Question 1:

a) Explain the thermal expansion of a material on the basis of the energy-distance curve.

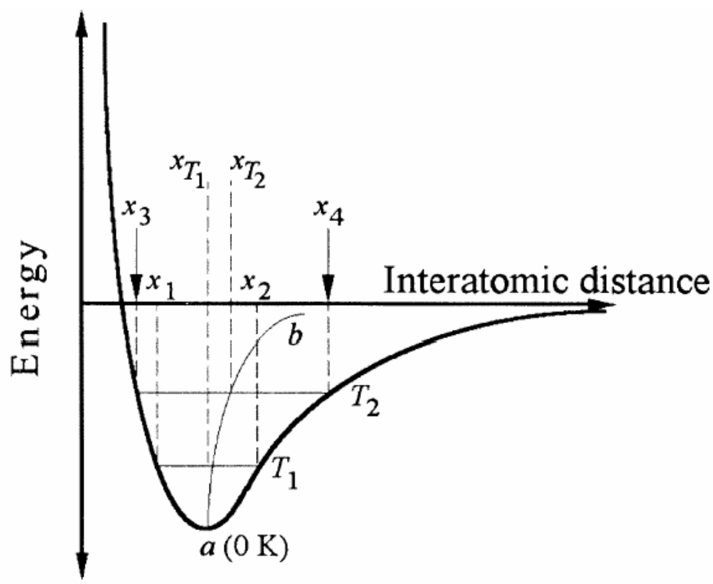
b) On the same plot sketch the energy-distance curve of a material with

i) higher thermal expansion

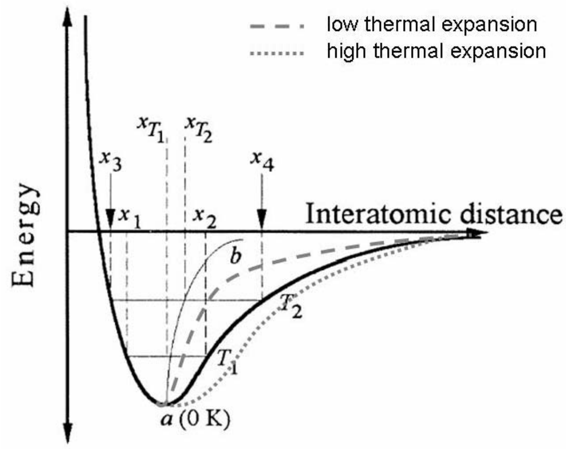
ii) lower thermal expansion

c) How can the Young's modulus be determined from the energy-distance curve?

a) The origin of thermal expansion can be traced to the asymmetry of the energy distance curve. The asymmetry of the curve expresses the fact that it is easier to pull two atoms apart than to push them together. At 0 K, the total energy of the atoms is potential, and the atoms are sitting at the bottom of the well (point a). As the temperature is raised to T_1, the average energy of the system increases correspondingly. The atoms vibrate between positions x_1 and x_2, and their energy fluctuates between purely potential at x_1 and x_2 (i.e., zero kinetic energy) and speed up somewhere in between. In other words, the atoms behave as if they were attached to each other by springs. The average location of the atoms at T_1 will thus be midway between x_1 and x_2, that is, at x_{T1}. If the temperature is raised to T_2, the average position of the atoms will move to x_{T2}, etc. It follows that with increasing temperature, the average position of the atoms will move along line ab, and consequently the dimensions of a crystal will also increase.

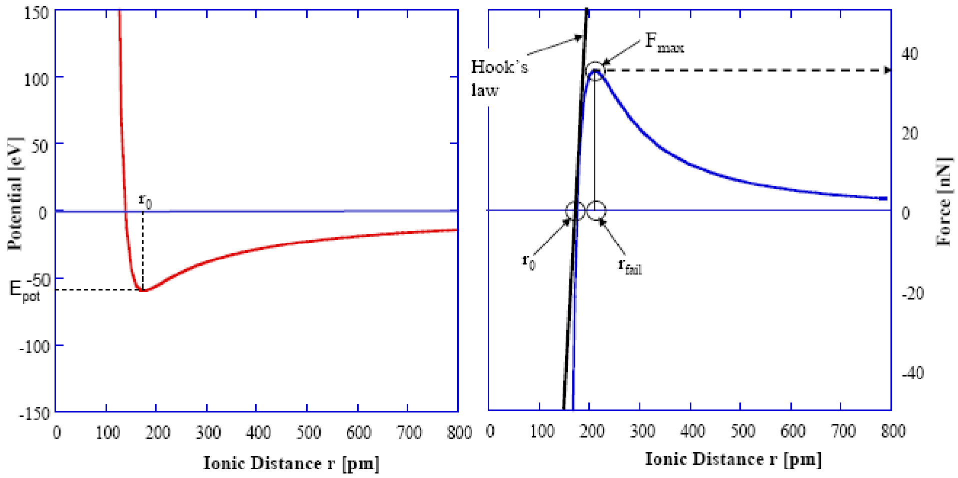


b)



c) The Young's modulus is proportional to the second derivative of the energy-distance curve.

$$E = \frac{1}{r_0}\left(\frac{\partial F}{\partial r}\right)_{r=r_0} = \frac{1}{r_0}\left(\frac{\partial^2 E_{net}}{\partial r^2}\right)_{r=r_0}$$



Question 2:

Why do ceramics exhibit much lower strength than their theoretically expected strength of E/10?

The reason for this state reflects the fact that real solids are not perfect, as assumed here, but contain many flaws and defects that tend to locally concentrate the applied stress, which in turn significantly weaken the material.