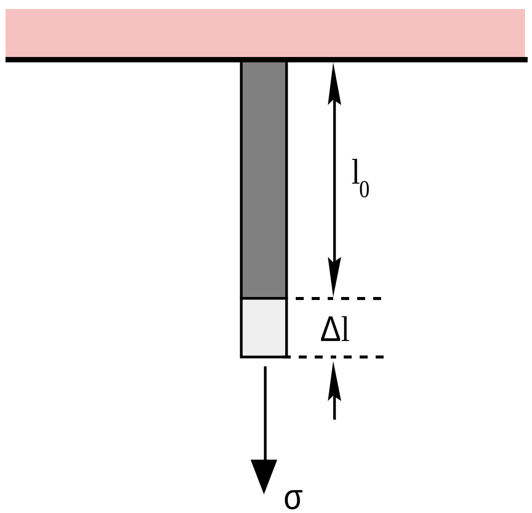
MECHANICAL AND RHEOLOGICAL PROPERTIES

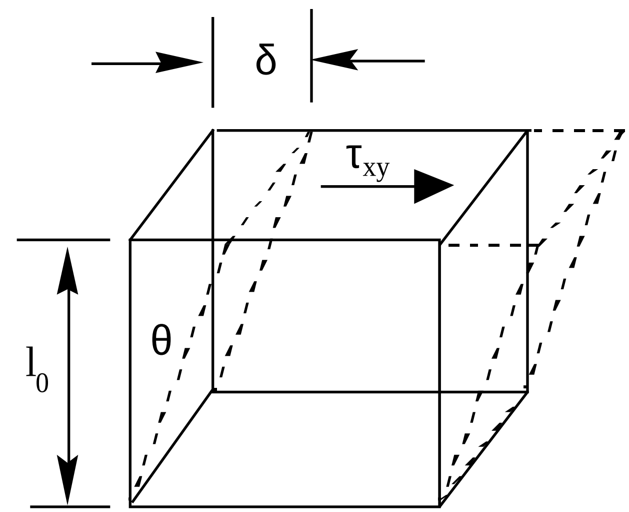
MECHANICAL PROPERTIES OF SOLIDS

Extension



Hooke's law $\sigma = E\varepsilon$

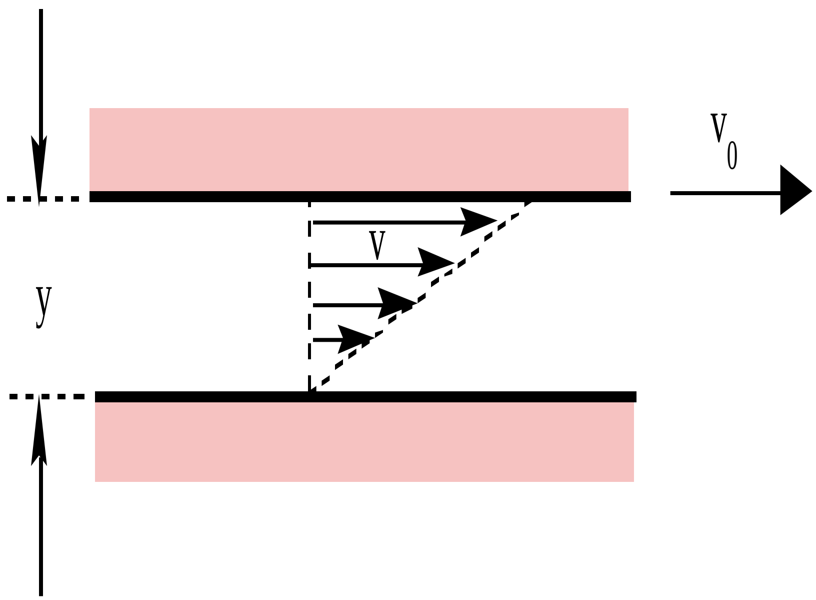
Shear



Hooke's law $\tau_{xy} = G\,\gamma_{xy}$

MECHANICAL AND RHEOLOGICAL PROPERTIES

RHEOLOGICAL PROPERTIES OF FLUIDS



Newtonian fluid

$$\tau_{xy} = \eta\dot{\gamma}$$

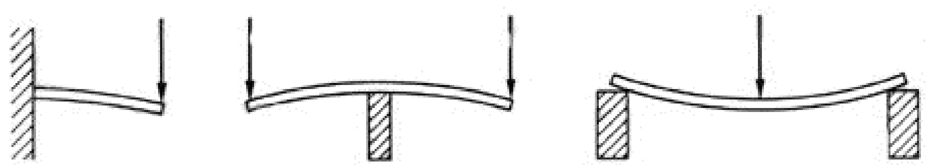
OVERVIEW

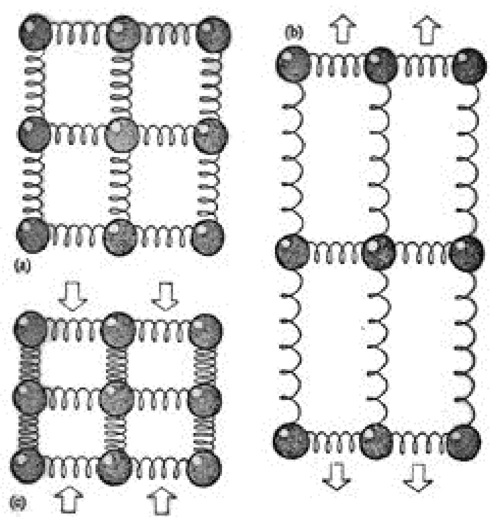
POLYMERS TREATED AS SOLIDS	***Strength*** ***Stiffness*** ***Toughness***
	↓
POLYMERS TREATED AS FLUIDS	***Viscosity of polymer melts*** ***Elastic properties of polymer melts !!!***
	↓
VISCOELASTIC PROPERTIES	***Creep*** ***Stress relaxation***

STRESSES AND STRAINS

(or why you don’t fall through the floor)

HOW DOES AN INANIMATE OBJECT SUPPORT A LOAD ?





HOOKE'S LAW

In 1676 hooke published "a decimate of the centesme of the inventions i intend to publish" (!!!)

Included "the true theory of elasticity or springiness"

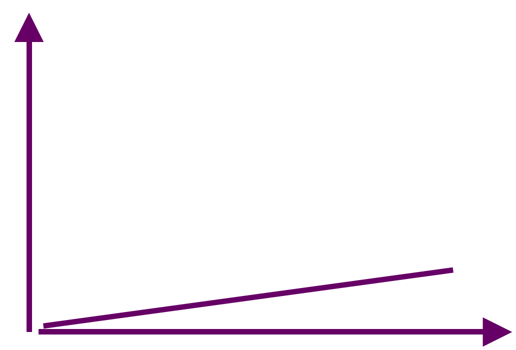
ceiiinosssttuu

As the extension, so the force

Force

Extension

Force



Extension

Questions : slope depends upon shape as well as the material being stretched - can we obtain a material property -stiffness ?

how linear is the response of real materials ?

THERMODYNAMICS REVISTED

$F = U - TS$

$$f = \left[\frac{\partial F}{\partial l}\right]_{V,T} = \left[\frac{\partial U}{\partial l}\right]_{V,T} - T\left[\frac{\partial S}{\partial l}\right]_{V,T}$$

Change in internal energy

Change in entropy

For crystalline and glassy solids

$$f \sim \left[\frac{\partial U}{\partial l}\right]_{V,T}$$

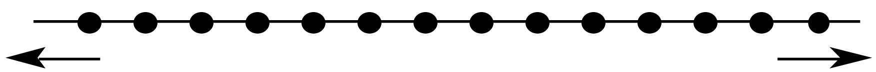
For elastomer networks

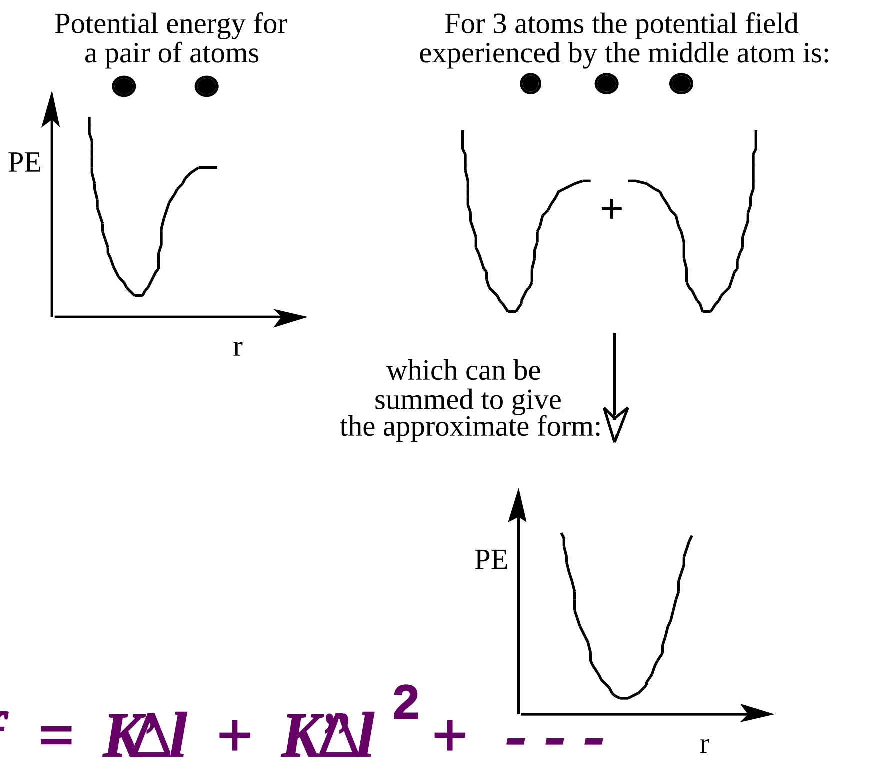
$$f \sim -T\left[\frac{\partial S}{\partial l}\right]_{V,T}$$

MOLECULAR ORIGIN OF HOOKE'S LAW

$$\left(\frac{dF}{dL}\right)_{V,T} = \left(\frac{dE}{dL}\right)_{V,T} - T\left(\frac{dS}{dL}\right)_{V,T}$$

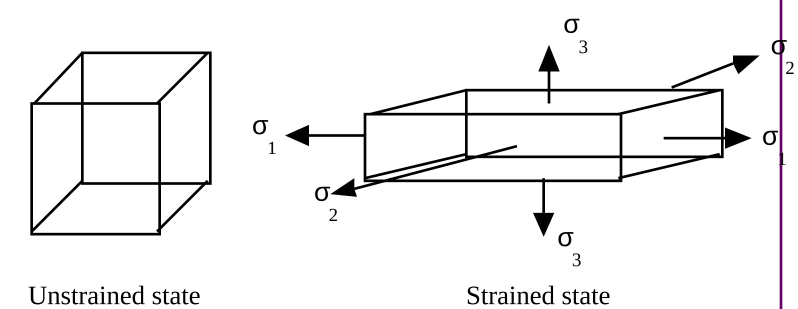
ONE DIMENSIONAL CRYSTALLINE SOLID

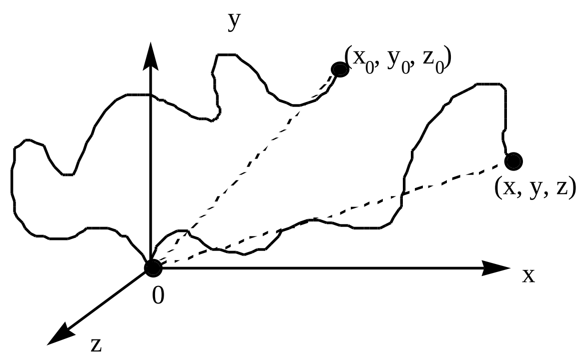




$$f = K\Delta l + K'\Delta l^{2} + - - -$$

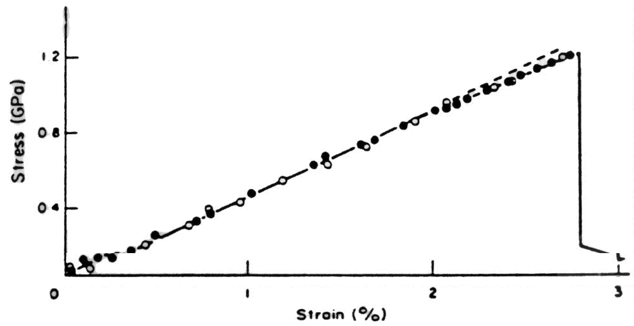
SINGLE POLMER CHAIN





$$f = kT\beta^{2} R$$

COMPARISON TO EXPERIMENT



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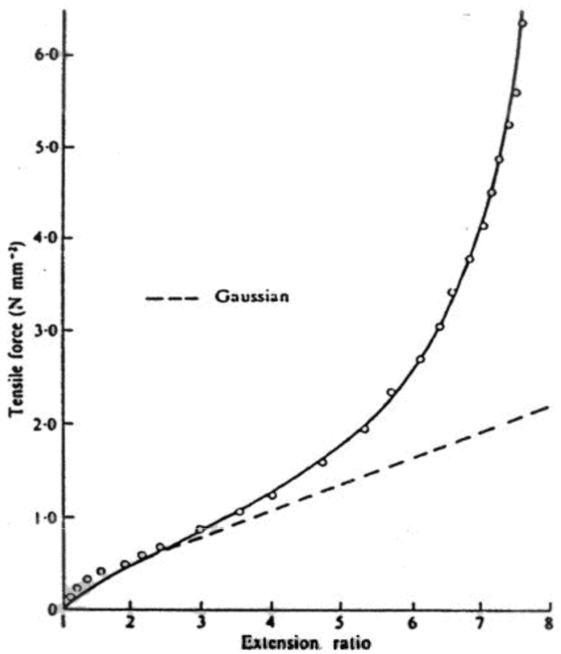
POLYDIACETYLENE SINGLE CRYSTAL

Hooke's law obeyed up to deformations ~ 2% Deviations beyond this could be due to defects as well as non linear terms in the force / extension equation



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ELASTOMER NETWORK

Rubber networks obey hooke's law at low extensions,but not,perhaps surprizingly,at high strains (considering that deformation is reversible).The simplest theory of rubber elasticity gives

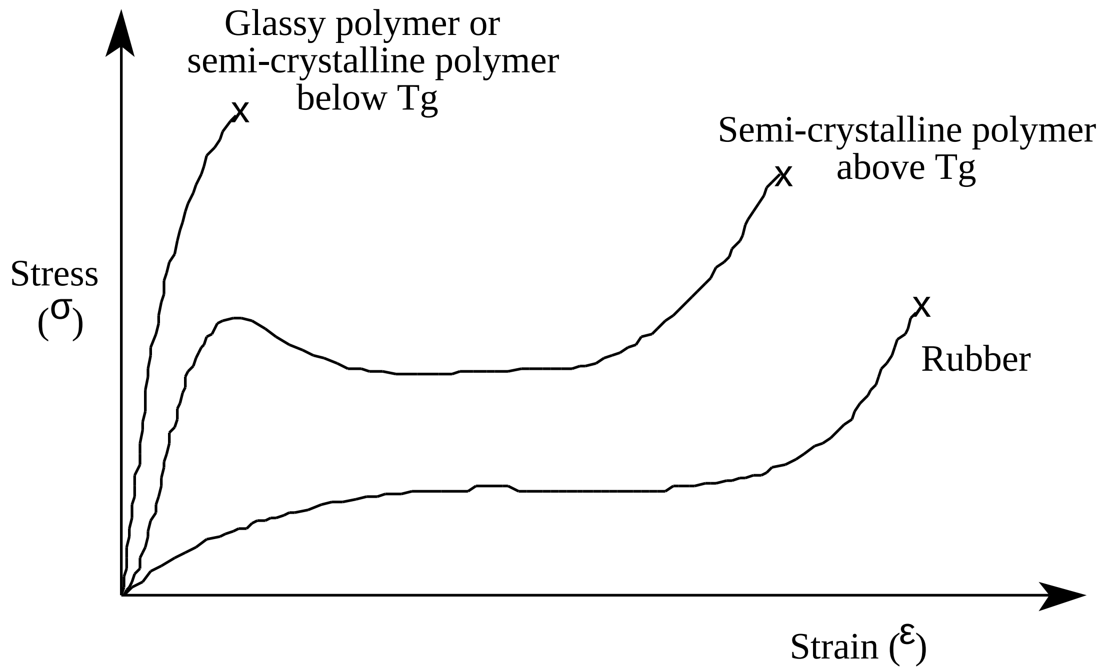
$$f = NkT(\lambda_1 - 1/\lambda_1^2)$$

but this is not that good.the semi - empirical Mooney - Rivlin equation provides a better fit

$$\sigma = 2(C_1 + C_2/\lambda_1)(\lambda_1 - 1/\lambda_1^2)$$

COMPARISON TO EXPERIMENT - POLYMERS

Once strains ~ 1% - 2% are reached, various types of deviations From ideal behavior are observed;



More on these later!

THE STIFFNESS OF MATERIALS

The stiffness of an object depends on its size and shape as Well as the material from which it is constructed.We are Interested in the inherent stiffness of materials and how They compare with one another

First define stress = force / unit area

$$\boxed{\sigma = F/A}$$

This in itself is a useful concept

gE BRICK 3"x 4" ; LOAD OF 200lbs

Stress = 16.67 lbs/sq.In.

BRIDGE 20' x 5' ; LOCOMOTIVE ~ 100 TONS

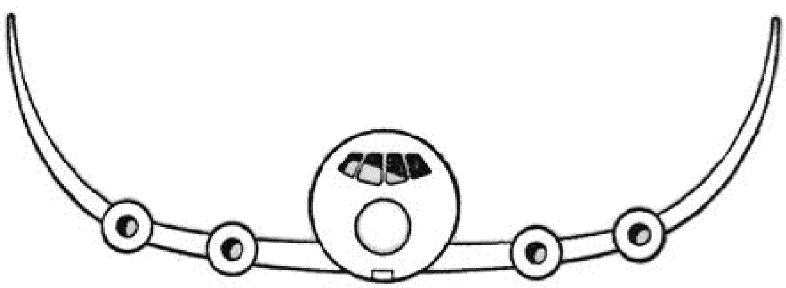
$$\text{Stress} = \frac{100 \times 2{,}240}{5 \times 20 \times 144} = 15.6 \text{ lbs/sq in}$$

THE STIFFNESS OF MATERIALS

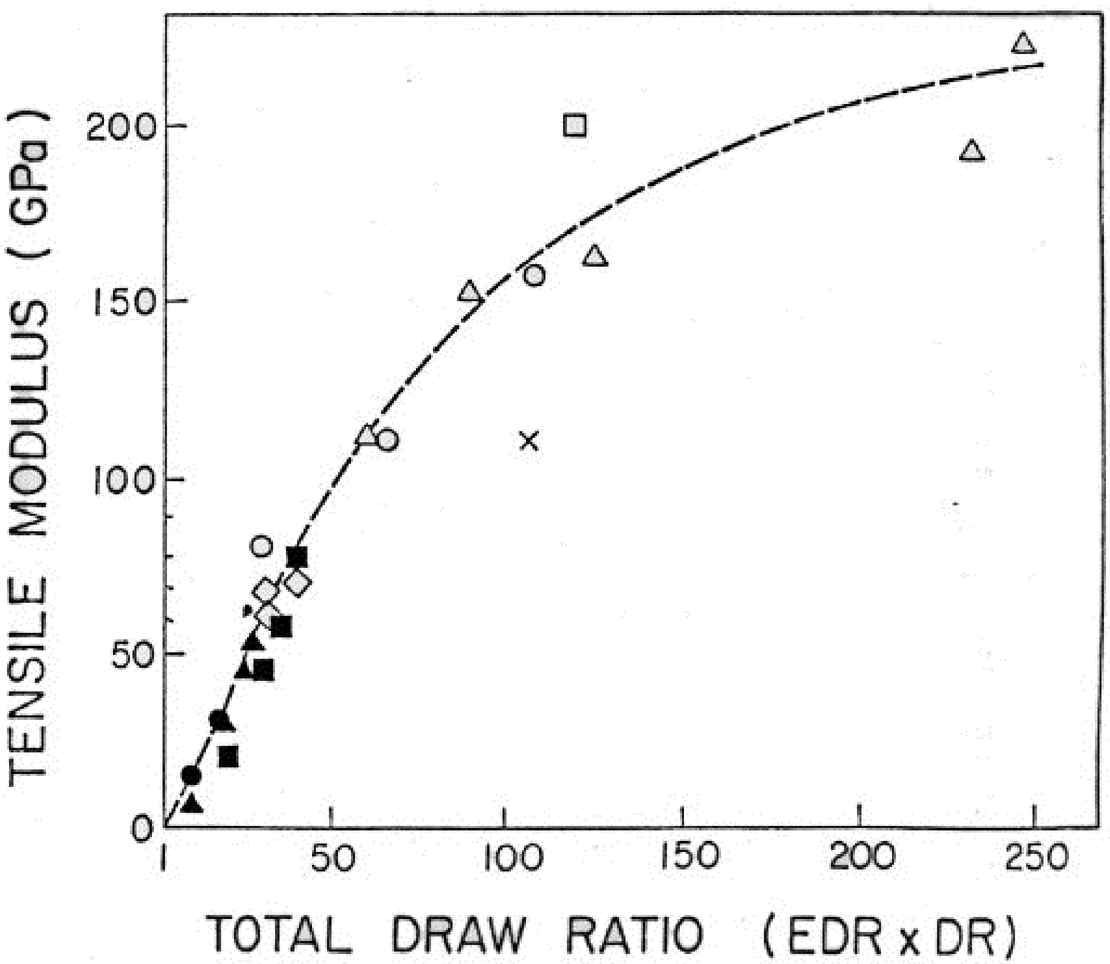
Now define strain ;

$$\boxed{\varepsilon = l/l_0}$$

Aircraft with strain of 1.6 % in wings



MODULUS OF DRAWN POLYETHYLENE



YOUNG'S MODULUS

YOUNG ~ 1800 $\dfrac{\text{STRESS}}{\text{STRAIN}}$ = CONSTANT

$$\boxed{\sigma = E\varepsilon}$$

(AFTER COMING UP WITH THIS, HE GOT FIRED)

MATERIAL	E (lbs/sq in)
RUBBER	$\sim 0.001 \times 10^{6}$
UNREINFORCED PLASTICS	$\sim 0.2 \times 10^{6}$
WOOD	$\sim 2.0 \times 10^{6}$
CONCRETE	$\sim 2.5 \times 10^{6}$
GLASS	$\sim 10.0 \times 10^{6}$
STEEL	$\sim 30.0 \times 10^{6}$
DIAMOND	$\sim 170 \times 10^{6}$

TENSILE STRENGTH

Material	*TS psi*
Steel piano wire	*450,000*
High - tensile steel	*225,000*
Aluminium alloys	*20,000 - 80,000*
Titanium alloys	*100,000 - 200,000*
Wood (spruce), along grain	*15,000*
Wood (spruce), across grain	*500*
Ordinary glass	*5,000 - 25,000*
Ordinary brick	*800*
Ordinary cement	*600*
Nylon fiber	*140,000*
Kevlar 29 fiber	*400,000*

QUESTION USUALLY ASKED

WHY IS ONE MATERIAL STRONGER THAN ANOTHER?

QUESTION SHOULD BE

WHY ISN'T ANY MATERIAL AS STRONG AS IT SHOULD BE?

HOW STRONG SHOULD MATERIALS BE?

GRIFFITHS; CALCULATED THE THEORETICAL STRENGTH OF GLASS TO BE ~ 1×10^6 p.s.i
MEASURED VALUES ~ 25,000 p.s.i.

MATERIAL	THEORETICAL STRENGTH	MEASURED STRENGTH
STEEL	~5 x 10 p.s.i	~ 400,000 p.s.i (BEST)
POLYETHYLENE FIBERS	~ 25 GPa	~ 0.35 GPa (TENSILE DRAWING) ~ 4 GPa (GEL SPUN)