Solid State Physics

[PHAS 1030]

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Module outline

L1 Intro, bond potentials	w14 (w1)
L2 Electron structure in atoms	w14 (w1)
W1 *Bond potentials*	w15 (w2)
L3 The periodic system, bonding	w15 (w2)
L4 Bonding	w16 (w3)
W2 *General bonding*	w16 (w3)
L5 X-ray diffraction, crystal structure	w17 (w4)
L6 Bravais lattice, general unit cell properties	w17 (w4)
W3 *X-ray diffraction and crystal structure*	w18 (w5)
L7 Structure of solids, unit cells	w18 (w5)
W4 *Unit cells*	w19 (w6)
L8 Crystal planes, Miller indices	w19 (w6)
W5 *Miller indices and lattice planes*	w20 (w7)
L9 Stacking of planes, ionic bonding	w20 (w7)
L10 Ionic crystals, allotropy, bond hybridisation (pre-recorded)	w21 (w8)
L11 Mechanical properties of solids	w22 (w9)
L12 Mechanical properties (macro-micro)	w22 (w9)
W6 *Ionic crystals and mechanical properties of solids*	w22 (w9)
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L13 Disordered solids (glasses)	w23 (w10)
L14 Scattering (x-ray, neutron, electron)	w23 (w10)
W7 *Revision material across the solid state content*	w24 (w11)
L15 Revision	w24 (w11)

Literature

- Callister WD & Rethwisch, D.G., *Fundamentals of Materials Science and Engineering*

- Turton, R., *The Physics of Solids*, (Oxford University Press, 2006)

- Holgate SA, *Understanding Solid State Physics* (Taylor & Francis, 2010)

- Understanding Chemistry in a Physics Context

- Tipler PA & Mosca, G., *Physics for Scientists and Engineers*

More advanced texts

- Hofmann, P., Solid State Physics - an introduction (Wiley, 2008)

- Ashcroft, N.W. & Mermin, N.D., *Solid State Physics*

- Kittel, C, *Introduction to Solid State Physics* (Wiley)

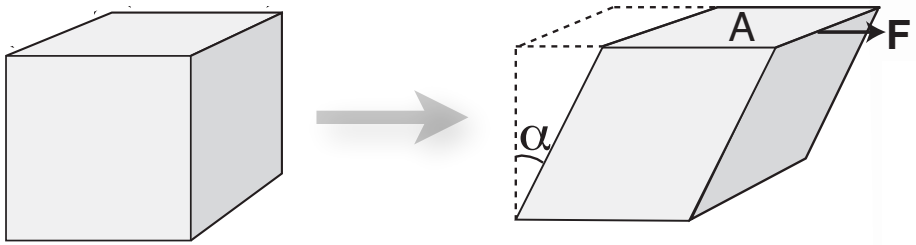
What is a solid?

Criteria for a solid:

i) Can sustain a shear stress without yielding

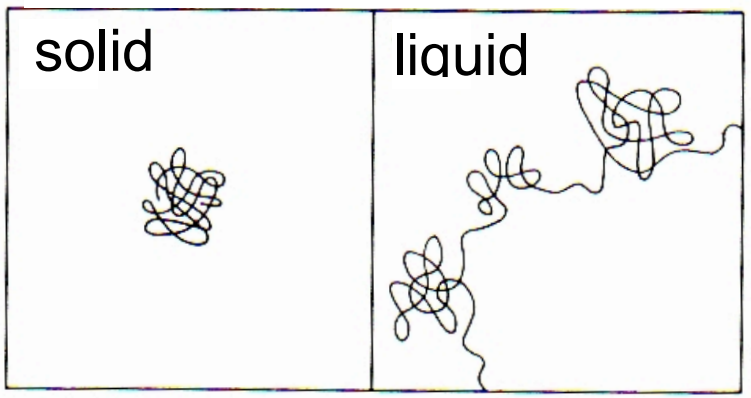
ii) The building blocks such as atoms or molecules have well defined average positions (atoms or molecules however undergo vibrations centered on these sites)

shearing a solid



shear stress: $\tau = \frac{F}{A}$

atomic motion over time

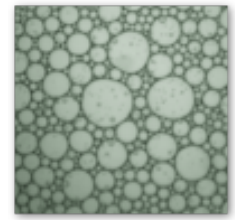


Examples of solids

semi-crystalline polymer

ice

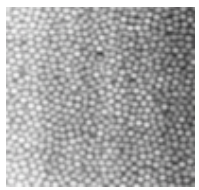
metal



emulsion

glassy polymer foam

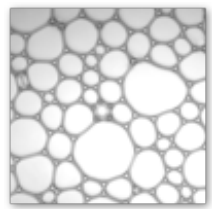
composite



colloidal solid

gel

glass



foam

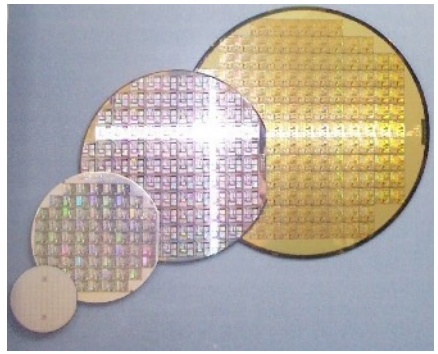
salt

glassy metal

Solids with ordered crystalline structures

metal

ice



silicon wafer

semi-crystalline polymer

salt

Solids with disordered glassy structures

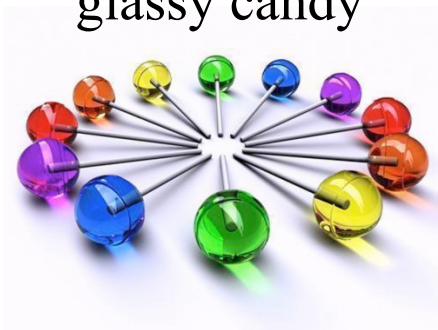
network glass

polymer glass as foam

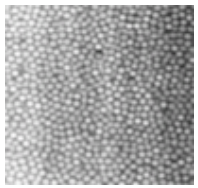
glassy paste

glassy medication

glassy candy



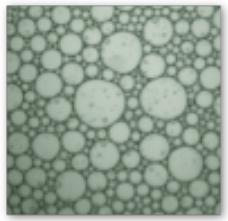
colloidal glass



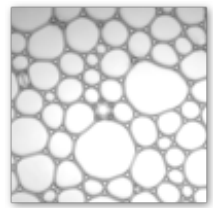
water in comets

water in clouds

emulsion glass



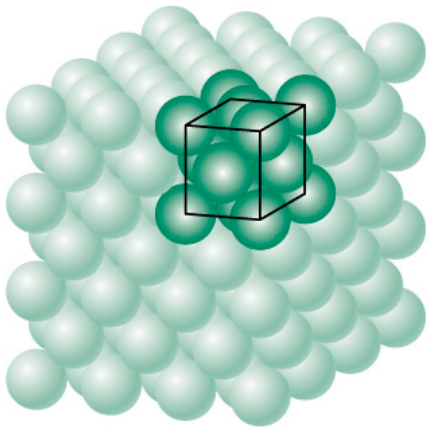
foam

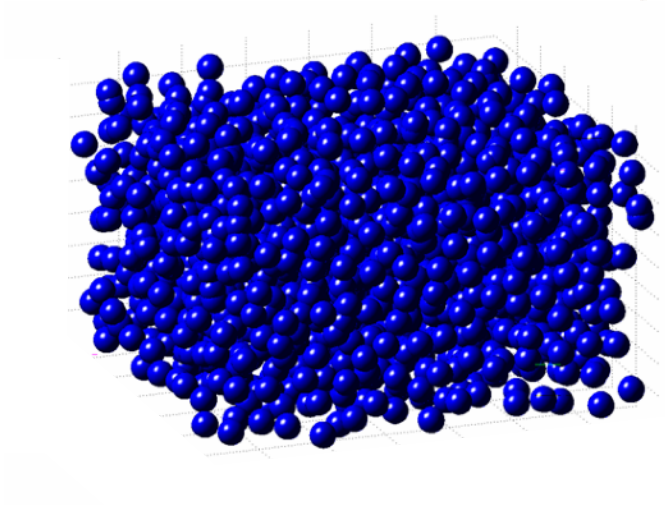


Ordered - disordered structures

crystalline metal (atomic order)

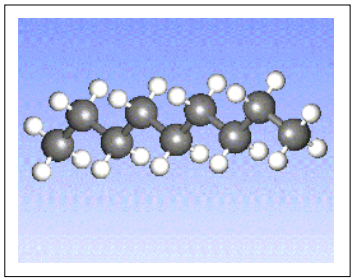
glassy metal (atomic disorder)





bonding

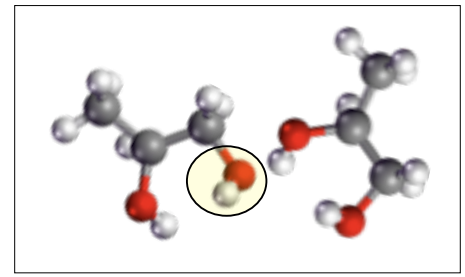
ionic bonding



covalent bonding

metallic bonding

van der Waals bonding



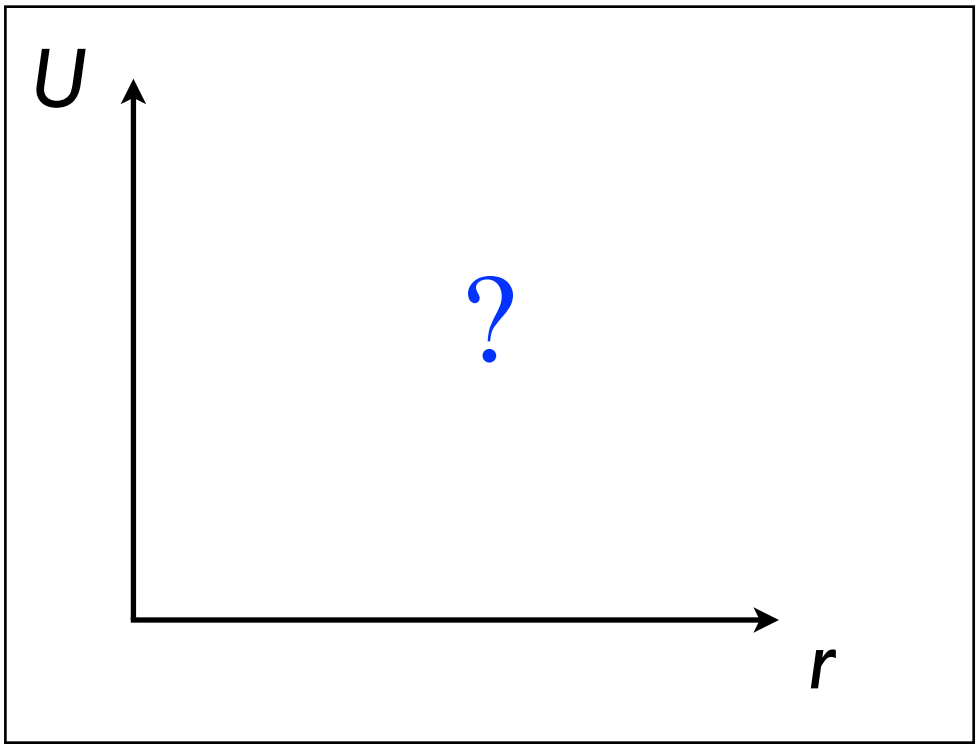
hydrogen bonding

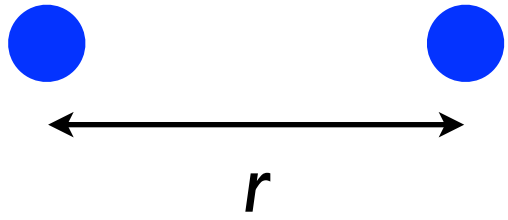
General form of the bond potential energy

- the potential energy should approach zero for large inter-particle distances, *r.*

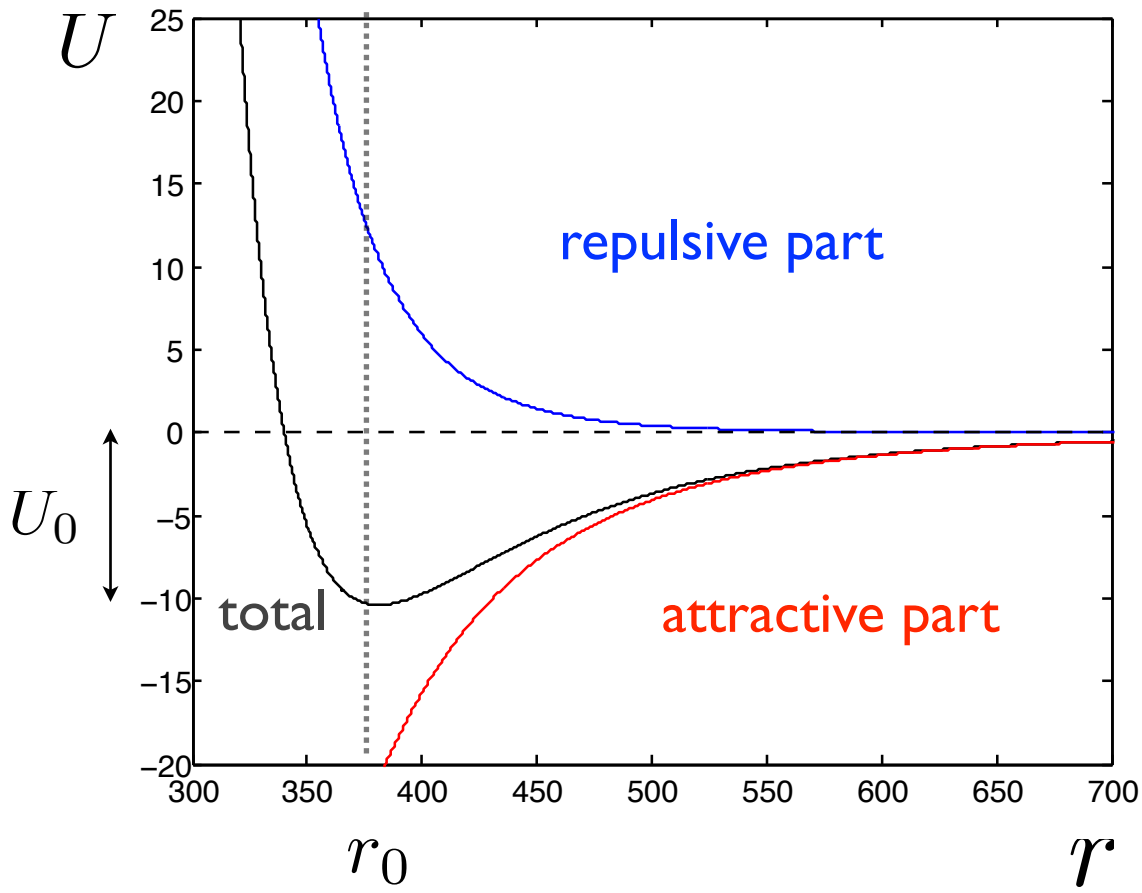
- For small inter-particle distances, the potential energy should be large and positive since two atoms/ molecules can not be superimposed (due to the Pauli exclusion principle).

- For a bond to form between two atoms/molecules there must be a minimum (negative value) in the potential energy at some characteristic separation corresponding to the equilibrium bond length, r_0. The depth of the minimum below zero corresponds to the bond energy (or bond strength), U_0.





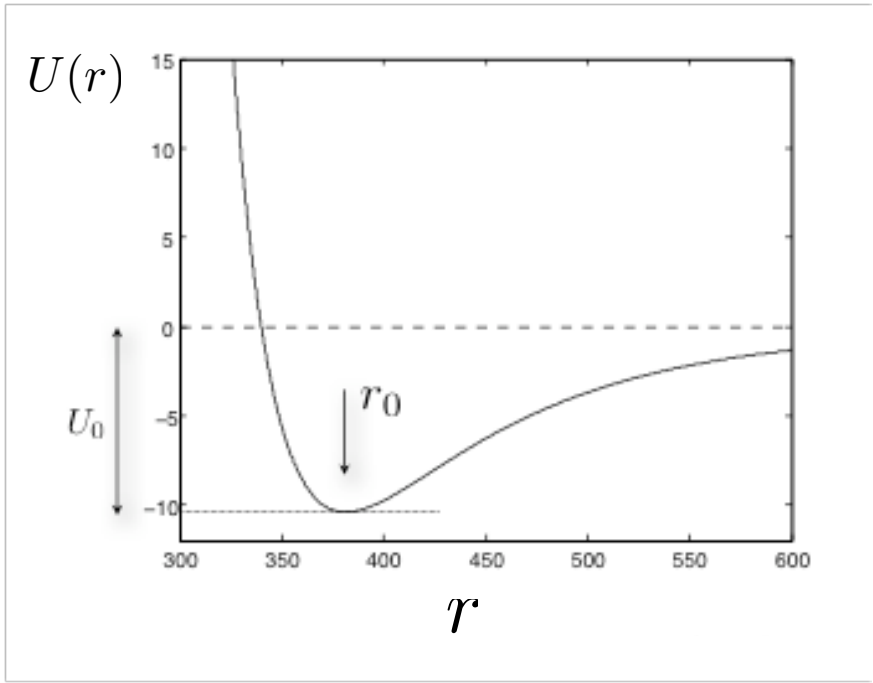
General form of the bond potential energy



r_0 : equilibrium bond distance

U_0 : bond energy

The bond potential energy



Taylor expansion around r_0:

$$U(r) = U(r_0) + \frac{dU(r_0)}{dr}(r - r_0) + \frac{1}{2}\frac{d^2U(r_0)}{dr^2}(r - r_0)^2 + \ldots$$ terms of order $(r\text{-}r_0)^3$

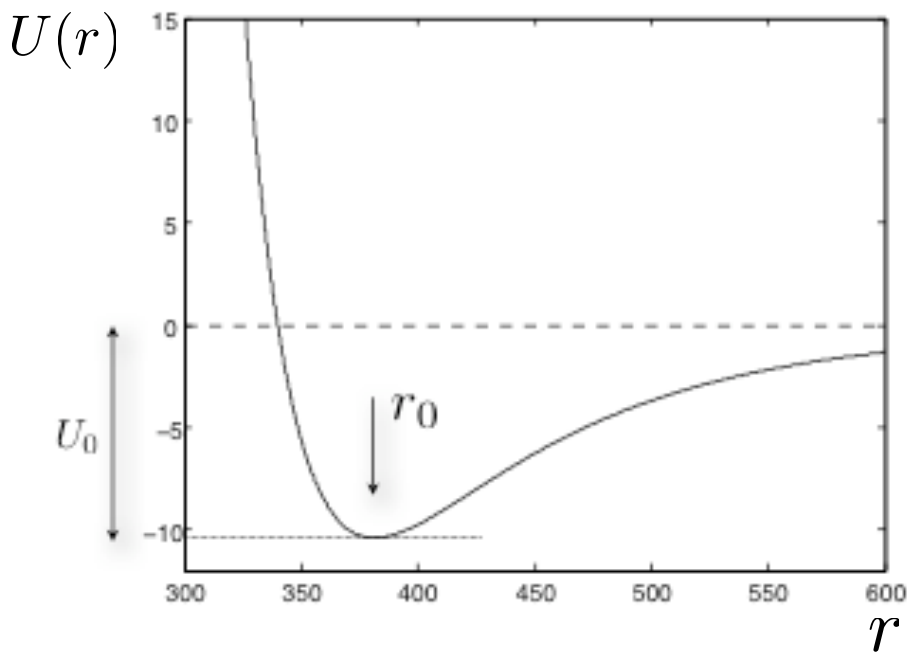
$[\approx 0$ for small $(\text{r-r}_0)]$

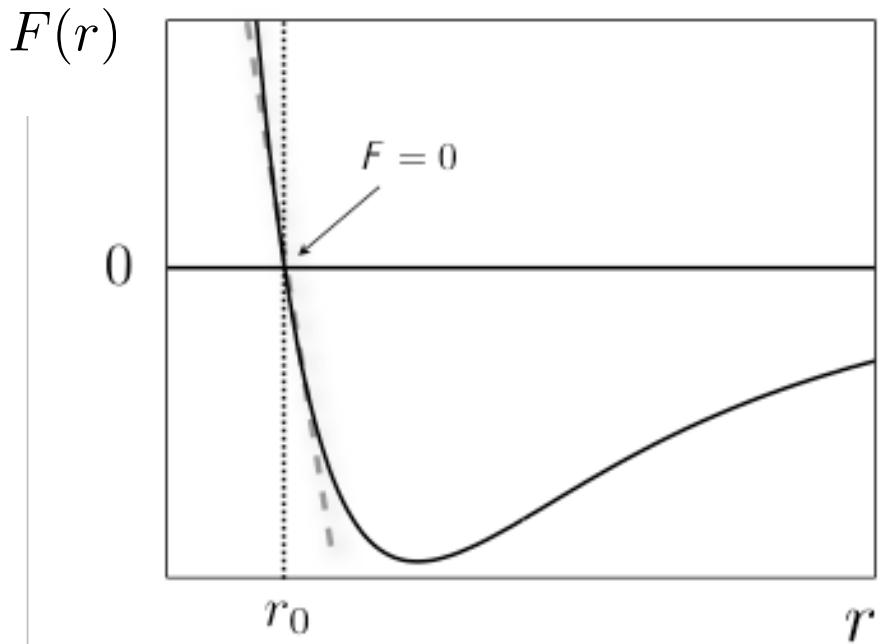
$$U(r) \approx U(r_0) + \frac{1}{2}k(r - r_0)^2$$

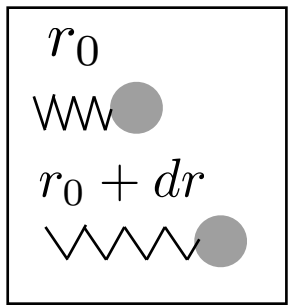
$\frac{1}{2}k(r - r_0)^2$ (potential energy of a spring)

$k = \frac{d^2U(r_0)}{dr^2}$ (spring constant)

The bond potential energy







$$F(r) = -\frac{dU(r)}{dr}$$

$$k = \frac{d^2U}{dr^2} \mid r_0$$

For a spring: $dF = -kdr$

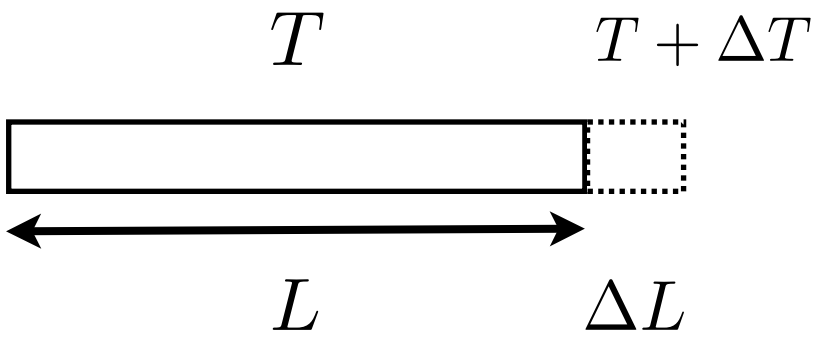
(Hooke's law)

$r \approx r_0$

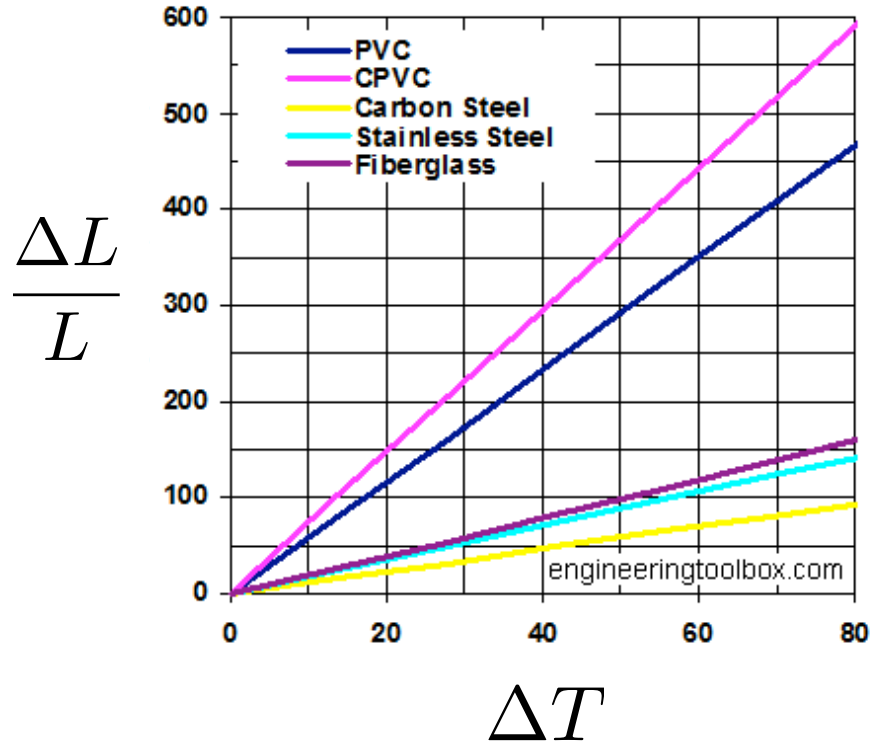
$$k = -\frac{dF}{dr}$$

Any interaction (with a minimum) acts like a spring for small deformations

Thermal expansion



$$\frac{\Delta L}{L} = \alpha \Delta T$$

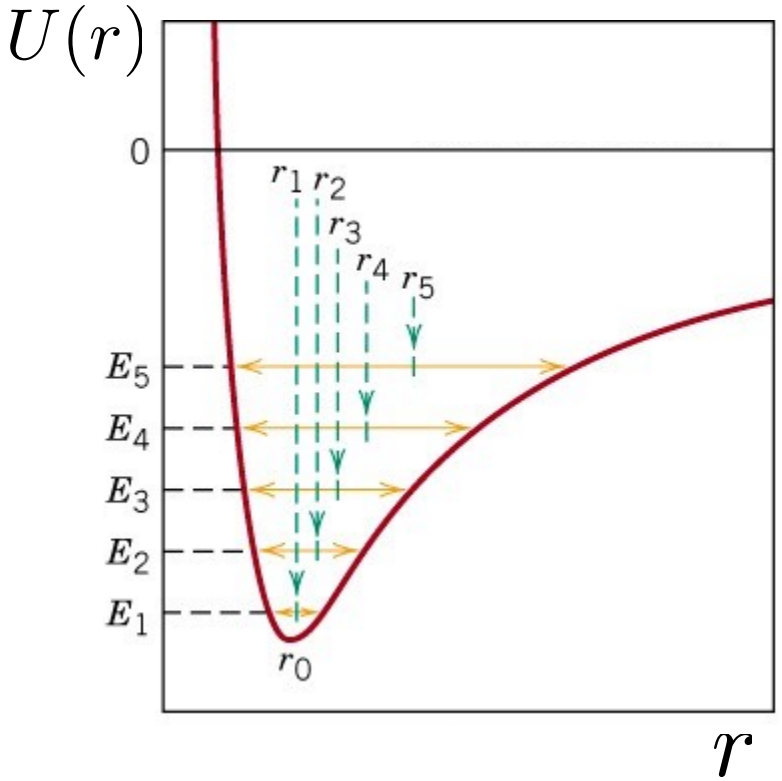


α thermal expansivity

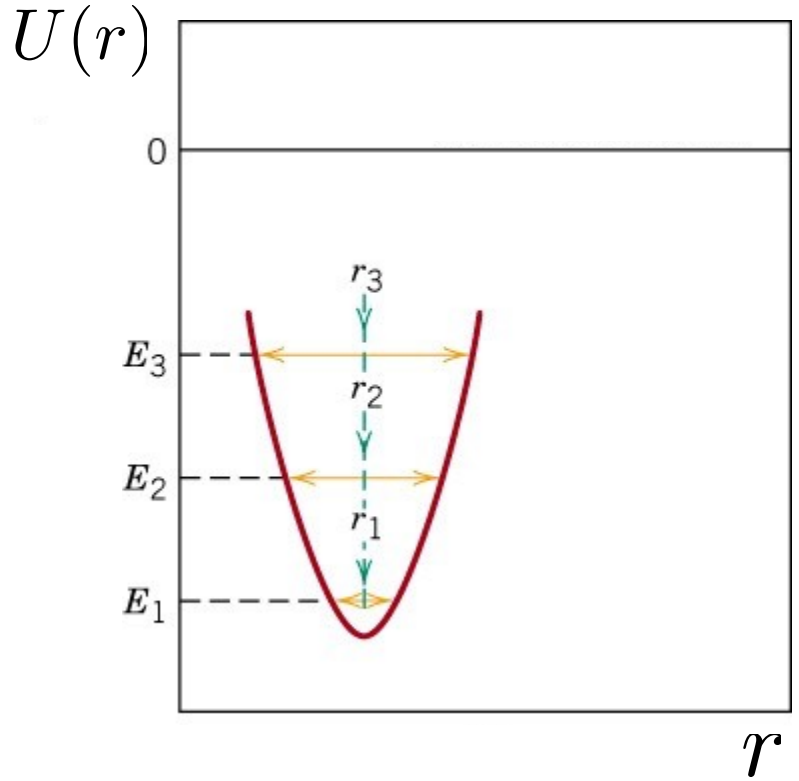
	α (x10^{-5} K^{-1})
glass	0.9
steel	1.1
invar	0.09
Al	2.4
brass	1.9
copper	1.7

Thermal expansion

anharmonic potential



harmonic potential



- Sufficiently close to the minimum in the potential energy, *U(r)* can be described as a parabola, i.e. $U(r) \propto (r - r_0)^2$. As one moves off the minimum higher order terms will come into play and *U(r)* will in general be anharmonic.

- As temperature is increased we move towards higher energy values within the potential well.

- For a harmonic system, the average bond-length is constant with thermal energy. For an anharmonic system, the average bond-length increases.

Before next lecture read through:

Appendix C: "Revision of Atomic Physics" from the book "Understanding Solid State Physics" by Holgate SA. The chapter is on the VLE