

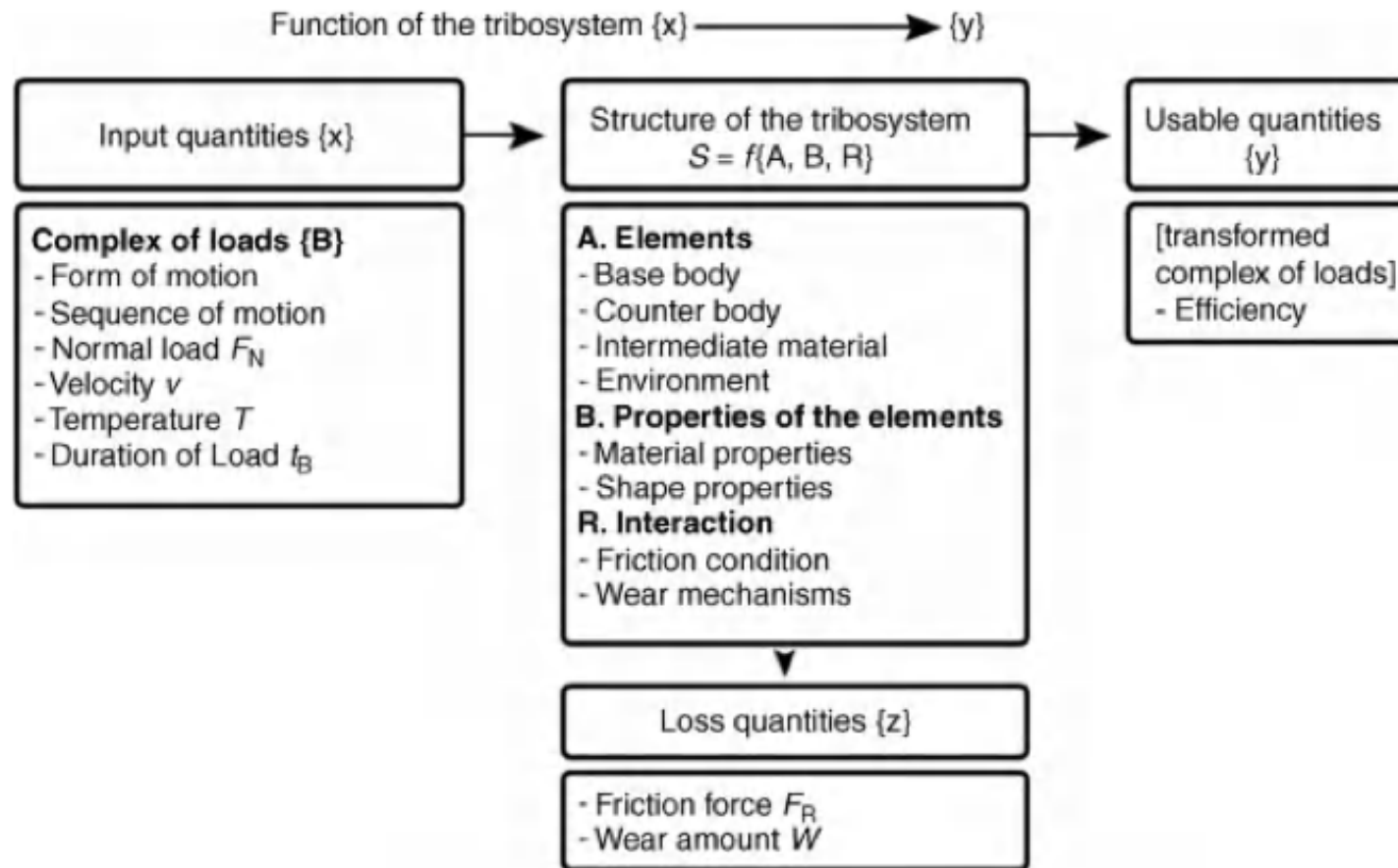
THE TRIBOLOGICAL SYSTEM

1. The Tribological System

- **Functional Character:** A tribological system performs technical tasks which are energy-, material-, or signal-oriented.
- **System Properties vs Material Properties:** Friction and wear are system properties, not material characteristics. Minor modifications to the system can drastically alter friction and wear behavior.

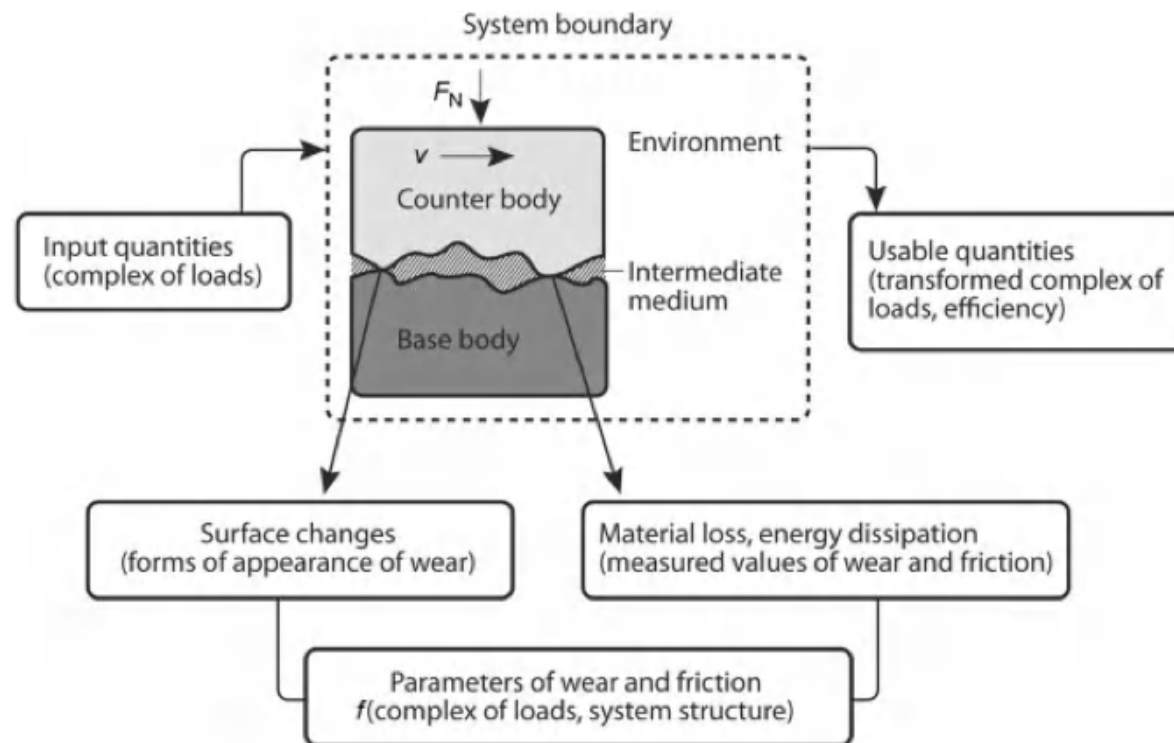
- **Types of Tribological Systems:**

- **Closed Tribo Systems:** System elements are permanent parts beyond loading duration and constantly participate in processes (e.g., lifetime-lubricated bearings). Wear processes of all elements must be considered.
- **Open Tribo Systems:** One or more tribo elements move through the system and are not in continuous contact (e.g., chain drives, cutting tools, bulk conveyor belts). Only permanently installed elements' wear is evaluated.



Complete description of a tribo-system.

- **Basic Structure:** Consists of two solid bodies - the Base body and Counter-body, moving relative to each other, with or without an intermediate medium. Base body is always solid; counter-body and intermediate material can be liquid or gaseous.



Schematic representation of a tribological system.

Functional Ranges of Tribological Systems and Examples.

Functional Range	Examples of Tribo Systems and Components
Guidance	Plane bearings, rolling bearings, linear guidance, running fit
Retardation of motion	Friction brakes, shock absorbers
Power/energy transmission	Gearwheels, belt drives, clutches, piston rings/cylinders, cams/tappets
Information transfer	Control gears, relays, read heads, printers
Sealing	Linear seals, stuffing boxes, radial shaft seals, piston ring-type sealing
Material transport	Wheel/rail, tire/road, conveyor belt, dredging shovel, chute, pipeline, pump



Material separation

Centrifuges, cutting tools for turning, milling, drilling, grinding

Material crushing

Ball-mill, jaw crusher, shredder

Material forming

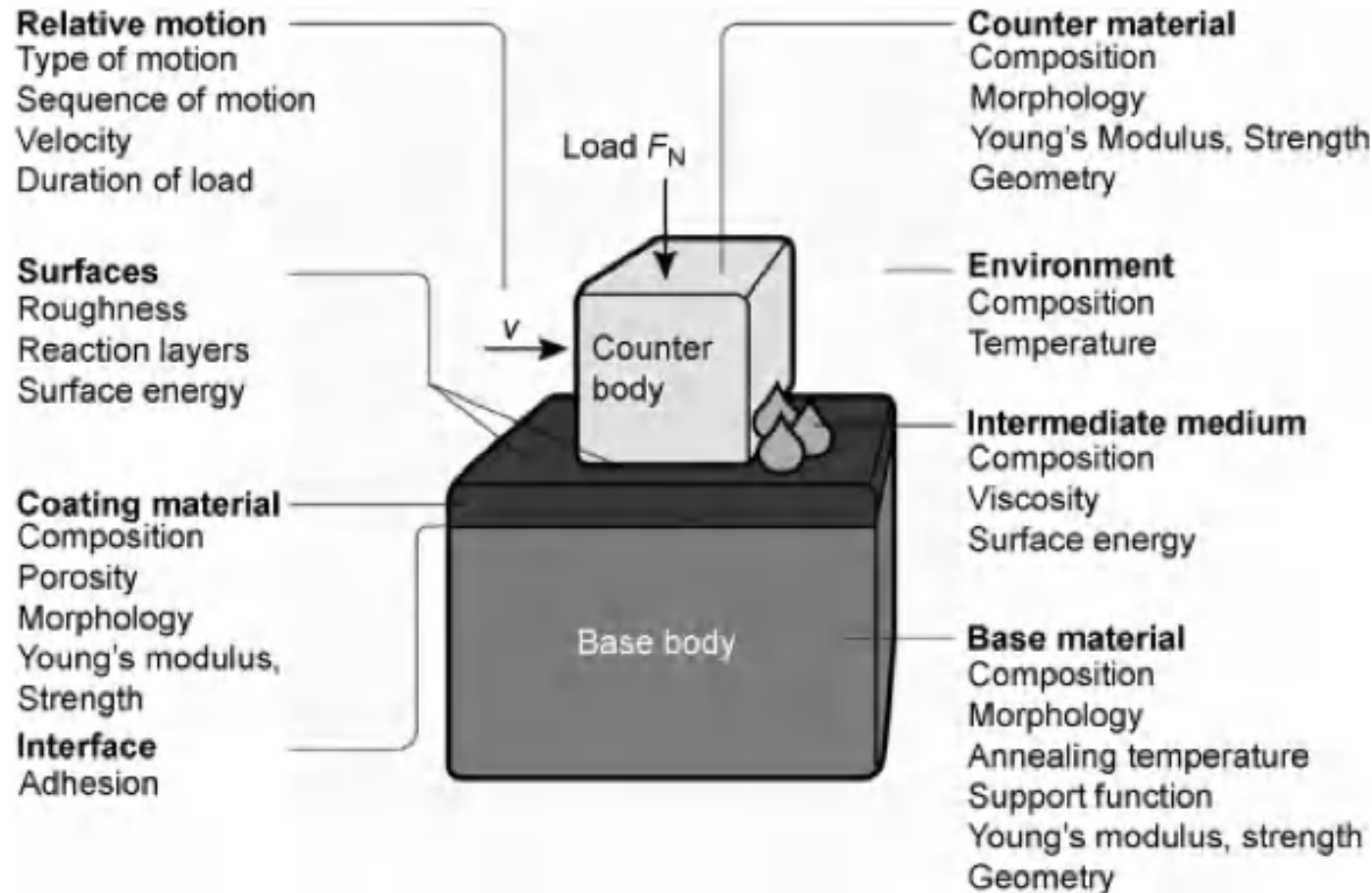
Forming tools for forging, drawing out, extruding, rolling, bending

Primary material shaping

Primary shaping tools for injection-molding, die-casting, sintering

- **System Analysis Steps (4 Steps):**

- 1. Characterization of technical functions.
- 2. Definition of the complex of loads.
- 3. Characterization of structure (elements, properties, interactions).
- 4. Definition of frictional and wear parameters.



Variables governing a tribo system with coated base material,

2. Tribological Surfaces

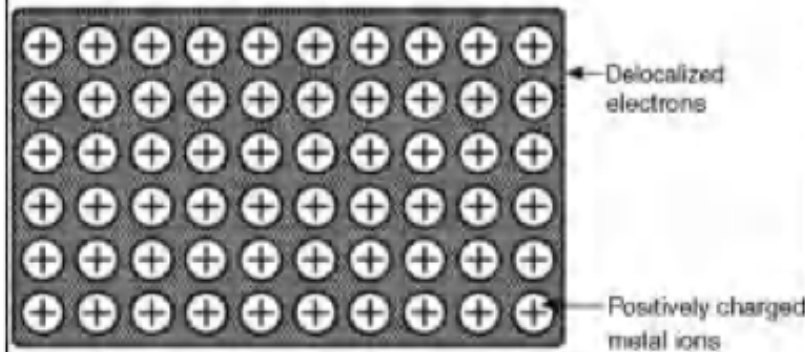
- **Phase Boundary Interactions:** Atomic bonding types govern surface cohesion and binding energy:
 - **Metallic Bonding:** Delocalized electron gas. High electrical/thermal conductivity, good plastic/elastic deformability.
 - **Ionic Bonding:** Electron transfer (Coulomb forces). Hard, brittle, non-conductive (e.g., oxide ceramics Al_2O_3 , ZrO_2).
 - **Covalent Bonding:** Electron sharing. Very hard, brittle, excellent high-temperature behavior (e.g., diamond, silicon, boron carbide).
 - **Van der Waals Bonding:** Weak intermolecular dipole forces. Low melting point, soft, poor electrical conductors (e.g., water, polymers).

Metallic bonding

Metal atoms lose their valence electrons to an electron gas, uniformly surrounding all metallic ions.

Examples: All metals and their alloys

- high electrical conductivity
- high thermal conductivity
- good plastic and elastic deformability
- high thermal expansion coefficient



Ionic bonding (heteropolar bonding)

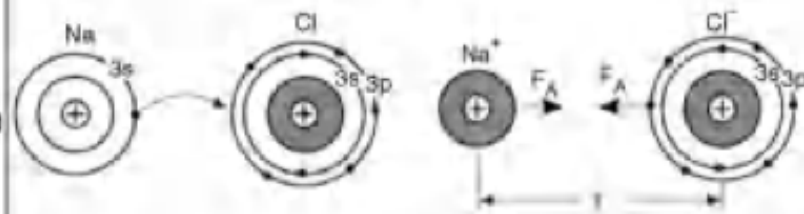
An atom loses an electron to another atom, resulting in a noble gas configuration for both atoms. (F_A : Coulomb force)

Examples: Oxide ceramics, sulfides, halogenides

partly water-soluble (NaCl)

Oxide ceramics (Al_2O_3 , ZrO_2):

- no electrical conductivity
- poor thermal conductivity
- hard, brittle
- high chemical stability



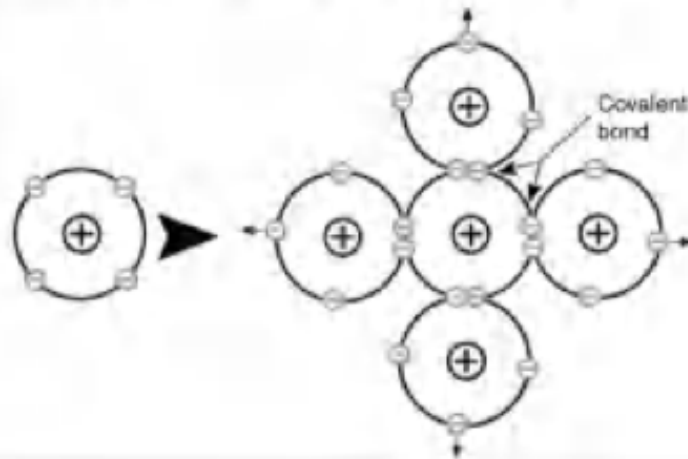
Structure and properties of atomic bonding types.

Covalent bonding (electron-pair binding)

Two atoms share their electrons, attaining a noble gas configuration. This permits restricted movement of the electrons.

Examples: Diamond, silicon, boron carbide

- very hard, very brittle
- low electrical conductivity
- good high-temperature behavior

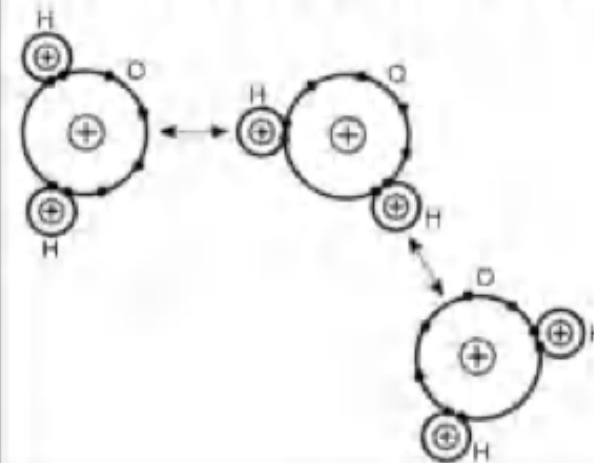


Vander Waals bonding

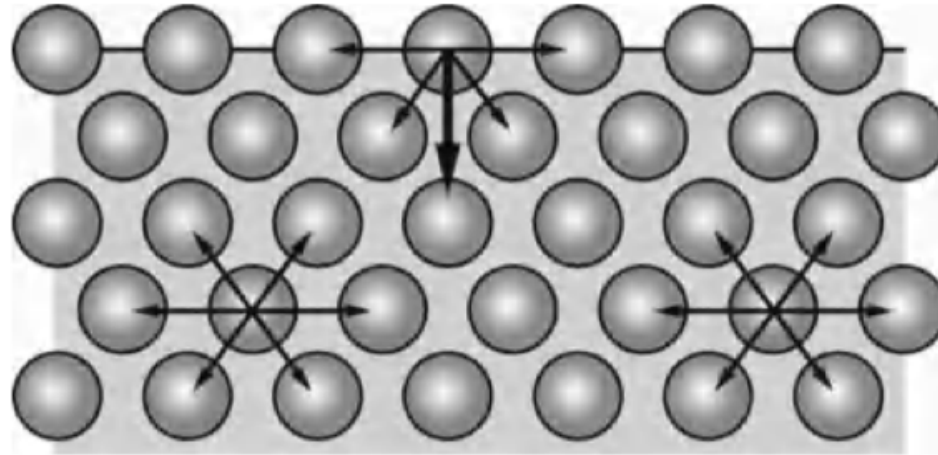
Overlapping of molecular orbits and electrostatic interactions between permanent or temporary dipole molecules.

Examples: Water, polymers, carbon dioxide

- very low melting point
- very soft and elastic
- very poor electrical conductors



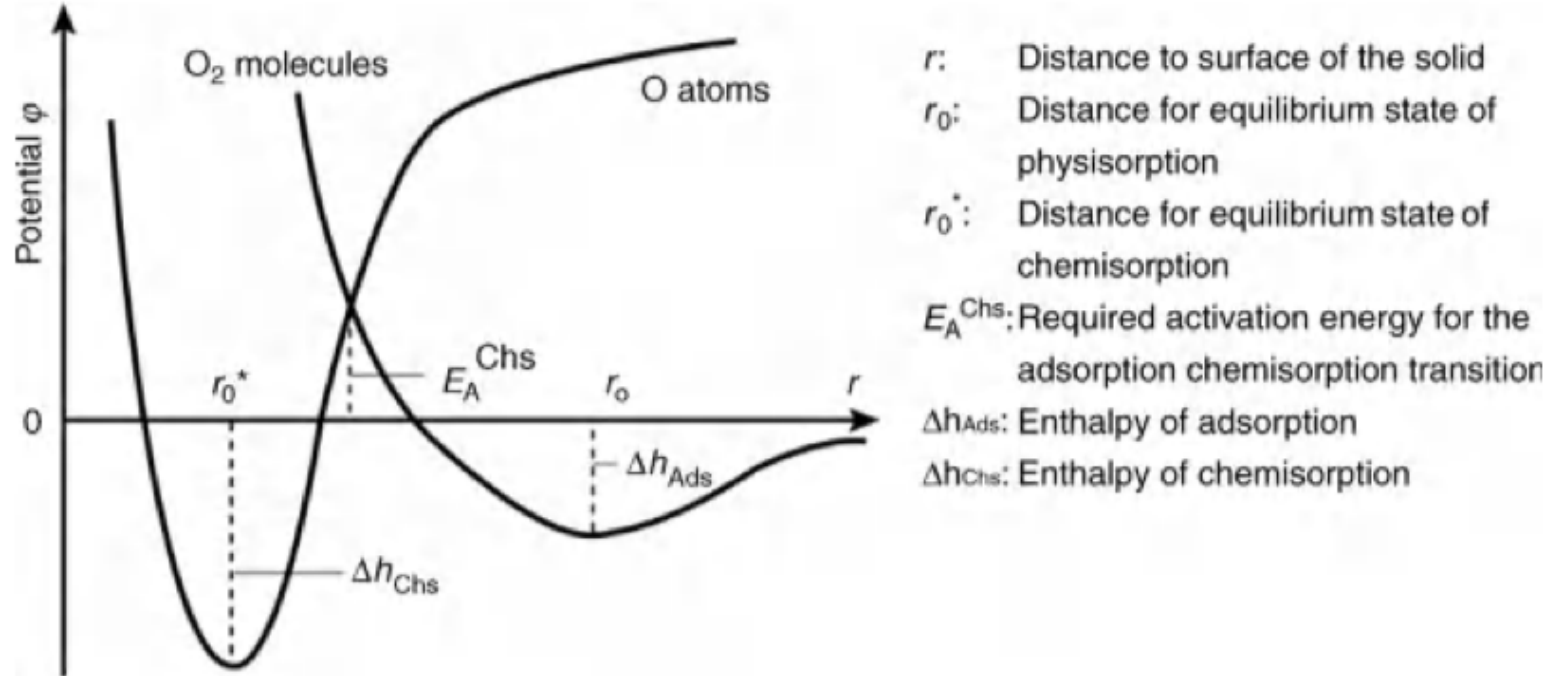
Structure and properties of atomic bonding types.



Schematic representation of intermolecular interactions within and at the surface of a phase.

- **Physisorption vs Chemisorption:**

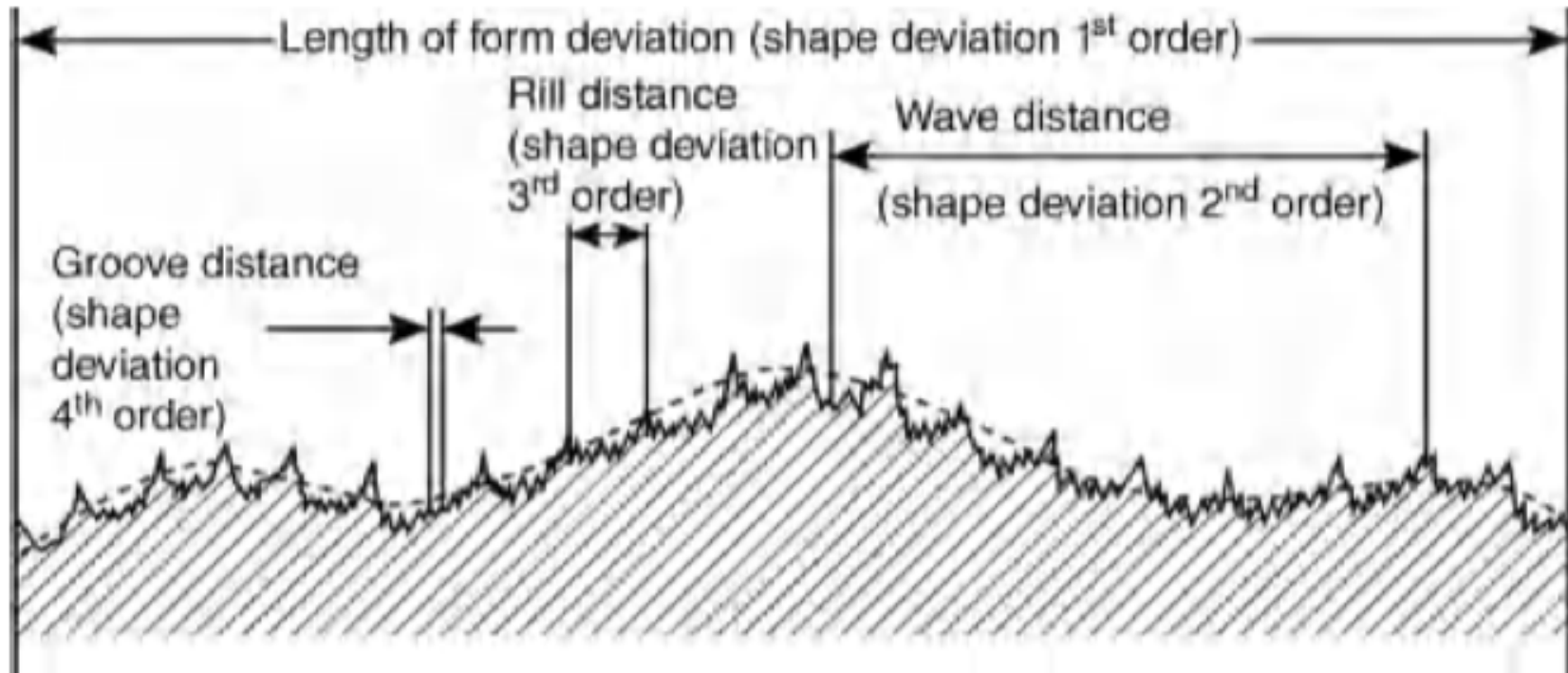
- **Physisorption:** Weak intermolecular forces (Van der Waals), reversible.
- **Chemisorption:** Requires higher activation energy, forms strong, irreversible surface bonds.



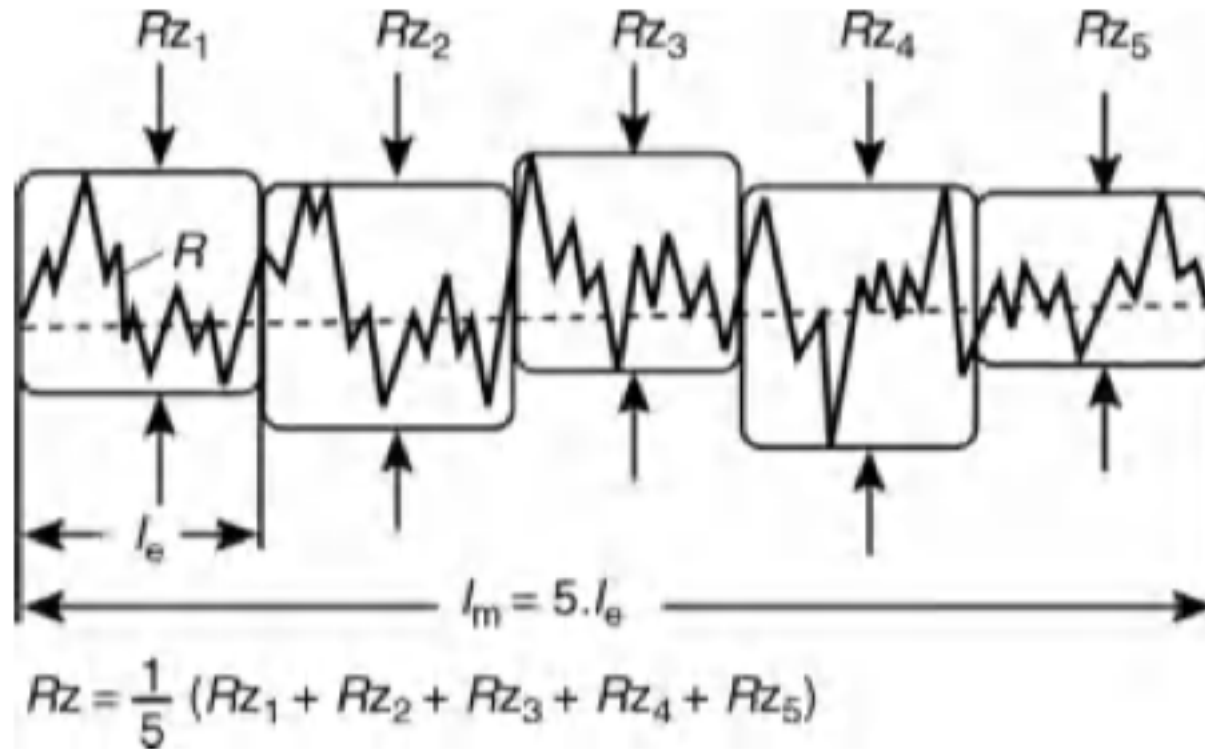
Schematic illustration of the potential curves for physisorption and chemisorption of O_2 on a metallic surface.



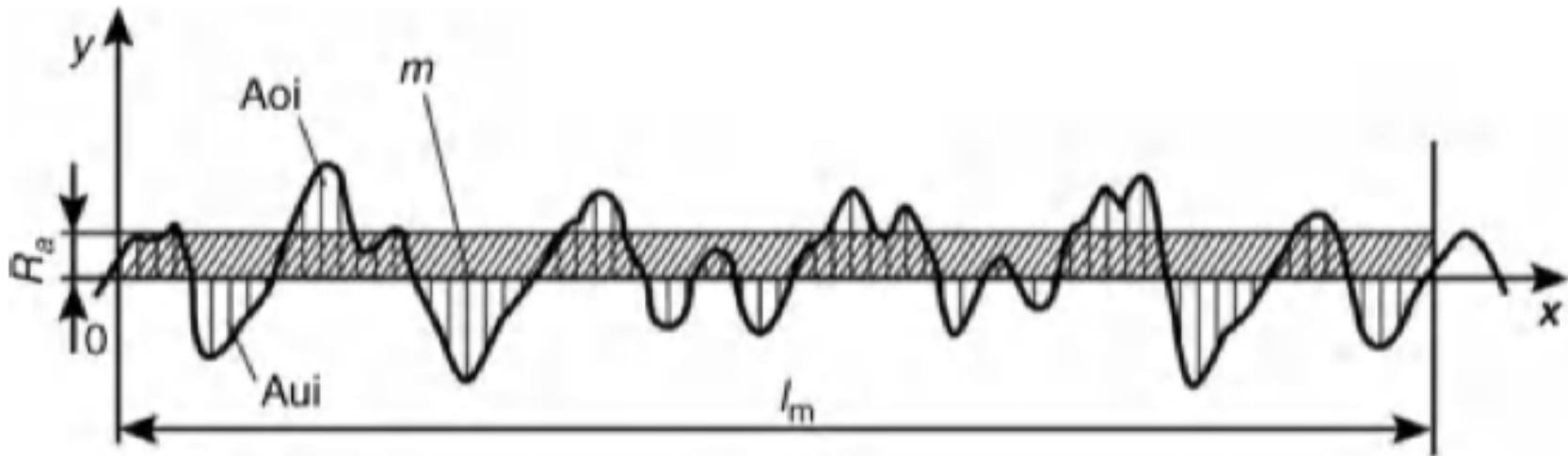
- **Surface Form Deviations (DIN 4760):**
 - **1st to 4th Order Deviations:** Macroscopic and microscopic profile (roughness).
 - **Mean Roughness Depth (R_z):** Mean value of individual roughness depths across 5 segments.
 - **Mean Roughness Value (R_a):** Arithmetic mean of all deviations from the center line.
 - **5th & 6th Order Deviations:** Microstructure and lattice structure deviations.



Schematic illustration of form deviations of the first to fourth order.

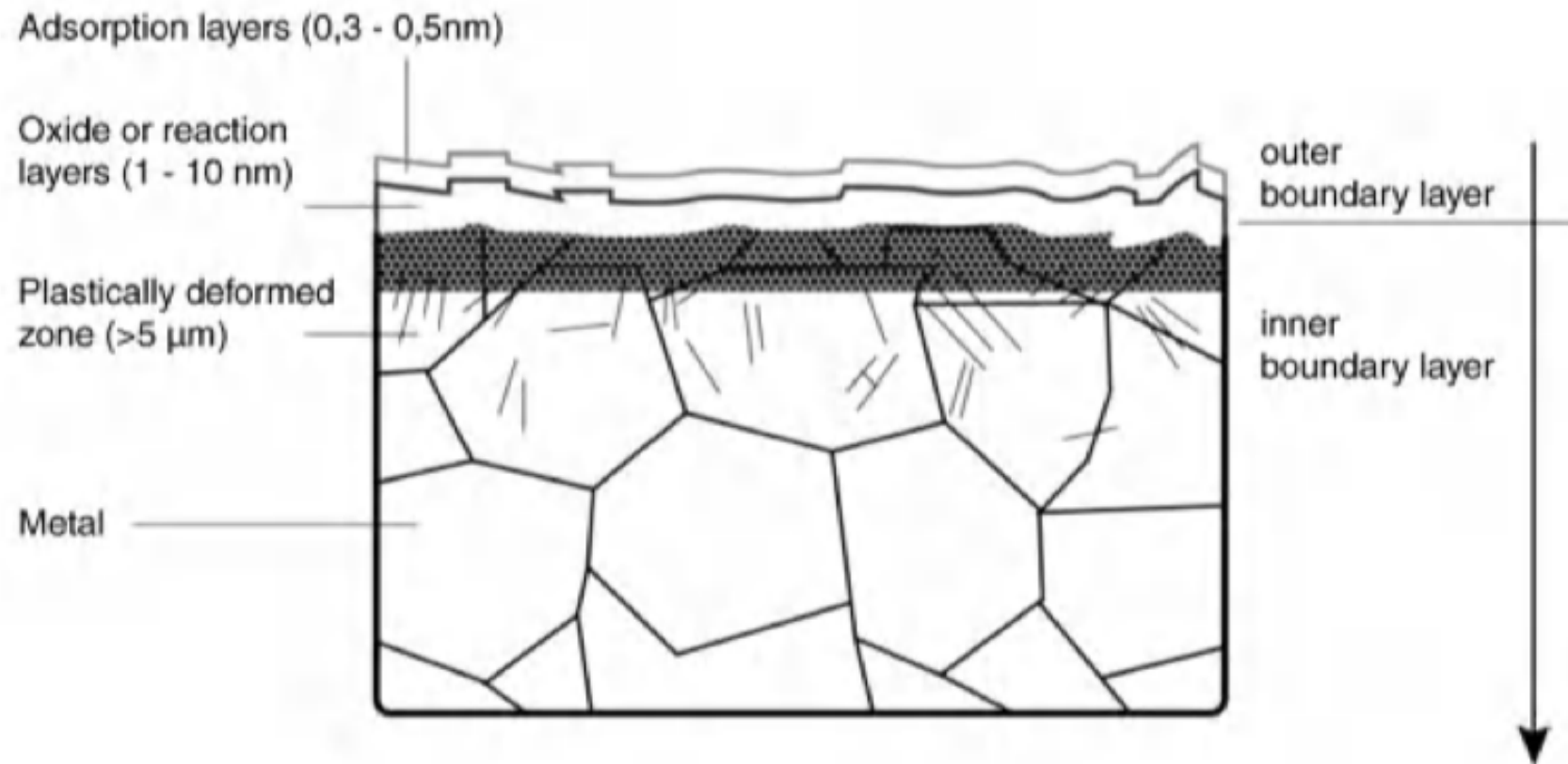


Mean roughness depth R_z : Mean value of the individual roughness depths ($R_{z1}.....R_{z5}$) of five successive individual measurement segments l_e .



$$R_a = \frac{1}{l_m} \int_0^{x-l_m} |y| dx \quad \text{with} \quad \Sigma A_{oi} = \Sigma A_{ui}$$

Mean roughness value R_a : Arithmetic mean of all deviations of the roughness profile R for the central reference line within the measurement segment l_m .



Structure of a metallic surface.



3. Wetting of Solid Surfaces

- **Young's Equation (1805):** Describes interfacial tension equilibrium at 3-phase boundary to determine contact angle (beta):

- **Equation:**

$$\sigma_{sv} = \sigma_{sl} + \sigma_{lv} \cdot \cos \beta$$

σ_{sv} : solid-vapor surface tension.

σ_{sl} : solid-liquid surface tension.

σ_{lv} : liquid-vapor surface tension.

β : contact angle.

- **Young-Dupré Equation:**

$$W_A = \sigma_{lv}(1 + \cos \beta)$$

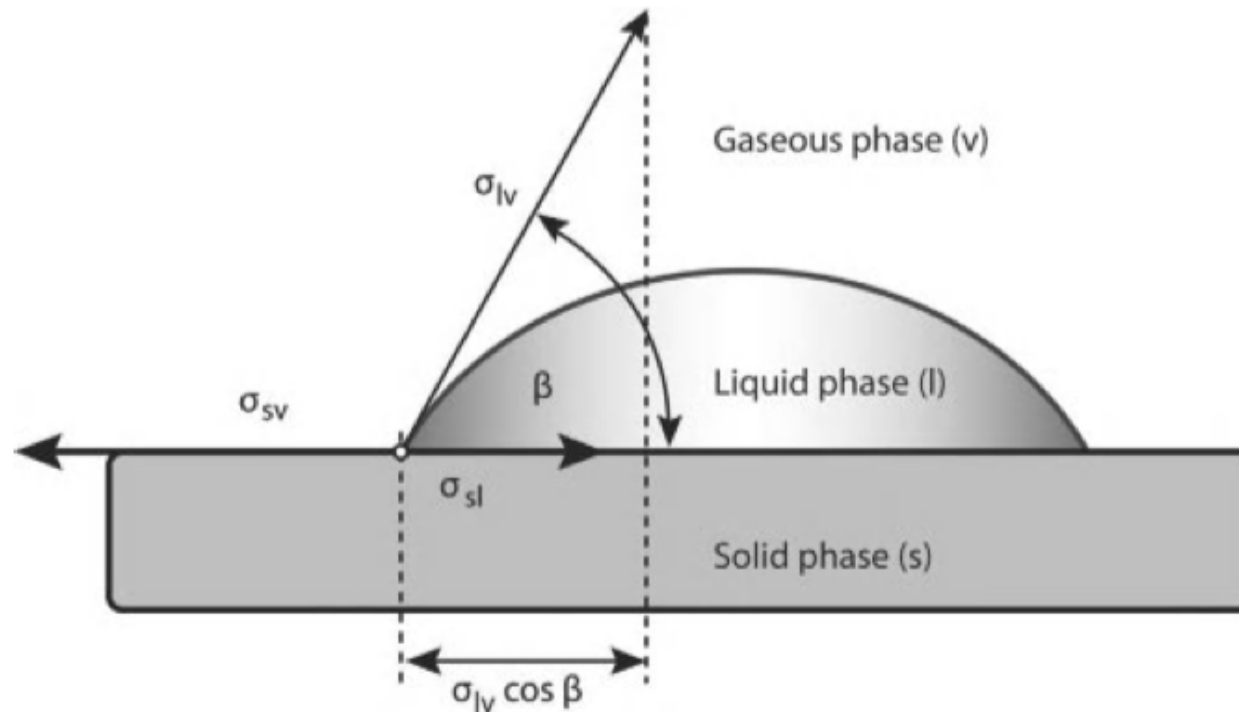
$$W_K = 2 \cdot \sigma_{lv}$$

W_A : Work of adhesion

W_K : Work of cohesion

- **Spreading Coefficient (S):**

$$S = W_A - W_K = \sigma_{sv} - (\sigma_{sl} + \sigma_{lv})$$



Tension relationships at the three-phase boundary acting on a liquid droplet.

4. Tribo Contact Surfaces

- **Surface Pressure (P):**

$$P = \frac{F_N}{A}$$

P : Pressure

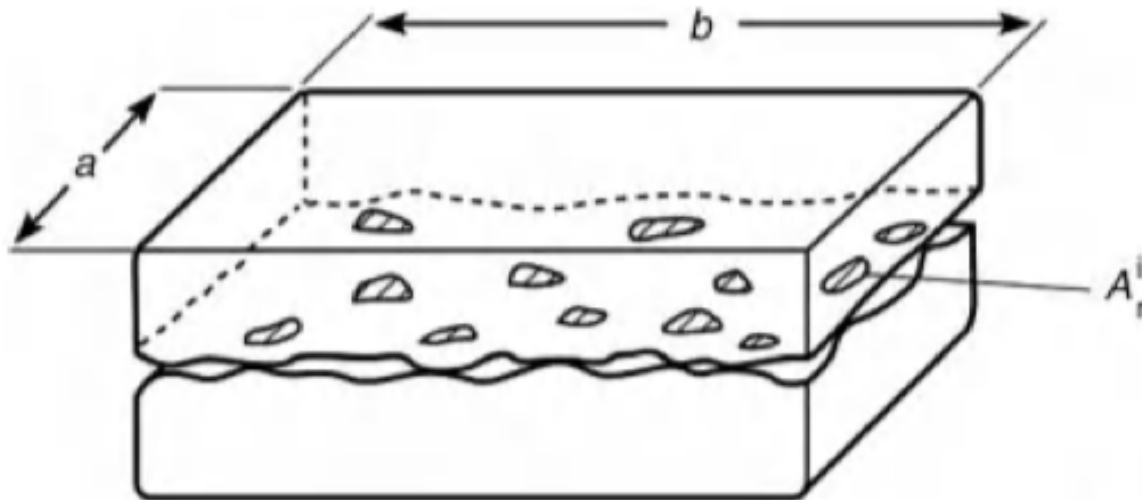
F_N : Normal force

A : Tribo contact area

- **Real Contact Area (A_r):**

Contact is restricted to discrete asperities/microcontacts ($A_0 \gg A_r$).

Processes occur primarily here.



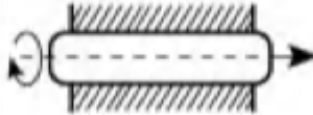
$$A_0 = a.b \gg A_r$$

$$\text{with } A_r = \sum_{i=1}^n A_r^i$$

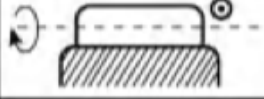
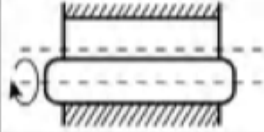
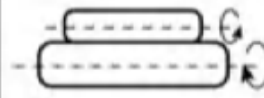
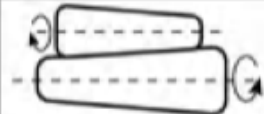
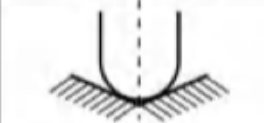
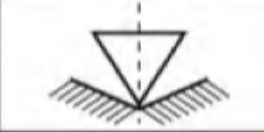
and n = number of microcontacts

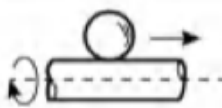
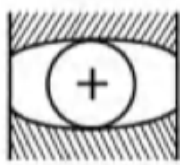
Geometric contact area A_0 and real contact area A_r at roughness peaks.



Contact shape		Base body I	Area of Counter-body II	Sketch	Application examples
Conform	Surface contact	Plane	Plane		Straight-line motion
		Hollow cylinder	Full cylinder		Plain bearing, cylindrical fits, cylinder slight ways
		Hollow cone	Full cone $d_I = d_{II}$		Bearing, conical fits



Contact shape		Base body I	Area of Counter-body II	Sketch	Application examples
Contra-conform	Line contact	Plane	Cylinder		Roller guides
		Hollow cylinder	Full cylinder $d_I \gg d_{II}$		Needle bearings
		Full cylinder	Full cylinder $d_I \leq d_{II}$		Roller mills, roller bearings
		Full cone	Full cone		Conical friction wheel gearing
		Hollow cone	Ball calotte		Toe bearing
		Full prism	V-prism		Knife-edge bearing
		Involute surface	Involute surface		Gearwheel

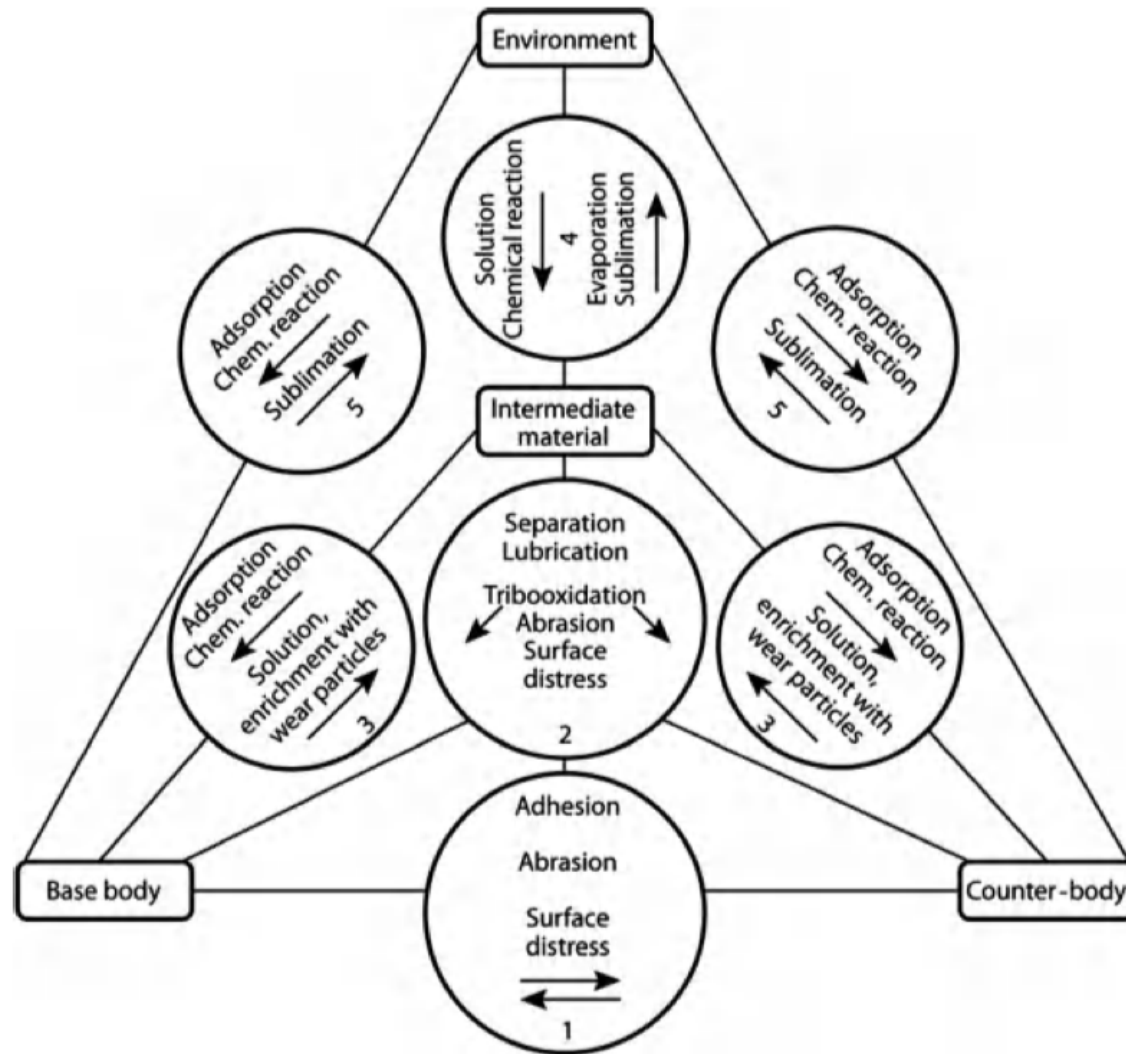
Contact shape		Area of		Sketch	Application examples
		Base body I	Counter-body II		
	Point contact	Plane	Ball		Ball guides
		Hollow cylinder	Ball		Ball guides
		Full cylinder	Ball		Ball guides
		Inner ring surface	Ball		Rolling bearings
		Outer ring surface	Ball		

Construction-conditioned contact geometries of tribological systems.



5. Tribological Loading & Material Strain

- **Complex of Loads:**
 - **Forms of Motion:** Gliding/Drilling, Rolling without slip, Impact, Flowing.
 - **Time Behavior:** Continuous, Oscillating, Intermittent.
 - **Parameters:** Normal force (F_N), Relative velocity (V), Temperature (T), Duration (t_B).



Possible interactions between the elements of a tribo system.



- **Equivalent Stress Hypotheses:**
 - **Tresca Shear Stress:**

$$\sigma_v = 2 \cdot \tau_{max} = \sigma_1 - \sigma_2$$

σ_v : Equivalent stress

σ_1 : Largest normal stress

σ_2 : Smallest normal stress

τ_{max} : Maximum shear stress

- **Von Mises Energy:**

$$\sigma_v = \frac{1}{\sqrt{2}} [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{\frac{1}{2}}$$

$\sigma_1, \sigma_2, \sigma_3$: Normal stress

- **Failure Limits:**

A material breaks or damages when the stress (σ_v) applied to it becomes higher than its limits:

Yield Strength (R_p): The point where the material starts to bend or deform permanently.

Tensile Strength (R_m): The maximum stress before the material snaps or breaks apart.

Fatigue Strength (σ_w): The limit when the material is pushed and pulled repeatedly over time.

Main Goal of Tribology:

Since the 1950s, tribology research focuses on:

Reducing wear (loss of material) and reducing friction (loss of energy).
Keeping moving parts working properly for a long time.



Two Types of Tribology Research:

Qualitative Research:

Looks at what type of load is applied, how the surface changes, and why the damage happens (the causes).

Quantitative Research (Tribometer):

Measures actual numbers and data, such as friction force, heat, noise, amount of worn particles, and changes in lubricants.

Surface interactions are very complex. Because of this, we cannot predict friction or wear rates using formulas alone. Real physical testing (tribological testing) is always necessary to see how materials will actually perform.