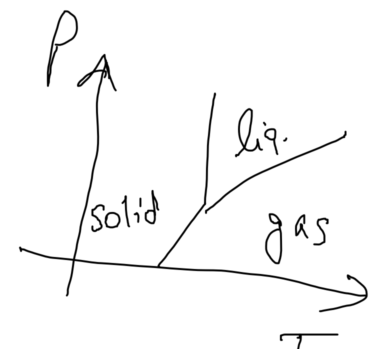
Soft Condensed Matter

Solids and liquids → Condensed Matter

P.E. → intermolecular interaction is must for condensed phases to exist



Intermolecular forces:

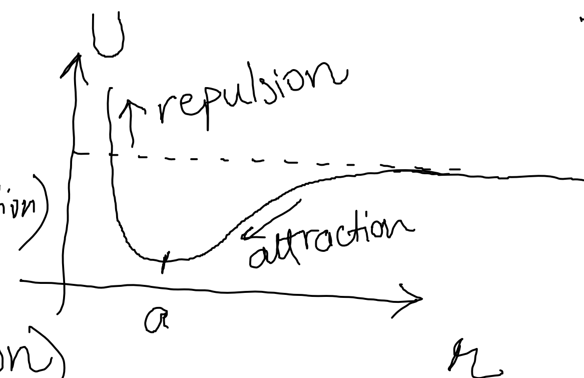
① It must be attractive

$$F = \frac{-dU}{dr}$$

For $r \to \infty$, $-\frac{dU}{dr} = 0$ (no interaction)

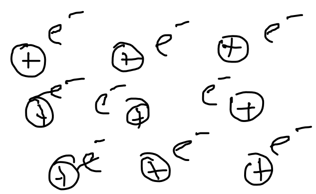
For $r \gtrsim a$ $\quad -\frac{dU}{dr} < 0$ (attractive interaction)

For $r \leq a$ $\quad -\frac{dU}{dr} > 0$ (repulsion)



(He)
(any spherically symmetric molecule)

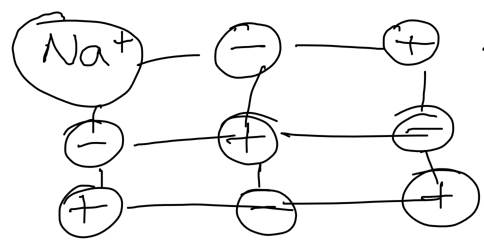
(1) Metallic bond: e^-s are free to move in space



Typical bond strength $\approx 10^{-18}$ J ≈ 6 eV $\approx 240\, k_BT$ ($T \approx 300$ K)

(2) Ionic bonds:

Bond energy $\approx 10^{-18}$ J
≈ 6 eV
$\approx 240\, k_BT$

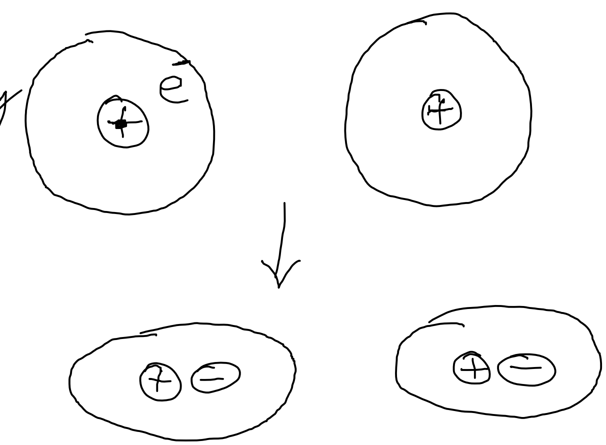


$$\frac{e^2}{r}$$

(3) Covalent bond: Bond strength $\approx 3 \times 10^{-19} - 10^{-18}$ J
≈ 5 eV $\approx 150\, k_BT$

4. Van der Waals interactions : (dipole-dipole interaction)

$U \sim \frac{\alpha^2}{r^6}$; α = polarizability



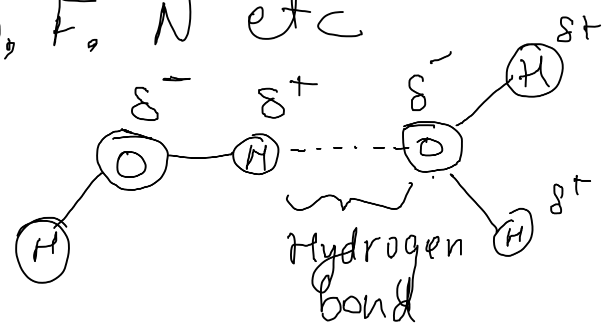
Bond strength $\simeq 10^{-21}$ J

$\approx k_B T$

5. Hydrogen bonding : O, F, N etc

Bond strength $\cong 2-6 \times 10^{-20}$ J

$\approx 20-100\, k_B T$



This is responsible for very anomalous behaviour of water

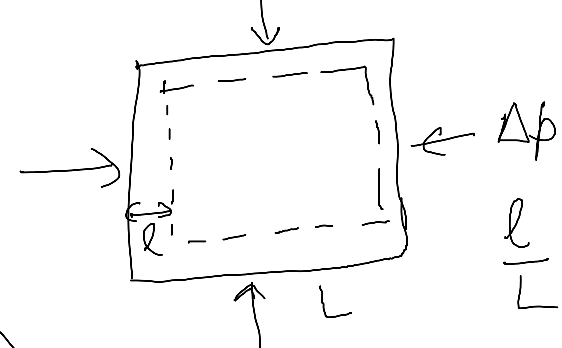
Soft : Basic building units are mesoscopic in size

$\mathring{A}$ $(10^{-10}\,m)$  1 m

$(10^{-8} - 10^{-9}$ m)

"Soft" : Low elastic moduli such that materials are unable to withstand weak mechanical deformations

We are compressing the material
(compressive modulus
bulk modulus)



$\Delta p \sim \frac{l}{L}$ $\qquad$ $\Delta p \approx K \frac{l}{L}$ $\qquad$ $\frac{l}{L}$

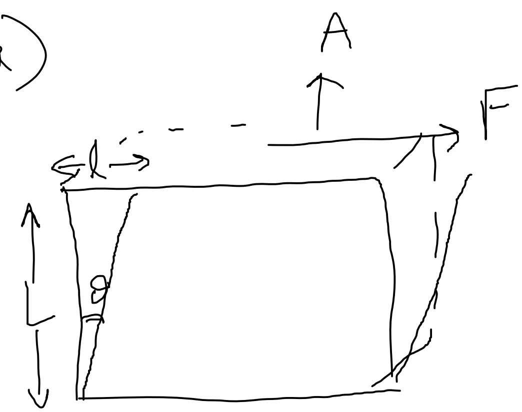
$\frac{\Delta V}{V}$

For condensed matter (liquids & solids)

For solids & liquids, $K \approx 10^{11}$ Pa $(10^{10}$ Pa$)$

For gases $K \approx 0$ $(100$ Pa$)$

Shear deformation $\Longrightarrow$ Shear modulus



Shear stress, $\sigma = \frac{F}{A}$

shear strain, $\gamma = \frac{l}{L}$

Shear modulus, $G = \sigma . \frac{l}{L}$

For solids; $G \approx 10^{11}$ Pa

For liquids, $G \approx 0$ Pa (there is no restoring force)

Soft

$G \simeq 10^{11}$ Pa (Solids)

$G \approx 1-100$ Pa (Soft) soft matter

$G \approx 0$ Pa (liquids)

Why do soft materials have low G

Shear modulus $= \frac{F}{A} = \frac{E}{V} = \boxed{\frac{E}{l^3}}$

For metals $l \approx 10^{-10}$ m

For soft materials, $l \approx 10^{-6} - 10^{-9}$ m

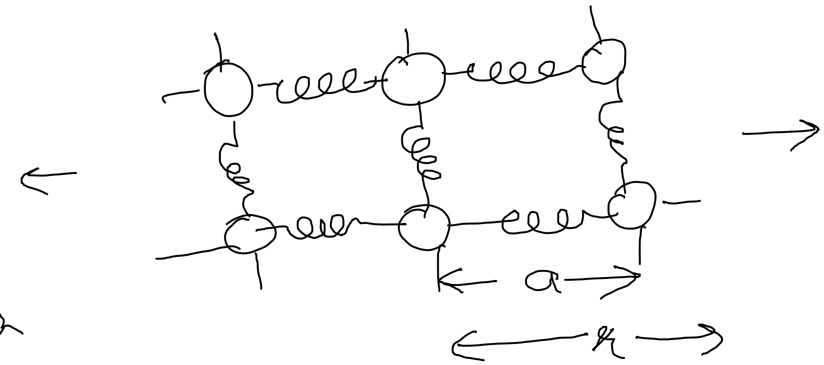
$$F = k(r-a)$$

$$\text{Stress, } \sigma = \frac{F}{A} = \frac{k(r-a)}{a^2}$$

$$\text{Strain, } \gamma = \frac{r-a}{a}$$

$$\text{Youngs modulus} = E = \frac{\sigma}{\gamma} = \frac{k\cancel{(r-a)}\cdot a}{a^2 \cdot \cancel{(r-a)}}$$

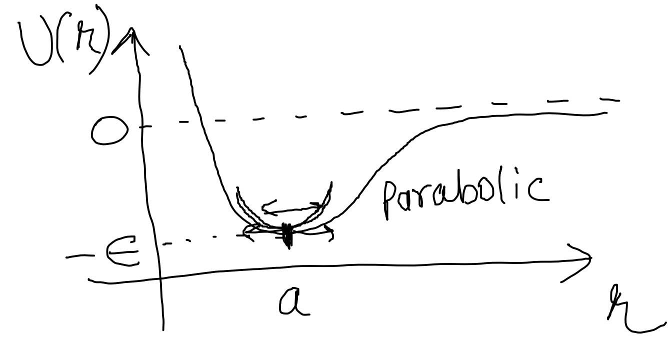
$$= \frac{k}{a}$$



$$U(r) = U(a) + \frac{1}{2!}(r-a)^2 \left.\frac{d^2U}{dr^2}\right|_{r=a} + \dots$$

$$= \text{const.} + \frac{1}{2}k(r-a)^2$$

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



$$y = ax^2$$

$U(r) = \epsilon f\left(\frac{r}{a}\right)$ such that at $r = a$, $U(r) = -\epsilon$

$$k = \left.\frac{d^2U}{dr^2}\right|_{r=a} = \frac{\epsilon}{a^2} f''(1)$$

$$\boxed{E = \frac{k}{a} \simeq \frac{\epsilon}{a^3}}$$

$\epsilon \rightarrow$ Bond strength

Shear modulus $\sim \frac{E}{l^3}$ $l \sim$ size of the constituent molecule

$l \sim a$

If we have a very small, E is very large

large, E is very small

$\therefore$ Soft materials ($a \sim \mu m$), E is very small

Some important properties of soft matter systems:

① <u>Disordered matter:</u> Energy scales $\approx k_B T$.

(ex. granular matter)

② <u>Non-linear matter:</u> low energy scales $\Rightarrow$ easy to drive system out of its linear response

③ <u>Far-from-Eq^m matter:</u> $D \sim \frac{k_B T}{6\pi\eta R}$; $D \sim \frac{R^2}{t}$, $\frac{R^2}{t} \sim \frac{k_B T}{\eta R}$

$t \sim R^3$

Underlying dynamics are very slow $\Rightarrow$ injection of energy ~~takes~~ forever to equilibriate the material

4. Thermal & entropic matter:

5. observable matter:

$$D \sim \frac{k_B T}{6\pi\eta r} \quad \therefore \quad D \sim \frac{r^2}{t}$$

$$\boxed{t \sim r^3}$$