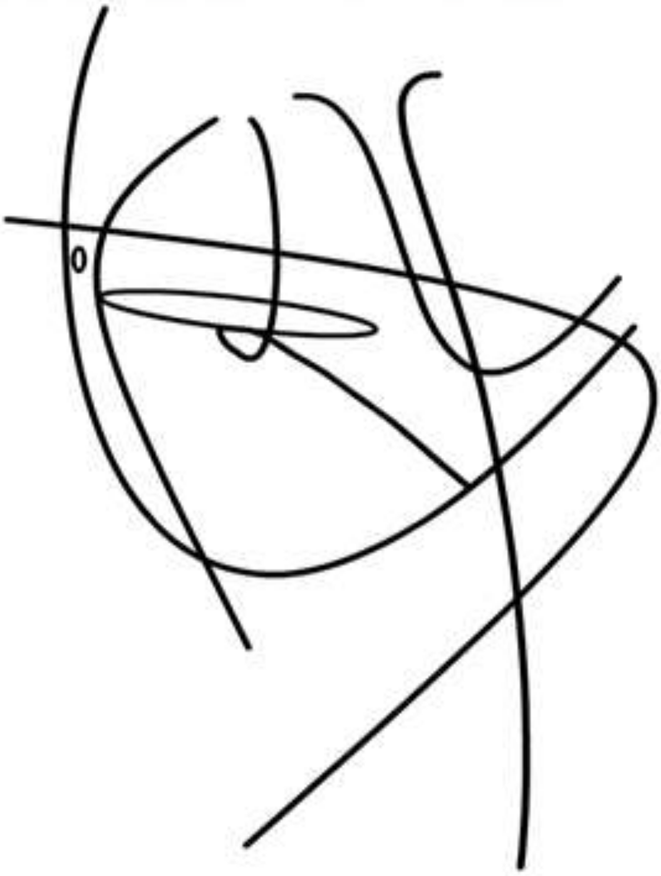
A-Level Physics Revision

Unit 2 – Mechanics, Materials & Waves



By Daniel Powell

Foreword

This book is created to form the basis of reference or revision for AS Unit 2 for AQA Physics. It should also be appropriate for other courses as well and is a comprehensive study of the topics that usually come up in exams. The ideas are pulled together from the past 20 years of study of Physics as student and then teacher so I hope it is of use.

Please Enjoy….

Daniel Powell

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Chapter 1 Materials

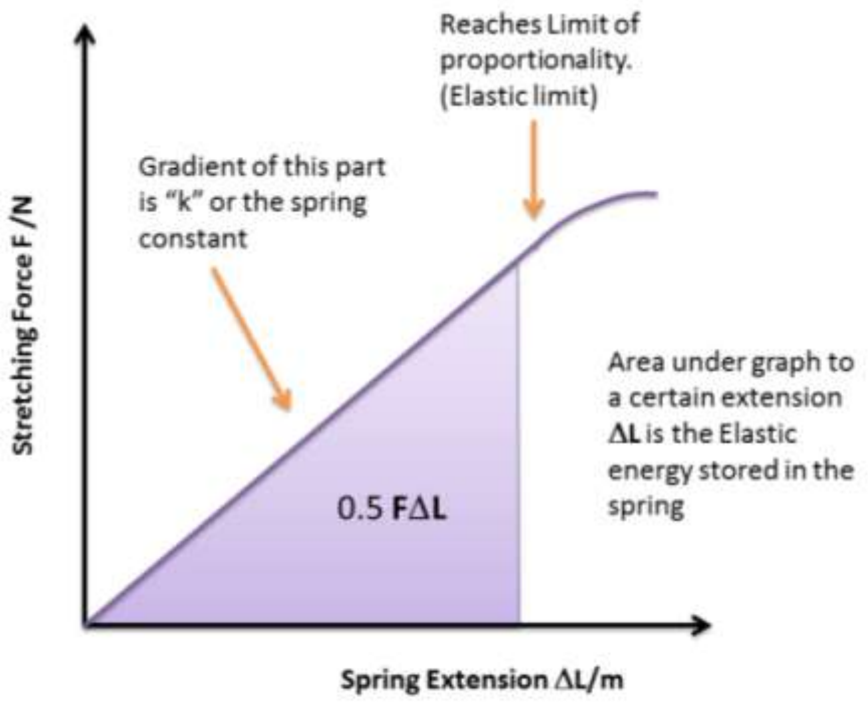
Hookes Law

This is quite a simple concept. A spring which experiences a force "F" will extend by a distance "ΔL". (Delta meaning "a change in")

The way it extends is a proportional relationship i.e. double the force is double the extension. We can formulate this into the equation for a spring…

$F = k\Delta L$ or $F=kx$ (x is extension)

Also you need to know how it looks graphically and be able to explain the parts of the graph, meaning of the gradient and area under the graph.



We also know that the energy required to extend the spring is..

Area = Energy Stored in the spring

$E_p = 0.5F\Delta L$

But we also know that $F = k\Delta L$

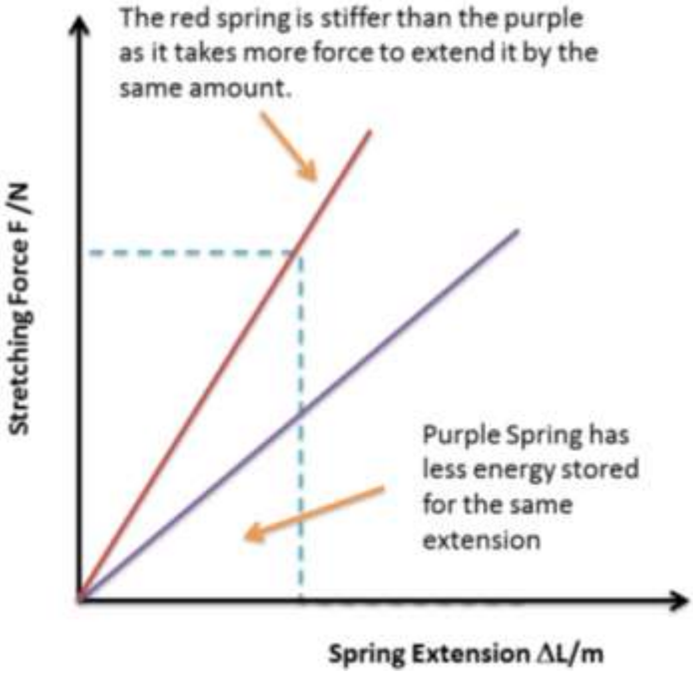
Hence…

$E_p = 0.5 \times k\Delta L \times \Delta L$

$E_p = 0.5 \times k\Delta L^2$

$E_p = 0.5kx^2$

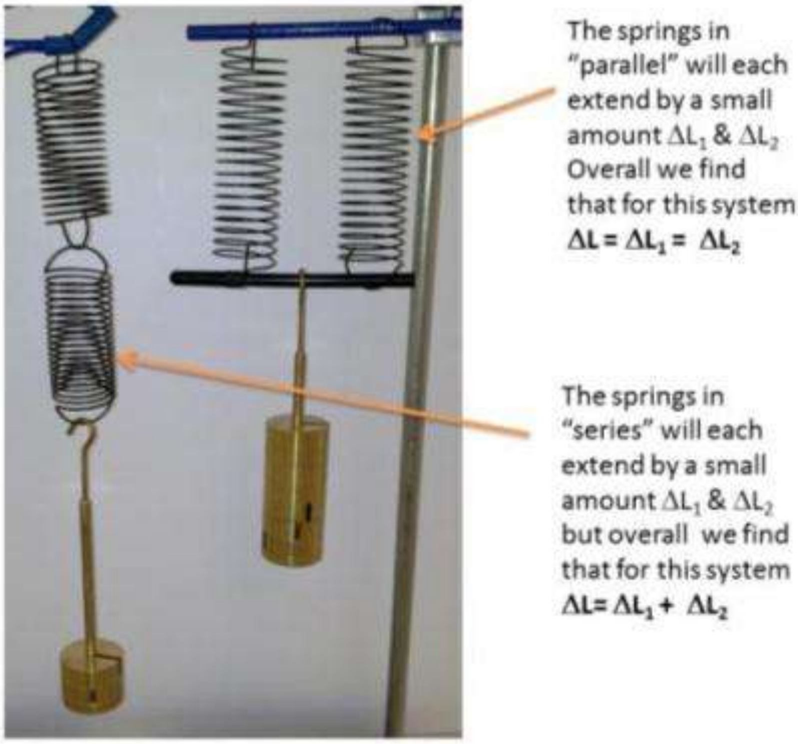
When we talk about "k" for a spring in fact we are talking about the constant of proportionality. The higher it is the more the spring resists the force when we try to extend it. This comparison graph clearly shows that the red spring has a higher gradient or "k". You need to know how to compare the gradient and areas for different springs.



The black spring is stiffer than the shiny one as under the same force it extends less. (i.e. k is higher)

Spring Systems

Placing springs in series or parallel will alter the overall "k" value of a combination but as extension is same for all springs we can simplify relations by using the idea of how they extend. It is crucial to think about the idea that for parallel springs the extension of each is the same as the overall extension. However, for a series system each spring will extend so the total is required.



If we consider the maths for a parallel system we find that…

$$k_1 \Delta L_1 = F_1$$

$$k_2 \Delta L_2 = F_2$$

$$W = F_1 + F_2$$

$$W = k_1 \Delta L_1 + k_2 \Delta L_2$$

$$k \Delta L = k_1 \Delta L_1 + k_2 \Delta L_2$$

$$if\ \Delta L_1 = \Delta L_2 = \Delta L$$

$$k \Delta L = k_1 \Delta L + k_2 \Delta L$$

$$k = k_1 + k_2$$

If we consider the series system we find that…

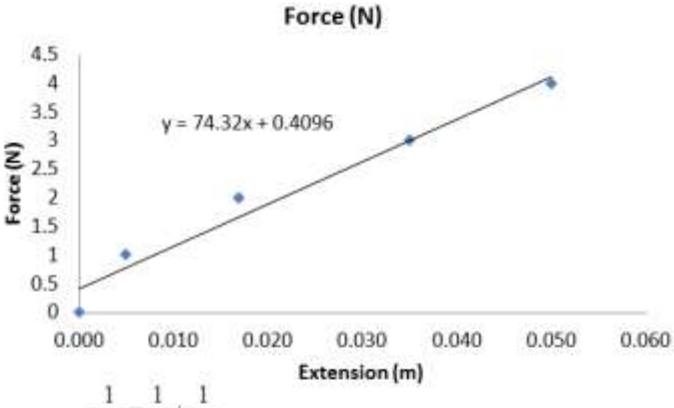
$$k_1 \Delta L_1 = F$$
$$k_2 \Delta L_2 = F$$
$$\Delta L = \Delta L_1 + \Delta L_2$$
$$\Delta L = \frac{F}{k_1} + \frac{F}{k_2}$$
$$\frac{F}{k} = \frac{F}{k_1} + \frac{F}{k_2}$$
$$\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2}$$

Hence the summary for the spring systems is the reverse of electrical resistors…

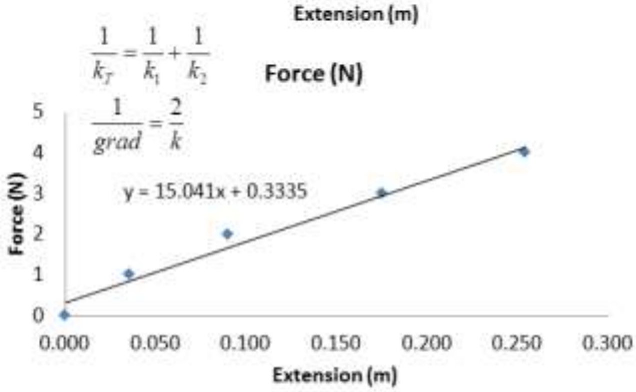
$$k = k_1 + k_2 \quad (parallel)$$
$$\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2} \quad (series)$$

We must take care when completing graphical experiments to work out the "k" of the system then reverse engineer it to the "k" for each spring. You can try out some calculations below using the results obtained here to work out "k" for each spring. The results should be 37Nm^{-1} and 30.1 Nm^{-1} for "k".

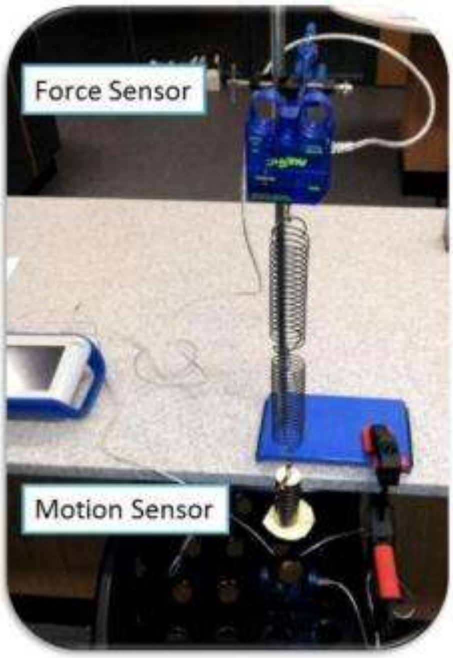
Parallel Results	
Extension (m)	Force (N)
0.000	0
0.005	1
0.017	2
0.035	3
0.050	4



Series Results	
Extension (m)	Force (N)
0.000	0
0.035	1
0.090	2
0.175	3
0.254	4



You can also use data loggers for this experiment to improve the precision of readings. A force sensor records the weight added, a motion sensor the distance to the spring. We can use a small disc of paper to help the sensor pick up the distance.



Density Calculations

We often talk about the properties of materials but if we want to compare how materials behave we have to consider things by way of a ratio. We can look at both mass and volume as physical properties. If we call the ratio of m/v as being the density rho of a material. It means for the same unit volume i.e. $1m^3$. We can consider these materials and compare the idea to a vast scale. However, in AS physics we are generally looking at densities of around 4000-10000. So if you get results much different to this you know you have a problem.

Also students have issues with working out volume for objects. It is best practice to convert every dimension w x l x d into metres first before you cube them. If you don't the conversions get confusing. Also remember that $(pi)r^2$ is the area of a circle. That means you must use the radius and not the diameter of the circle!

When looking at density it is easy when you have only one substance. However, if you are dealing with an alloy or mixture then you must take this into account. Think about two metals which are alloyed and you can create a new formula. Just be careful when completing problems that you identify each variable correctly…

Material	**ρ in kg/m³**
Interstellar medium	$10^{-25} - 10^{-15}$
Earth's atmosphere	1.2
Water	1000
Plastics	850 – 1400
The Earth	5515.3
Copper	8920 – 8960
Lead	11340
The Inner Core of the Earth	~13000
Uranium	19100
The core of the Sun	~150000
White dwarf star	1×10^9
Atomic nuclei	2.3×10^{17}
Neutron star	$8.4 \times 10^{16} — 1 \times 10^{18}$
Black hole	4×10^{17}

Mass of substance A is density x volume A → $m_A = \rho_A V_A$

Mass of substance B is density x volume B → $m_B = \rho_B V_B$

Total mass of substances as alloy → $m = \rho_A V_A + \rho_B V_B$

The density of the new alloy must be its mass/volume → $\frac{m}{V} = \frac{\rho_A V_A + \rho_B V_B}{V}$

So we have the new density → $\rho = \frac{\rho_A V_A + \rho_B V_B}{V}$

NB: **Mass cannot be changed!**

Strain

To be able to compare different materials in terms of how they behave when a load is added to them (i.e. a copper wire) we can look at something called the "Tensile Strain". Strain is a decimal i.e. 0.01 or 0.06 which tells us how much a material extends when subjected to a force. Strain has no units and can be expressed as elongation or ΔL as the extension over the original length. Most exam questions require you to explicitly put all the details for the marks.

Tensile Strain	If I load a wire with weights it will get longer and thinner. It is the ratio of the extension or elongation to the original length... (no units)	$\varepsilon = \frac{e}{L} = \frac{\Delta L}{L}$

Stress

There are two types of stress which can be expressed. There is the stress on an object of a defined area due to the force on it. Also there is the force on a unit area which actually breaks the object (Ultimate Breaking Stress or Ultimate Tensile Strength). The important part is to make sure you define it clearly in the exam and express it in Nm^{-2} which is equivalent to Pascals. (Pa)

Tensile Stress

If I load a wire with weights. The "stress" on the wire is the force per unit area that a material is subjected to... Nm^{-2}

$$\sigma = \frac{T}{A} = \frac{F}{A}$$

Material	Yield strength (MPa)	Ultimate strength (MPa)	Density (g/cm^3)
Steel	250	400	7.8
Carbon steel 1090	250	841	7.58
Human Skin	15	20	2,2
Aluminium alloy 6063-T6		248	2,63
Copper 99.9% Cu	70	220	8,92
Bone (limb)	104-121	130	1,6
Nylon, type 6/6	45	75	1,15
Epoxy adhesive	-	12 - 30	-
Rubber	-	15	
Ultra-pure silica glass fiber-optic strands		4100	

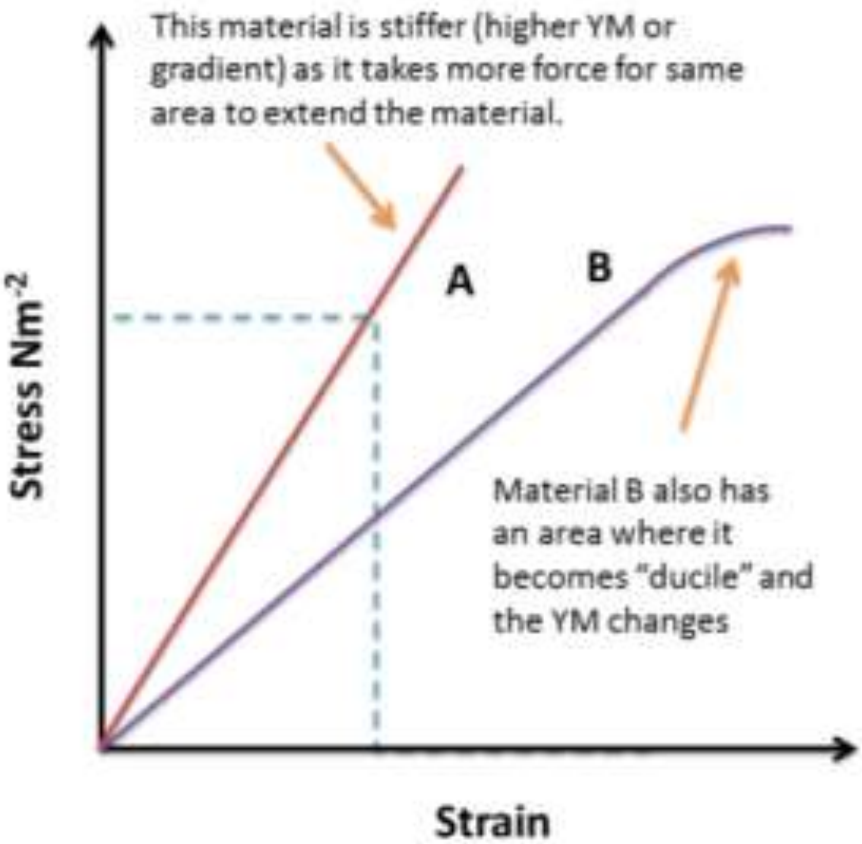
Young Modulus

The Young Modulus, "E" or YM is simply the ratio of Stress to Strain. It is very useful to compare how a material behaves and compares to another. The gradient on the graph in effect is the stiffness of the material (per unit area)

You can see on a graph that it represents the gradient….

y = mx

Stress = YM * Strain



The maths is easier than it first looks and you need to be able to combine the two. You need to use the inverse reciprocal…

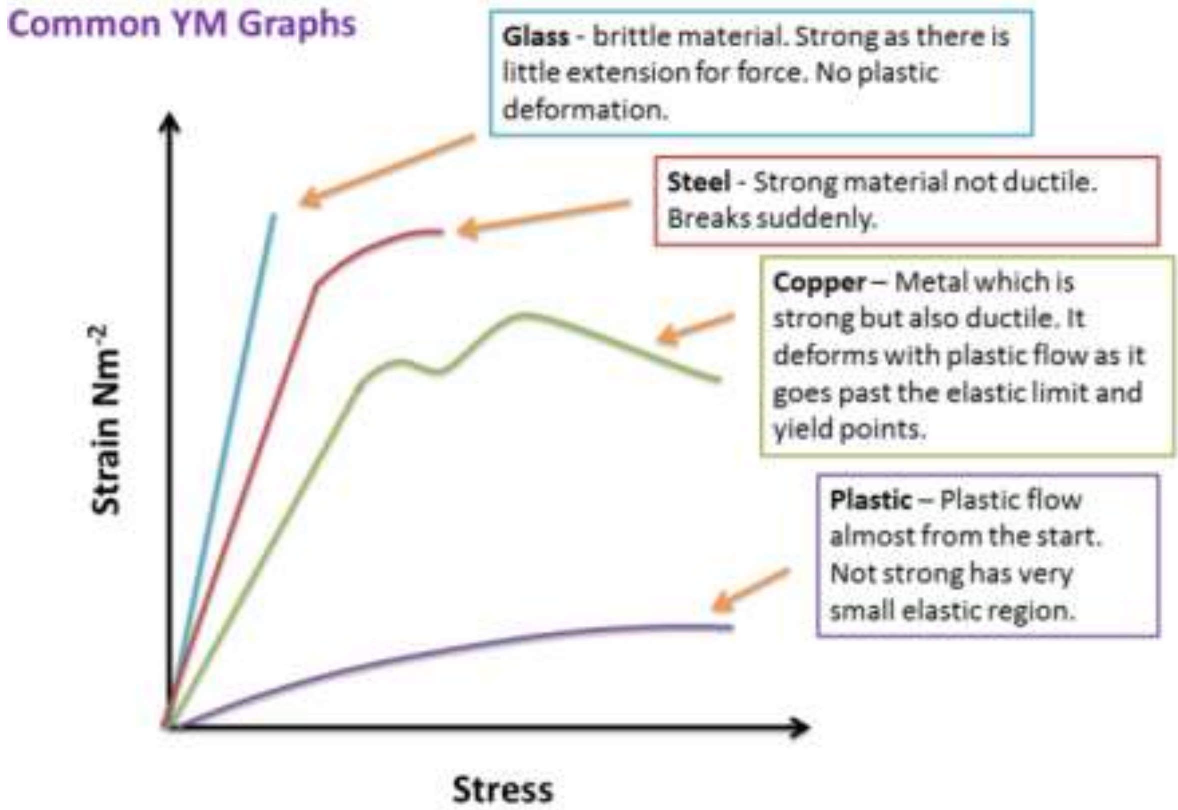
$$\sigma = \frac{T}{A} = \frac{F}{A}$$

$$\varepsilon = \frac{e}{L} = \frac{\Delta L}{L}$$

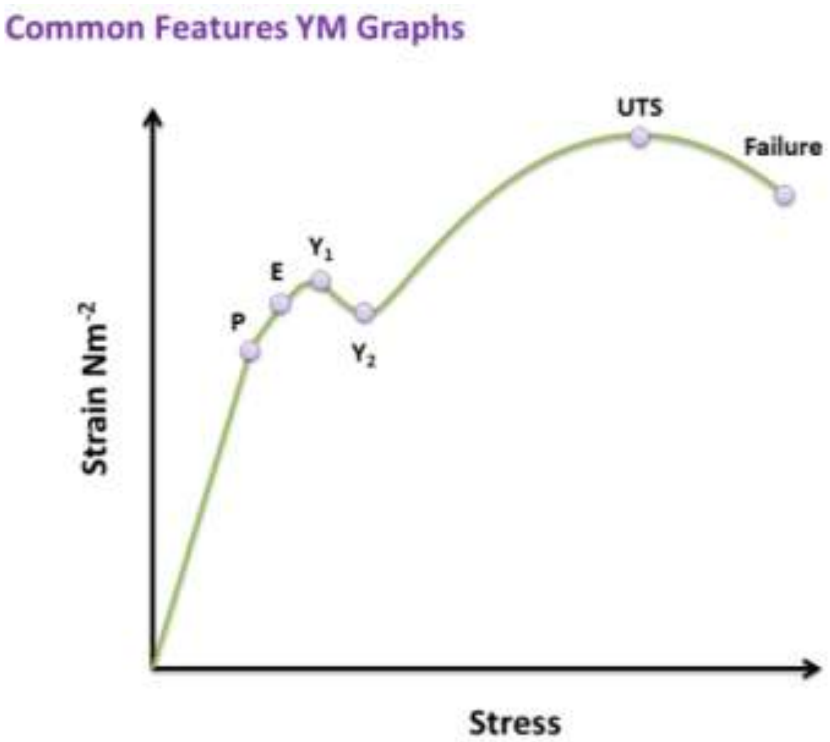
$$\frac{\sigma}{\varepsilon} = \frac{\frac{F}{A}}{\frac{e}{L}} = \frac{FL}{Ae} = YM$$

NB: Stress has units of Nm^{-2} and so does the YM

For your exam you should be able to explain various shaped YM graphs and relate them to features of their physical properties.



In terms of specifics there are several main points to be able to talk about..



P = limit of proportionality (i.e. double stress gives double strain)

E = elastic limit (permanently deformed)

Y_1 = yield point where it is weakened temporarily

Y_2 = yield point beyond which it is permanently weakened. Then plastic flow occurs. (Meaning that force reduces to hold it at that length)

UTS = ultimate tensile stress – loses strength and thins (necking) causing stress to increase (smaller area / but less force required to hold at that length)

Failure = catastrophic failure the material breaks.

More on Load-Extension Graphs

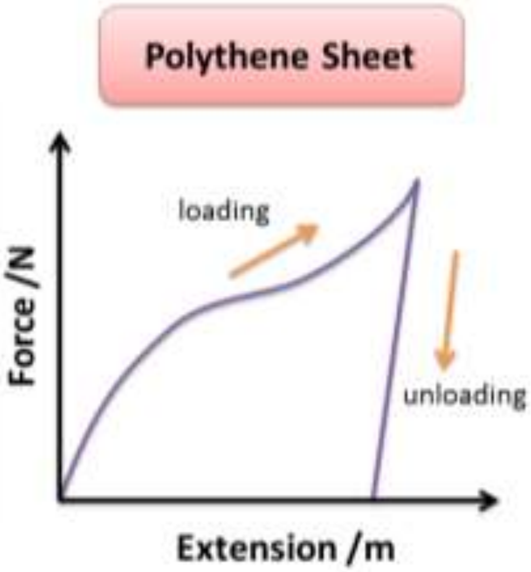
You should be able to express ideas for load-extension graphs for various materials such as rubber, metals and plastics. Using the terms from the previous section each material behaves differently.

Weak cross links break as the polythene coiled polymer chains extend.

This weakens the structure and k reduces. The material is then unloaded but is deformed permanently.

If the polymer is only initially stretched a little (below elastic limit) it will return back to its original length.

The energy lost in the process is converted to internal energy and then thermal inside the material.

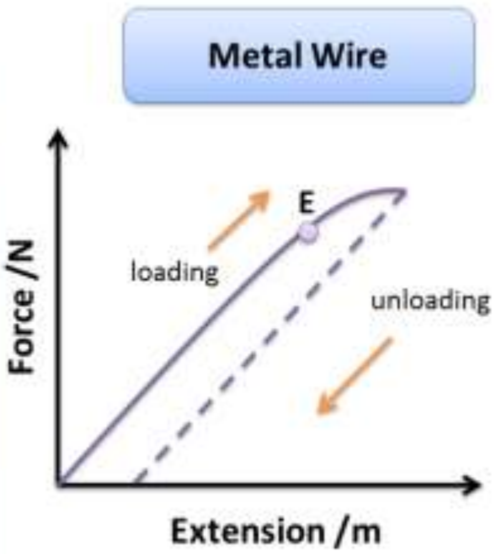


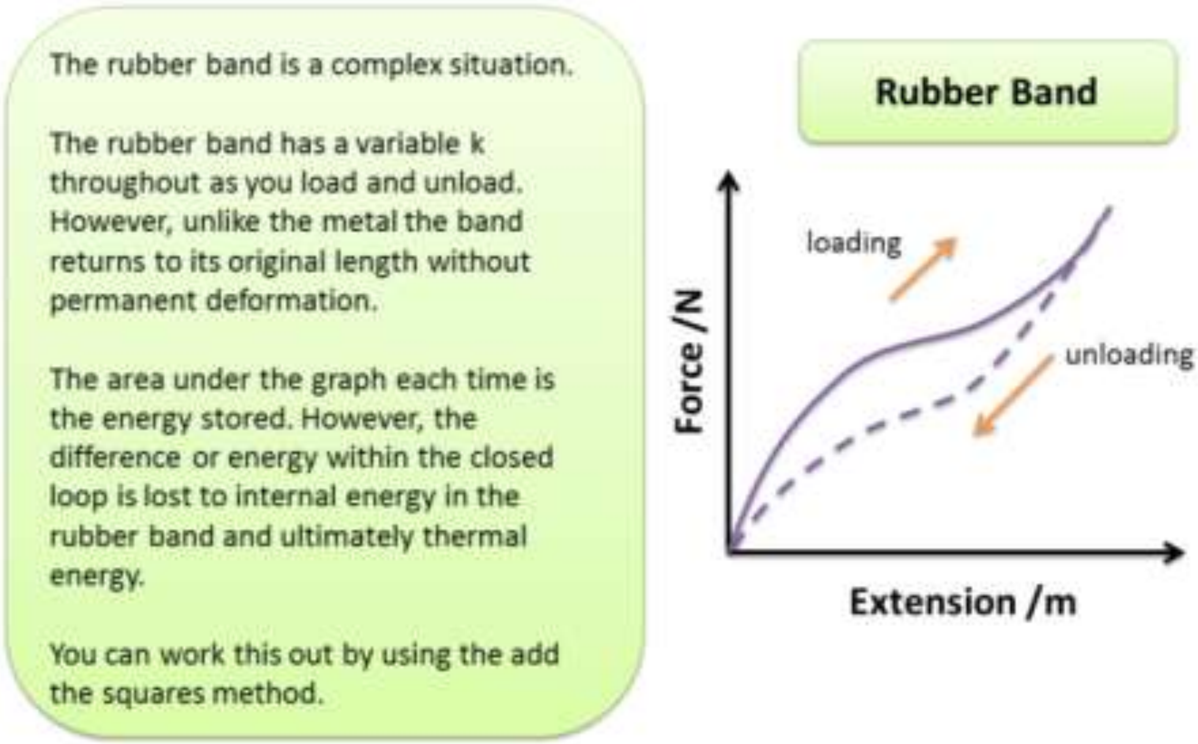
The metal wire is loaded by a force and it extends elastically.

Then it gets to the elastic limit "E" the wire permanently deforms.

The wire is now longer so when we unload the wire it does not return back to the original length.

The area under the graph before the elastic limit is the potential energy (as we saw before). This energy is returned when we unload the wire. However, some is wasted where the wire deforms permanently.





AQA Spec A Physics Unit 2

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