E_a	energy of attraction between spherical particles in vacuo (J)
F	Faraday number (9.6485×10^4 C g-mol^{-1})
I	ionic strength (M)
j	constant in equation for extent of cell disruption in a bead mill and equivalent to the number of continuous stirred tank reactors in series [Equation (3.3.5)] (dimensionless)
k	constant in equations for extent of cell disruption in homogenizers [Pa^{-a} in Equation (3.3.3); s^{-1} in Equations (3.3.4) and (3.3.5)]
k	Boltzmann constant (1.3807×10^{-23} J K^{-1})
N	number of passes of fluid through homogenizer (dimensionless)
[illegible]	Avogadro's number (6.022×10^{23} molecules g-mol^{-1})
P	pressure (Pa)
r	distance from surface of spherical particle (nm)
R	gas constant (8.3145 J g-mol^{-1} K^{-1})[*]
R	extent of cell disruption (dimensionless)
t	time (s)
T	temperature (K)
U	electrophoretic mobility (cm^2 s^{-1} V^{-1})
z	valence of ion (dimensionless)

Greek Letters

γ	constant in equation for critical flocculation concentration [Equation (3.4.5)] (dimensionless)
δ	distance from Stern plane to solid surface (nm)
ε	absolute dielectric constant of liquid (C^2 J^{-1} m^{-1})
ε_0	permittivity of free space (vacuum) ($= 8.8542 \times 10^{-12}$ C^2 J^{-1} m^{-1})
ε_r	relative dielectric constant of liquid (dimensionless)
ζ	zeta potential (J C^{-1}, or V)
κ	Debye–Hückel constant (nm^{-1})
μ	liquid viscosity (g cm^{-1} s^{-1})
π	osmotic pressure (Pa)
ψ	total potential (J C^{-1}, or V)
ψ_E	electrical potential (J C^{-1}, or V)
ψ_L	attractive potential (J C^{-1}, or V)

PROBLEMS

3.1 **Osmotic Cell Disruption** Use the van't Hoff relationship to estimate the osmotic pressure drop across the membrane of a cell undergoing rupture in a 0.01 M salt solution, assuming the internal salt concentration is 0.2 M and that all salts are fully dissociated. Would you call this a negligible, ordinary, or large pressure drop? Why?

3.2 **Osmotic Disruption of Blood Cells** It is customary to prepare hemoglobin by the osmotic lysis of red blood cells. What is the van't Hoff pressure drop across the membrane of a red blood cell that is isotonic (0.30 osM) on the inside and submerged in a 0.01% NaCl solution? What is the expected outcome of this situation?

3.3 **Breakage of Yeast Cells in a Valve-Type Homogenizer** For the breakage of *Candida utilis* yeast cells in a valve-type continuous homogenizer, it is known that the constants in Equation (3.3.2) are $k = 5.91 \times 10^{-4}$ MPa^{-a} and $a = 1.77$ for the operating pressure range of 50 MPa $< P <$ 125 MPa. It is desired that the extent of disruption be ≥ 0.9. Plot how the number of passes varies with operating pressure over the pressure range of 50 to 125 MPa. What pressure range would you probably want to operate in? (Data from C. R. Engler and W. R. Campbell, "Disruption of *Candida utilis* cells in high pressure flow devices," *Biotechnol, Bioeng.*, vol. 23, p. 765, 1981.)

3.4 **Estimation of the Debye Radius and the Electrostatic Potential** Estimate the Debye radius for particles in a solution of 50 mM NaCl at 4°C. If the surface electrostatic potential of particles in this solution is 10 mV, estimate the electrostatic potential 1 nm from the surface. How significant is the electrostatic potential at this distance from the surface?

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[*] Other values of the gas constant R with different units are given in Appendix A.

3.5 **Flocculant Choice** In a suspension of lysate consisting of a variety of anionic particles, you find that 0.22 M KCl produces the required clarification. However, a downstream adsorption process requires <0.01 M salt, so this will not work. Knowing the Schulze–Hardy rule, you resort to $Al(NO_3)_3$ as flocculant. What concentration of this salt do you expect to need? Will this concentration fulfill the downstream requirement?

3.6 **Ionic Versus Polymeric Flocculant** You find that you are able to flocculate yeast cell debris in 1 M NaCl in a 100 liter tank at 20°C. The use of this much salt is unsatisfactory for the next downstream step. You then find that a company markets a bridging cationic polymer for $15/kg and that this polymer (molecular weight 9000) is at least the equivalent on a molar basis of a tetravalent indifferent cation. Furthermore, this polymer can be cleared by a downstream cation exchange adsorption step that is part of the process anyway. What will it cost you to use this polymer, per tank, and how difficult would it be to convince your supervisor to pay for it? What would be the cost savings of chilling the tank to 4°C?

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