Lecture 27

Mechanical Behaviour of Materials

Textbooks:

- Introduction to materials science and Engineering: V. Raghavan
- Materials Science and Engineering: Callister and Rethwisch

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Recap…

1. Polymers semi-crystallinity: lamellae and spherulites
2. Engineering Stress and Strain
3. Tensile test
4. Different mechanical properties from tensile test

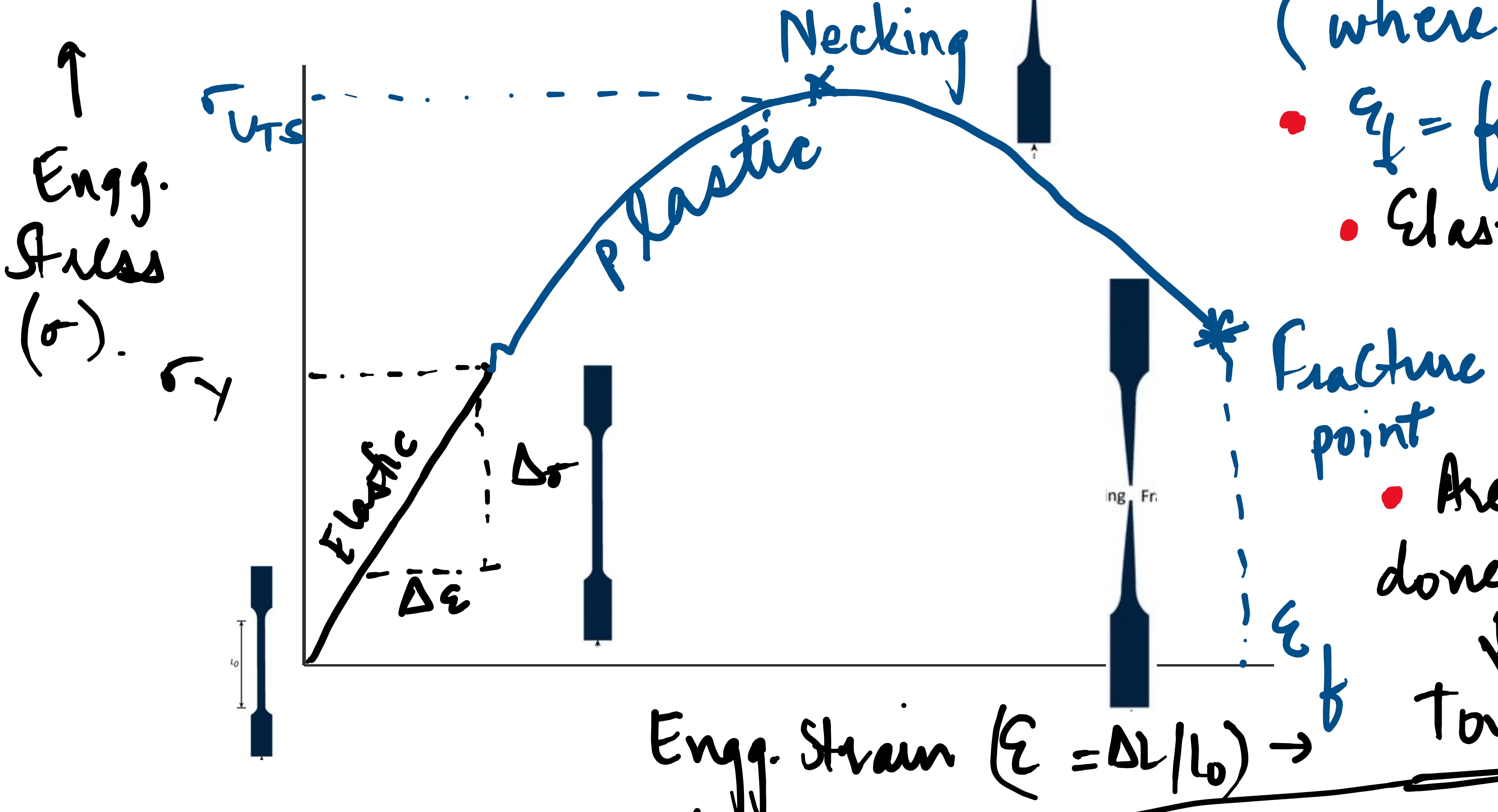
Mechanical behaviour of materials

Robert Hooke

Isaac Newton

Stress-strain curve

Load-Elongation curve



- σ_Y = Yield stress (plastic deformation begins)
- σ_{UTS} = Ultimate tensile stress (where Necking happens: decrease in A_0)
- ε_f = fracture strain
- Elastic modulus or Young's modulus

$$Y = \frac{\Delta\sigma}{\Delta\varepsilon} \text{ (stiffness)}$$

- Area under curve = work done to fracture

⇓

Toughness

Units of area = $N m^{-2} = \frac{Nm}{m^3} = J m^{-3}$

Energy per unit vol. reqd. to cause fracture

- Tensile strength $= \frac{\text{Max. load}}{A_0}$

Mechanical Properties derived from Tensile test

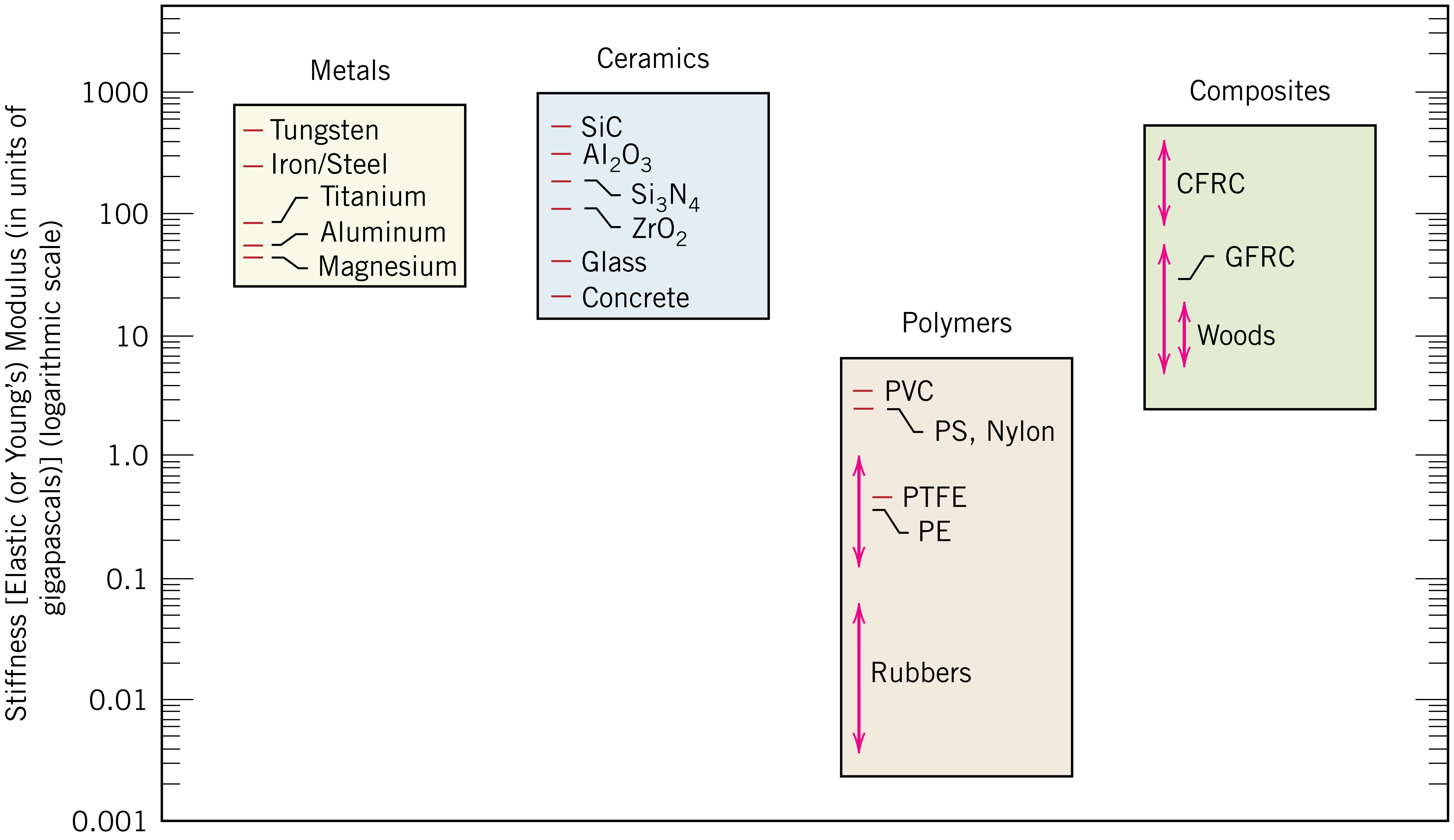
- **Strength**: Yield stress or ultimate tensile strength (σ_{UTS})

(σ_Y)

(*Ability to resist plastic deformation*)

- **Stiffness**: Young's modulus: Ability to resist elastic deformation
- **Toughness:** Area under the curve: Energy absorbed per unit volume upto fracture.
- **Ductility**: Elongation strain at fracture point: Ability to undergo plastic deformation

Classification of materials based on elastic modulus

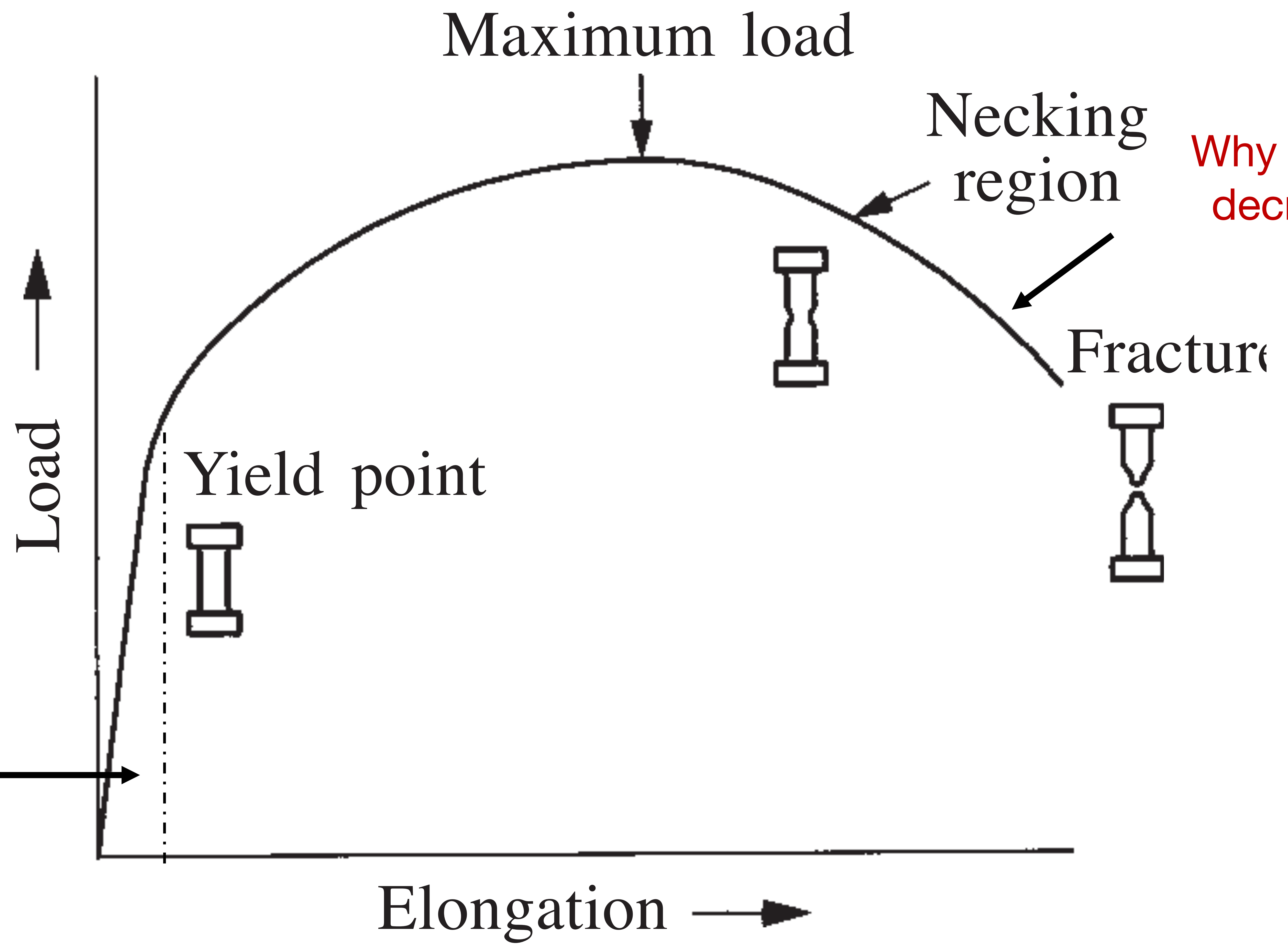


Some obvious questions from stress-strain curve?

What if the elastic regime is non-linear? How to find Young's modulus?

What if elastic-to-plastic deformation is smooth? How to find the yield point?

What property does this area provide?



Why the Engineering stress decreases after necking?

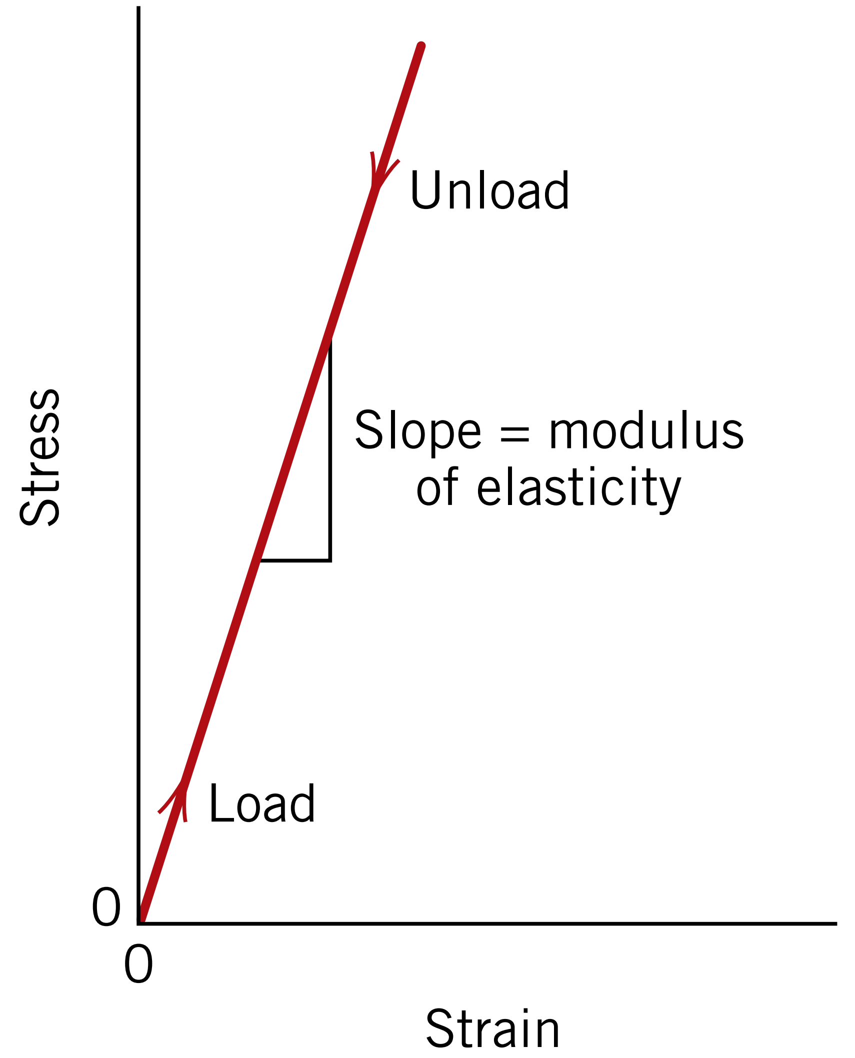
Elastic deformation

Deformation in which stress and strain are linearly proportional

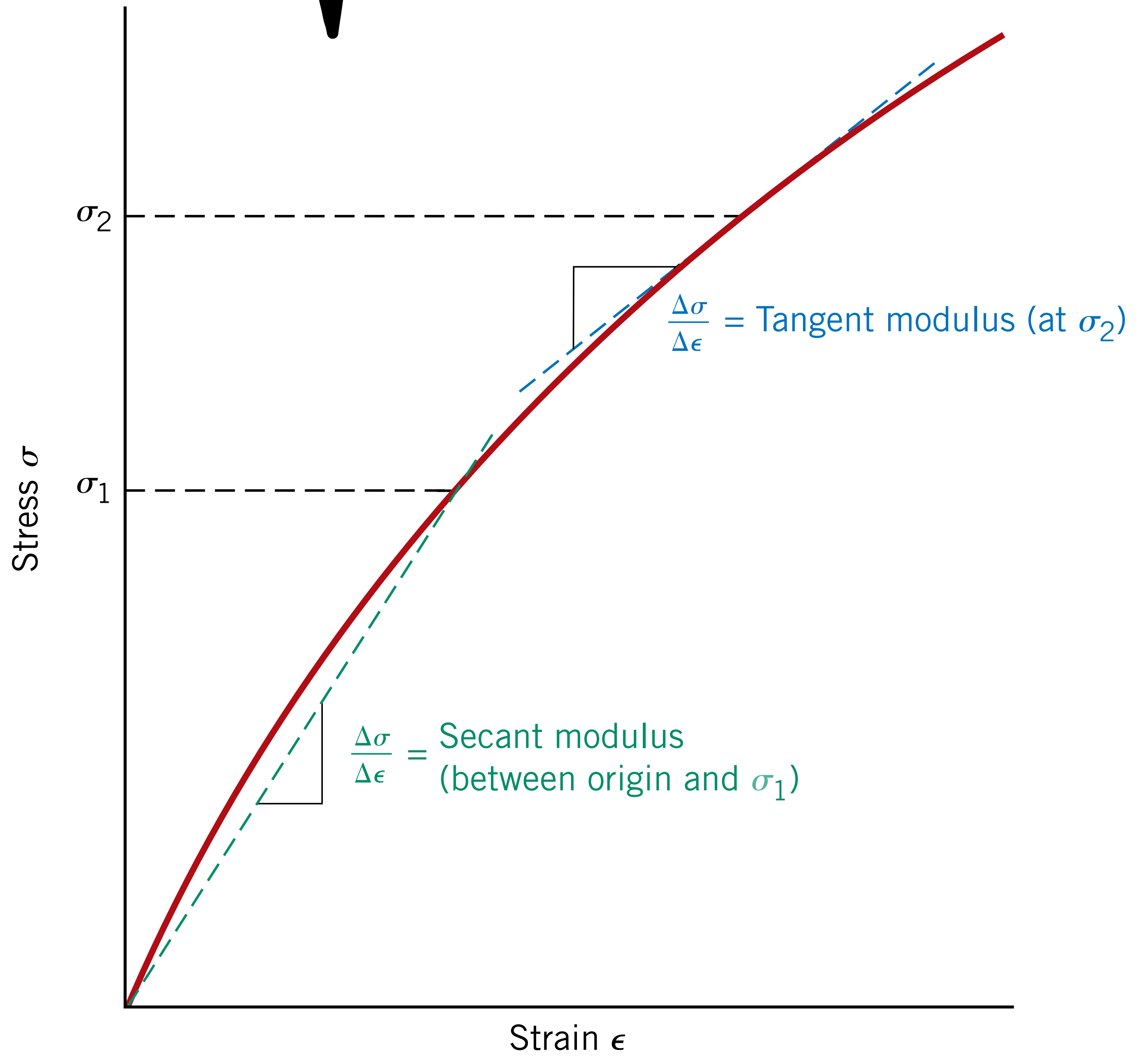
- Hooke's law:

$(F = k \cdot \Delta x) \Rightarrow \sigma = Y \varepsilon$, where Y = Young's modulus or modulus of elasticity

- For most typical metals the magnitude of this modulus ranges between 45 GPa (6.5×10^6 psi), for magnesium, and 407 GPa (59×10^6 psi), for tungsten.
- The greater the modulus, the stiffer the material, or the smaller the elastic strain that results from the application of a given stress.
- Elastic deformation is *non-permanent*: when the applied load is released, the piece returns to its original shape
- Young's modulus is a characteristic of each substance due to its chemical nature.



stress–strain diagram showing linear elastic deformation for loading and unloading cycles



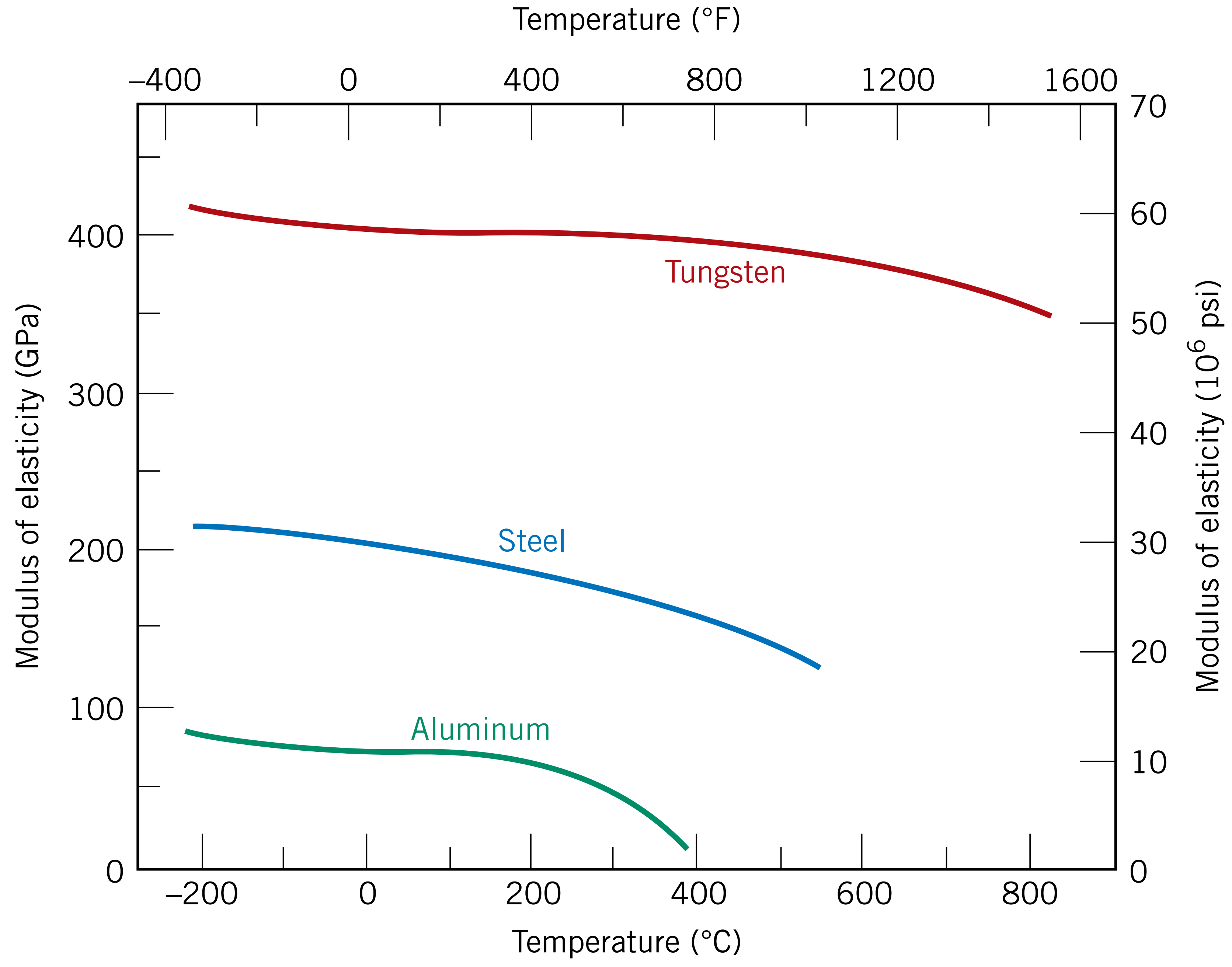
tangent or *secant modulus* for gray cast iron, concrete, and many polymers

Tensile properties: Young's modulus

Element	Li	Be	B	C (dia)
Atomic number Z	3	4	5	6
Young's modulus Y, GN m^{-2}	11.5	289	440	1140

Elements beyond carbon do not form solids with a three-dimensional network of covalent bonds. These would have moduli according to the strength of the secondary bonds in the solid, which are primarily stretched by an external stress

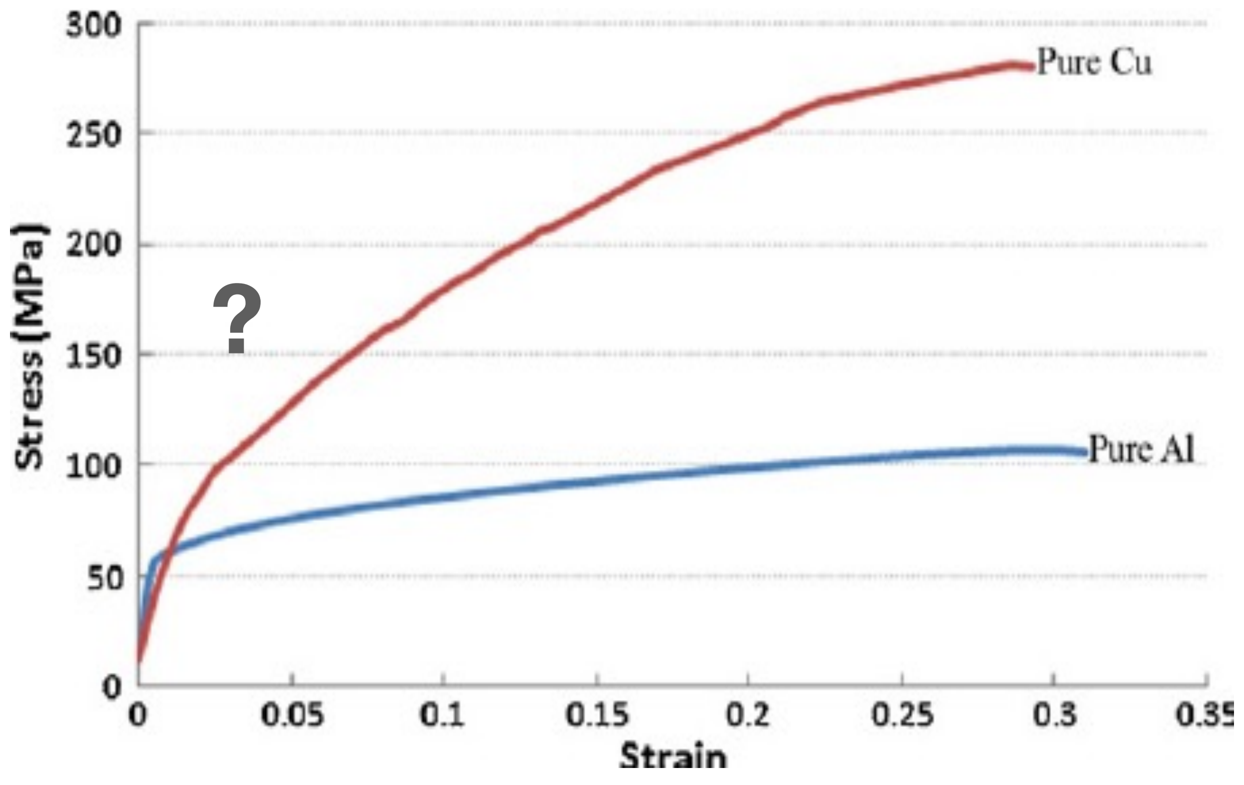
Element	C (dia)	Si	Ge	Sn	Pb	**Graphite**
Atomic number Z	6	14	32	50	82	**6**
Young's modulus Y, GN m^{-2}	1140	103	99	52	16	**8**

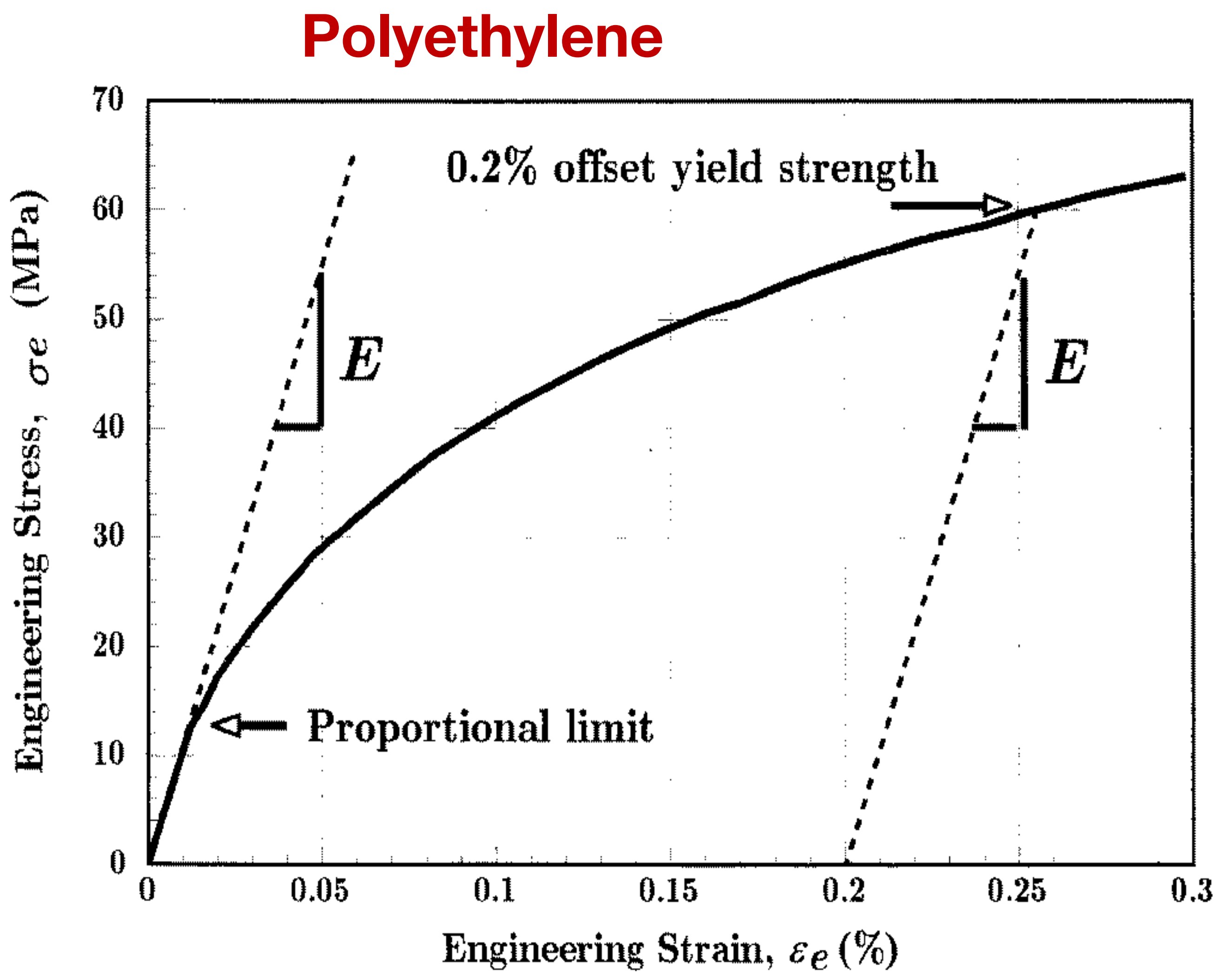


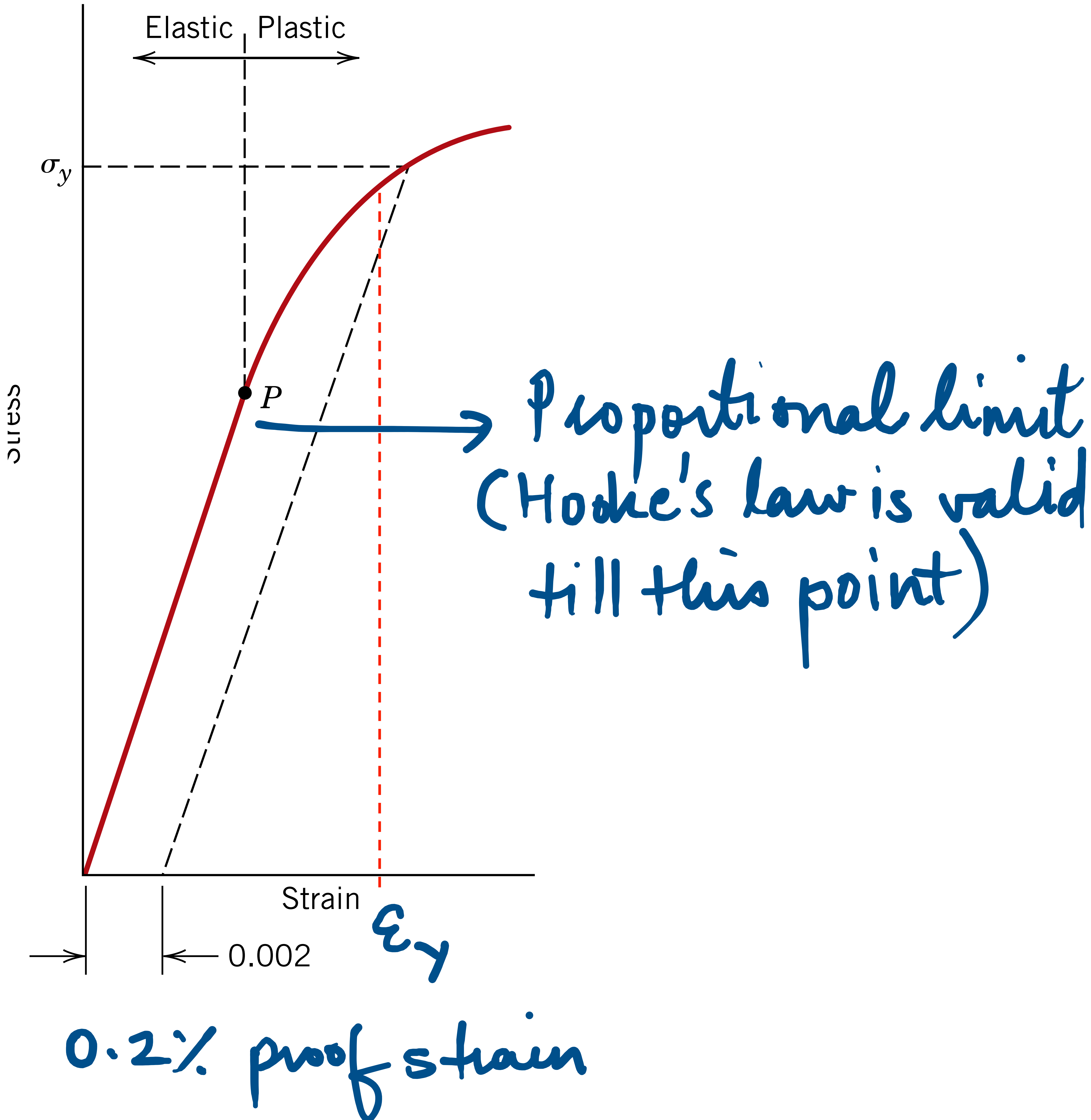
Elastic anisotropy: the elastic properties become a function of the crystal direction. This anisotropy is particularly evident in materials which have two kinds of bonds. For example, the Young's modulus of graphite in the *a* direction parallel to the sheets is 950 GN m^{-2}, which is much larger than that averaged over all directions, which is only 8 GN m^{-2}.

Tensile Properties: Yield stress

Offset yield stress: How to determine yield stress for gradual elastic-plastic deformation?







- **Proportional Limit:** initial departure from linearity of the stress–strain curve
- A straight line is constructed parallel to the elastic portion of the stress–strain curve at some specified strain offset, usually 0.002.
- For those materials having a nonlinear elastic region, use of the strain offset method is not possible, and the usual practice is to define the yield strength as the stress required to produce some amount of strain (e.g., ε= 0.005).