Chapter 15

Surface Tension

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INTRODUCTION TO RIGID BODY

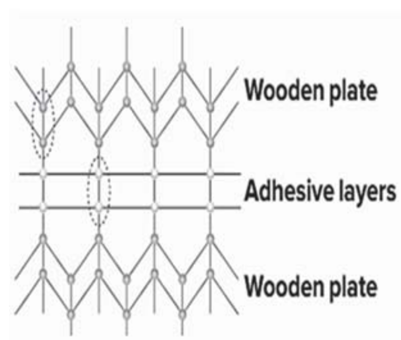
Intermolecular Forces:

Interactions of attraction or repulsion occurring between molecules are referred to as intermolecular forces. Two main categories of intermolecular forces exist:

1) Cohesive forces
2) Adhesive forces

1) **Cohesive force:**
   The attractive force acting between molecules of the same substance is termed cohesive force.

Ex. Let's adhere two wooden plates together using an adhesive.



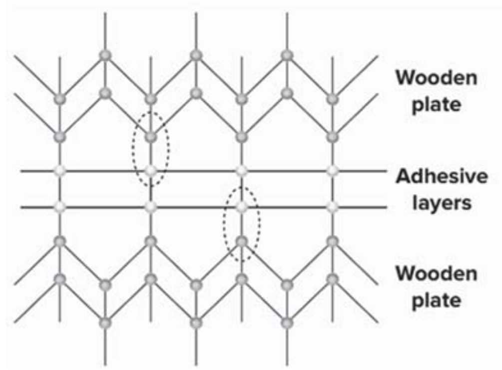
By examining the intermolecular structure provided, we can discern the attractive forces between individual wood molecules and also between the adhesive layers. These forces exemplify cohesive forces.

Adhesive force:

The attractive force between molecules of different substances is referred to as adhesive force. In the given example, we can also note the presence of attractive forces between the molecules of wood and those of the adhesive. These interactions represent instances of adhesive force.

Examples of adhesive force:

Adhesive forces facilitate writing on a blackboard by causing the molecules of chalk to adhere to the molecules of the blackboard.



In the construction of a building, cement is applied between layers of bricks, functioning as an adhesive to bond the bricks together.

Surface Tension:

Consider a beaker containing water. Now, let's select two molecules—one from the water's surface and another from within the bulk of the liquid.

1. **For the molecule in the bulk:**
   The molecule within the bulk is encompassed by adjacent water molecules from all directions. Consequently, cohesive forces of the same nature act uniformly from all sides, resulting in a balanced net force that maintains the particle in equilibrium.

2. **For the molecule on the free surface of the liquid:**
   The molecules at the free surface experience two distinct types of attractive forces. Firstly, there's the adhesive force between the air and water, and secondly, the cohesive force between water molecules surrounding the drop. It's understood that the force between air and water is less potent than the cohesive forces between water molecules.
   Consequently, the water molecules at the surface encounter a resultant force directed downward. This downward force causes either the molecules on the surface or the entire surface of the liquid to undergo stretching. Thus, the liquid surface behaves akin to a stretched membrane.

Definition of surface tension:

Surface tension is the tangential force exerted per unit length on the free surface of a liquid, aiming to reduce its area. This property is scalar in nature.

Surface tension $= T = \frac{F}{J}$

Factors Affecting Surface Tension:

1. Temperature As temperature rises, the surface tension of the liquid decreases.
2. Impurities
   (a) Soluble Impurities
   (i) Highly Soluble The inclusion of highly soluble impurities elevates the surface tension.

Ex: NaCl

(ii) Sparingly Soluble The addition of sparingly soluble impurities lowers the surface tension.

Ex: Detergent

(b) Insoluble Impurities Incorporating insoluble impurities reduces the surface tension.

Ex: Oil

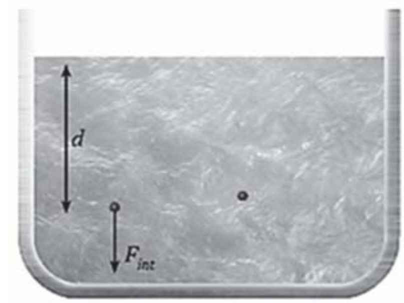
Surface Energy:

Let's revisit the scenario of two molecules—one within the bulk and the other at the surface. It's evident that the surface molecule experiences a net downward force, whereas the bulk molecule remains in equilibrium.

Since the bulk molecules are stable, those at the surface endeavor to attain stability by moving into the bulk. This inward force prompts the molecules to migrate towards the bulk, causing others from beneath the surface to occupy their place. The molecules occupying the vacant space require energy to reach the surface, known as surface energy.

Now, consider the molecules moving a distance d from the surface into the bulk.

Thus, the performed work is as follows:



$$W_{int} = -\Delta U$$

$$\Rightarrow W_{int} = -(\Delta U_f - \Delta U_i)$$

$$\Rightarrow W_{int} = -(\Delta U_b - \Delta U_s)$$

$$\Rightarrow W_{int} = -\Delta U_b + \Delta U_s$$

$$\Rightarrow \Delta U_s = W_{int} + \Delta U_b$$

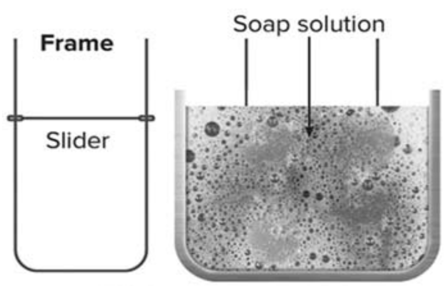
The energy present at the surface exceeds that within the bulk.

$$\therefore U_s > U_b$$

The variance in energy between the bulk of the liquid and its surface is termed surface energy.

Relation between Surface Tension and Surface Energy:

Consider a container of soap solution where a frame is immersed. Upon removal of the frame, a soap solution film adheres to it. This film on the frame features two interfaces on either side, effectively doubling the surface tension exerted across the frame.

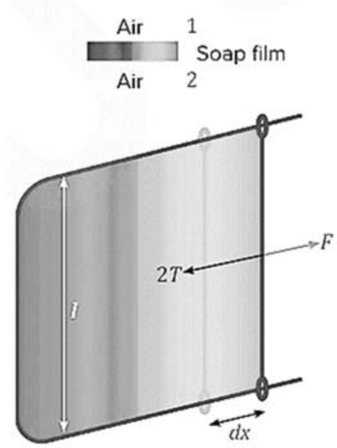


A slider is then subjected to a force F and displaced a short distance dx.

In a state of equilibrium, the external force,

$$F = 2l \times T$$

Now, the surface energy (the work performed by the force),



$$dW = F \cdot dx$$

$$\Rightarrow dW = 2Tldx$$

$$\Rightarrow dW = T \times 2ldx$$

We know, $2ldx = \text{Change in area} = dA$

$$\Rightarrow dW = TdA$$

$$\Rightarrow T = \frac{dW}{dA}$$

$$\text{Surface tension} = \frac{\text{Surface energy}}{\text{Area}}$$

$$\text{Surface energy} = \text{Surface tension} \times \text{Area}$$

Ex. If the work done to extend a rectangular film of liquid from (4 cm × 2 cm) to (5 cm × 4 cm) amounts to 3 × 10–4 J, determine the surface tension of the liquid.

Sol. Provided:

Initial surface area of the film, $A_i = 8\ cm^2$.

Final surface area of the film, $A_f = 20\ cm^2$.
Work performed, $W = 3 \times 10^{-4} J$
Change in surface area. $\Delta A = (A_f - A_i) \times 2$
$\Rightarrow \triangle A = (20 - 8) \times 2$
$\Rightarrow \triangle A = 24\ cm^2 = 24 \times 10^{-4}\ m^2$
The surface tension of the film, $T = \frac{W}{\Delta A} = \frac{3\times10^{-6}\ J}{24\times10^{-4}\ m^2}$.
$\Rightarrow T = 0.125 Nm^{-1}$