

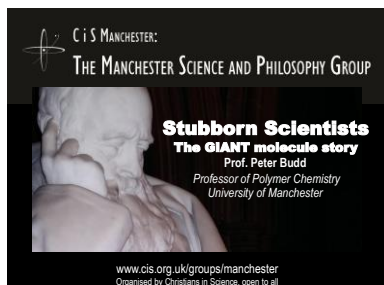
# Stubborn Scientists: The GIANT molecule story

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*Thursday 9<sup>th</sup> March 2017, Oxford Room, St. Peter's House, Manchester*



I'm a scientist.

A Professor of Polymer Chemistry at the University of Manchester.

In science, we always try to be as objective as possible.

To be honest in how we evaluate our experimental evidence.

To be critical in how we develop our ideas.

But we scientists are also people.

People with our own personalities, beliefs and cultural backgrounds.

People who bring our own presuppositions and assumptions to our work.

So, how much of an impact does human nature have on scientific progress?

Do stubborn scientists help or hinder our quest to understand something about the world we inhabit?

And perhaps a particularly interesting question concerns what role might be played by a scientist's beliefs about God.

Of course, there are some well-known scientists who have made plain their belief that there's no God.

And sometimes that gives the impression that a belief in a God is somehow incompatible with science.

But is that generally true, for real scientists doing real science?

What I'm going to do this evening, is tell you a bit of the story of my own subject area.

And of some of the scientists involved in that story.

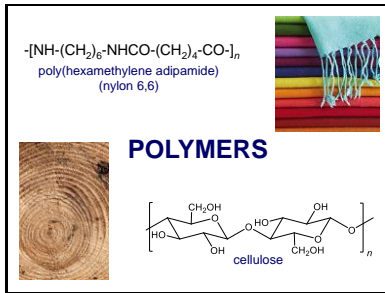
The story of giant molecules.

It's a story involving people who stubbornly pursued a new idea, against all odds.

And people who desperately clung to old ideas, against growing evidence.

It's a story including people who worked right here in Manchester, and in the North West of England.

And it's a story involving many scientists who had a profound belief in God.



I'm a Professor of Polymer Chemistry.

If we look around, much of what we see is made up of polymers.

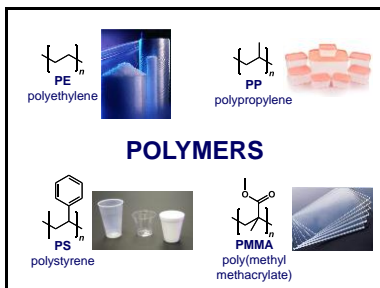
The textiles in the clothes we wear.

They may be man-made – synthetic – polymers, like polyesters and polyamides.

Or they may be natural polymers, like cotton – cellulose, a polysaccharide.

Then there's wood and paper.

It's that same polysaccharide – cellulose – that gives them structure.

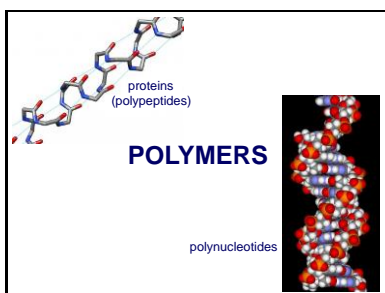


The plastics that are ubiquitous in modern life.

They're polymers like polyethylene, polypropylene, poly(styrene), poly(methyl methacrylate) and so on.

The paint we put on our walls.

It's a polymer that holds it together.



And our own bodies.

Our hair, skin and nails contain keratin – a fibrous protein – a polypeptide,

a polymer of amino acids.

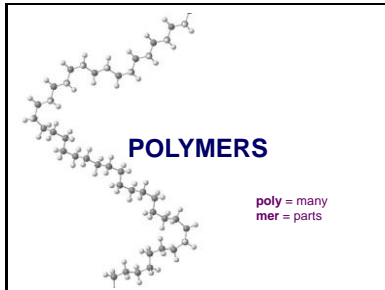
And other proteins are enzymes – catalysts for the biochemical reactions that keep us alive.

And as for the material that carries the genetic information that defines us:

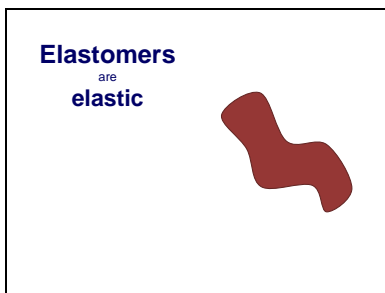
Deoxyribonucleic acid, DNA, is a polynucleotide.

If we look around, much of what we see is made up of polymers.

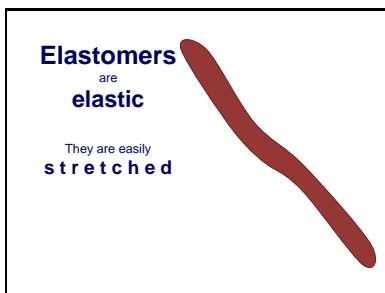
Much of what we are, depends on polymers.  
And we now understand that polymers are composed of enormous molecules.  
Giant molecules.  
Macromolecules.  
Molecules built up from many, many smaller repeat units.



We now understand that polymers are composed of giant molecules.  
But it took a long time for that understanding to develop.  
Polymers were known, polymers were used, polymers were called “polymers”,  
long before people really understood what they were.  
So how did the story of giant molecules come about?




Some polymers are rubbery or elastomeric materials.  
Have you ever picked up a rubbery material, like a balloon, and thought:  
“Wow. This is amazing.



I can stretch it, and when I let go it snaps right back into its original shape.

**Elastomers**  
are  
**elastic**

They are easily  
**stretched**  
then  
**recover**  
their original shape



Somehow, it remembers the shape it was before.

How does it do that?

How do we explain that?"


Those are the sorts of question a scientist asks.

The sorts of question a scientist tries to answer.

**NATURAL RUBBER**

$$\left[ \begin{array}{c} \text{CH}_3 \\ | \\ \text{C} = \text{C} \\ | \quad | \\ \text{CH}_2 \quad \text{CH}_2 \end{array} \right]_n$$

cis-1,4 polyisoprene



Natural rubber – nowadays we know it chemically as *cis* 1,4-polyisoprene – is produced by a variety of plants, including dandelions.

Commercially, it's usually obtained from the Pará rubber tree, *Hevea brasiliensis*.


A tree that originally came from the Amazon rainforest,

but is now cultivated in many places, such as India and Malaysia.

**NATURAL RUBBER**

$$\left[ \begin{array}{c} \text{CH}_3 \\ | \\ \text{C} = \text{C} \\ | \quad | \\ \text{CH}_2 \quad \text{CH}_2 \end{array} \right]_n$$

cis-1,4 polyisoprene



When the bark is cut, a milky fluid – a latex – oozes out.


The latex is an aqueous suspension of tiny rubber particles,

that can be isolated and processed into a rubbery material.

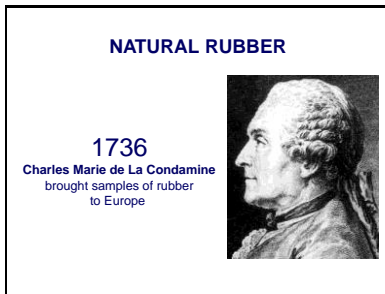
**NATURAL RUBBER**

$$\left[ \begin{array}{c} \text{CH}_3 \\ | \\ \text{C} = \text{C} \\ | \quad | \\ \text{CH}_2 \quad \text{CH}_2 \end{array} \right]_n$$

cis-1,4 polyisoprene



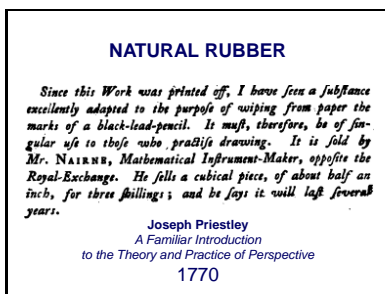
Natural rubber has been known for a very long time.  
In central America, rubber balls were used for games, and votive offerings,  
more than 3<sup>1</sup>/<sub>2</sub> thousand years ago.



It was a Frenchman named **Charles Marie de La Condamine**  
who first brought samples of rubber to Europe, in 1736.



The first scientific paper on the properties of rubber,  
written by **François Fresneau de La Gataudière**,  
was presented by Charles Marie in 1751 to the French **Académie Royale des Sciences**,  
and published in 1755.



In 1770, in England, **Joseph Priestley** noted,  
“I have seen a substance excellently adapted to the purpose of wiping from paper  
the marks of a black-lead pencil”

(Footnote on p. xv in the preface to  
*A Familiar Introduction to the Theory and Practice of Perspective*)

It was the ability to rub out pencil marks that led to this stuff being called “rubber.”

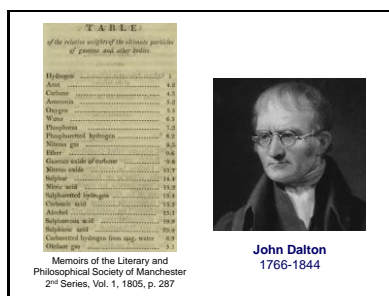
Joseph Priestley, of course, as well as noting the ability of rubber to rub out,  
is famous for isolating a number of gases, including what we now call “oxygen.”  
But science was his hobby.

He was a theologian, a philosopher, and a church minister.  
 Albeit one who pursued a highly unorthodox theology.  
 He helped to found the Unitarian church.

This amazing stuff, natural rubber, reached Europe in the 1700s.  
 But at that time, nobody thought about matter as being made up of atoms and molecules.

Let alone giant molecules.

Some ancient Greek philosophers talked about atoms as a philosophical concept.  
 But it wasn't until the early 1800s that an evidence-based atomic theory began to develop.  
 And the person we have to thank for that, is **John Dalton**.



Dalton was born in 1766 in Eaglesfield,  
 North West of the Lake District.

His family were Quakers,  
 members of the Religious Society of Friends,  
 and throughout his life, as a Quaker,  
 he lived modestly and tried, not entirely successfully, to avoid honour and fame.

His early education was in a small Quaker school.  
 When he was 12, he started teaching local children.

At 15, he moved to Kendal,  
 South East of the Lake District.  
 to teach, along with his brother, at a Quaker boarding school.

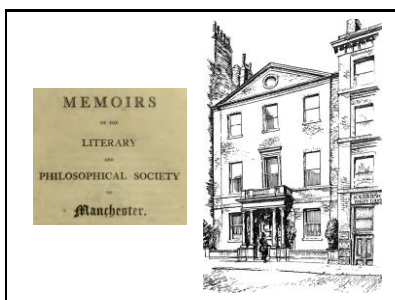
But he always had difficulty making ends meet,  
 and occasionally worked as a farm labourer.

When he was 27, he moved to Manchester,  
 to teach at an academy, the “New College”, set up by Unitarians.

In 1803 the college moved to York, but Dalton stayed in Manchester.

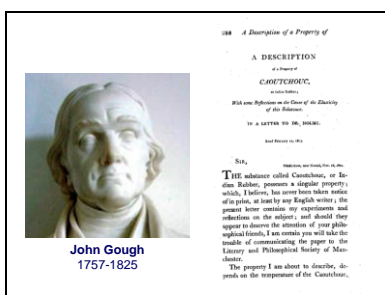
And in 1803, Dalton presented a paper  
 to the Literary and Philosophical Society of Manchester,  
 the Manchester Lit and Phil,  
 with a Table of the relative weights of  
 the ultimate particles of gaseous and other bodies.

The beginnings of modern atomic theory.

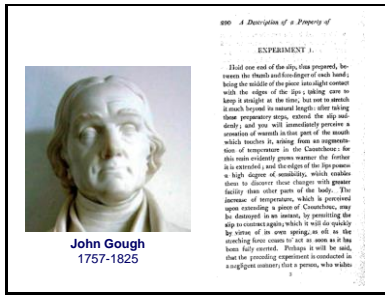


The Manchester Lit and Phil began around 1781 as a dining club,  
 but was soon established as a Society,  
 and by 1799 it had its own premises at 36 George Street in Manchester.  
 The building included a chemical laboratory,  
 which Dalton, who was secretary of the Society from 1800, made good use of.

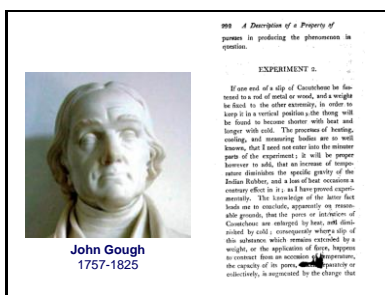
While Dalton was developing his ideas about atoms,  
 back in the Lake District, another Quaker,  
 a teacher and friend of Dalton,  
 was carrying out key experiments on natural rubber.



**John Gough** was born in Kendal in 1757.  
 When he was two years old, he contracted smallpox, and became blind.  
 Without his sight, he developed his other senses, learning to identify animals by touch.  
 He was bright, excelling in the classics,  
 and becoming interested in botany, meteorology, physics and mathematics.  
 In 1778–1779 he spent 18 months in Mungrisedale,  
 in the North of the Lake District,  
 learning mathematics from a teacher named John Slee.  
 Back in Kendal, he got to know the young John Dalton,  
 teaching Dalton Latin and Greek.  
 And Dalton assisting the blind John Gough,  
 by reading, writing and making calculations for him.  
 It was John Gough who recommended Dalton for the position at New College in Manchester.  
 In a letter written in 1802,  
 and read to the Manchester Lit and Phil in 1803,  
 Gough described some properties of what was then called Caoutchouc, or India Rubber.



The first experiment he described,  
 showed that when a piece of rubber is stretched, its temperature increases.  
 Now remember, Gough was blind.  
 But he used his lips to detect the changes in temperature.  
 “A sensation of warmth”, as he put it.



The second experiment he described,  
 showed that if a piece of rubber is first stretched by hanging a weight from it,  
 when it's heated, it becomes shorter.  
 Most things expand on heating.  
 So it's a surprise that a stretched piece of rubber contracts on heating.

**Thermomechanical properties of rubber**

(1) It gets warmer when you stretch it.

(2) When a force is applied, it gets shorter on heating

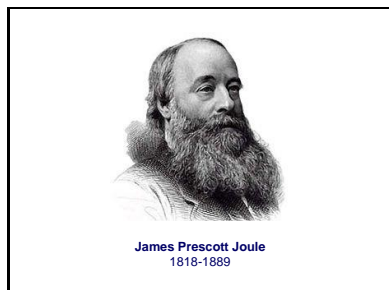
Two key things about rubber:  
 (1) It gets warmer when you stretch it.  
 (2) When a force is applied, it gets shorter on heating.

These are two of the thermomechanical properties of rubber.  
 These properties tell us something about the nature of rubber.

But what do they tell us?  
 John Gough tried to explain these properties in terms of “Caloric fluid.”  
 The idea at that time was that heat was a kind of fluid – caloric –  
 that flowed from hotter bodies to colder bodies.



Later this idea was replaced by the principle of conservation, not of heat,  
but of what we now call energy.  
That led to the science of thermodynamics.  
And the principle of conservation of energy found expression as  
the first law of thermodynamics.

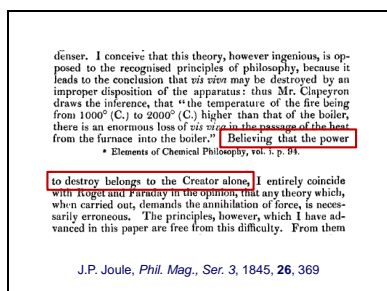


A key character in that development was **James Prescott Joule**,  
after whom a unit of energy is now named.

James Joule was born in 1818 in Salford,  
the son of a wealthy brewer.  
As a young man, he was tutored by John Dalton.  
Later he helped to run the family brewery,  
and probably it was thinking about whether he could replace  
the brewery's steam engines with new-fangled electric motors,  
that got him interested in questions about heat and work.  
Joule spent his whole life in the area around Manchester,  
living in Pendlebury, in Whalley Range, in Salford, in Old Trafford,  
and finally in Sale.

Joule did many careful and precise experiments which showed that  
a certain amount of work was equivalent to a certain amount of heat.  
Whereas caloric theory assumed that heat was conserved – couldn't be created or destroyed –  
these experiments suggested that heat and work are interchangeable.  
This supported the idea that something else was conserved.  
Something we now call energy.

At the time, there were lots of arguments about this.  
So why did Joule pursue the idea?



A hint as to the way he thought is in a paper published in 1845,  
*On the Changes of Temperature produced by the Rarefaction and Condensation of Air.*  
(*Phil. Mag. Ser. 3*, 1845, **26** (174), 369-383)

In it, Joule writes:

“Believing that the power to destroy belongs to the Creator alone,  
I entirely coincide with Roget and Faraday in the opinion,  
that any theory which, when carried out, demands the annihilation of force,  
is necessarily erroneous.”

Believing that the power to destroy belongs to the Creator alone.  
Joule clearly indicated that what he believed about God  
influenced the way he thought about science.

Whereas many of the scientists we’ve mentioned were dissenters,  
people who believed in God but didn’t accept the doctrines of the established church,  
Joule was a good Anglican.



Towards the end of his life, he worshipped at St. Paul’s church in Sale.  
A plaque on the pew he used, reads:

To the Glory of God and in memory of James Prescott Joule who used this pew.  
He was eminent as a Scientific Investigator.  
Born 1818 at Salford.  
Died 1889 at Sale.

But what about the giant molecule story.

In the 1850s, half a century after

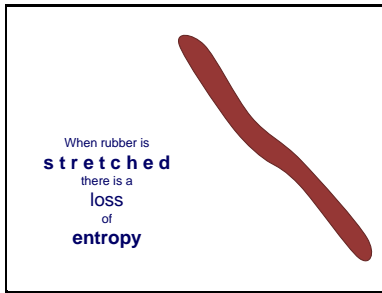
John Gough first reported the thermomechanical properties of rubber,  
James Joule did further experiments to confirm Gough’s work.

The contraction of rubber when heated under tension is now called  
the Gough-Joule effect.

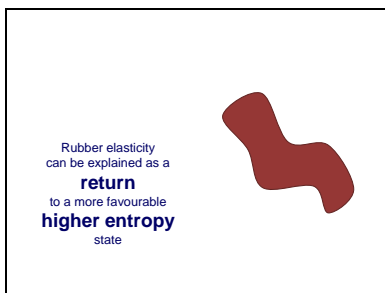
But what does it tell us?

Joule’s work was important to the development of thermodynamics.

And thermodynamics tells us something about  
what happens when we stretch a piece of rubber.



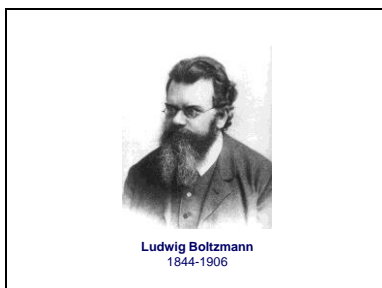
In modern terminology, the thermomechanical properties of rubber indicate that when rubber is stretched, there's a loss of entropy. Now, spontaneous processes involve an increase in the entropy of the universe; that's an expression of the second law of thermodynamics.



So rubber elasticity, the way a stretched piece of rubber snaps back into its original shape if you let go, can be explained as a return to a more favourable, higher entropy, state.

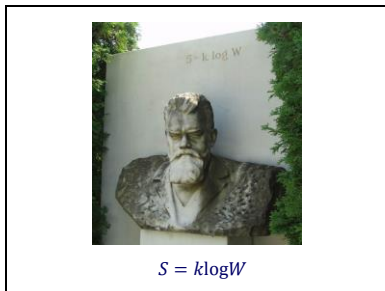
Except, that doesn't really explain "Why?"  
 Why does entropy decrease when rubber is stretched?  
 What's going on that leads to an increase in entropy when rubber contracts?

The thing about thermodynamics – what we now consider classical thermodynamics – is that it makes no assumptions about the nature of matter. It's purely based on relationships between measurable properties. But, of course, Dalton introduced the idea that matter is actually composed of atoms. So is there a way of linking the behaviour of atoms to thermodynamic quantities?



That's the realm of statistical thermodynamics. And a key character in the development of statistical thermodynamics was **Ludwig Boltzmann**. Boltzmann was born in 1844 in Vienna.

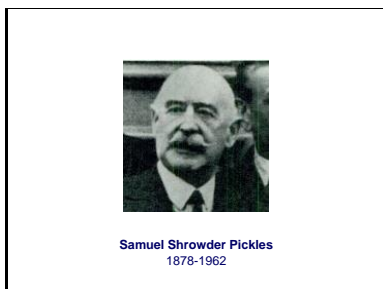
In 1863 he went to the University of Vienna to study Physics.  
 Later he had positions as Professor in Graz, in Vienna, in Munich and in Leipzig.  
 He came up with an equation relating entropy,  $S$ ,  
 to the number of microstates of a system,  $W$ ,  
 often referred to as the “disorder” of a system.  
 However, Boltzmann encountered a lot of opposition,  
 because his theories assumed the existence of atoms and molecules.  
 Despite Dalton’s efforts in the early 1800s,  
 many European physicists, right into the early 1900s,  
 rejected the idea that atoms were real.  
 Poor Boltzmann went through periods of depression.  
 In 1906, while on holiday, he hanged himself.



On his tombstone is inscribed his equation for entropy.  
 $S = k \log W$ .

The thermomechanical properties of rubber imply  
 that when rubber is stretched, there’s a loss of entropy.  
 The statistical definition of entropy suggests that when rubber is stretched,  
 there are fewer possible microstates, or arrangements of the atoms.  
 Over the years there were many attempts to explain this in molecular terms.  
 But a satisfactory explanation wasn’t found,  
 until it was understood that rubber was made up of giant molecules.

Now, chemists knew the chemical composition of natural rubber.  
 They’d worked out that isoprene could be “polymerised” to form rubber.  
 There were even experiments that suggested a high molecular weight for rubber,  
 but they thought these weren’t real values.  
 They assumed the properties of rubber came about because  
 small molecules formed aggregates through physical affinity.  
 They didn’t think small molecules could join together to form much, much larger molecules  
 through the formation of strong, chemical bonds,

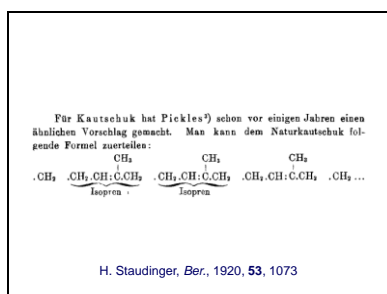


The first person to suggest a long chain formula for rubber was **Samuel Shrowder Pickles**. Pickles was born in Rochdale in 1878.

He was a former student of my own Department,  
studying chemistry at Owens College,  
the precursor to the Victoria University of Manchester.

He completed his bachelor's degree in 1903, and went on to do research.

Between 1905 and 1908 he worked for his doctorate at the Imperial Institute in London,  
studying, amongst other things, rubber.

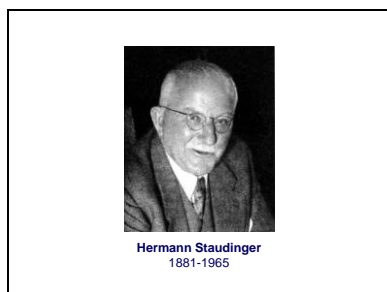


Pickles first suggested in 1906,  
at a meeting in York of the British Association for the Advancement of Science,  
that rubber was a long chain molecule.

He subsequently published the idea in 1910.

*(J. Chem. Soc., Trans., 1910, 97, 1085-1090)*

However, even Pickles couldn't quite conceive of just how big a rubber molecule might be. He thought at least eight repeat units, and suggested that the ends would join to form a ring.



The person who really pushed the idea of truly long chain molecules  
was **Hermann Staudinger**.

Staudinger was born in 1881 in Worms, Germany.

He was an organic chemist, who obtained his PhD from the University of Halle in 1903.

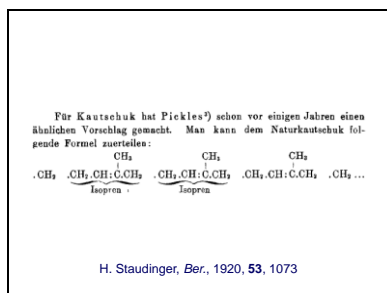
Subsequently he held positions at the University of Strasbourg,

the Technical University of Karlsruhe,

the Swiss Federal Institute of Technology in Zurich,

and the University of Freiburg.

He became interested in the chemistry of natural rubber and similar materials.



In a lecture in 1917, he rejected the notion of “aggregates”,  
and supported Pickles’ concept of long chain molecules.

In a paper published in 1920 he argued  
that polymerization really, truly did give high molecular weight products.

(*Ber.*, 1920, 53, 1073)

Over the following years he stubbornly pursued this idea – the macromolecular hypothesis –  
despite considerable opposition.

As one of Staudinger’s students later recalled

“He was completely sure that his idea of the existence of macromolecules was right  
and he had practically all his colleagues against him and his opinions.”

(Rudolf Signer, quoted in P.J. Bernal, *J. Chem. Educ.*, 2006, 83, 870)

Another account said:

“I remember Staudinger’s lecture to the Zurich Chemical Society in 1925  
on his high polymer thread molecules with a long series of Kekulé valency bonds.

All the great men present:

the organic chemist, Karrer,

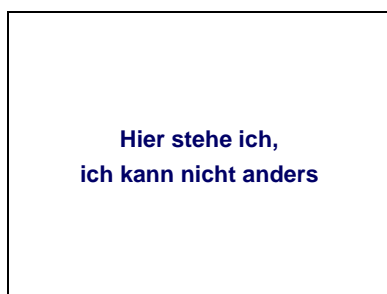
the mineralogist, Niggli,

the colloidal chemist, Wiegner,

the physicist, Scherrer,

and the X-ray crystallographer, Ott,

tried in vain to convince Staudinger of the impossibility of his idea  
because it conflicted with exact scientific data.



The stormy meeting ended with Staudinger shouting

‘Hier stehe ich, ich kann nicht anders’ [Here I stand, I can do no other]”

(Frey-Wyssling, quoted in P.J. Bernal, *J. Chem. Educ.*, 2006, 83, 870)

‘Here I stand, I can do no other.’

A phrase reputedly used by the church reformer Martin Luther,  
at the Diet of Worms in 1521,

when he defended writings that were critical

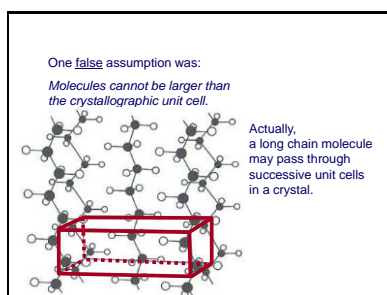
of some of the practices of the Roman Catholic Church.  
Staudinger clearly identified himself with Luther,  
in standing against the prevailing authority.

Staudinger was convinced  
by the evidence he had.  
His contemporaries were misled  
by assumptions they made.

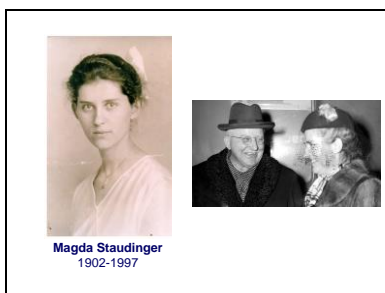
But why did most scientists at the time object so vociferously to the idea of giant molecules?  
Part of the problem was that they couldn't let go of some key assumptions,  
as it turned out, false assumptions.

One false assumption was:  
*Molecules cannot be larger than  
the crystallographic unit cell.*

One false assumption was that  
a molecule cannot be larger than its crystallographic unit cell.  
Some crystalline polymers had been studied by X-ray diffraction  
and found to have a small crystalline unit cell,  
so they assumed the molecules must be small.



Actually, of course, a long chain molecule composed of repeating units  
may pass through successive unit cells in a crystal.  
But they just didn't realise that at the time.



Eventually, Staudinger's stubbornness, and a lot of hard work, won out. His wife, Magda, an exceptional scientist herself, later wrote:

"My husband encountered opposition in all his lectures. Only in the autumn of 1929 when in a lecture ... in Frankfurt he put forward his viscosity formula, for the first time there was no opposition. This both astonished and pleased us."

(Yarsley, V. E. *Chem. Ind.*, 1967, **7**, 262,  
quoted in P.J. Bernal, *J. Chem. Educ.*, 2006, **83**, 870)

From the 1930s, the new science of macromolecules really took off. In 1953, when he was 72, Staudinger received the Nobel Prize in Chemistry for "his discoveries in the field of macromolecular chemistry." Giant molecules had arrived.

But while Staudinger was ultimately proved right in believing that polymers really were giant molecules, there was one key thing he got wrong. He thought they were rigid, rodlike molecules. He didn't accept that chain-like molecules could be flexible. But it's the flexibility of a long-chain molecule that's important for understanding rubber elasticity.



The person who came up with an explanation for rubber elasticity was **Kurt H. Meyer**.

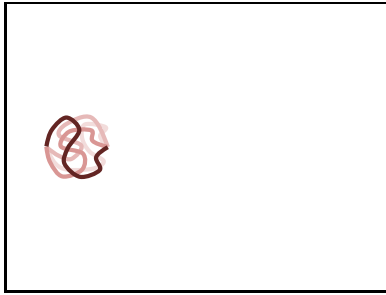
Meyer was interested in polymers

as director of the research laboratories at BASF in Ludwigshafen.

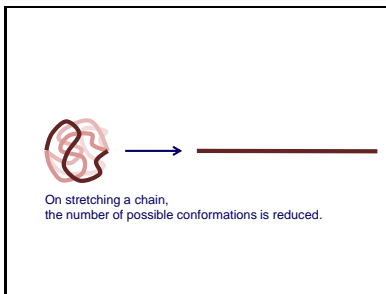
A paper in 1932 introduced a kinetic theory for reversible stretchability.

(Kurt H. Meyer, G. v. Susich and E. Valkó, *Kolloid Z.*, 1932, **59**, 308)

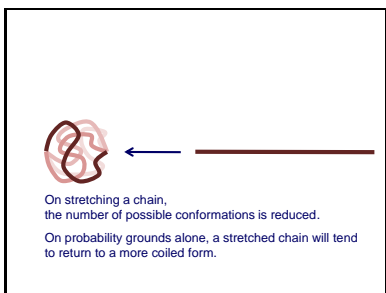




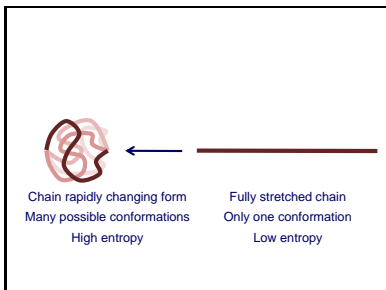
The basic idea is that in the rubbery state,  
 a long chain molecule will be continually changing its shape – its conformation –  
 as a result of rotations about backbone bonds.



When a chain is stretched,  
 the number of possible conformations is reduced.



Therefore, on probability grounds alone,  
 a stretched chain will tend to return to a more coiled form.



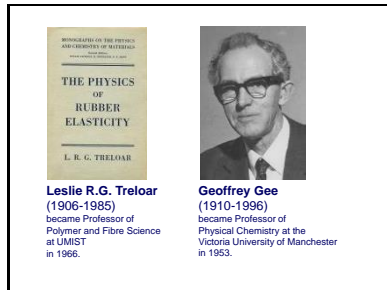
In the extreme of a fully stretched chain there's only one conformation;  
 that's low entropy.

Allow the chain to coil and there are many possible conformations;  
 that's high entropy.

Now if rubber molecules are elastic, a piece of rubber is elastic,

provided the polymer chains don't just slip past each other,  
and that's prevented by introducing some crosslinks between the chains.

So, at last, there was a molecular explanation for the thermomechanical properties  
that John Gough studied, up in the Lake District, back in the early 1800s.  
And that sparked much more research on rubber elasticity.



Two scientists who became involved in research on rubber elasticity  
were **Leslie Treloar** and **Geoffrey Gee**.

Both worked at one time for the British Rubber Producers Research Association,  
and both ended up in Manchester.

In 1966, Treloar became Professor of Polymer and Fibre Science at UMIST,  
now part of the merged University of Manchester.

After his retirement in 1974, he continued to give lectures on rubber elasticity.  
As a PhD student, I attended his lectures, and I remember his boyish enthusiasm.

Back in 1953, Geoffrey Gee took up the Chair of Physical Chemistry  
at the Victoria University of Manchester.

Within a year he became Head of Department,  
which he remained for the next 20 years.

By the time I became a student in that same Department, he had retired.

But he continued to think about rubber elasticity.

And as a PhD student, I remember him coming to talk about his latest results.

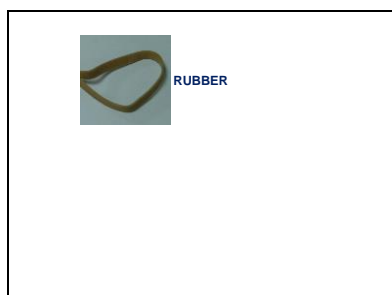
And much later, I visited him at his home.

Geoffrey Gee was an active Methodist,

attending the Methodist Church in Cheadle Hulme, near where I now live.

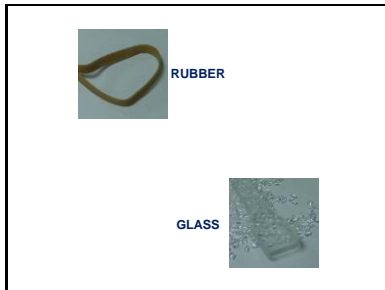
And he contributed to a Methodist book,

“God of Science, God of Faith.”



We now understand that rubber elasticity is all about the flexibility of a long chain molecule.

But, of course, if a long chain molecule in a material with many other molecules, is actually to stretch out and coil up again, there needs to be a certain amount of space between the molecules, for them to be able to move.



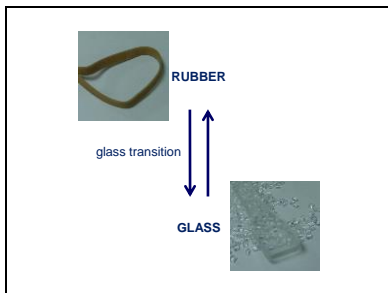
If there isn't enough space within the material – we call it free volume – the molecules are locked in position.

We're then dealing with a polymer in a glassy state.

A rigid, brittle material.

Many polymers are used as glasses.

Poly(methyl methacrylate), for example, which is sold commercially as Perspex or Plexiglass.



Now any rubbery polymer becomes glassy if we cool it to below its glass transition temperature.

And most glassy polymers become rubbery, or fluid, if we heat them to above their glass transition temperature.

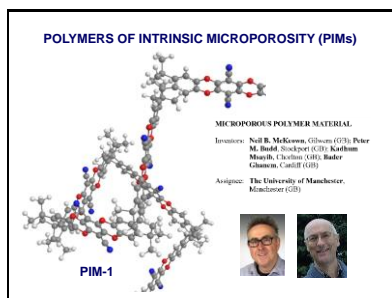
But can we design a polymer molecule that doesn't have the sort of flexibility that gives rise to rubber elasticity?

That's a subject of my own research.

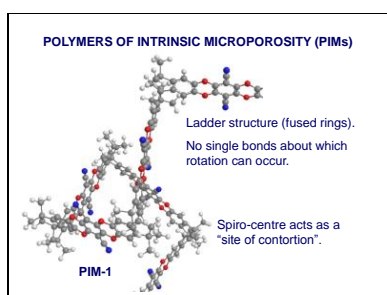
Staudinger thought that polymer molecules were rigid, rodlike molecules.

And actually, in my PhD, I studied some polymers – polypeptides – that did behave like rigid, rodlike molecules in certain solvents, because they formed a helical structure.

But what about polymers that have a randomly coiled structure, but cannot uncoil in the way a rubber molecule can?



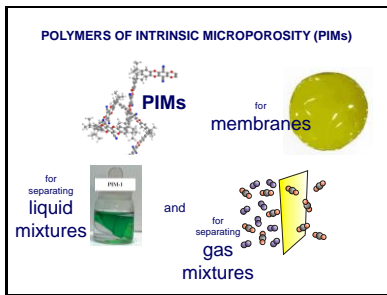
In 2003, a colleague, Neil McKeown, now at Edinburgh University, and I, were inventors on a patent application concerning a new type of polymer. We called these polymers Polymers of Intrinsic Microporosity, or PIMs. And the archetypal, solution processable PIM, we called PIM-1.



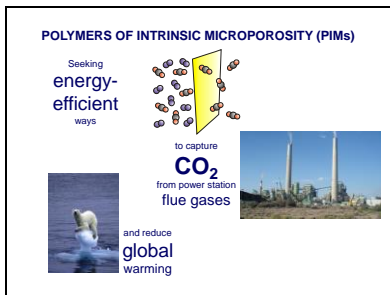
The backbone of PIM-1 is made up of little rings joined together. It's like a tiny ladder. But the ladder twists and turns. Because we also have spiro-centres, carbon atoms linked into two five-membered rings. This polymer has a randomly coiled structure, But it can't be stretched out like a rubber molecule can, because there are no single bonds in the backbone about which rotation can occur. In the solid state, it's a glassy polymer, and it remains glassy if you heat it, right up to the temperature at which it degrades, over 350 °C. But the PIM molecules can't pack together well. They trap a lot more space – more free volume – than you normally get in a glassy polymer. And that's space that other, little molecules can get into. A PIM behaves like a molecular sieve.



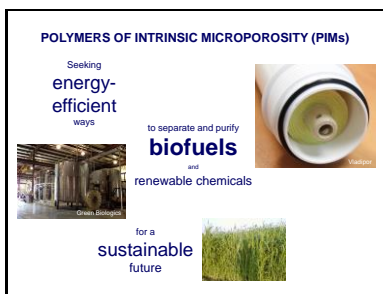
The first commercial use of a PIM is in a sensor – an end-of-life indicator – developed by 3M for their organic vapour absorbing cartridges. 3M make masks used by people working where there are lots of organic vapours, paint-spraying cars, for example. The cartridges contain activated carbon to take up the vapours. But the cartridges have to be replaced before they reach capacity. Previously, that had to be estimated on the basis of how much vapour there was for how long. But now, on the side of the cartridge there's a little green window, and a red bar moves across the window as the cartridge is used up. At the heart of that, is a PIM.



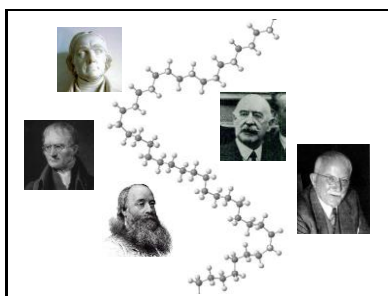
In current research we're looking at many other potential applications for PIMs. In industrial membranes, for example,



for removing carbon dioxide from power station flue gases,



or for concentrating up new biofuels.



I've told you a little bit of the story of giant molecules.  
A story that stretches back over 3<sup>1</sup>/<sub>2</sub> thousand years,  
with the use of rubber balls in Central America.

A story involving some very stubborn scientists.  
Like Hermann Staudinger,  
who persisted with an idea despite the opposition of his colleagues.  
But whose stubbornness perhaps also blinded him  
to some of the implications of his own idea.

A story involving scientists, many of whom had a profound belief in God.  
Like James Joule,  
whose thinking about conservation of energy was driven  
by his understanding of the Creator.

Now, you don't have to believe in God to do Science, but it helps,  
and there's a good reason for that.

The scientific method rests on the assumption that the universe is consistent in its behaviour.  
That if I do an experiment in my lab today,  
someone else should be able to reproduce it, more or less,  
in another place at another time.

That consistency of behaviour,  
the notion that the universe follows rules, even if we don't always understand them,  
is at odds with some world-views.

But it's exactly what you expect if, as in the Judeo-Christian tradition,  
you believe the universe is the product of the imagination of a God  
who's consistent in character.

A God who, as it says in the Bible,  
"does not change like shifting shadows" (*James 1:17*)

If you take away a belief in such a God,  
you still need a reason to believe the universe follows rules  
that science can uncover.

And that seems a good point at which to open this up to wider discussion.