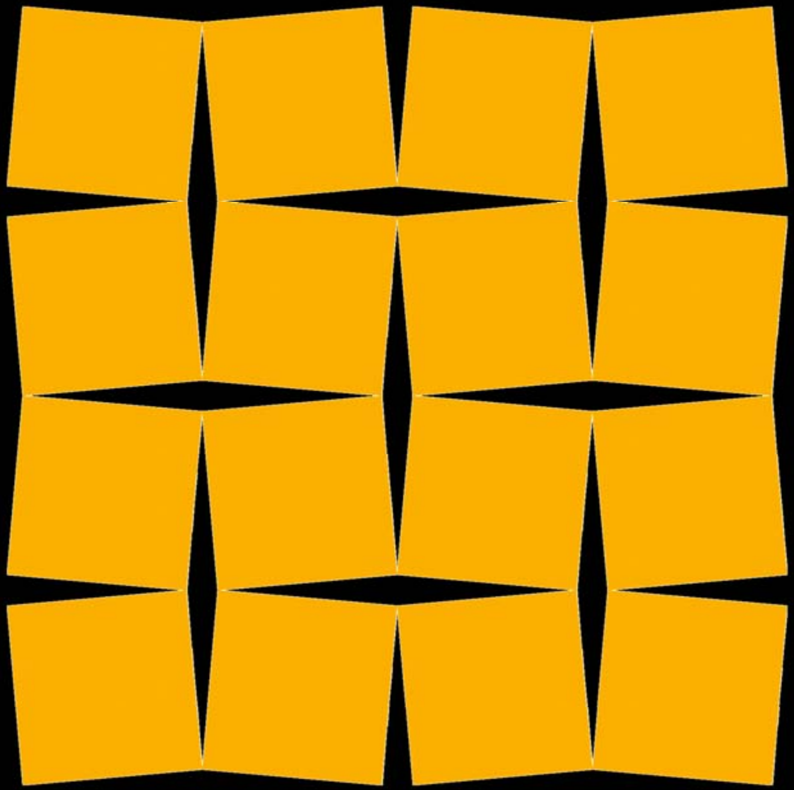


http://www.auxetic.info

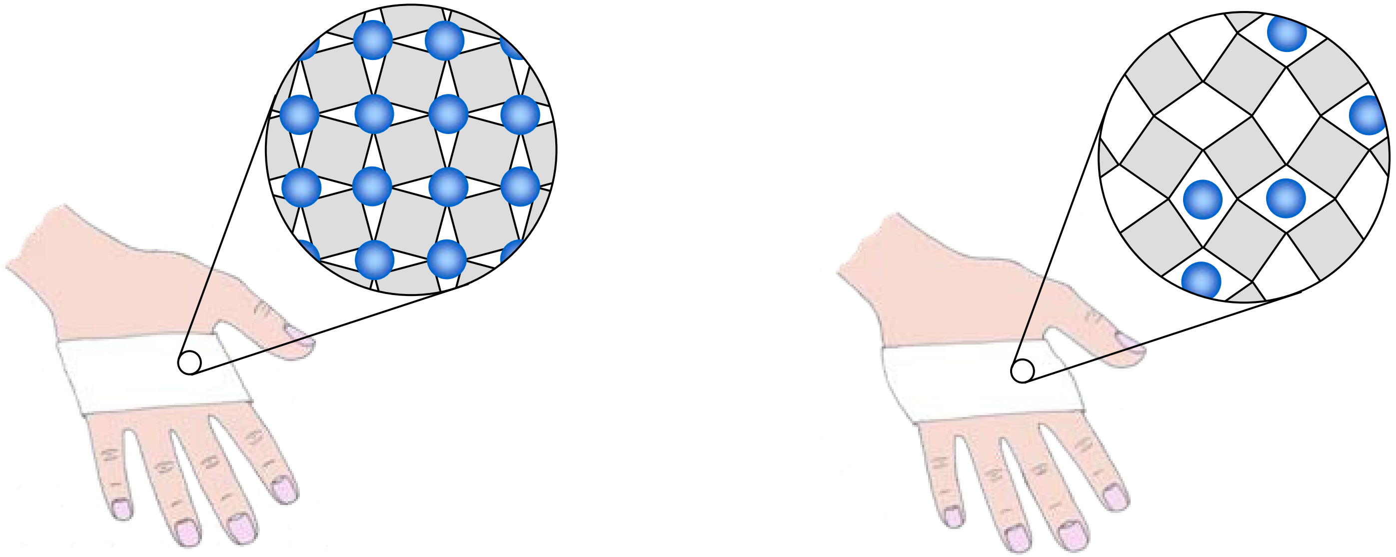
Properties / Applications

- Smart filters





- Smart dressings



Other Properties

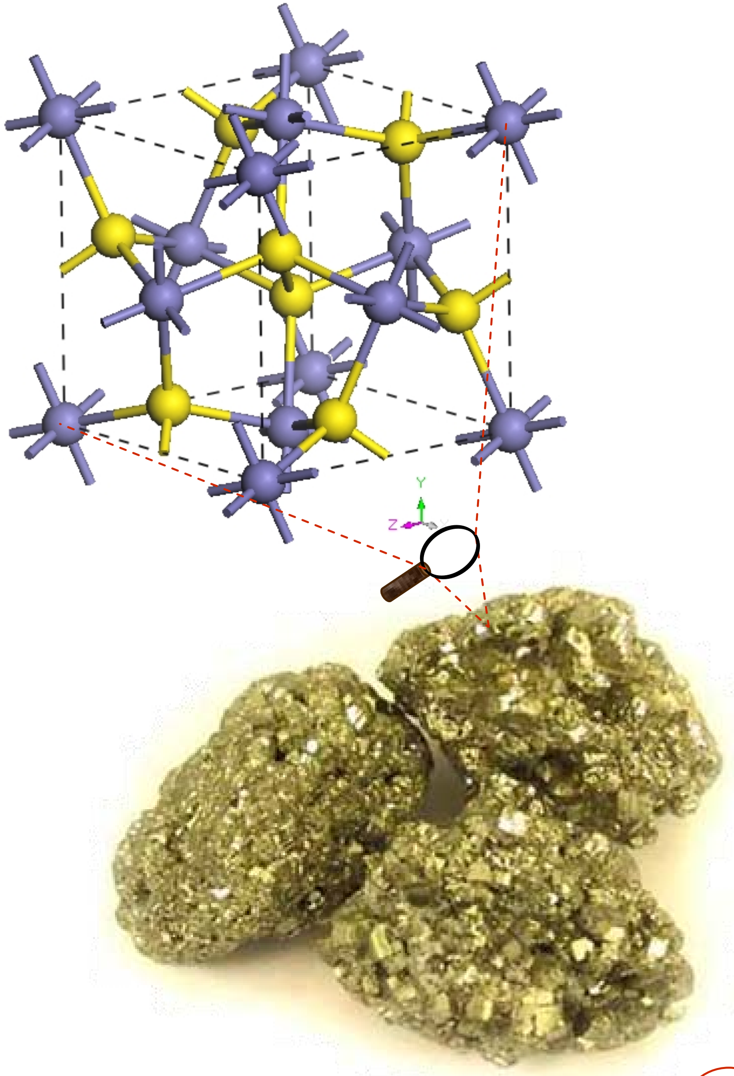
- An increased shear stiffness

- Higher plane fracture toughness

Historical note

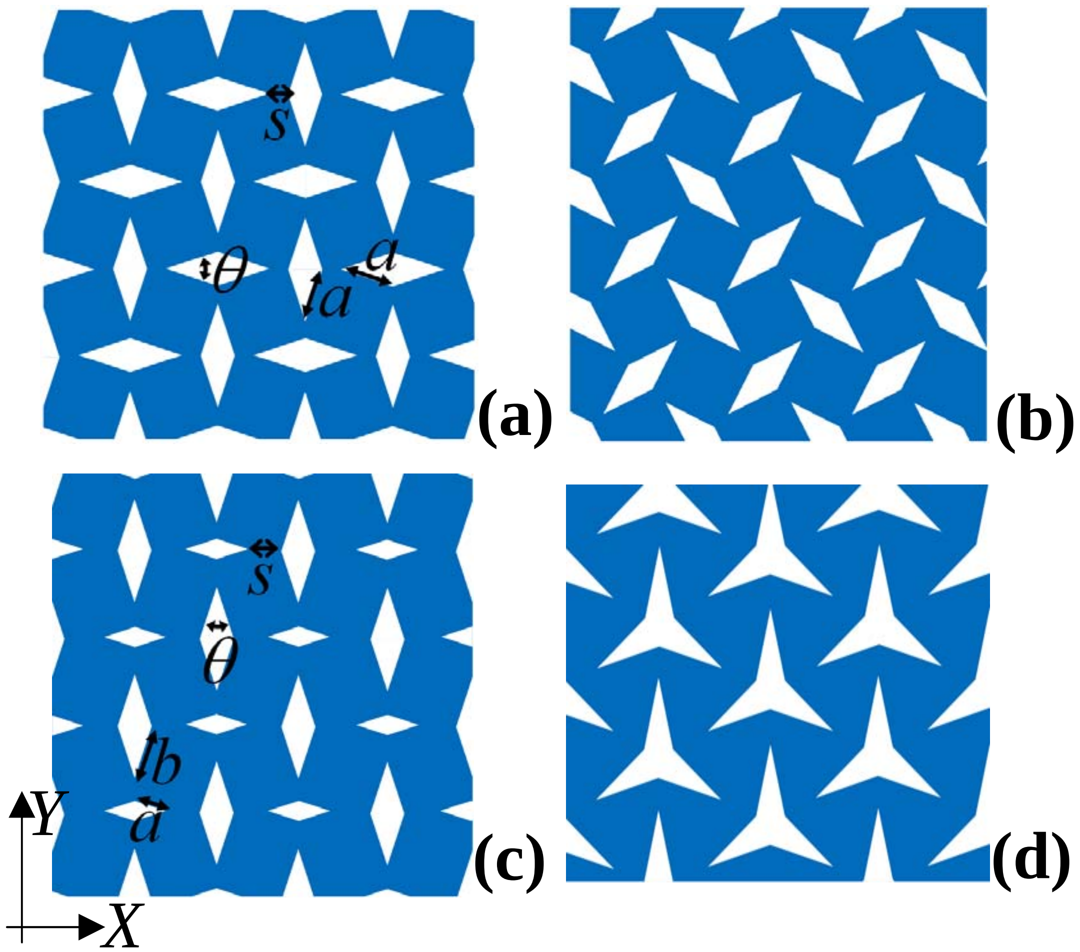
- First Report: A negative Poisson's ratio was first reported in single crystals of **iron pyrites** and was attributed to **crystal twinning** [Voigt, 1928].

- This was followed by some isolated reports mostly in the 1970s and 1980s

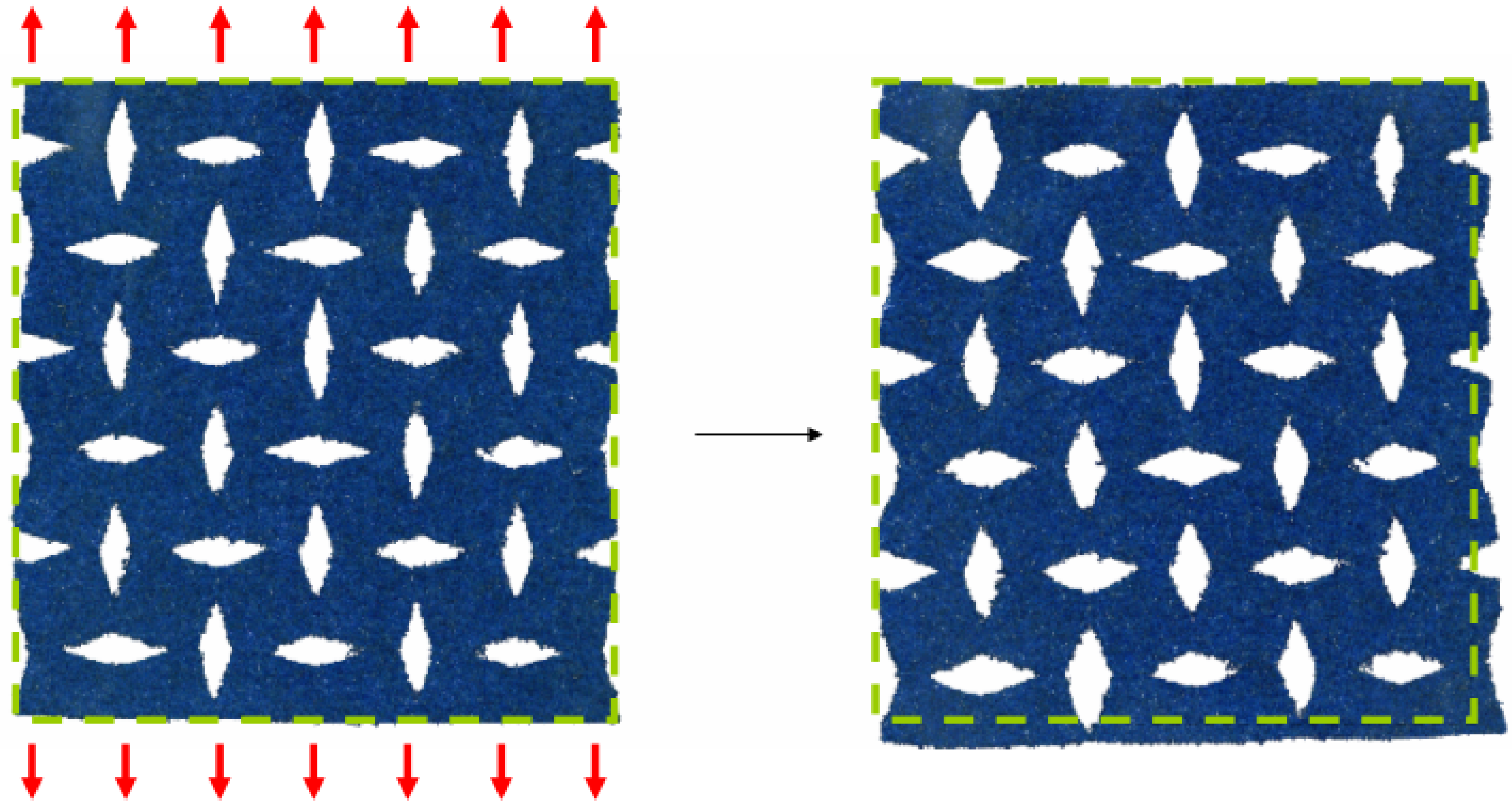


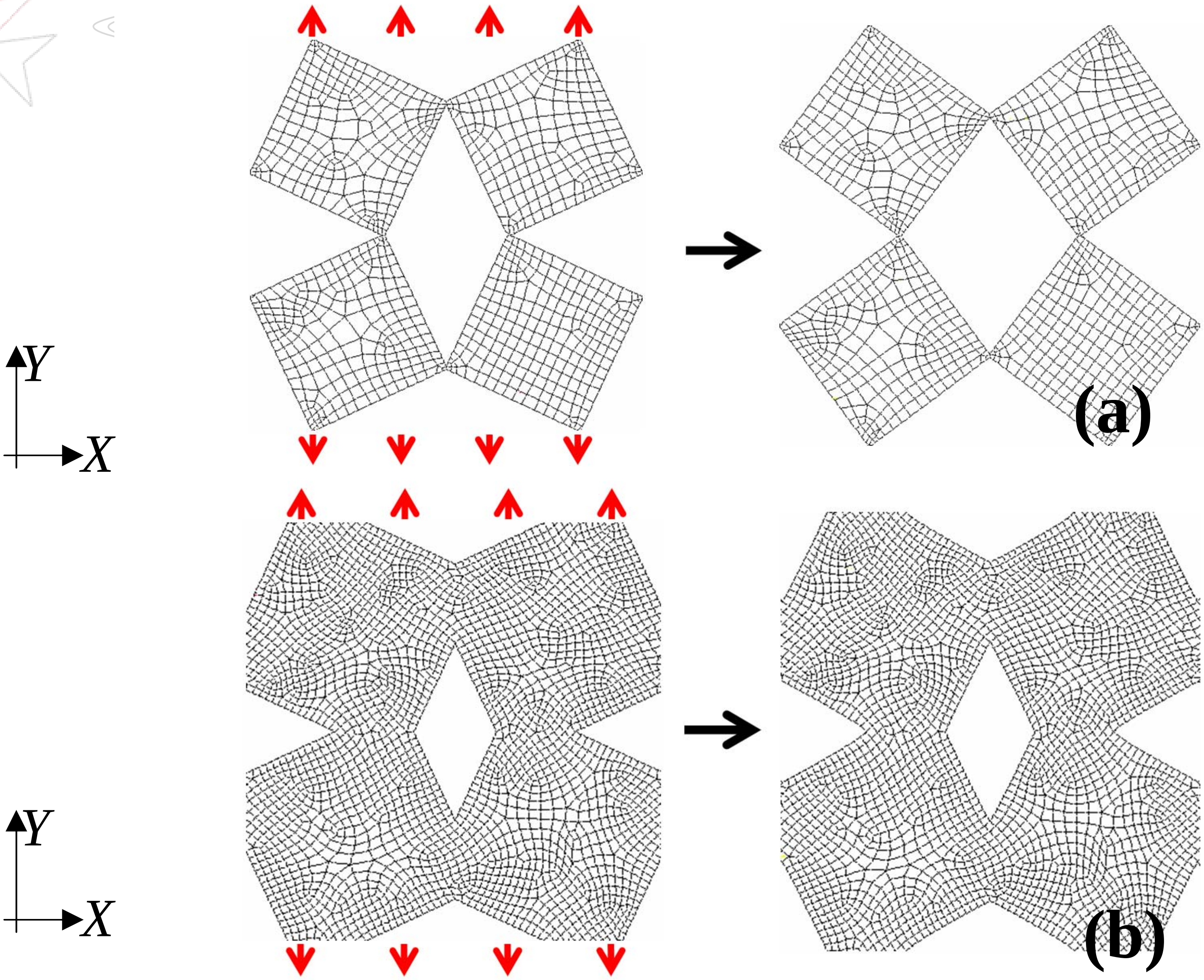
Macro auxetics … an example

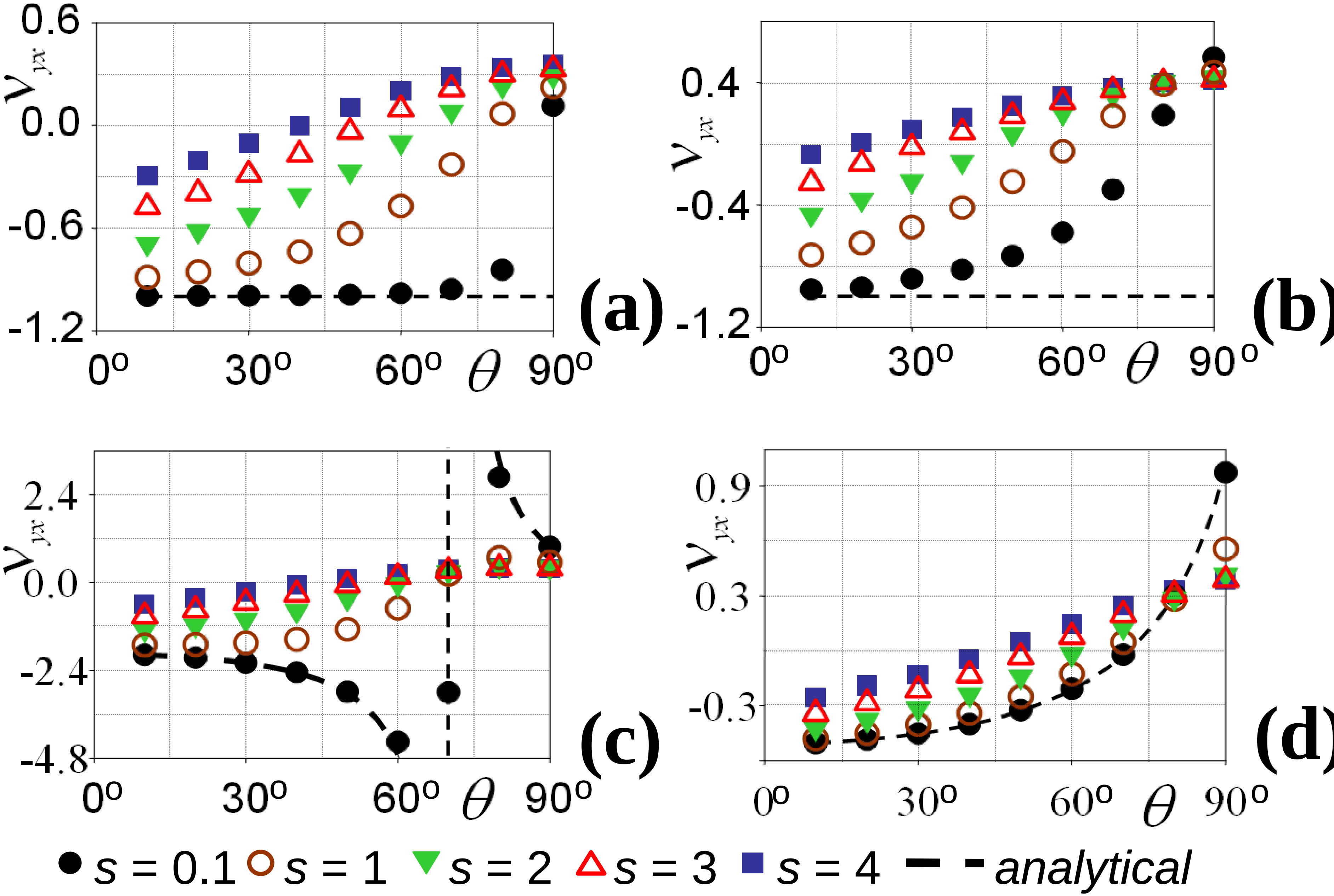
Perforated sheets



Experiment on Carpet Fabric



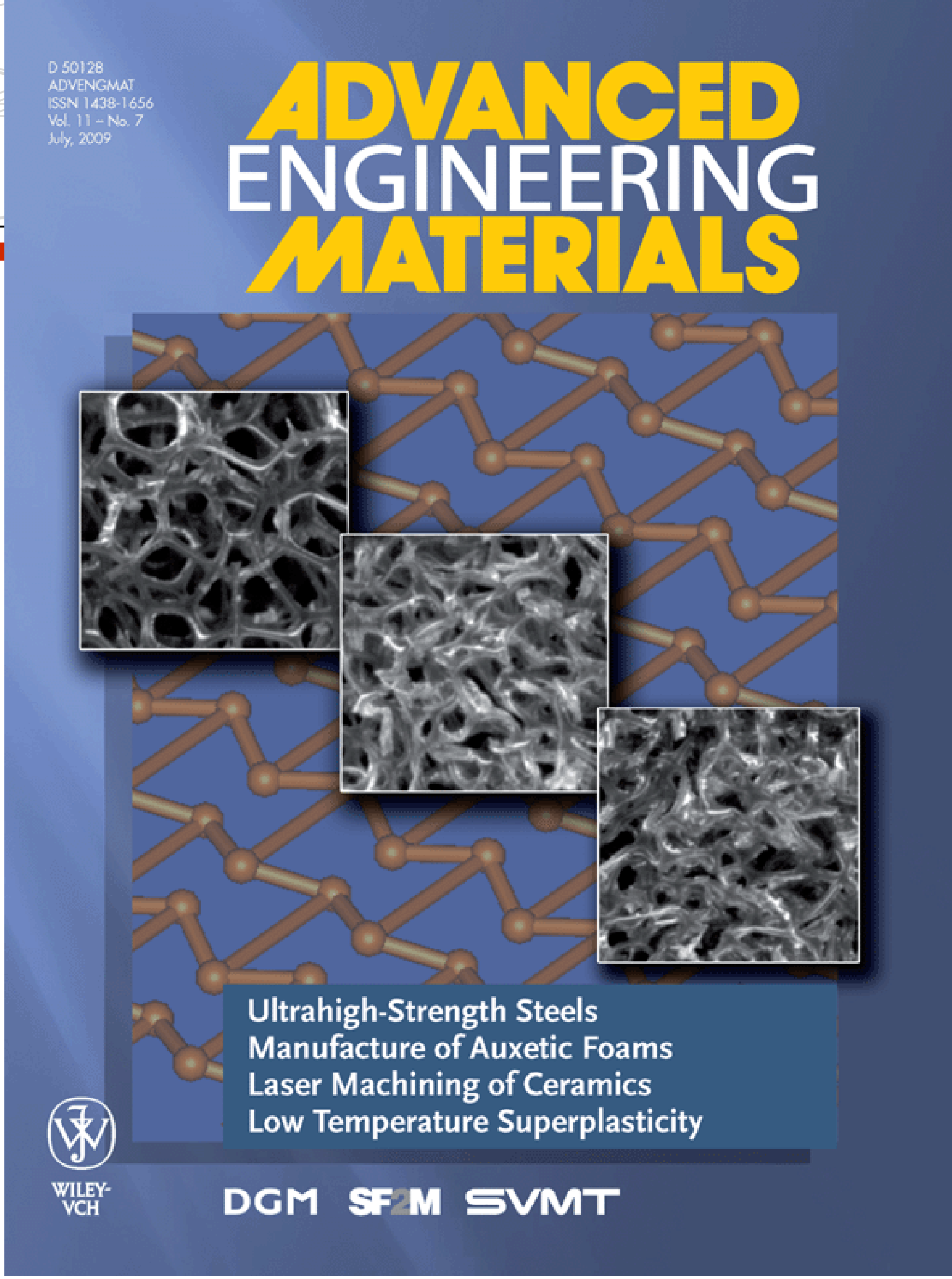

Y
X
(a)
Y
X
(b)



(a)
(b)
(c)
(d)
ν_{yx}
θ
0.6
0.0
-0.6
-1.2
0.4
-0.4
2.4
-2.4
-4.8
0.9
0.3
-0.3
0°
30°
60°
90°
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

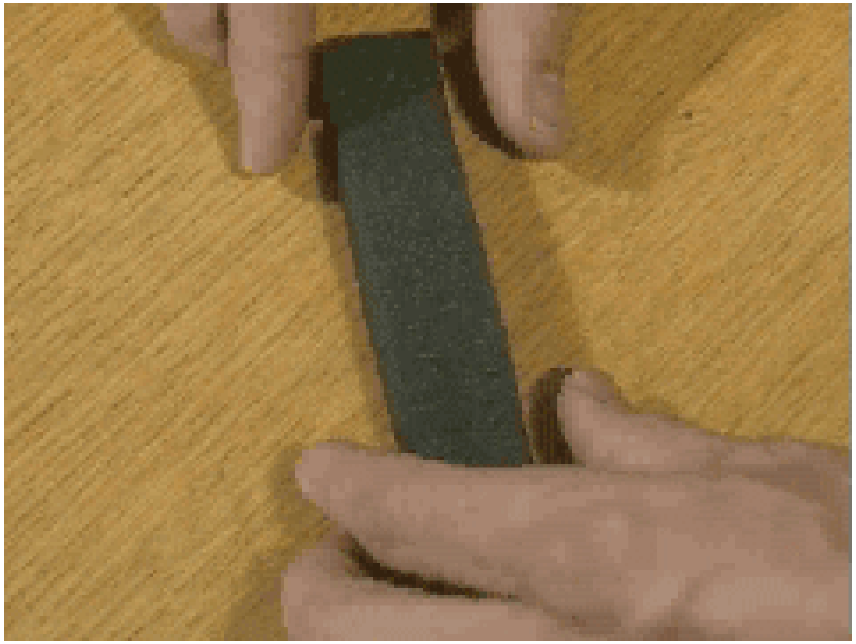
Starting from: Reticulated 30 ppi polyester polyurethane

- 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

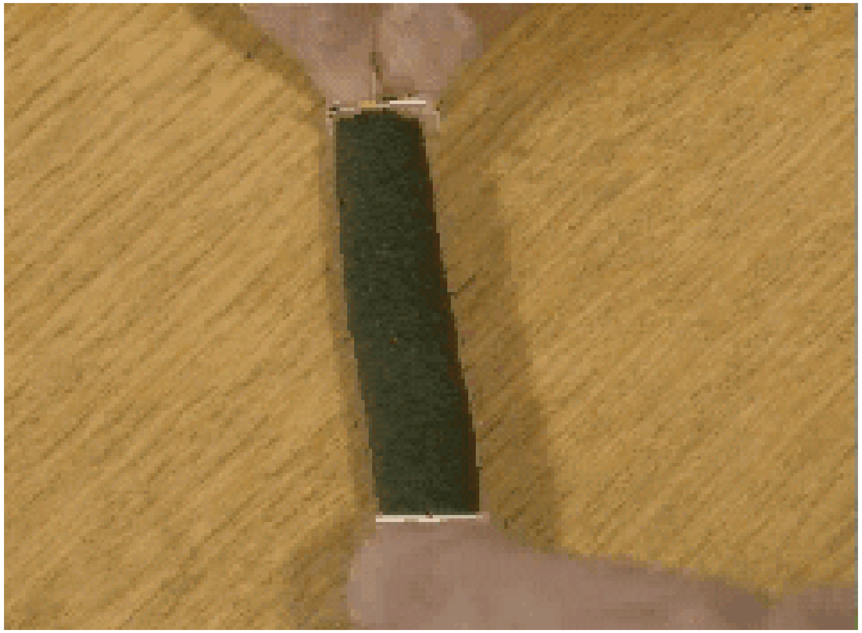
Taken from: Smith, Grima, Evans, *Acta Mater*. **48** (2000) p.4349-4356.

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

Before ...



. . . and after



New approach

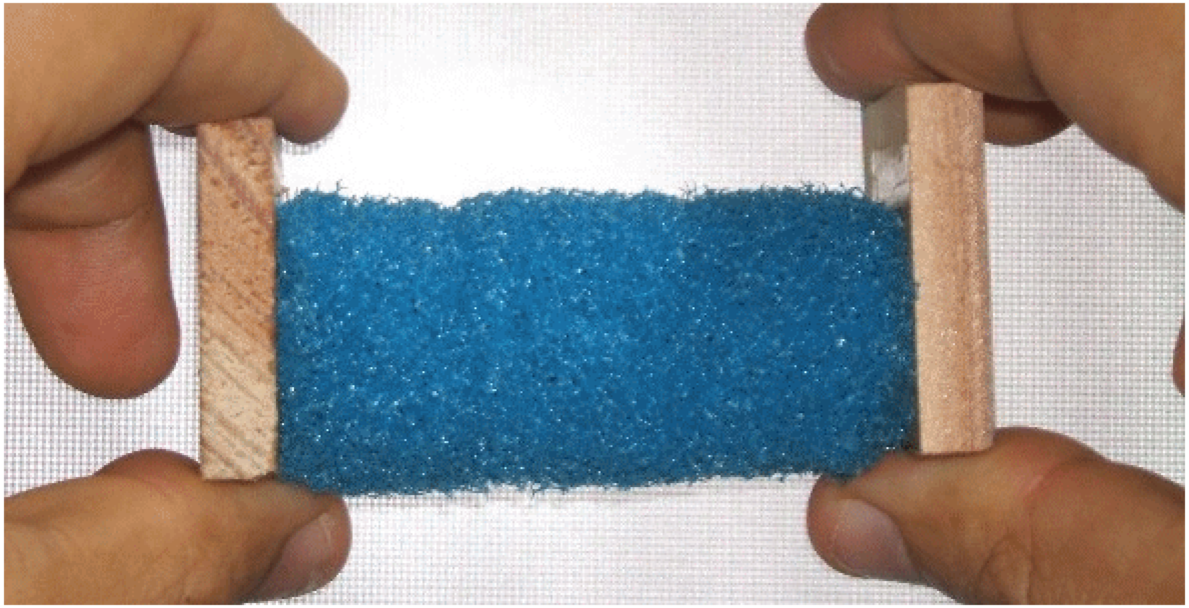
- Uses solvent instead of heat
- Process involves
  - Wetting foam with appropriate solvent
  - Compressing the foam volumetrically by 30%
  - Allowing the foam to dry well

Typical Process

- Starting from: Reticulated 30 ppi polyurethane foam (Dongguan Dihui Foam Sponge, China)

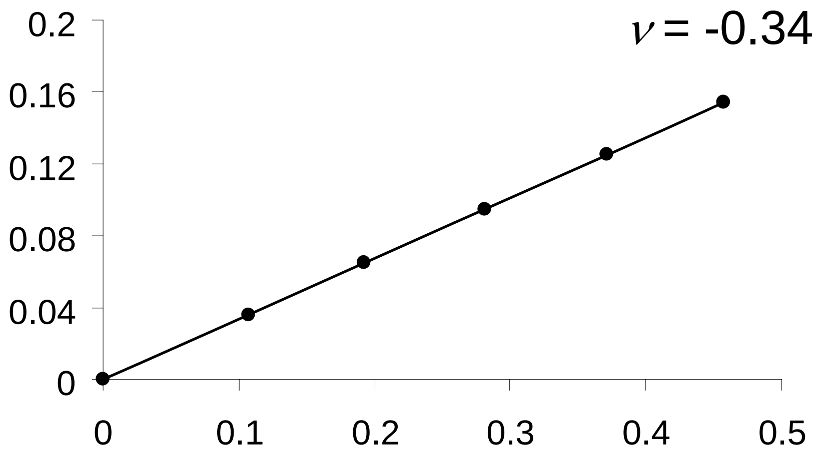
- Cut conventional foam in the shape of a cylinder of diameter 40mm and length 84mm
- Wet the foam with acetone
- Remove excess solvent
- Press sample into a mould of diameter 26 mm and length 55mm (~35 % strain along each axis);
- Allow the sample to dry completely before removing from mould

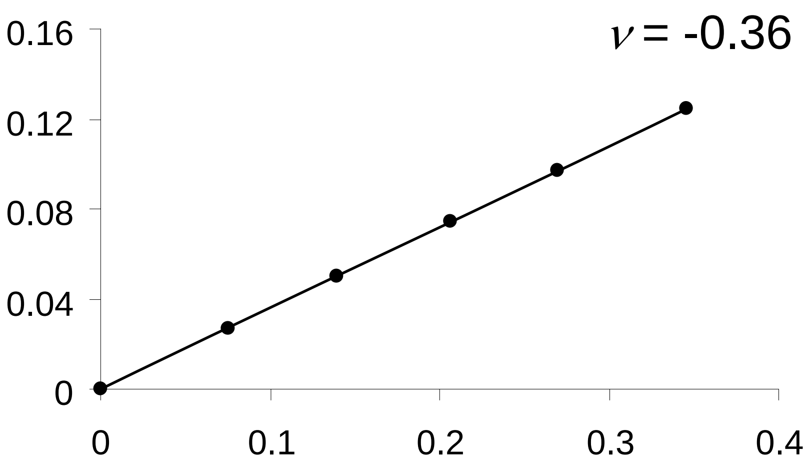
Result

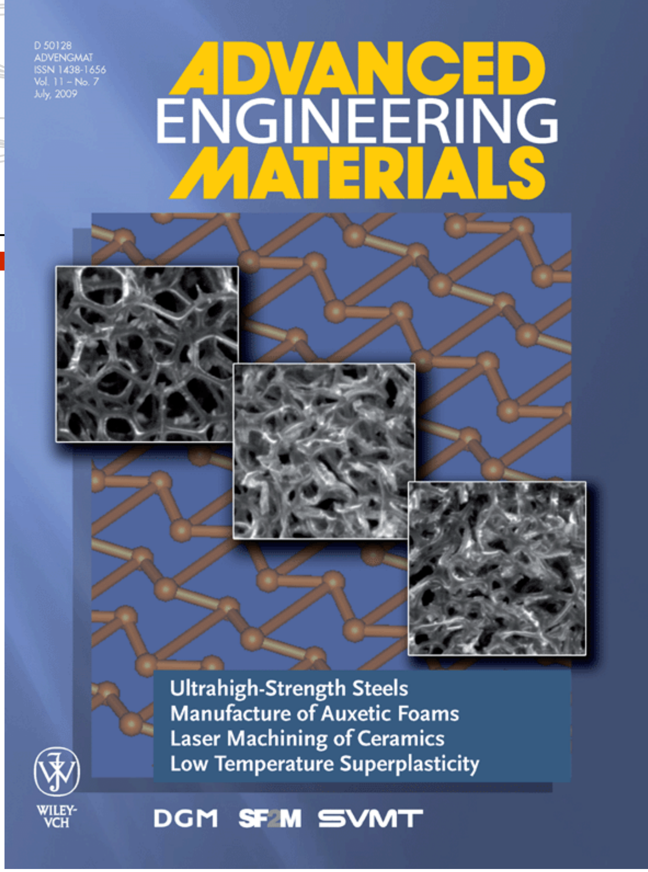


JN Grima, D Attard, R Gatt and RN Cassar, *Adv. Eng. Mater.*, **21** (2009)

Measurements

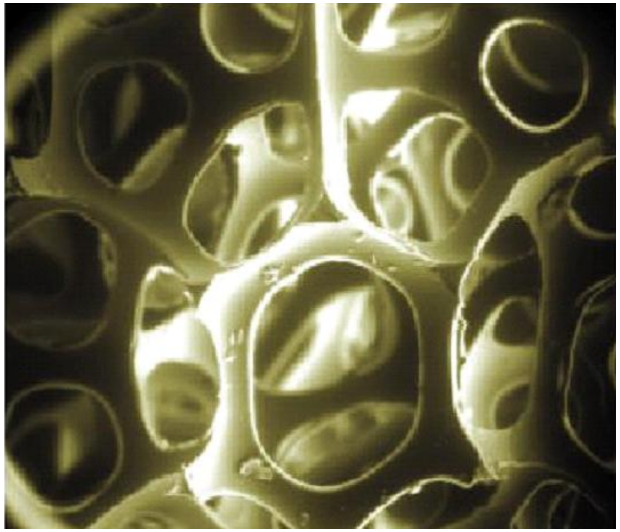




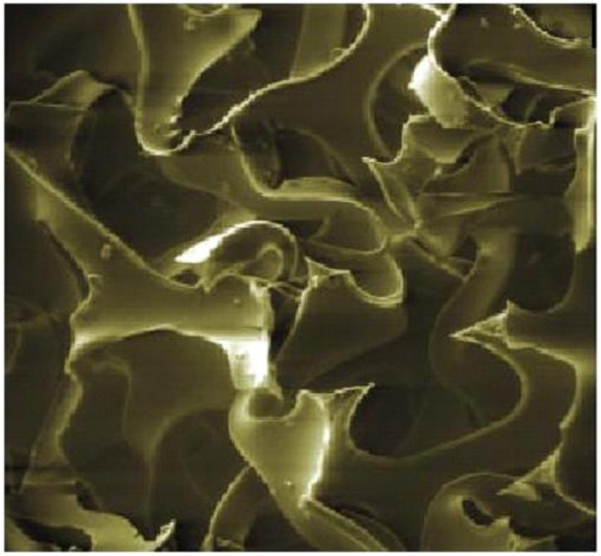


Foams – The Models

Microstructure in auxetic foams



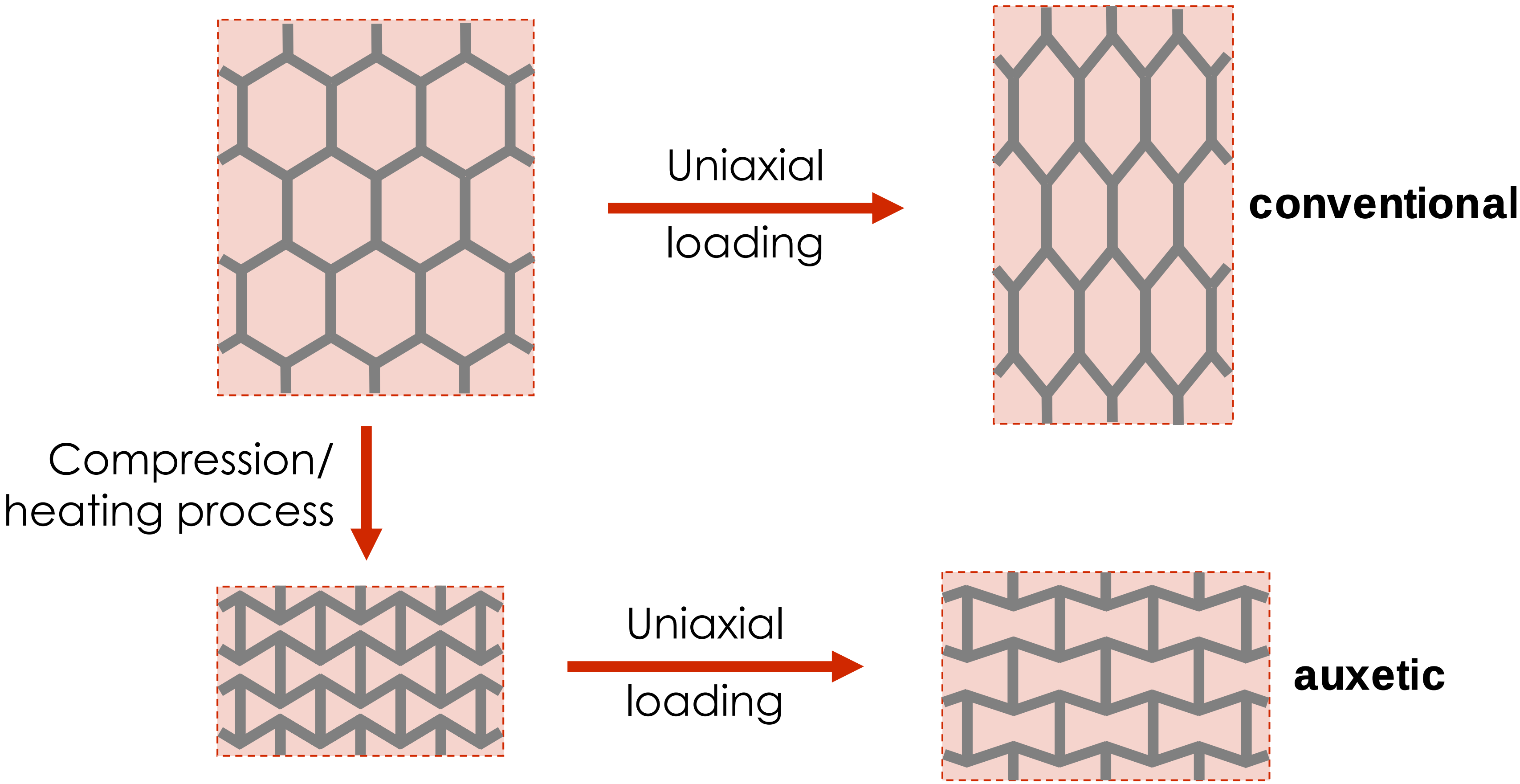
Conventional foam



Auxetic foam

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

Re-entrant structures

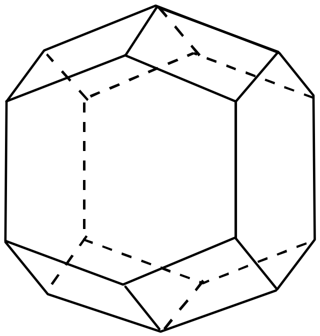


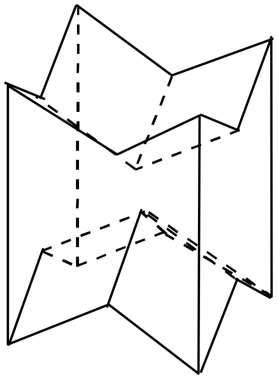
LJ Gibson and MF Ashby, *Cellular Solids*, Cambridge Uni. Press, 1997.
IG Masters and KE Evans, *Composite Struct*, **35** (1996) 403.
KE Evans, A Alderson and FR Christian, *J. Chem. Soc. Faraday Trans.*, **91** (1995) 2671.

3D Re-entrant structures

conventional **Re-entrant**

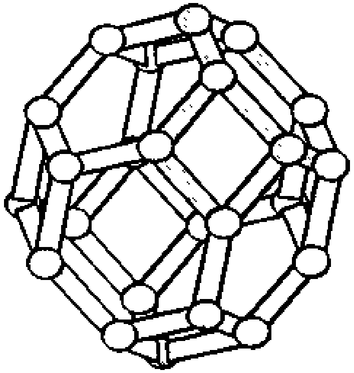
dodecahedron
foam models

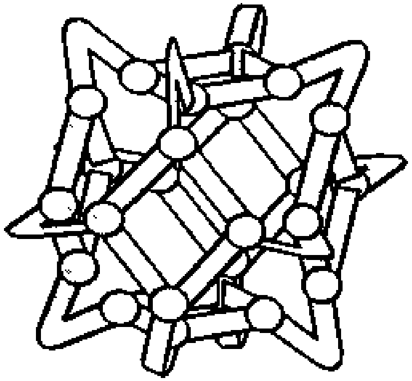




(KE Evans, MA Nkansah and IJ Hutchinson, *Acta Metall. Mater.*, **2** (1994) 1289)

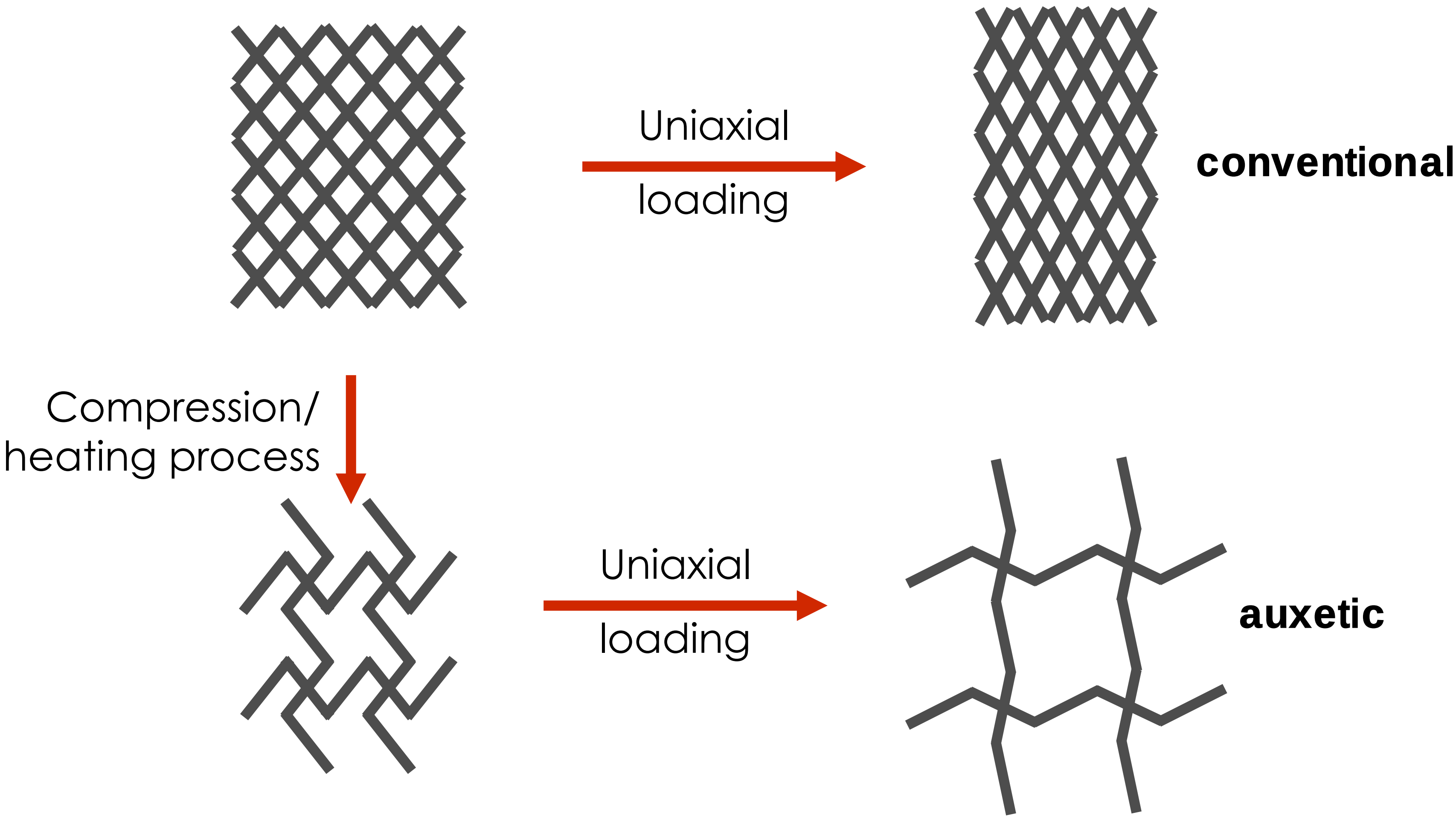
tetrakaidecahedron
foam models





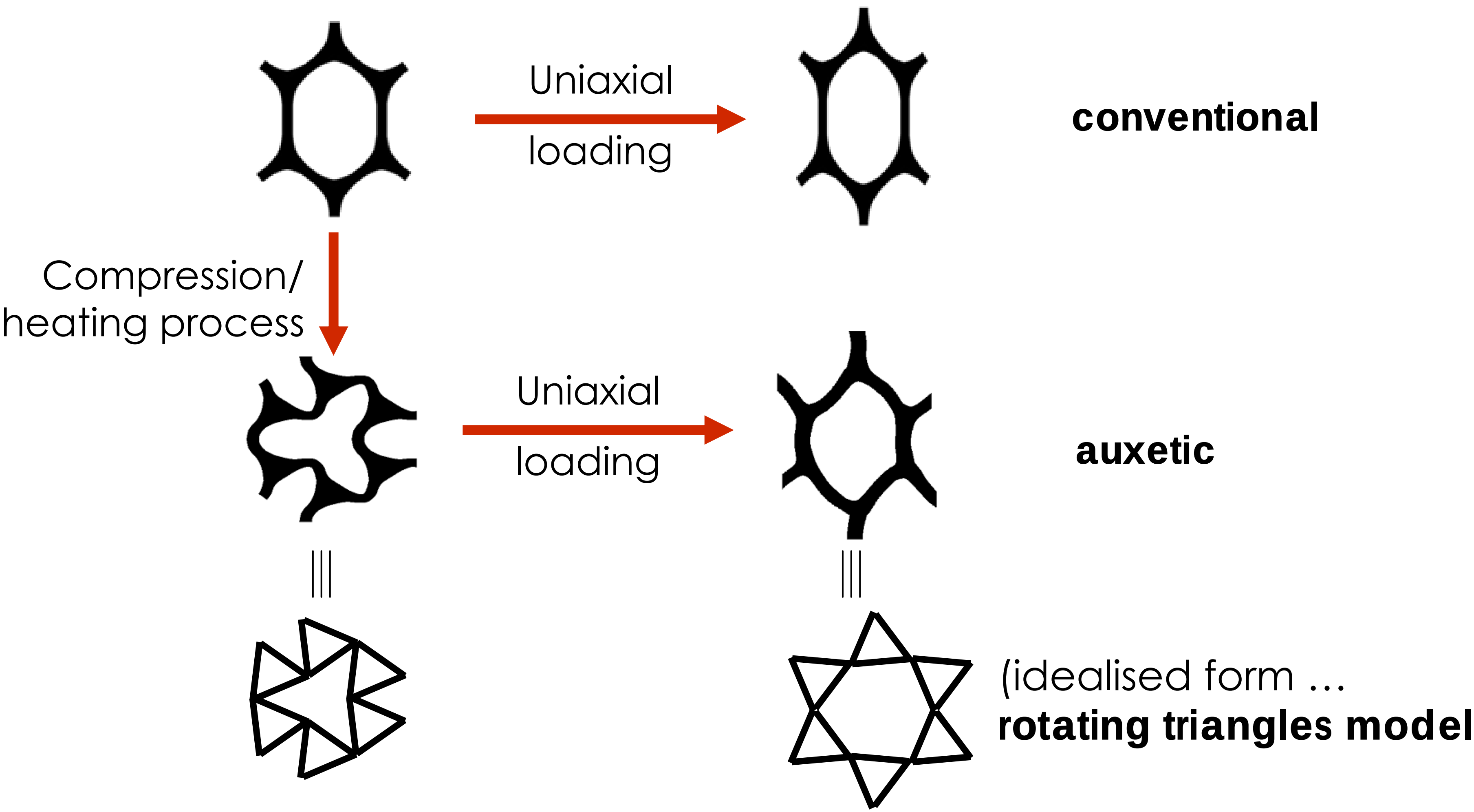
(JB Choi, RS Lakes, *J Compos. Mater.*, **29** (1995) 113.)

Missing rib model



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

Rotating rigid units



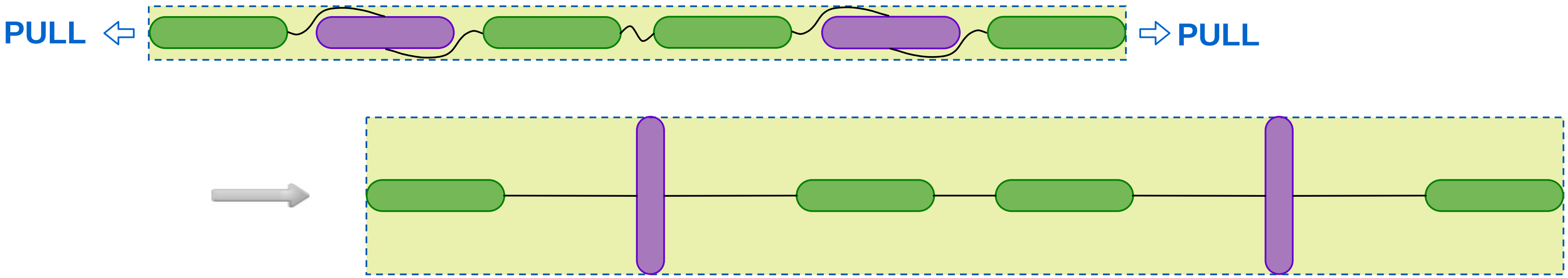
JN Grima, A Alderson and KE Evans, *J. Phys. Soc. Jpn*, **74** (2005) 1341.

Later on … The evidence

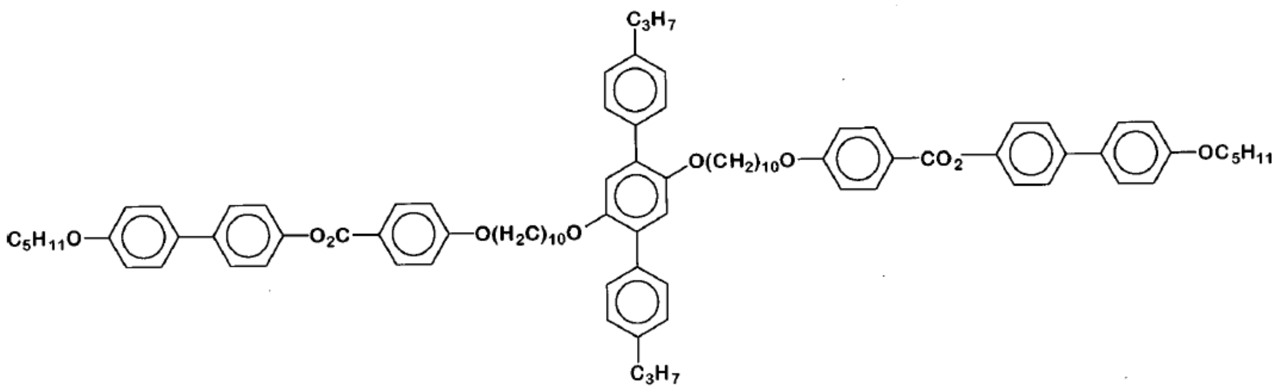
- **In situ three-dimensional X-ray microtomography of an auxetic foam under tension, S.A. McDonald, N. Ravirala, P.J. Withers, A. Alderson, Scripta Mater. (2009) p. 232-235** *which says:*
  - *X-ray microtomography has the potential to unambiguously identify the predominant deformation mechanisms responsible 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.***

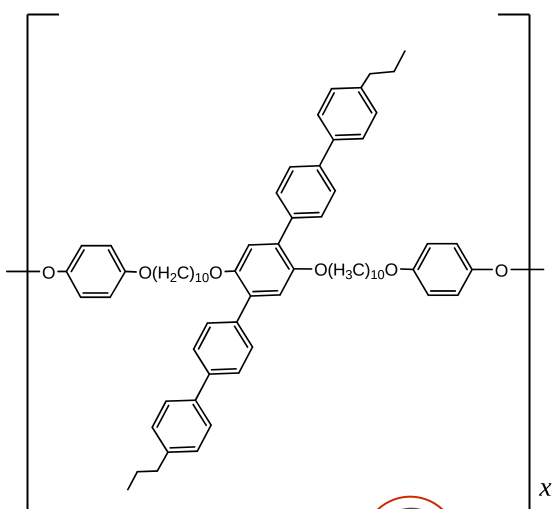
Synthesized ‘molecular level’ Auxetics: LCPs

concept ….

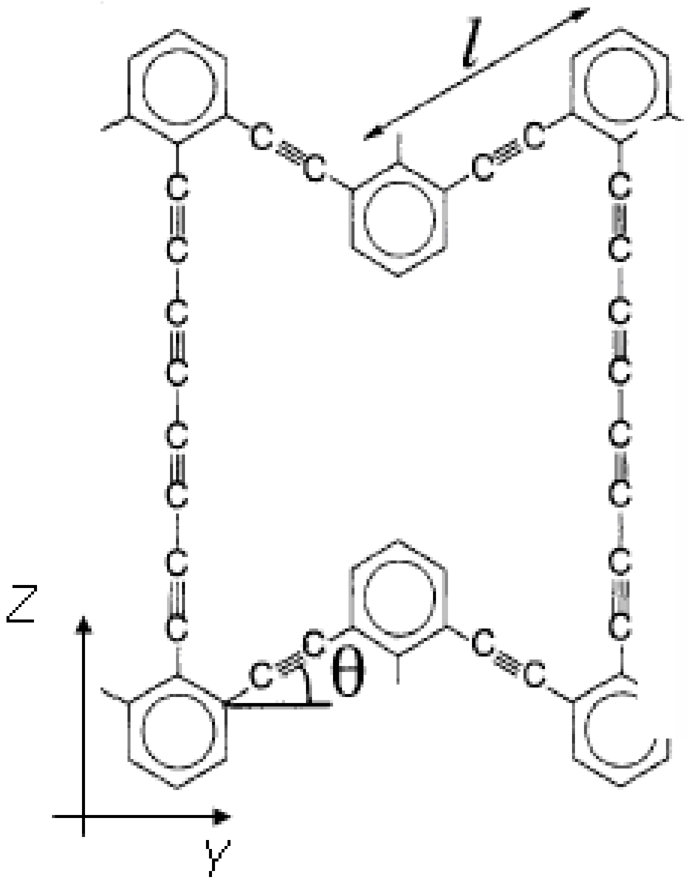


molecular level equivalents ….

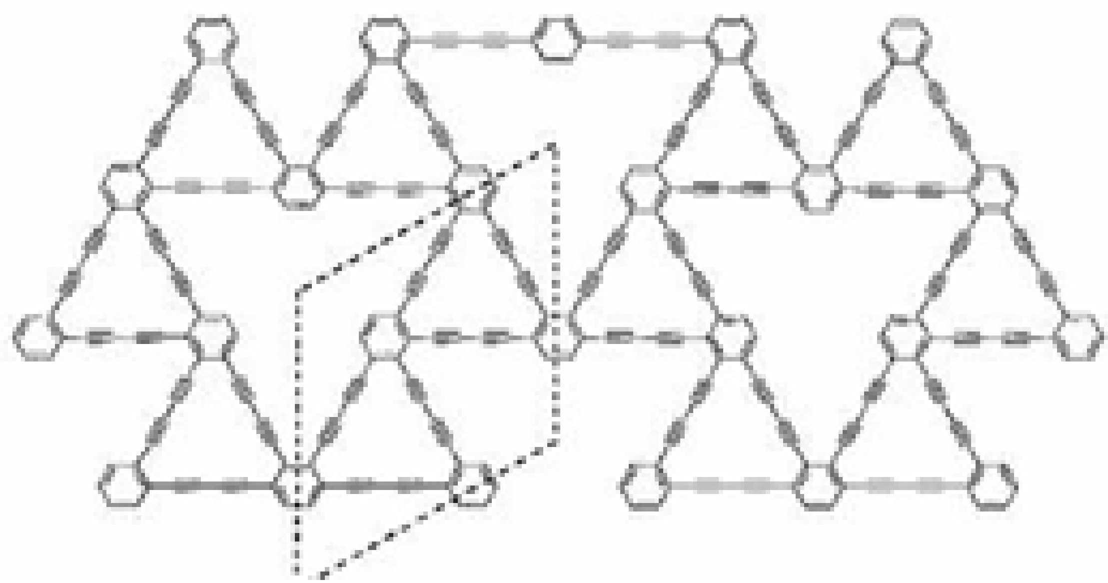




Other possible auxetic polymers

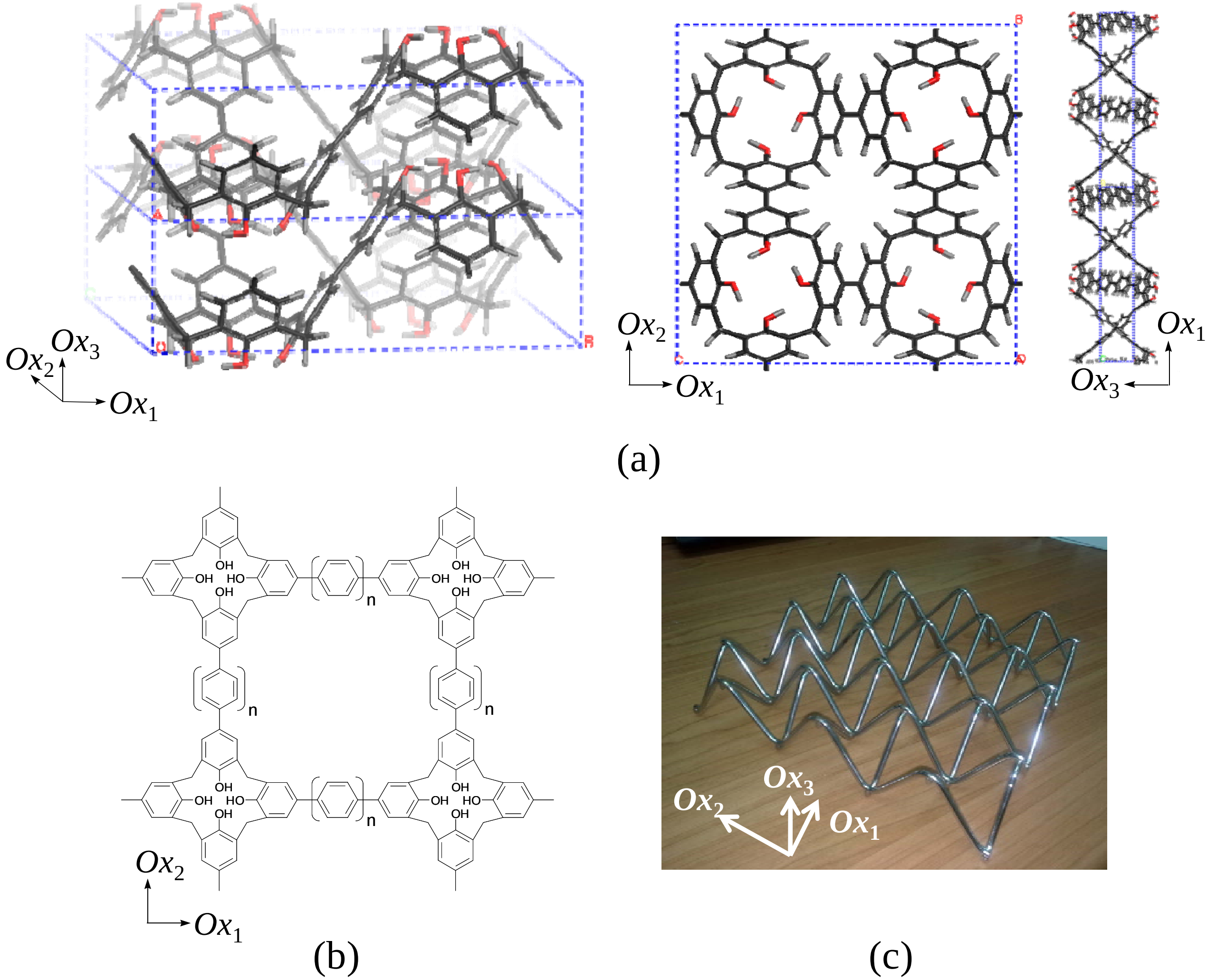


Evans *et al.*, *Nature* (1991)



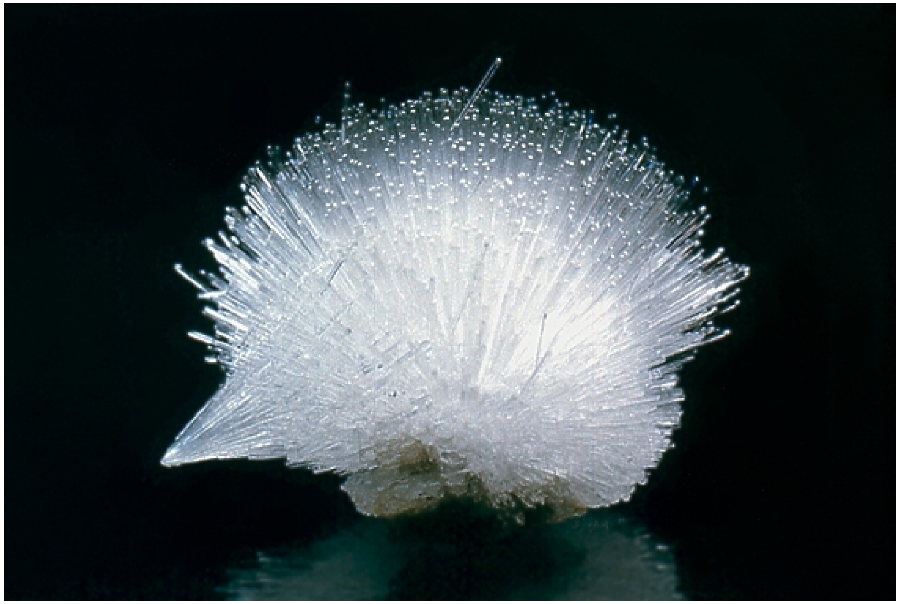
Grima *et al.*, *Chem. Comm.* (2000)

Other possible polymers …



Grima *et al.*, *Chem. Comm.* (2004)

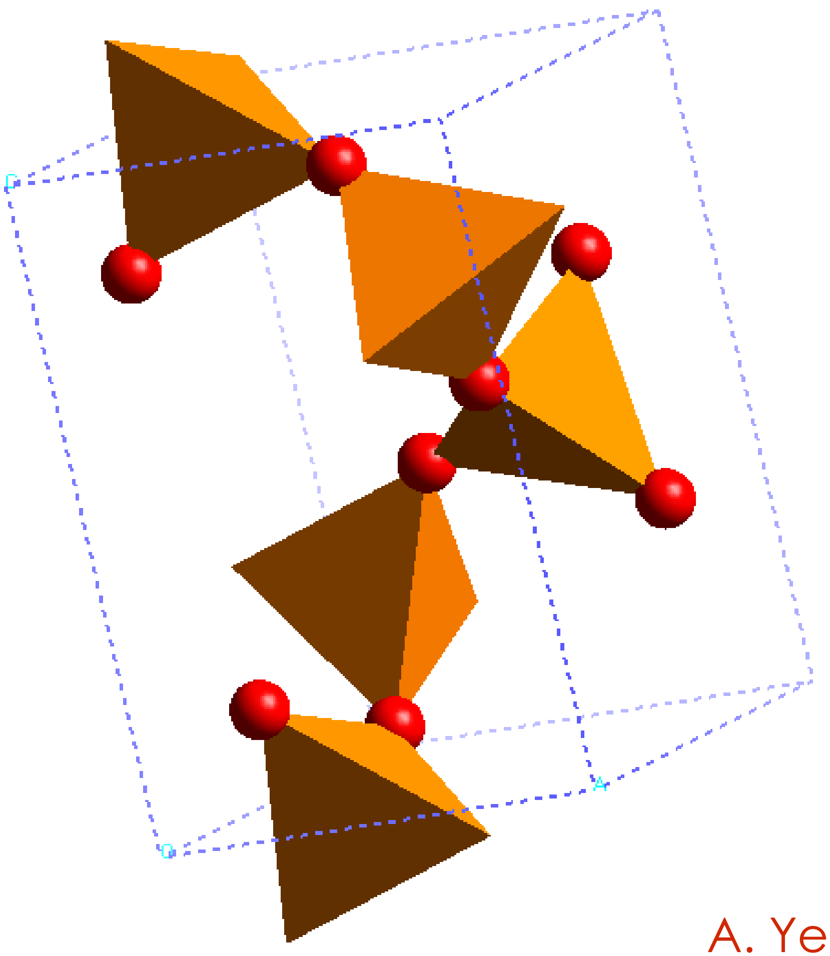
Auxeticity in Naturally Occurring minerals

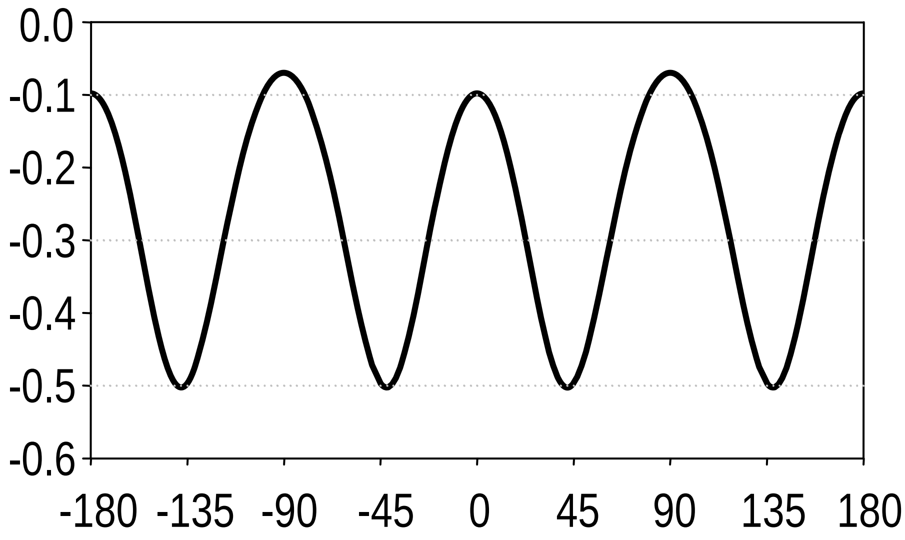


Case Study (i) - Cristobalite

- 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.

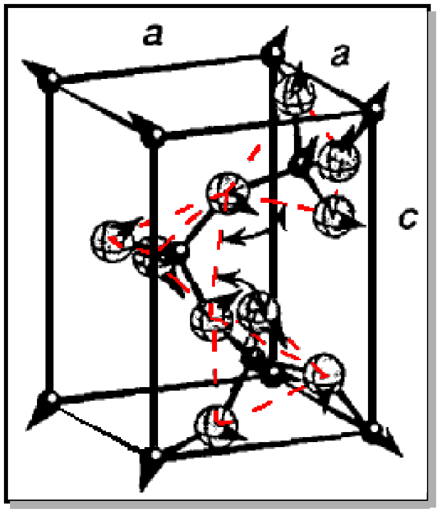
A. Yeganeh-Haeri *et al.*, *Science*, **257** (1992) 650

Deformation mechanisms: Rotating tetrahedra

Keskar & Chelikowsky

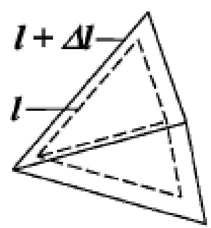
CTM

Alderson *et al.*

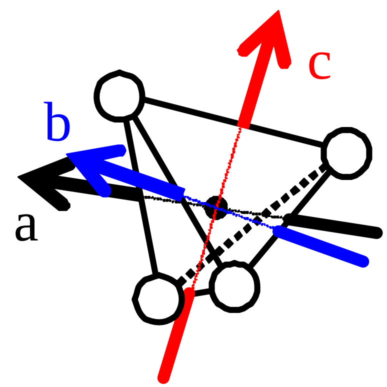


. . . *rotation of* SiO_4 *tetrahydra*

DTM



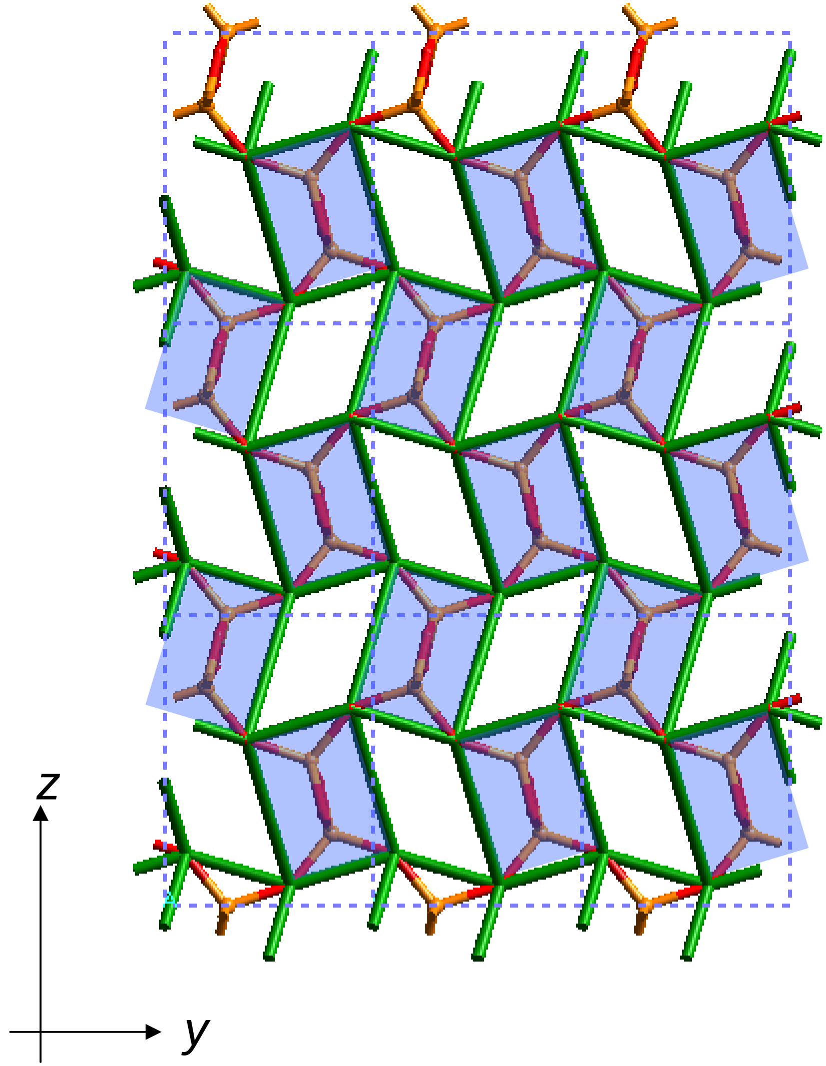
RTM 1 + 2



tetrahedra expand / shrink without changing relative orientation

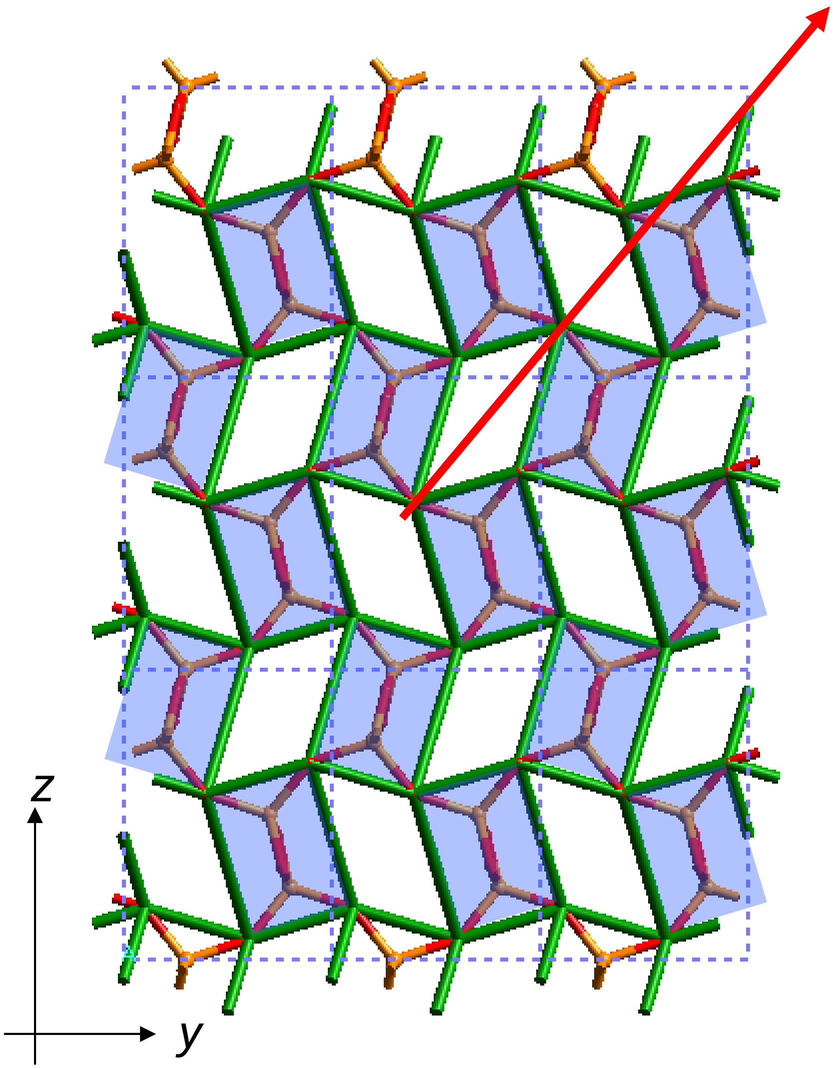
Tetrahedra rotate relative to each other @ two distinct local axis without changing shape

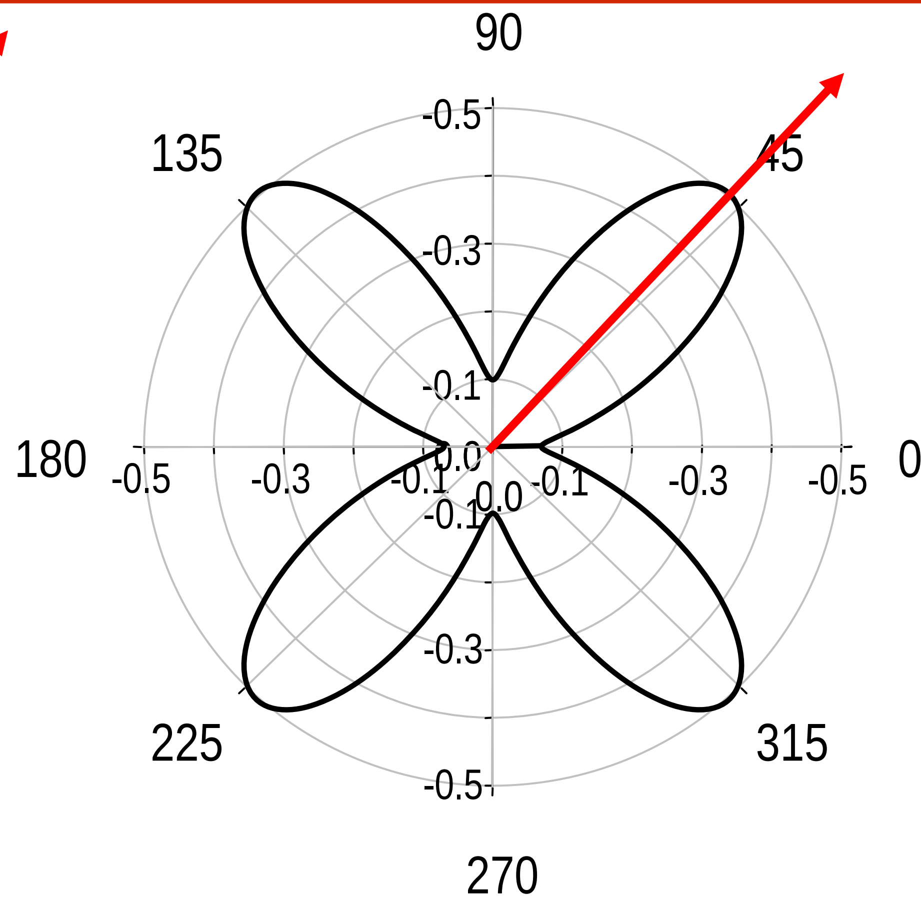
Deformation mechanisms – 2D model



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

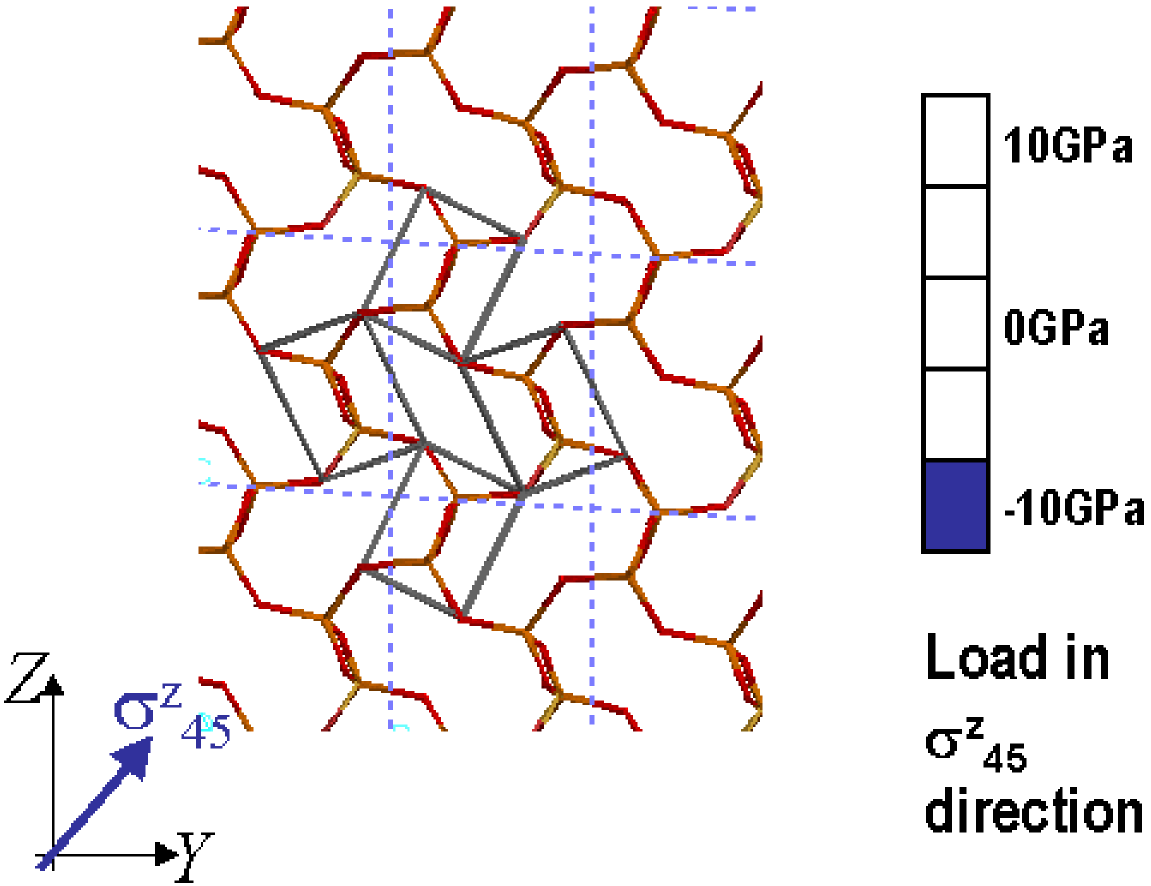
Deformation mechanisms – 2D model





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

Rotating rectangles model: Molecular Modelling

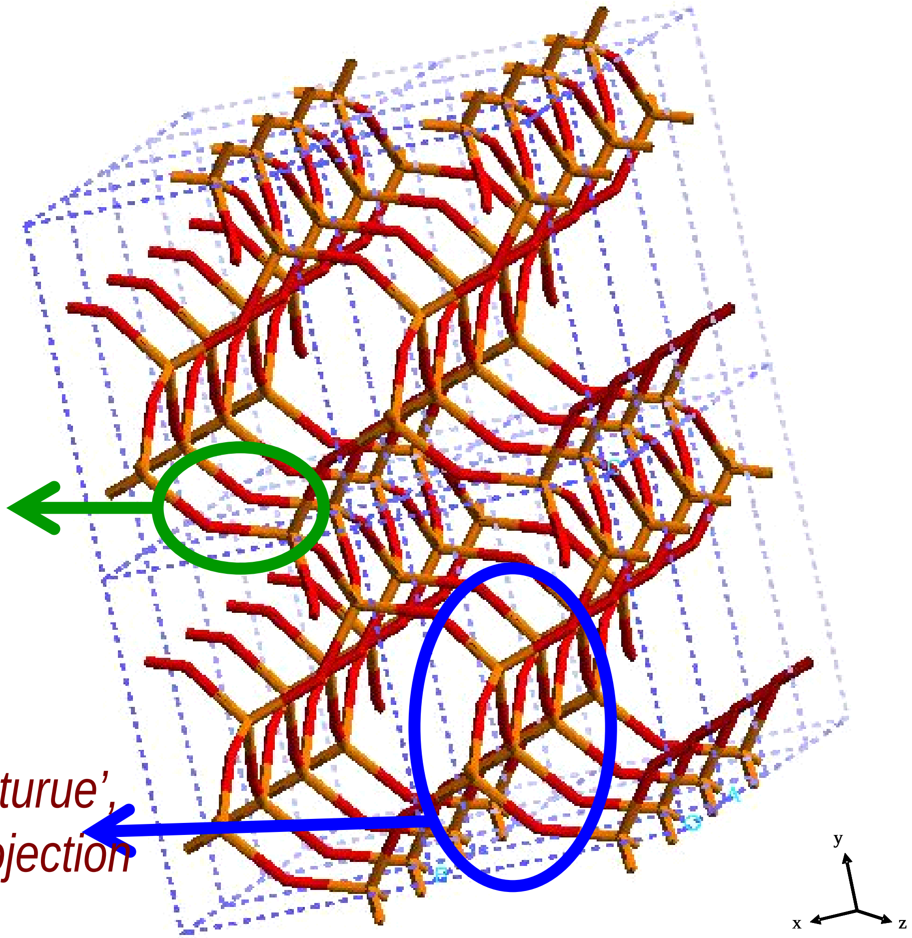


Load in σ^z_{45} direction

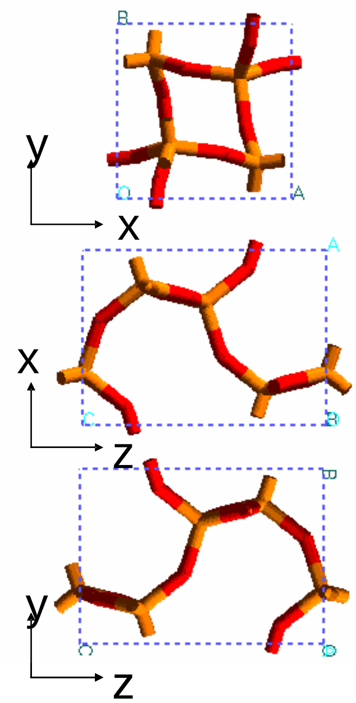
. . . Rotating Rectangles mechanism taking place in the (100) plane

Rotating Rectangles model: Molecular Modelling

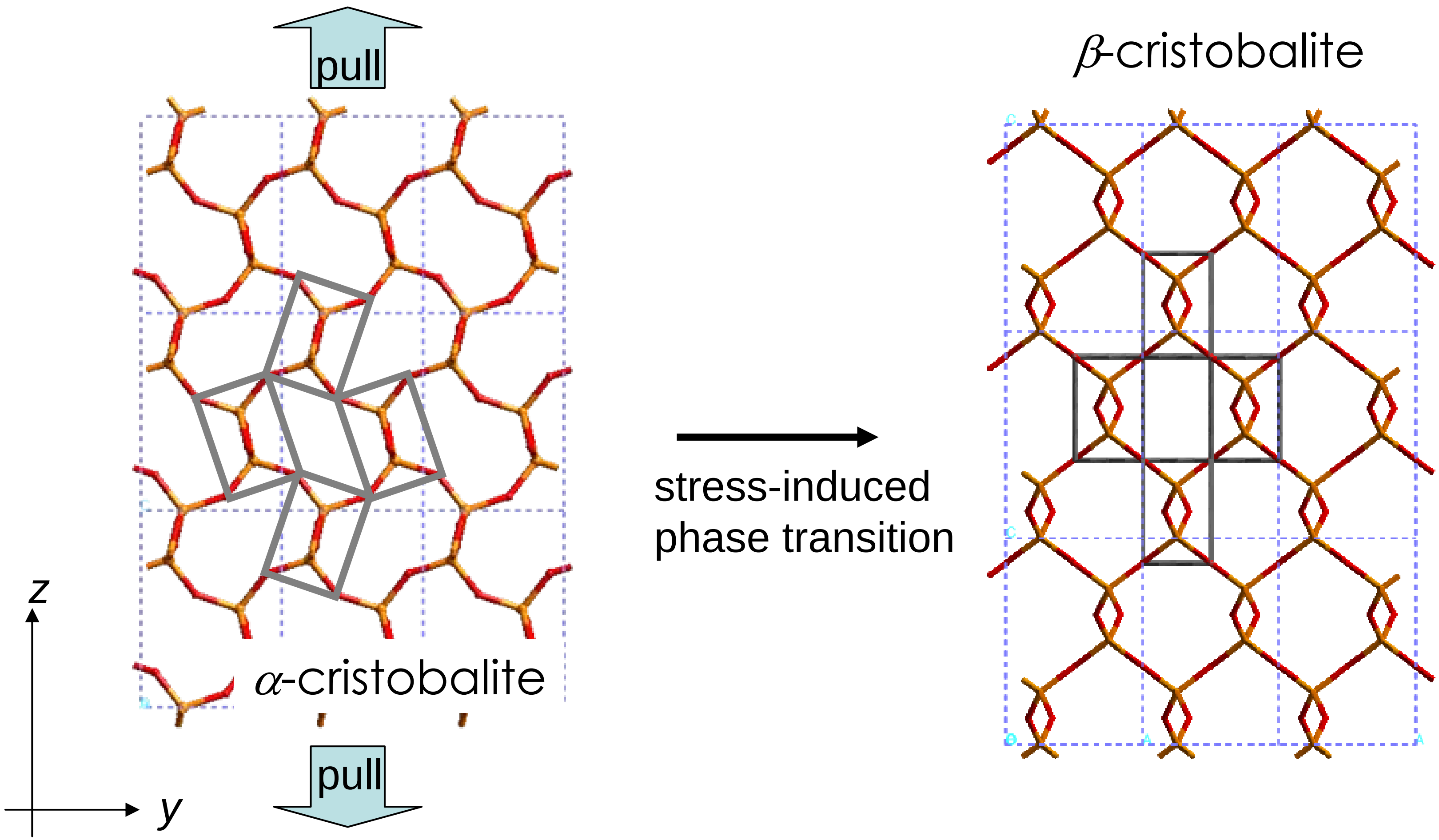
Soft Si – O – Si bonds representing the hinges



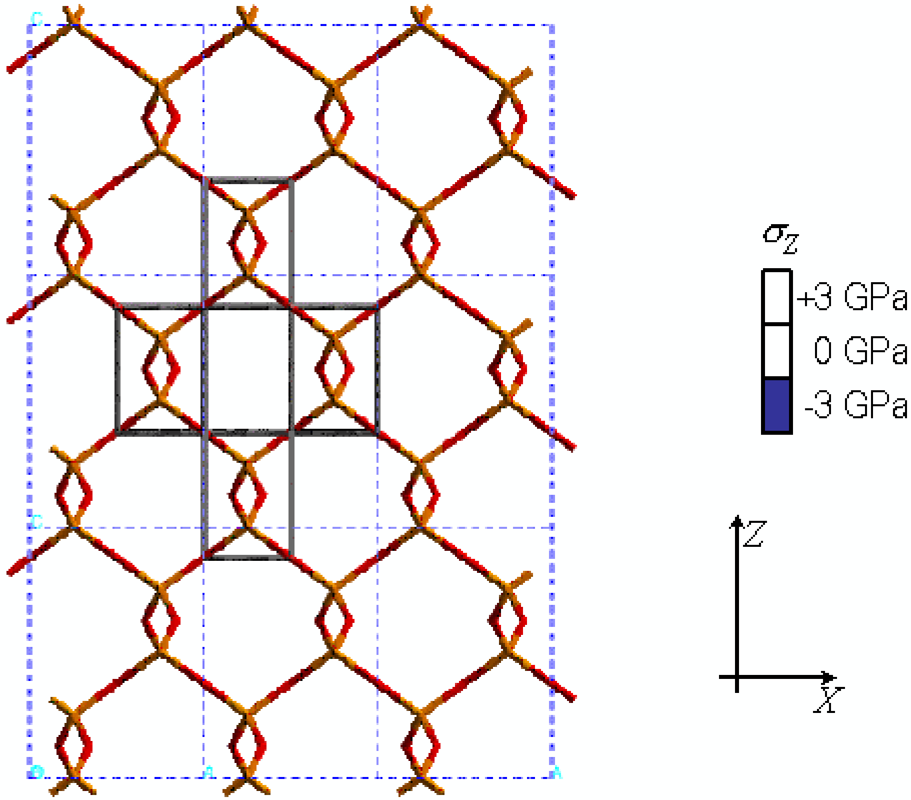
A rigid 'columnar structurue', with a 'rectangular' projection in yz-plane



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

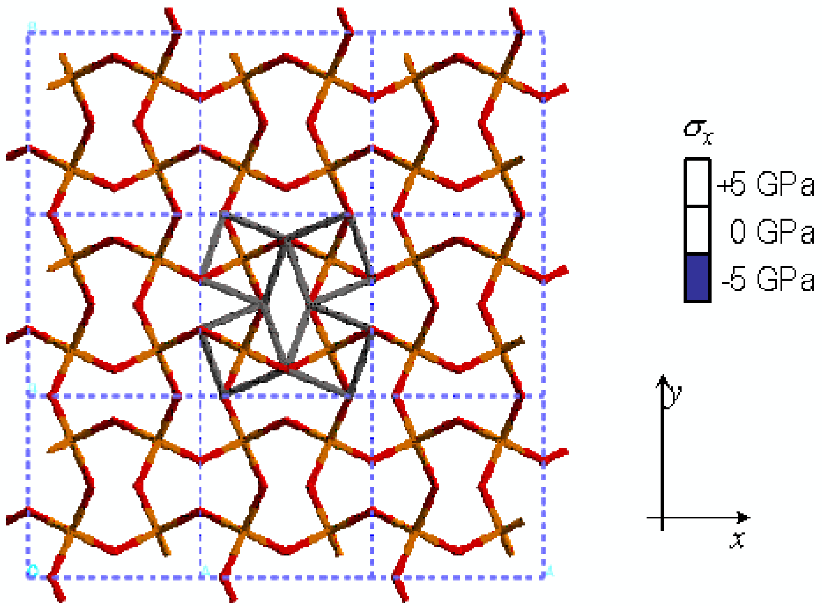


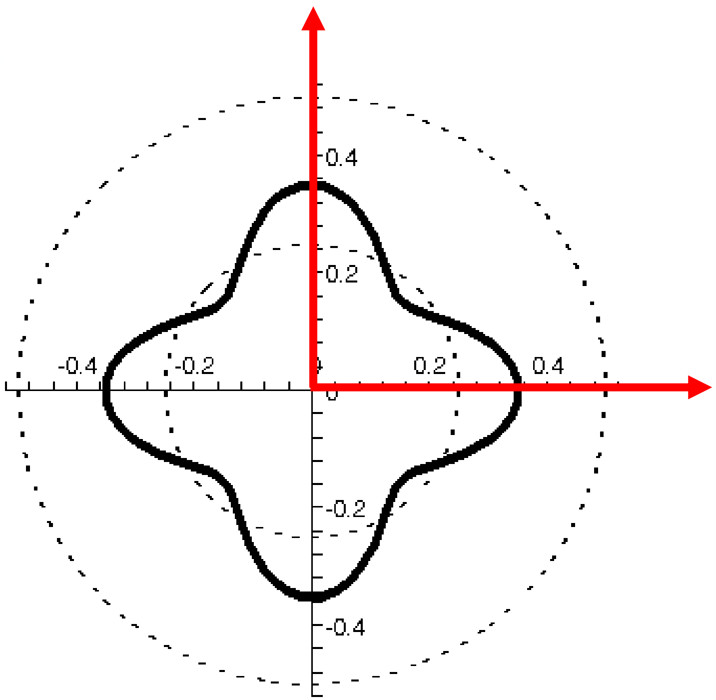
Loss of NPR for the $\alpha \rightarrow \beta$ transition: an explanation



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

NPR in 'ordered' β-cristobalite – an explanation

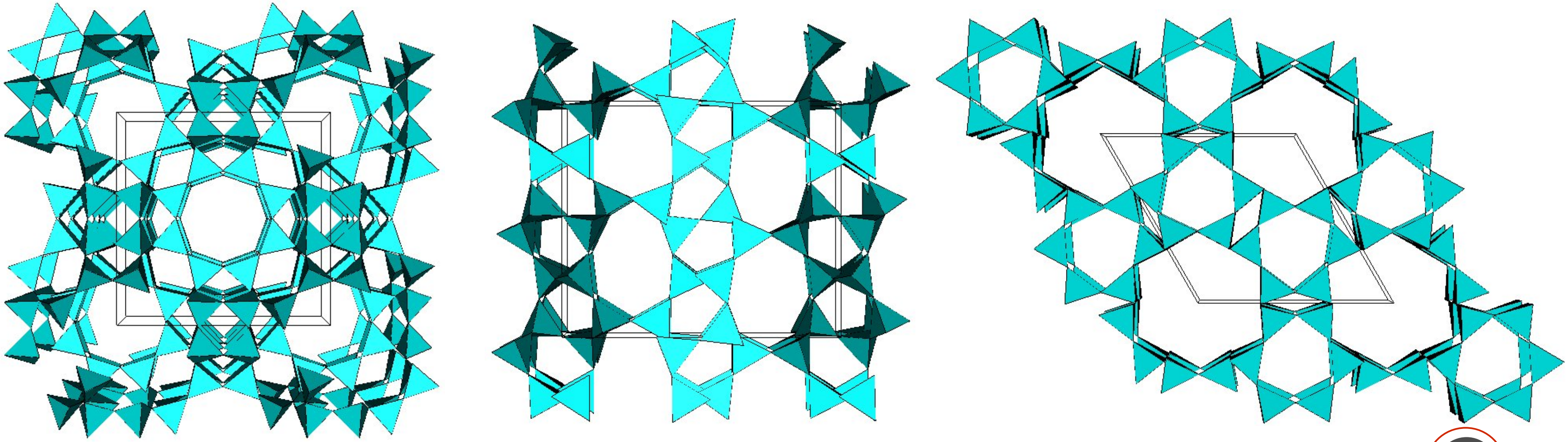




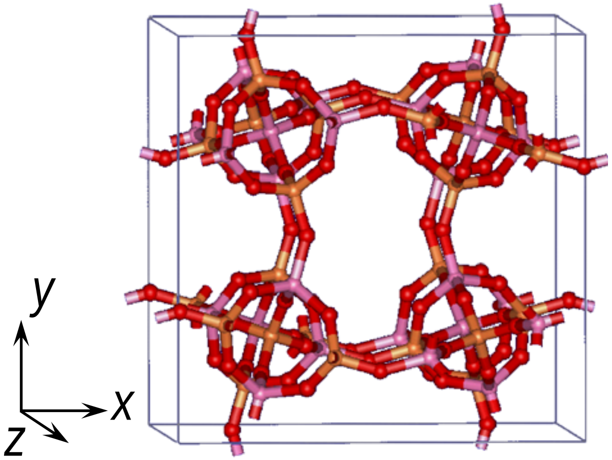
. . . Rotating squares mechanism taking place in the (001) plane

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)*

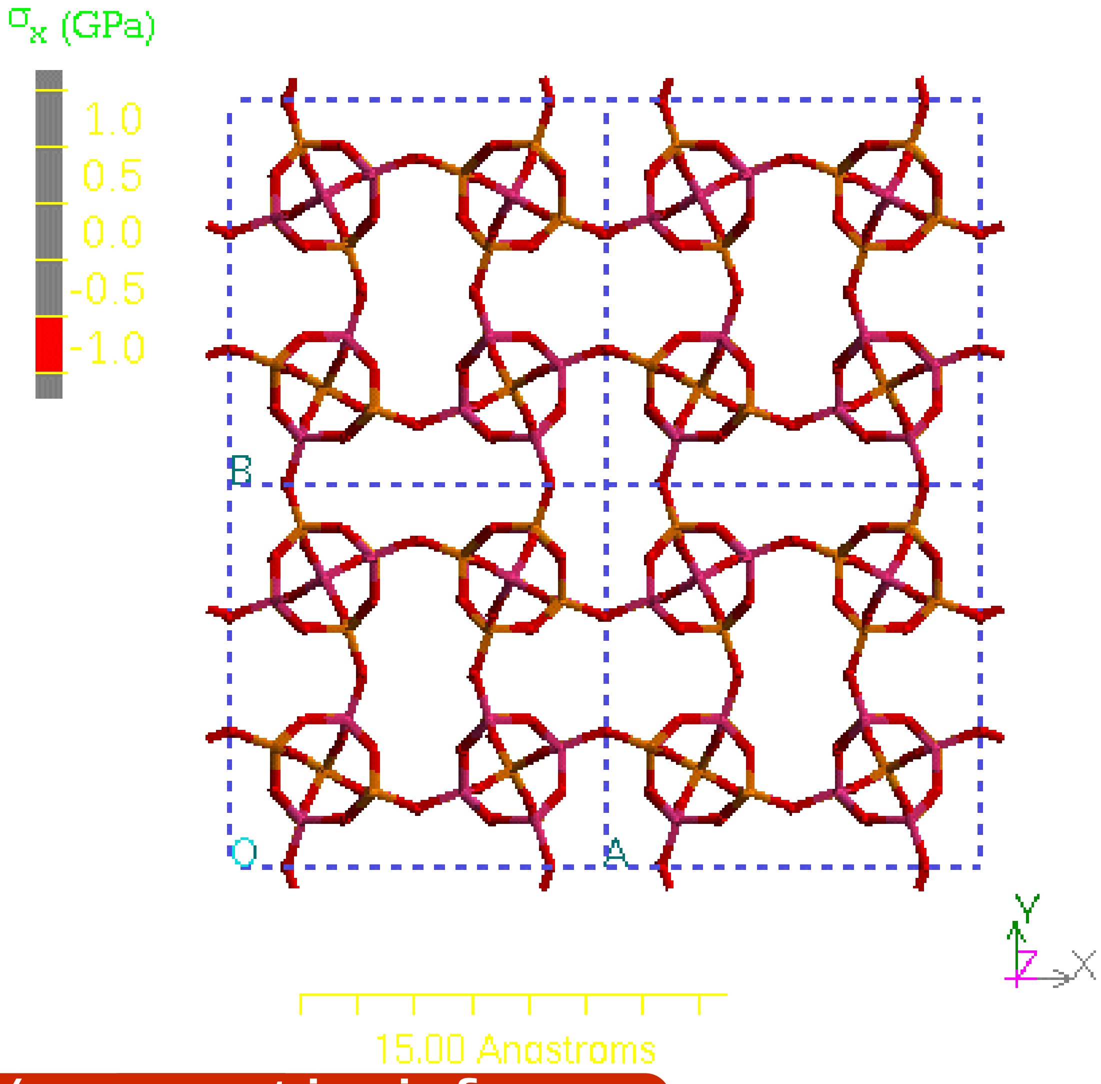
$Na_4Ca_8[\mathbf{Al_{20}Si_{20}O_{80}}]\ .\ 24\ H_2O$

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

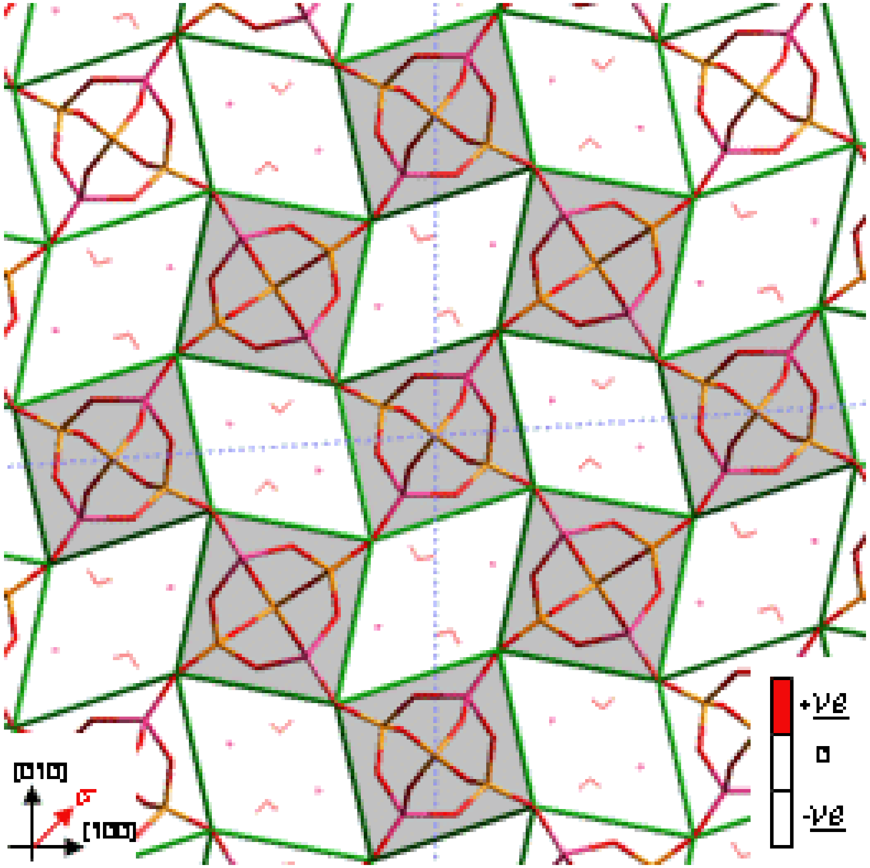
Force-field	ν_{xy}	ν_{yx}
Burchart[1]	-0.55	-0.55
BKS[2]	-0.33	-0.53
Universal[3]	-0.33	-0.40
CVFF[4]	-0.46	-0.46

(1) Burchart, PhD. Thesis, Delft. Univ. Tech, (1992)
(2) Van Beest *et. al.*, *Phys. Rev. Lett.*, **64** (1990) 1955
(3) Rappe *et al.*, *J. Am. Chem. Soc.* **114** (1992) 10046
(4) Cerius[2] User Guide, MSI Inc., San Diego, USA (1996)

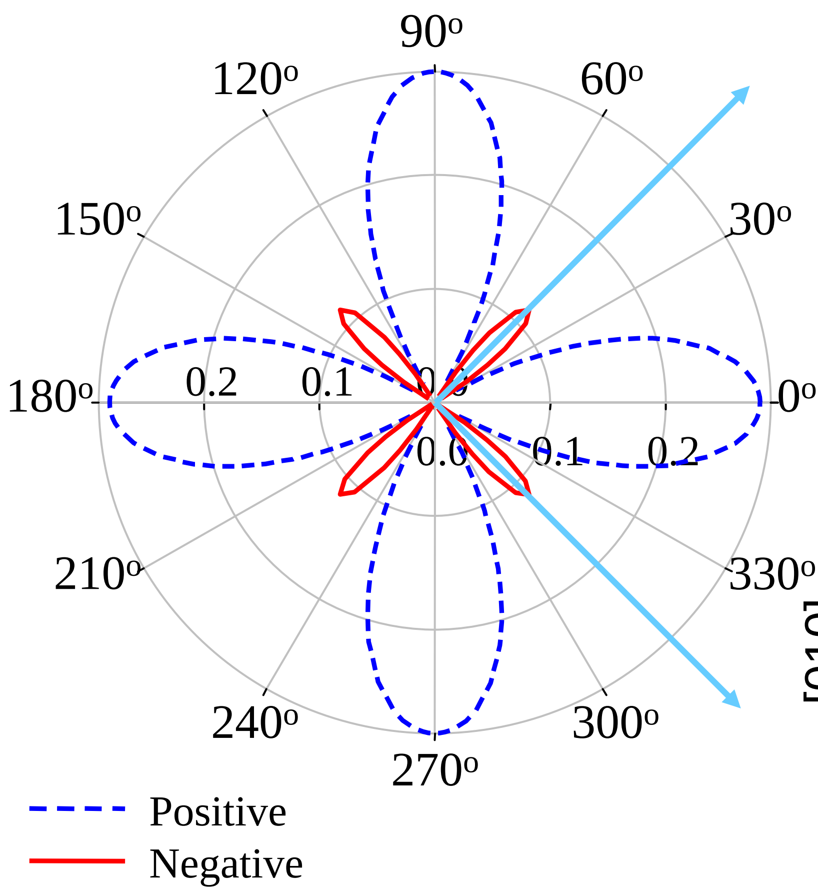
THO: deformations

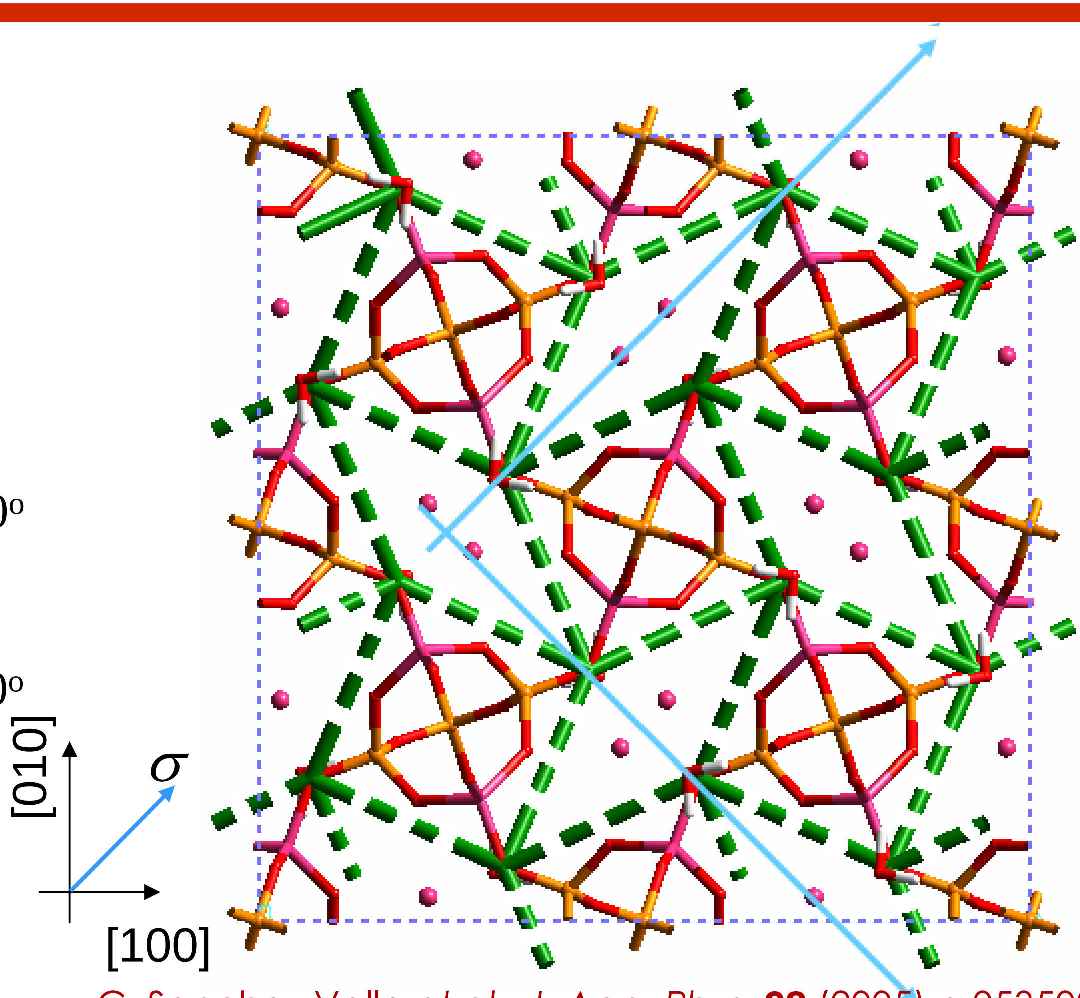


Natrolite (NAT): Deformation



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;**

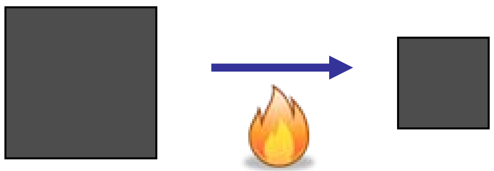
- There are various types of auxetics … model structures, polymers, foams, zeolites, etc. etc.

- Can be explained by 'geometry-deformation mechanism' based models;

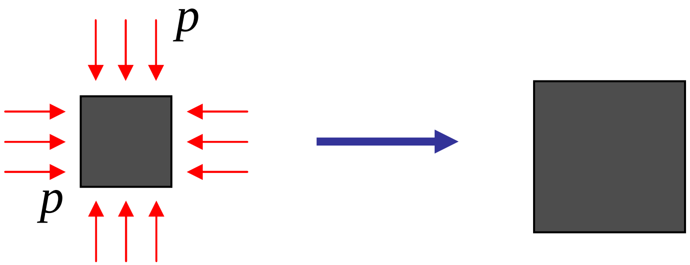
- Nature can teach us how to 'make' auxetics.

Other thermo-mechanical metamaterials

- Negative Thermal Expansion



- Negative compressibility



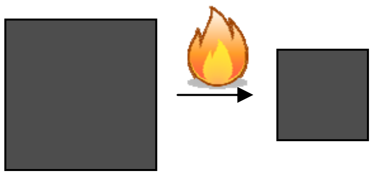
Negative Thermal Expansion: NTE

$$\alpha_V = \frac{1}{V}\frac{\partial V}{\partial T} \qquad \alpha_L = \frac{1}{L}\frac{\partial L}{\partial T}$$

NTE

Cooling … systems get larger

Heating … systems get smaller

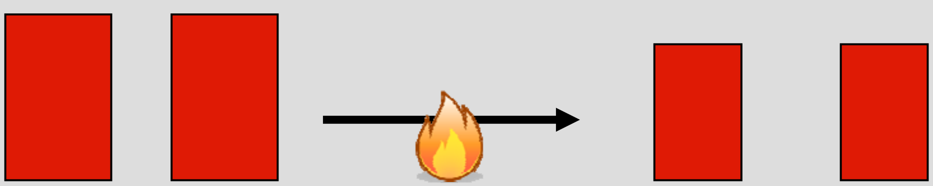


e.g. water near its freezing point

Applications

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

- Ensure that gap remains in diffraction gratings / sensors

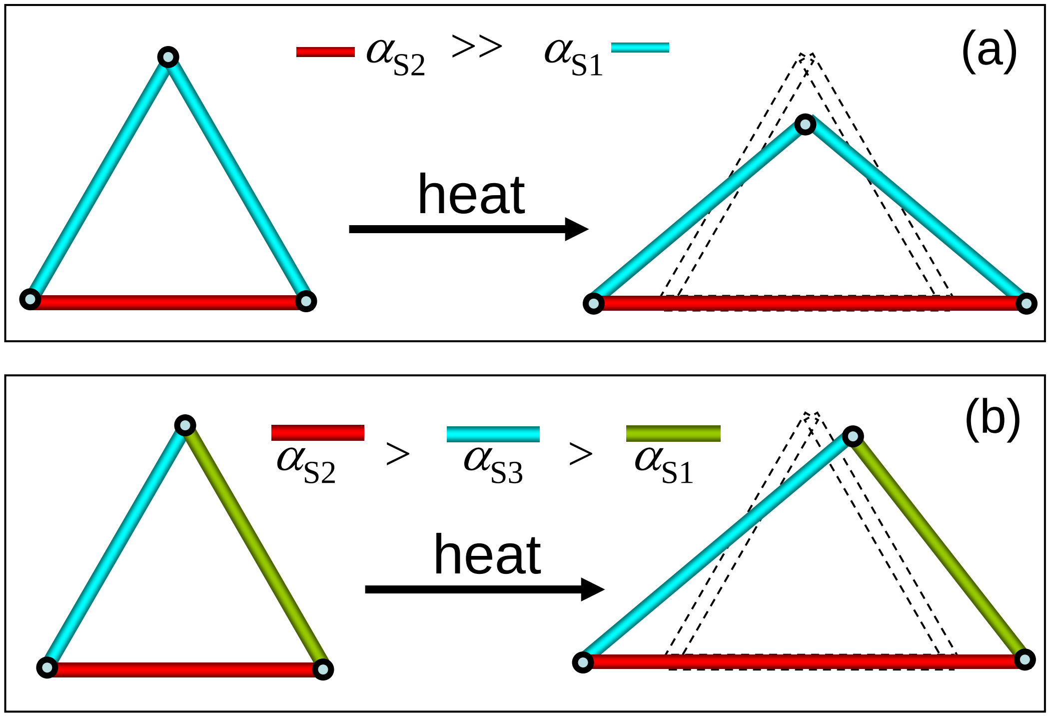


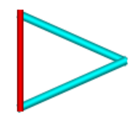
Problem …

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

Solution ????

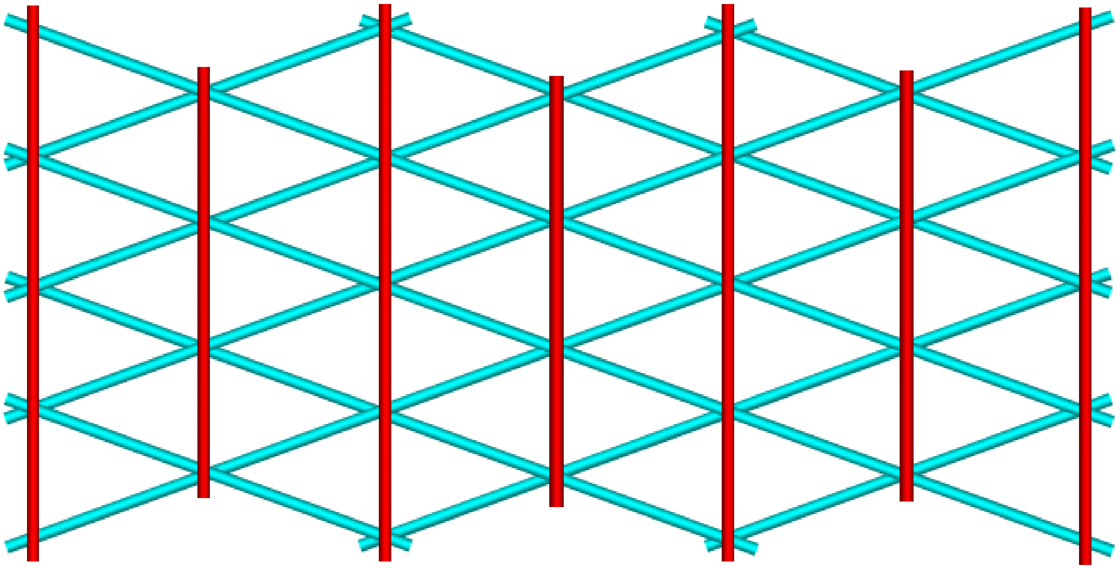
Concept: the flattening of a triangle





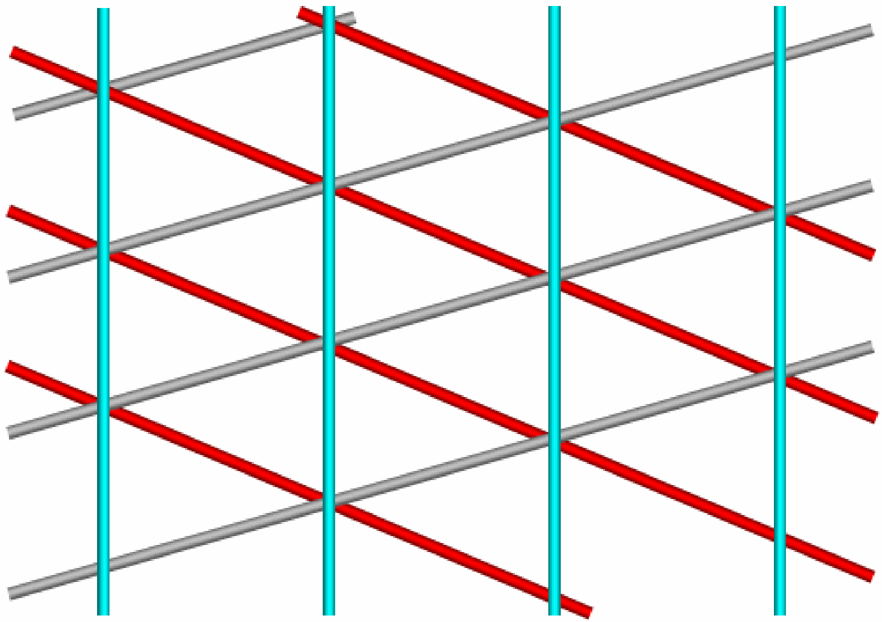
[1] LJ Vandeperre, A Howlett, & WJ Clegg, *Int. Conf. on Modern Materials and Technologies, Florence* (2002).
[2] LJ Vandeperre & WJ Clegg, *MRS Symposium Proceedings*, **785** (2003) D11.4.
[3] D Cao, F Bridges, GR Kowah & AP Ramirez, *Phys. Bev. B*, **68** (2003) 014303.
[4] CW Smith *et al.*, *Auxetic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

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

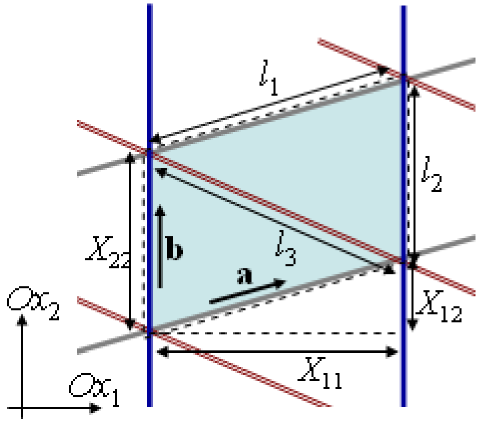
$$- \left[2 l_2^2 X_{11}^2 \alpha_{S2} + l_1^4 \alpha_{S1} + l_2^4 \alpha_{S2} + l_3^4 \alpha_{S3} \right] \frac{1}{2 l_2^2 X_{11}^2}$$

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

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

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

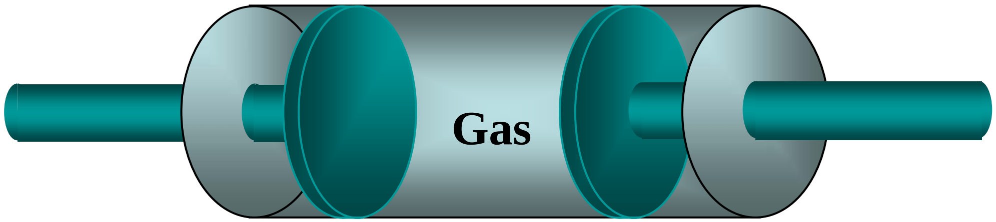
$$\alpha(\zeta)_{\max/\min} = \frac{\alpha_{11} + \alpha_{22}}{2} \pm \sqrt{\left(\frac{\alpha_{11} - \alpha_{22}}{2} \right)^2 + \alpha_{12}^2}$$

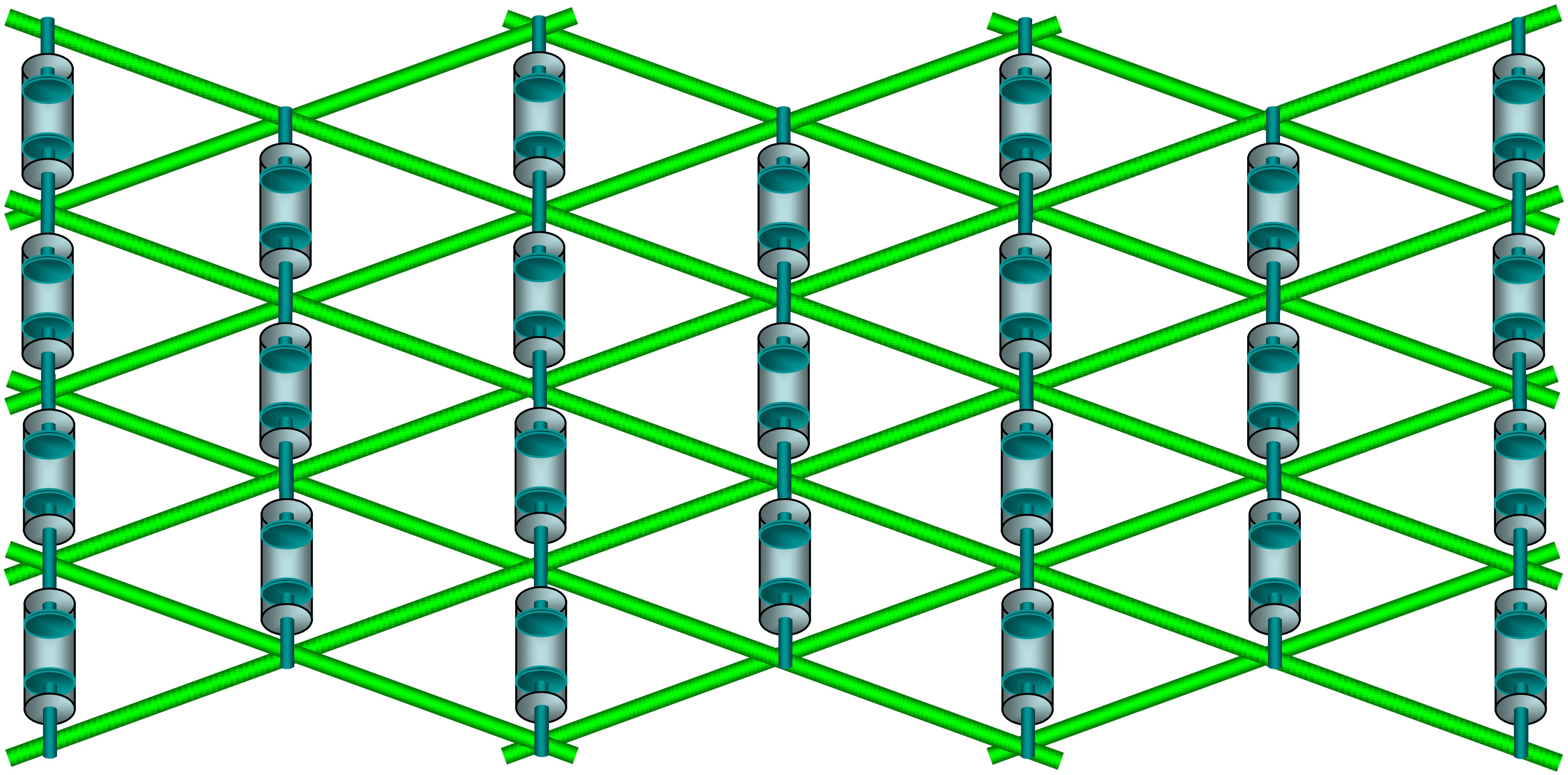


Implementation (3) ...

Maximizing the effect

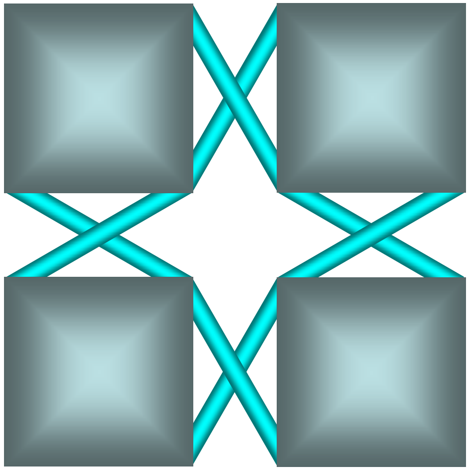
... use of gases

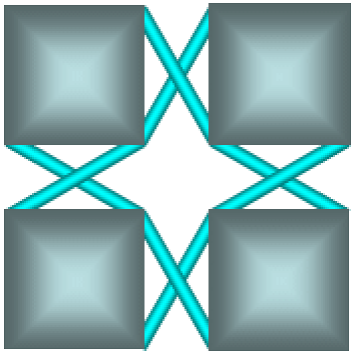




Implementation (4)...

- Clegg & Vandeperre

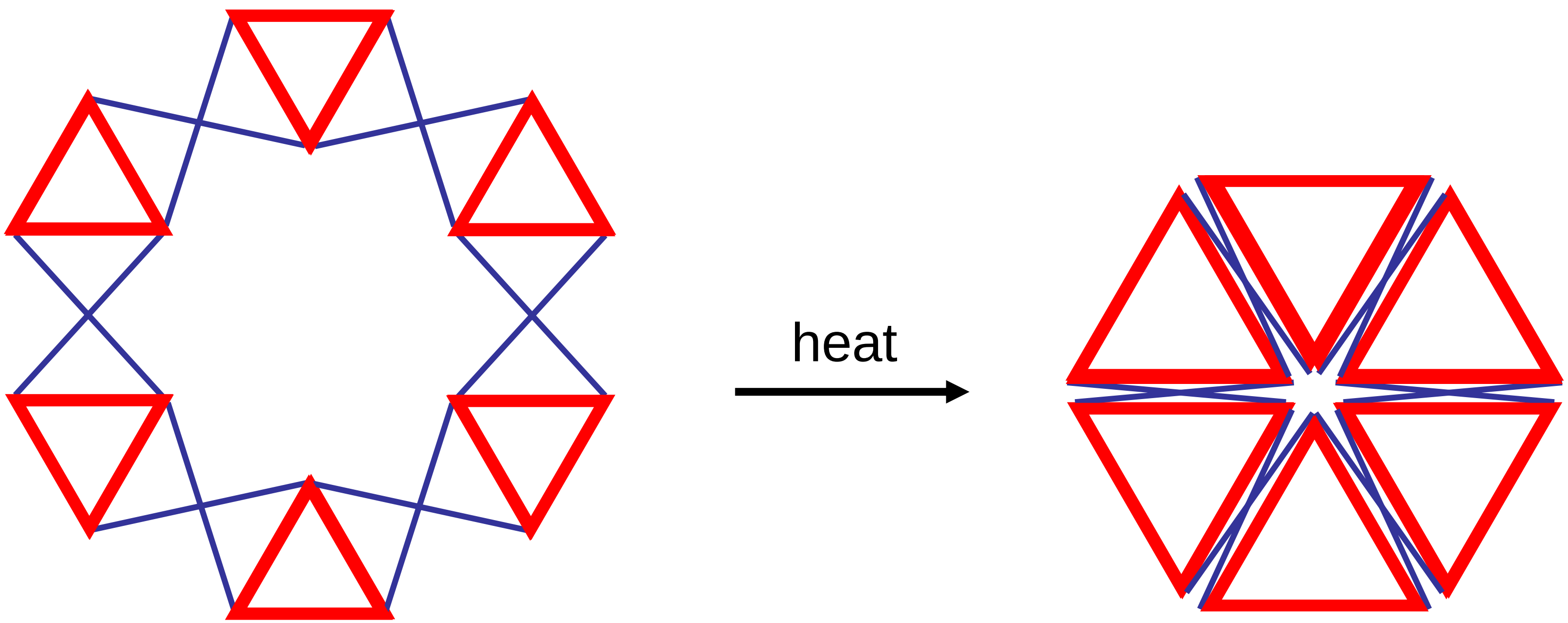




A 2D network which can generate isothermal NTE
(squares can be hexagons or triangles)

Implementation

- Also possible with triangles & hexagons …



Is this important??? …New Scientist

29 March 2007

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."

...CORDIS focus Newsletter

Issue number 278 — May 2007

ISSN 1022-6559

CORDIS focus Newsletter

http://cordis.europa.eu

In this issue

CORDIS

EN

Publications Office

MEPs approve regulation for innovative therapies

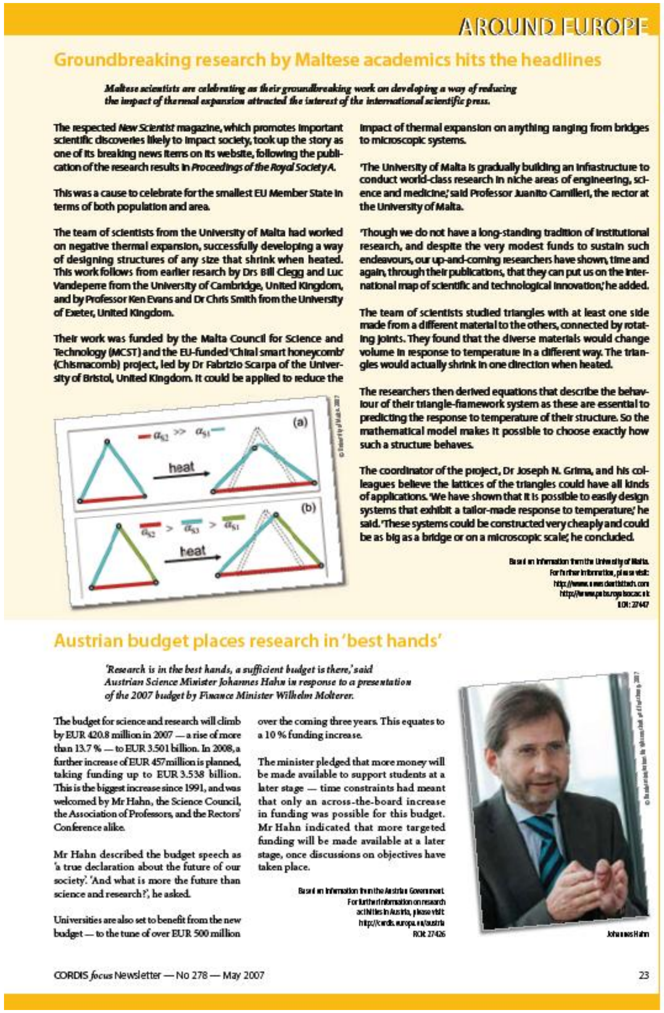
A proposed regulation on marketing innovative therapies and on monitoring patients and products post-authorisation, was approved by the European Parliament (EP) on 25 April 2007.

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



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 resarch by Drs Bill Clegg and Luc Vandeperre 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.

Based on information from the University of Malta.
For further information, please visit:
http://www.newscientisttech.com
http://www.pubs.royalsoc.ac.uk
RCN: 27447

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 Wilhelm Molterer.

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 457 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.

Based on information from the Austrian Government.
For further information on research activities in Austria, please visit:
http://cordis.europa.eu/austria
RCN: 27426

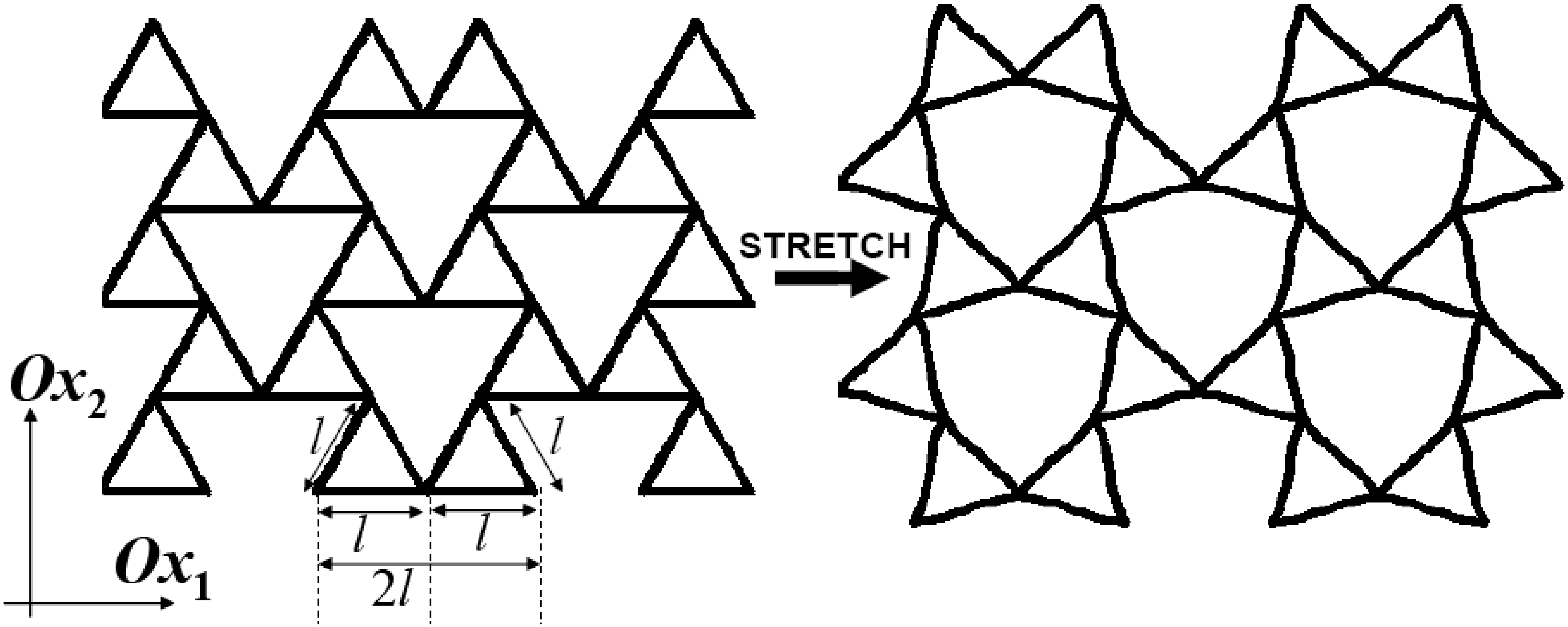
Johannes Hahn

Can a system exhibit both NPR and NTE?

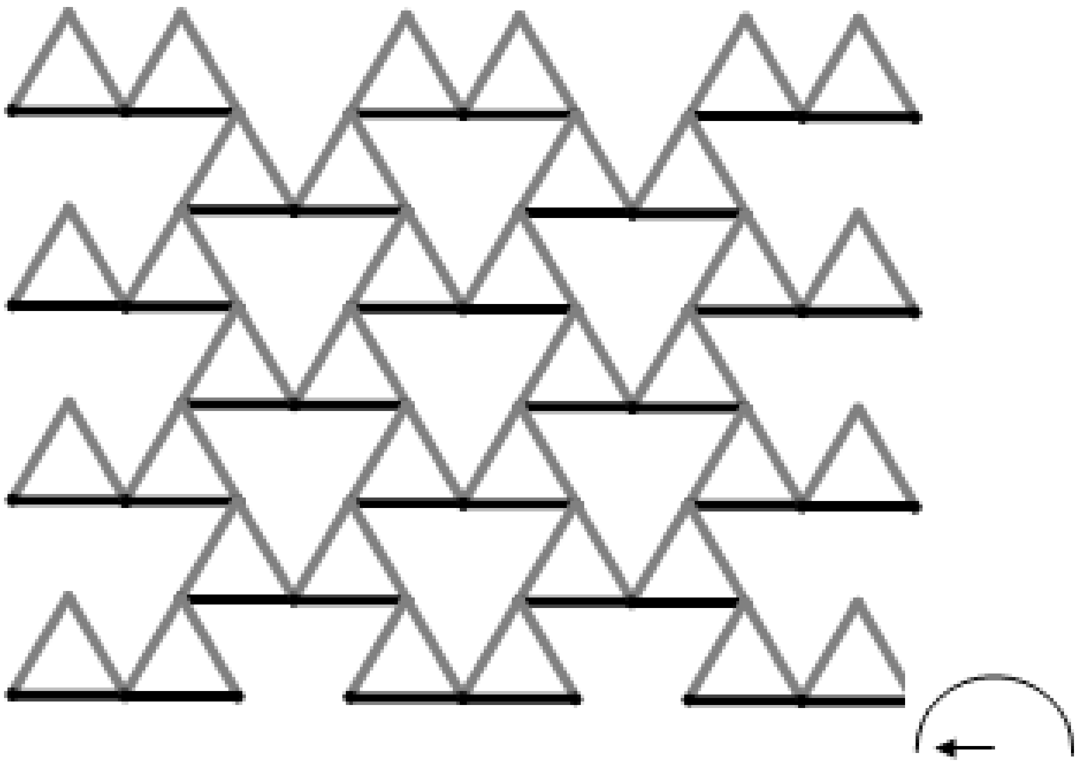
… For example the rotating triangles system

Auxeticity from 'Rotating Triangles' geometry

Negative Poisson's ratio

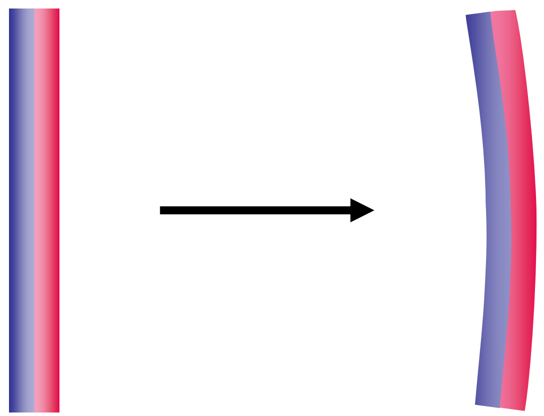


J.N. Grima, *et al.*, *J. Phys. Soc. Jpn.*, **76** (2007) 025001



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

Case Study 2: Bi-materials

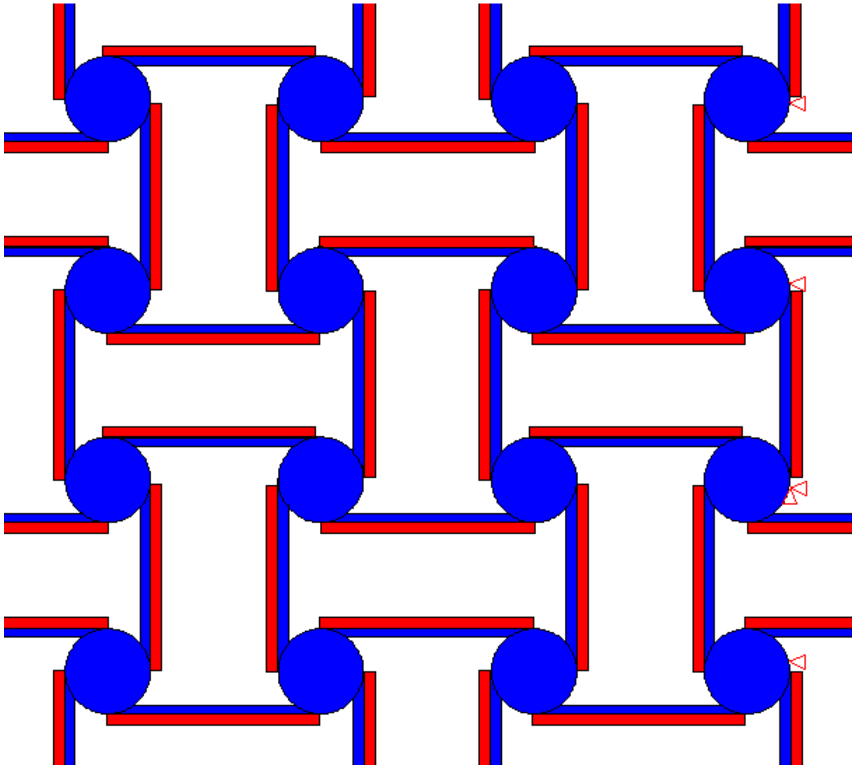


Heating a bi-material with components having different thermal expansion coefficients will cause a curvature

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

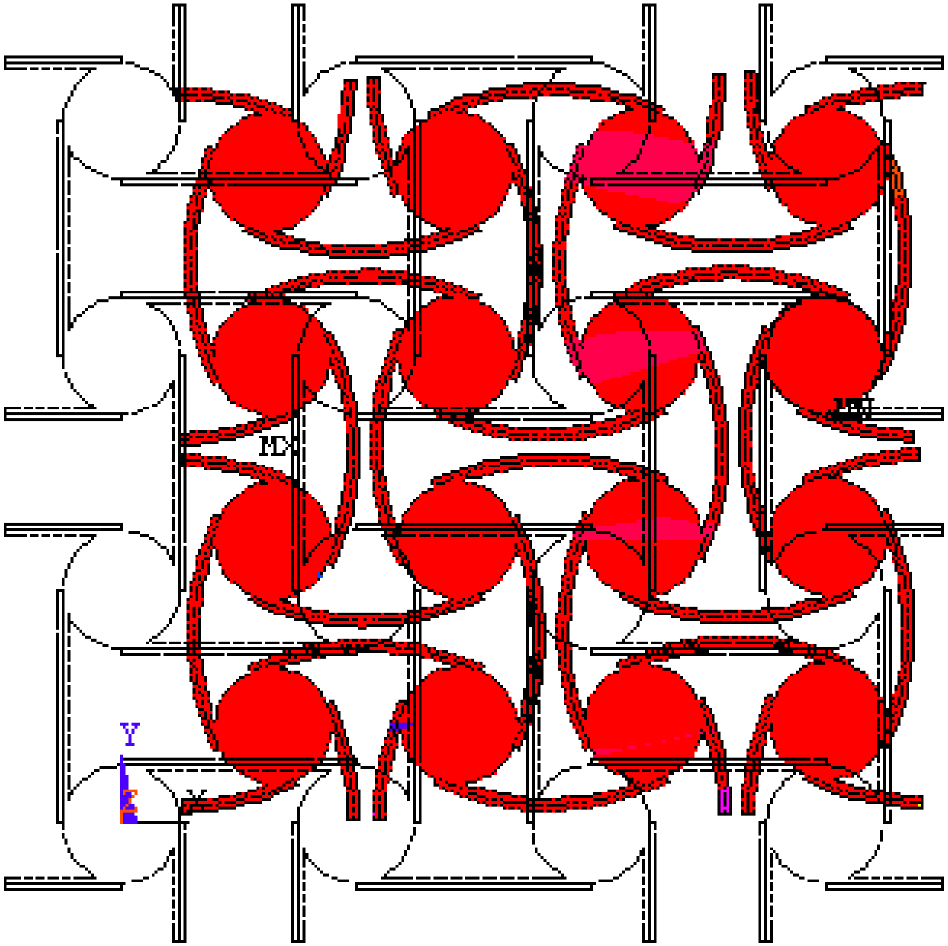
Implementation ...

- 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 x 10^5	1.20 x 10^5
Poisson's ratio:	0.3	0.3
Coefficient of Thermal Expansion:	5 x 10^{-7}	0.00011

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

***i* MA**

engineering & research

(Ing. Michael Attard)

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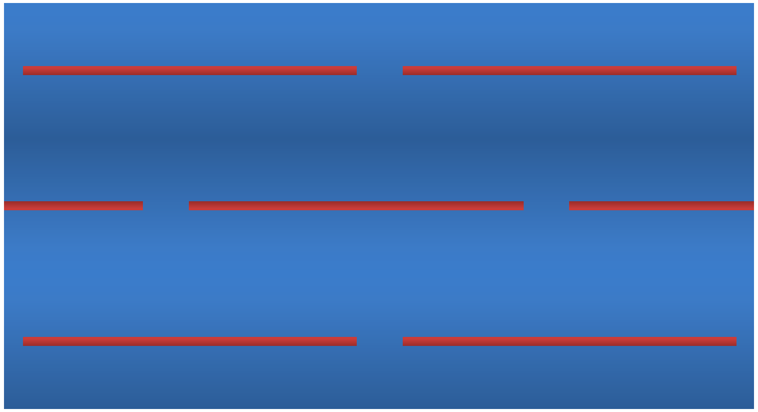
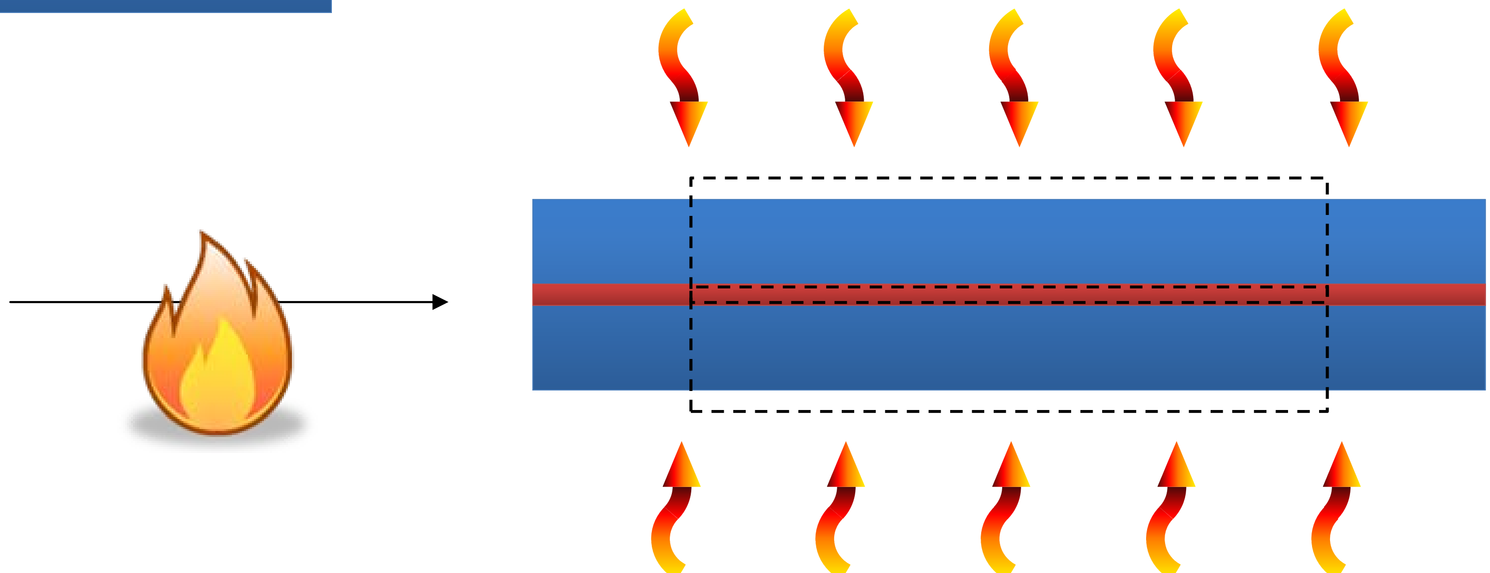


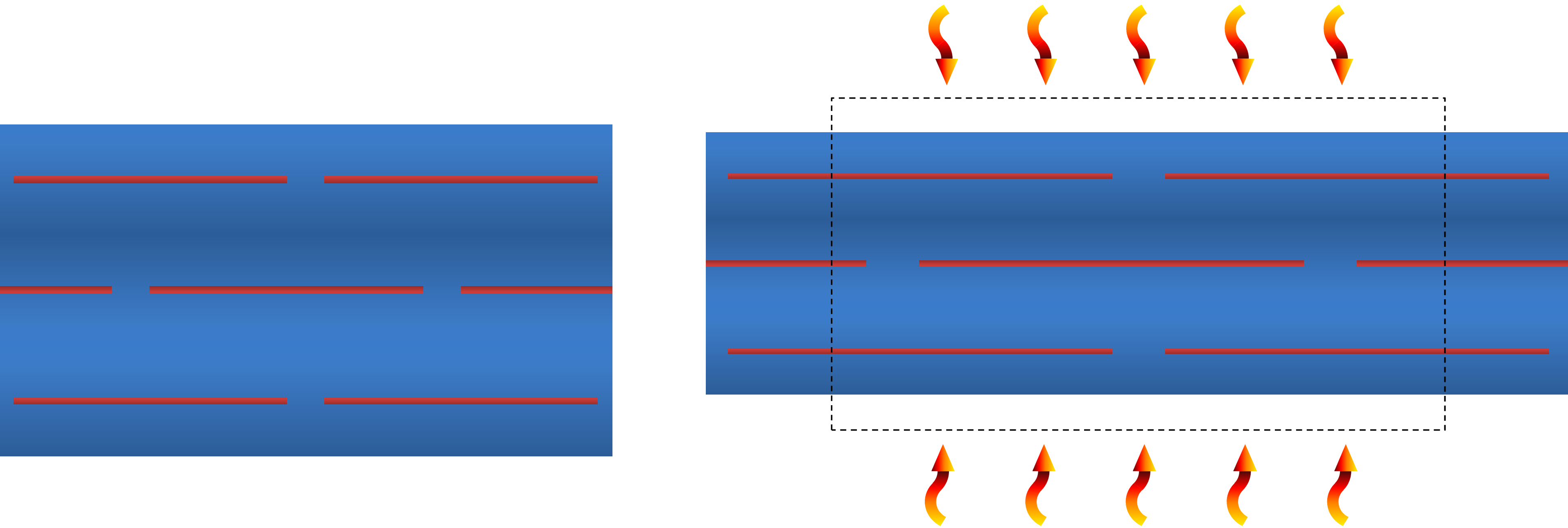
Case Study 3: NTE in composites with Needle-Like inclusions

i MA
engineering & research

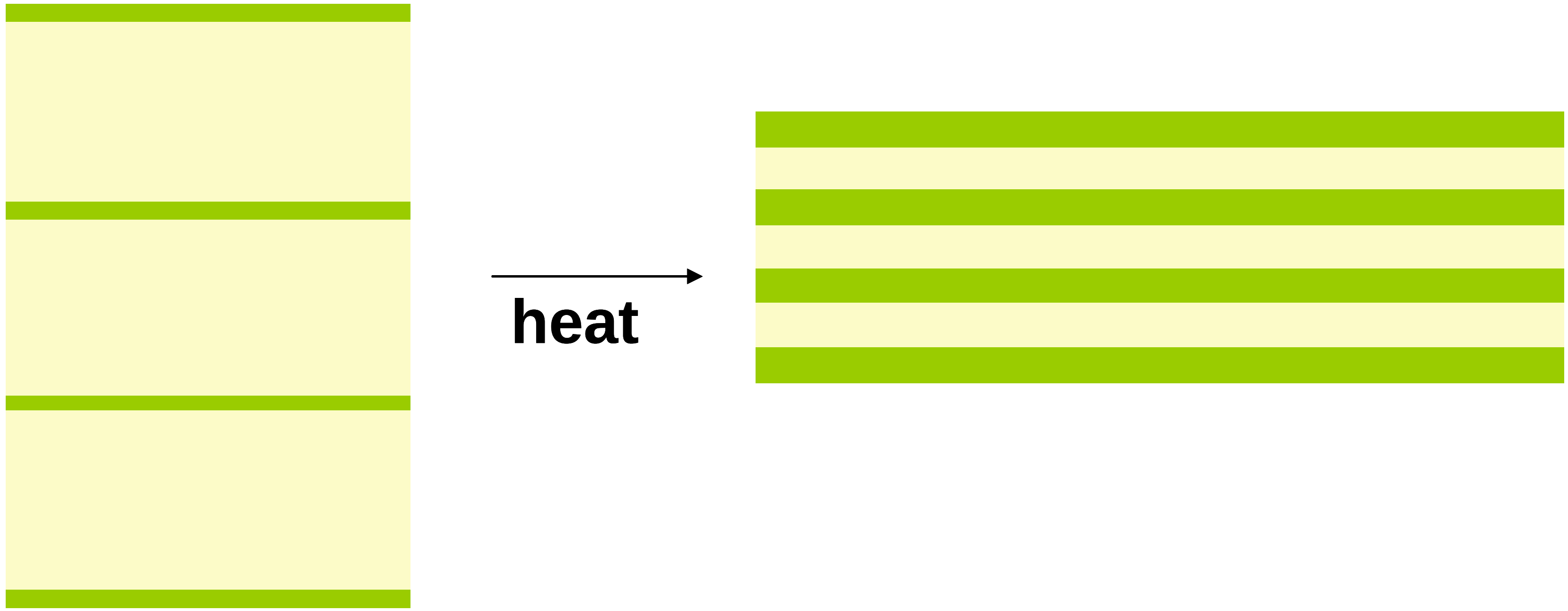


J.N. Grima *et al.*, Comp. Sci. Tech. (2010)

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.

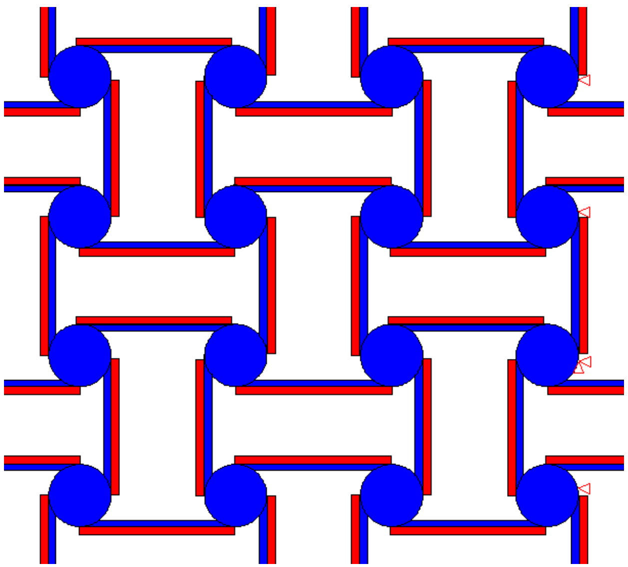
$$\beta = \frac{1}{K} = -\frac{1}{V}\frac{\partial p}{\partial V}$$

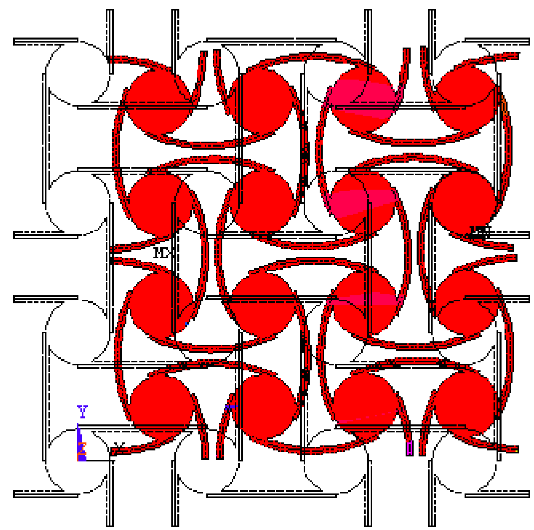
← **Normally negative**

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

Negative Compressibility

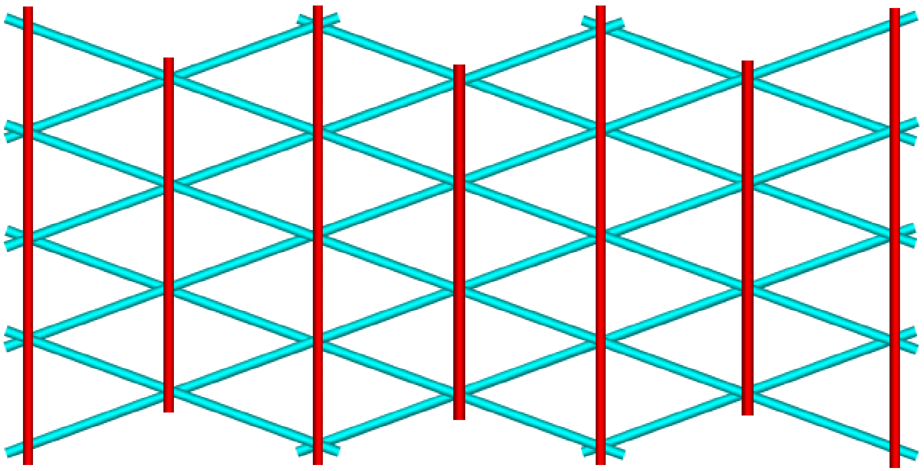
- Bimaterials also bend when subjected to a change in pressure if constituent materials have different Young's moduli and/or Poisson's ratio

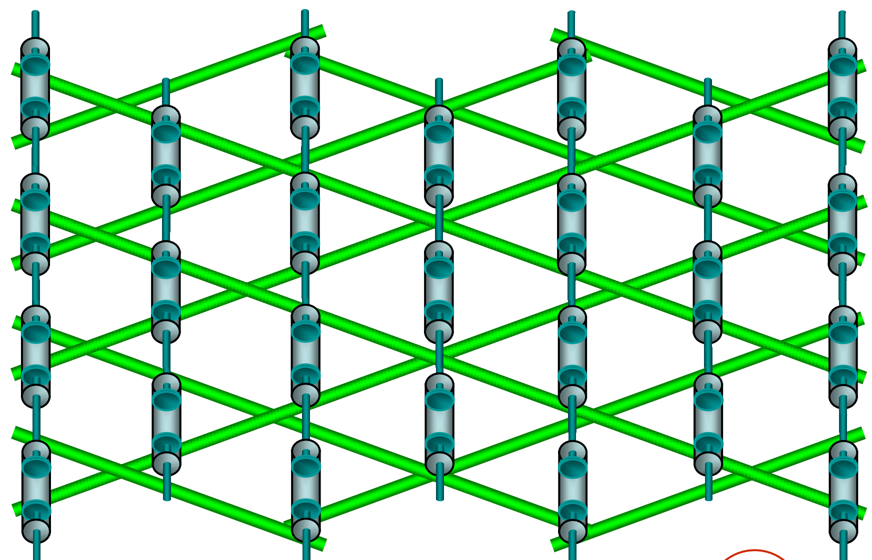




R. Gatt & JN Grima, Scripta Mater. (2007)
R. Gatt & JN Grima, Phys. Stat. Sol RRL. (2007)

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