**Problem 4. (6 points)**
Define the surfactant packing parameter $P$ and explain its physical meaning. What physical or chemical factors determine the values of the different quantities in $P$? How could one control the value of $P$ in the case of some given surfactant?
Finally, show that surfactants form cylindrical micelle aggregates when $\frac{1}{3} < P \leq \frac{1}{2}$.

**Problem 5. (6 points)**
**a)** Consider two flat, semi-infinite surfaces parallel to each other, and separated by a distance $D$ in vacuum. Let the atomic densities of the surfaces be $\rho_1$ and $\rho_2$. Starting from the general expression of the van der Waals interaction between two atoms, $U_{vdw} = -C/r^6$, use the Hamaker theory to derive the interaction free energy per unit area between the surfaces.

**b)** Assuming a typical value for the Hamaker constant, $A = \pi^2 C \rho_1 \rho_2 \approx 10^{-19}$ J, at which distance $D$ is the attractive force per unit area between the surfaces comparable to the atmospheric pressure (1 bar $= 10^5$ Pa)?

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**Useful constants, equations etc.**
Avogadro's number $N_A = 6.0221 \times 10^{23}$ mol$^{-1}$
Boltzmann's constant $k_B = 1.3807 \times 10^{-23}$ J/K
Elementary charge $e = 1.60218 \times 10^{-19}$ C
Permittivity of vacuum $\varepsilon_0 = 8.85419 \times 10^{-12}$ F/m
Molar mass of water: $M_{H_2O} = 18.015$ g/mol
Chemical potential of an ideal solution: $\mu_k(x_k, p, T) = \mu_k^0(p, T) + k_B T \ln x_k$