National Exams May 2011

04-CHEM-B1, Transport Phenomena

3 hours duration

NOTES

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. The examination is an OPEN BOOK EXAM.
3. Candidates may use any **non-communicating** calculator.
4. Not all problems are of equal weight.
5. **Answer all four questions**.
6. State all assumptions clearly.

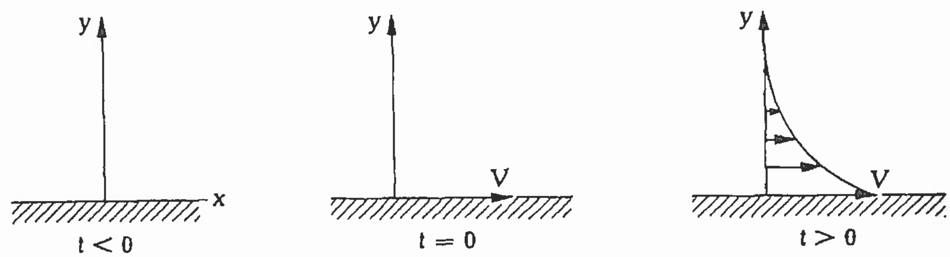
Q1. **[50 marks overall]** This is a four-part question with each part being of equal weight. In each case you are to start with the appropriate form of the conservation equations [see Tables 1-4 on pp 4-6 taken from Brodkey, R.S. and Hershey H.C. (1988) *Transport Phenomena – A Unified Approach*], make simplifying assumptions and thereby set up the governing differential equation, or equations, that describe the particular problem. **Do not attempt to solve the resulting equations**, however, state appropriate initial and boundary equations and any simplifying assumptions that would be needed to obtain a solution.

(i) Show that the steady-state temperature profile for a fluid flowing under laminar flow within a horizontal cylindrically heated tube is governed by:

$$u_{max}\left[1-\left(\frac{r}{R}\right)^2\right]\frac{\partial T}{\partial x}=\frac{\alpha}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)$$

in which u_{max} is the maximum velocity.

(ii) A wall is in contact with a fluid. Suddenly the wall is set in motion as illustrated in Fig. 1. What is the governing differential equation, and the initial and boundary conditions that describe the developing velocity profile?



(a) Wall and fluid at rest (b) Wall moves at velocity V (c) Resultant velocity profile

Fig. 1: Fluid in contact with a wall

(iii) A Newtonian fluid in a horizontal pipe is initially at rest. Suddenly a pressure drop dP/dz is imposed on the fluid in the axial direction. What is the governing differential equation, and the initial and boundary conditions that describe the developing velocity profile?

(iv) Transpiration cooling is a process in which fluid is injected through a porous wall whose outer surface is subjected to a severe thermal environment. As the relatively cold fluid passes through the wall, its temperature increases as it absorbs thermal energy: if the flow rate is sufficient, the outer surface of the wall can be maintained at an acceptable temperature. Consider the situation shown in Fig. 2 where the outer surface of a porous wall is subjected to a steady radiative heat flux $\dot{q}_2''$ [kW/m^2]. Fluid is injected through the wall at a rate $\dot{m}''$ [kg/m^2·s] from a reservoir (plenum chamber) where the temperature is T_0. Cooling coils are brazed to the inlet face of the wall, and an additional cooling flux $\dot{q}_1''$ [kW/m^2] can be supplied by passing refrigerant through the coils. If k is the thermal conductivity of the fluid, and k_{eff} is the thermal conductivity of the fluid-solid mixture in the wall, show that the temperature distributions $T(y)$ in the reservoir and $T_w(y)$ in the wall are governed by:

$$\frac{d^2T}{dy^2} - \frac{\dot{m}''C_p}{k}\frac{dT}{dy} = 0$$

and

$$\frac{d^2T_w}{dy^2} - \frac{\dot{m}''C_p}{k_{eff}}\frac{dT_w}{dy} = 0$$

State the bounds for which these equations are valid and stipulate appropriate boundary conditions.

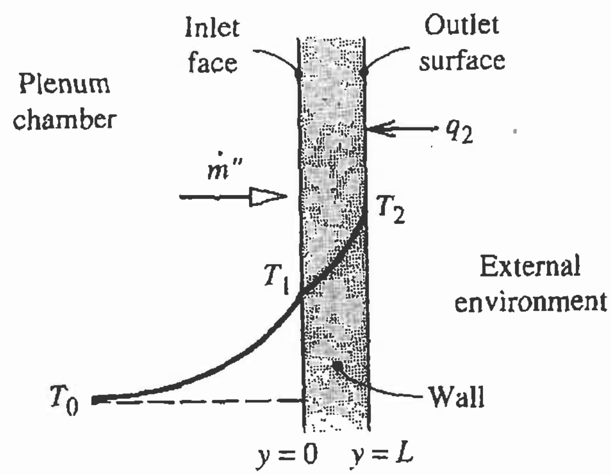


Fig. 2: Transpiration cooling

Q2. [15 marks] Two infinite parallel plates are 2-in apart between which is a fluid of viscosity 150 cP. Calculate the shear stress on each plate when the lower plate velocity is 10 ft/min in the positive x-direction and the upper plate velocity is 35 ft/min in the negative x-direction. Also calculate the fluid velocity at □-in intervals.

Q3. [15 marks] Calculate the heat loss per linear foot from a 3-in sch. 40 steel pipe (3.07-in ID; 3.50-in OD; k = 25 Btu/h ft °F) covered with □-in thickness of asbestos insulation (k = 0.11 Btu/h ft °F). The pipe transports a fluid at 300°F with an inner convective heat transfer coefficient of 40 Btu/h ft^2 °F and is exposed to ambient air at 80°F with and average outer convective heat transfer coefficient of 4.0 Btu/h ft^2 °F.

Q4. [20 marks] Use Chapman-Enskog theory to calculate the mass diffusivity of the following:

(i) **[10 marks]** Argon in hydrogen at 1 atm. and 175°C. The Lennard-Jones parameters for hydrogen are $\sigma = 2.827\text{x}10^{-10}$ m and $(\varepsilon/k_B) = 59.7$ K^{-1}; likewise for argon $\sigma = 3.542\text{x}10^{-10}$ m and $(\varepsilon/k_B) = 93.3$ K^{-1}. Collision integrals are given in Table 5 on p 7. Comment on your answer in comparison to the experimental value of 1.76 cm^2/s.

(ii) **[10 marks]** Argon in zinc vapour at 1037 K and 1 atm. given the molar volume of zinc is 10.19 cm^3/g-mol and the boiling point is 906°C.

Table 1: The Navier-Stokes equations for fluids of constant ρ and μ[1]

Navier–Stokes equation in vector form (rectangular coordinates only)

$$\partial U/\partial t + (U \cdot \nabla)U = -(1/\rho)\nabla p + g + \nu(\nabla^2 U) \qquad (5.15)$$

Rectangular coordinates

x component: $$\frac{\partial U_x}{\partial t} + U_x\frac{\partial U_x}{\partial x} + U_y\frac{\partial U_x}{\partial y} + U_z\frac{\partial U_x}{\partial z} = -\frac{1}{\rho}\left(\frac{\partial p}{\partial x}\right) + g_x + \nu\left(\frac{\partial^2 U_x}{\partial x^2} + \frac{\partial^2 U_x}{\partial y^2} + \frac{\partial^2 U_x}{\partial z^2}\right) \qquad (A)$$

y component: $$\frac{\partial U_y}{\partial t} + U_x\frac{\partial U_y}{\partial x} + U_y\frac{\partial U_y}{\partial y} + U_z\frac{\partial U_y}{\partial z} = -\frac{1}{\rho}\left(\frac{\partial p}{\partial y}\right) + g_y + \nu\left(\frac{\partial^2 U_y}{\partial x^2} + \frac{\partial^2 U_y}{\partial y^2} + \frac{\partial^2 U_y}{\partial z^2}\right) \qquad (B)$$

z component: $$\frac{\partial U_z}{\partial t} + U_x\frac{\partial U_z}{\partial x} + U_y\frac{\partial U_z}{\partial y} + U_z\frac{\partial U_z}{\partial z} = -\frac{1}{\rho}\left(\frac{\partial p}{\partial z}\right) + g_z + \nu\left(\frac{\partial^2 U_z}{\partial x^2} + \frac{\partial^2 U_z}{\partial y^2} + \frac{\partial^2 U_z}{\partial z^2}\right) \qquad (C)$$

Cylindrical coordinates

r component: $$\frac{\partial U_r}{\partial t} + U_r\frac{\partial U_r}{\partial r} + \frac{U_\theta}{r}\frac{\partial U_r}{\partial \theta} + U_z\frac{\partial U_r}{\partial z} - \frac{U_\theta^2}{r}$$
$$= -\frac{1}{\rho}\left(\frac{\partial p}{\partial r}\right) + g_r + \nu\frac{\partial^2 U_r}{\partial r^2} + \frac{\nu}{r}\frac{\partial U_r}{\partial r} - \nu\left(\frac{U_r}{r^2}\right) + \frac{\nu}{r^2}\frac{\partial^2 U_r}{\partial \theta^2} - \frac{2\nu}{r^2}\frac{\partial U_\theta}{\partial \theta} + \nu\frac{\partial^2 U_r}{\partial z^2} \qquad (D)$$

θ component: $$\frac{\partial U_\theta}{\partial t} + U_r\frac{\partial U_\theta}{\partial r} + \frac{U_\theta}{r}\frac{\partial U_\theta}{\partial \theta} + U_z\frac{\partial U_\theta}{\partial z} + \frac{U_r U_\theta}{r}$$
$$= -\frac{1}{\rho r}\frac{\partial p}{\partial \theta} + g_\theta + \nu\frac{\partial^2 U_\theta}{\partial r^2} + \frac{\nu}{r}\frac{\partial U_\theta}{\partial r} - \nu\left(\frac{U_\theta}{r^2}\right) + \frac{\nu}{r^2}\frac{\partial^2 U_\theta}{\partial \theta^2} + \frac{2\nu}{r^2}\frac{\partial U_r}{\partial \theta} + \nu\frac{\partial^2 U_\theta}{\partial z^2} \qquad (E)$$

z component: $$\frac{\partial U_z}{\partial t} + U_r\frac{\partial U_z}{\partial r} + \frac{U_\theta}{r}\frac{\partial U_z}{\partial \theta} + U_z\frac{\partial U_z}{\partial z}$$
$$= -\frac{1}{\rho}\frac{\partial p}{\partial z} + g_z + \nu\frac{\partial^2 U_z}{\partial r^2} + \frac{\nu}{r}\frac{\partial U_z}{\partial r} + \frac{\nu}{r^2}\frac{\partial^2 U_z}{\partial \theta^2} + \nu\frac{\partial^2 U_z}{\partial z^2} \qquad (F)$$

Spherical coordinates

r component: $$\frac{\partial U_r}{\partial t} + U_r\frac{\partial U_r}{\partial r} + \frac{U_\theta}{r}\frac{\partial U_r}{\partial \theta} + \left(\frac{U_\phi}{r\sin\theta}\right)\frac{\partial U_r}{\partial \phi} - \frac{U_\theta^2}{r} - \frac{U_\phi^2}{r} = -\frac{1}{\rho}\frac{\partial p}{\partial r} + g_r + \frac{\nu}{r^2}\left(\frac{\partial}{\partial r}\left(r^2\frac{\partial U_r}{\partial r}\right)\right)$$
$$+ \left(\frac{\nu}{r^2\sin\theta}\right)\left(\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial U_r}{\partial \theta}\right)\right) + \left(\frac{\nu}{r^2\sin^2\theta}\right)\left(\frac{\partial^2 U_r}{\partial \phi^2}\right) - \frac{2\nu U_r}{r^2}$$
$$- \frac{2\nu}{r^2}\frac{\partial U_\theta}{\partial \theta} - \frac{2\nu U_\theta}{r^2}\cot\theta - \left(\frac{2\nu}{r^2\sin\theta}\right)\frac{\partial U_\phi}{\partial \phi} \qquad (G)$$

θ component: $$\frac{\partial U_\theta}{\partial t} + U_r\frac{\partial U_\theta}{\partial r} + \frac{U_\theta}{r}\frac{\partial U_\theta}{\partial \theta} + \left(\frac{U_\phi}{r\sin\theta}\right)\left(\frac{\partial U_\theta}{\partial \phi}\right) + \frac{U_r U_\theta}{r} - \frac{U_\phi^2}{r}\cot\theta$$
$$= -\frac{1}{\rho r}\frac{\partial p}{\partial \theta} + g_\theta + \frac{\nu}{r^2}\left(\frac{\partial}{\partial r}\left(r^2\frac{\partial U_\theta}{\partial r}\right)\right) + \left(\frac{\nu}{r^2\sin\theta}\right)\left(\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial U_\theta}{\partial \theta}\right)\right) + \left(\frac{\nu}{r^2\sin^2\theta}\right)\frac{\partial^2 U_\theta}{\partial^2 \phi}$$
$$+ \frac{2\nu}{r^2}\frac{\partial U_r}{\partial \theta} - \left(\frac{\nu U_\theta}{r^2\sin^2\theta}\right) - \left(\frac{(2\nu)\cos\theta}{r^2\sin^2\theta}\right)\frac{\partial U_\phi}{\partial \phi} \qquad (H)$$

φ component: $$\frac{\partial U_\phi}{\partial t} + U_r\frac{\partial U_\phi}{\partial r} + \frac{U_\theta}{r}\frac{\partial U_\phi}{\partial \theta} + \left(\frac{U_\phi}{r\sin\theta}\right)\frac{\partial U_\phi}{\partial \phi} + \frac{U_r U_\phi}{r} + \frac{U_\theta U_\phi}{r}\cot\theta$$
$$= -\left(\frac{1}{\rho r\sin\theta}\right)\frac{\partial p}{\partial \phi} + g_\phi + \frac{\nu}{r^2}\left(\frac{\partial}{\partial r}\left(r^2\frac{\partial U_\phi}{\partial r}\right)\right) + \left(\frac{\nu}{r^2\sin\theta}\right)\left(\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial U_\phi}{\partial \theta}\right)\right)$$
$$+ \left(\frac{\nu}{r^2\sin^2\theta}\right)\frac{\partial^2 U_\phi}{\partial \phi^2} - \left(\frac{\nu U_\phi}{r^2\sin^2\theta}\right) + \left(\frac{2\nu}{r^2\sin\theta}\right)\frac{\partial U_r}{\partial \phi} + \left(\frac{2\nu\cos\theta}{r^2\sin^2\theta}\right)\frac{\partial U_\theta}{\partial \phi} \qquad (I)$$

[1] Brodkey, R.S. and Hershey H.C. (1988) *Transport Phenomena – A Unified Approach* Table 5.7 p147.

Table 2: Shear stress-velocity gradient relationships for constant viscosity[2]

Rectangular coordinates

$$\tau_{xx} = -2\mu(\partial U_x/\partial x) + (2\mu/3)(\nabla \cdot U) \quad \text{(A)}$$

$$\tau_{yy} = -2\mu(\partial U_y/\partial y) + (2\mu/3)(\nabla \cdot U) \quad \text{(B)}$$

$$\tau_{zz} = -2\mu(\partial U_z/\partial z) + (2\mu/3)(\nabla \cdot U) \quad \text{(C)}$$

$$\tau_{xy} = \tau_{yx} = -\mu[(\partial U_x/\partial y) + (\partial U_y/\partial x)] \quad \text{(D)}$$

$$\tau_{yz} = \tau_{zy} = -\mu[(\partial U_y/\partial z) + (\partial U_z/\partial y)] \quad \text{(E)}$$

$$\tau_{xz} = \tau_{zx} = -\mu[(\partial U_x/\partial z) + (\partial U_z/\partial x)] \quad \text{(F)}$$

Cylindrical coordinates

$$\tau_{rr} = -2\mu(\partial U_r/\partial r) + (2\mu/3)(\nabla \cdot U) \quad \text{(G)}$$

$$\tau_{\theta\theta} = -2\mu\left[\frac{1}{r}\left(\frac{\partial U_\theta}{\partial \theta}\right) + \frac{U_r}{r}\right] + (2\mu/3)(\nabla \cdot U) \quad \text{(H)}$$

$$\tau_{zz} = -2\mu(\partial U_z/\partial z) + (2\mu/3)(\nabla \cdot U) \quad \text{(I)}$$

$$\tau_{r\theta} = \tau_{\theta r} = -\mu\left[r\frac{\partial}{\partial r}(U_\theta/r) + \frac{1}{r}\left(\frac{\partial U_r}{\partial \theta}\right)\right] \quad \text{(J)}$$

$$\tau_{\theta z} = \tau_{z\theta} = -\mu\left[\left(\frac{\partial U_\theta}{\partial z}\right) + \frac{1}{r}\left(\frac{\partial U_z}{\partial \theta}\right)\right] \quad \text{(K)}$$

$$\tau_{rz} = \tau_{zr} = -\mu[(\partial U_r/\partial z) + (\partial U_z/\partial r)] \quad \text{(L)}$$

Spherical coordinates

$$\tau_{rr} = -2\mu(\partial U_r/\partial r) + (2\mu/3)(\nabla \cdot U) \quad \text{(M)}$$

$$\tau_{\theta\theta} = -2\mu\left[\frac{1}{r}\left(\frac{\partial U_\theta}{\partial \theta}\right) + \frac{U_r}{r}\right] + (2\mu/3)(\nabla \cdot U) \quad \text{(N)}$$

$$\tau_{\phi\phi} = -2\mu\left[\frac{1}{r\sin\theta}\frac{\partial U_\phi}{\partial \phi} + \frac{U_r}{r} + (U_\theta/r)(\cot\theta)\right] + (2\mu/3)(\nabla \cdot U) \quad \text{(O)}$$

$$\tau_{r\theta} = \tau_{\theta r} = -\mu\left[r\frac{\partial}{\partial r}(U_\theta/r) + \frac{1}{r}\left(\frac{\partial U_r}{\partial \theta}\right)\right] \quad \text{(P)}$$

$$\tau_{\theta\phi} = \tau_{\phi\theta} = -\mu\left[\frac{\sin\theta}{r}\left[\frac{\partial}{\partial \theta}\left(\frac{U_\phi}{\sin\theta}\right)\right] + \frac{1}{r\sin\theta}\frac{\partial U_\theta}{\partial \phi}\right] \quad \text{(Q)}$$

$$\tau_{r\phi} = \tau_{\phi r} = -\mu\left[\frac{1}{r\sin\theta}\frac{\partial U_r}{\partial \phi} + r\frac{\partial}{\partial r}(U_\phi/r)\right] \quad \text{(R)}$$

[2] B&H *ibid* Table 5.2 p137.

Table 3: The energy equation[3]

General equation

$$\frac{\partial(\rho c_p T)}{\partial t} + (U \cdot \nabla)(\rho c_p T) = \dot{T}_G + [\nabla \cdot \alpha \nabla(\rho c_p T)] - (\rho c_p T)(\nabla \cdot U) \quad (5.13)$$

Incompressible media, rectangular coordinates

$$\frac{\partial T}{\partial t} + U_x \frac{\partial T}{\partial x} + U_y \frac{\partial T}{\partial y} + U_z \frac{\partial T}{\partial z} = \frac{\dot{T}_G}{\rho c_p} + \frac{\partial}{\partial x}\left(\alpha \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\alpha \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\alpha \frac{\partial T}{\partial z}\right) \quad (A)$$

Incompressible media, cylindrical coordinates

$$\frac{\partial T}{\partial t} + U_r \frac{\partial T}{\partial r} + \frac{U_\theta}{r}\frac{\partial T}{\partial \theta} + U_z \frac{\partial T}{\partial z} = \frac{\dot{T}_G}{\rho c_p} + \frac{1}{r}\frac{\partial}{\partial r}\left(r\alpha \frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial}{\partial \theta}\left(\alpha \frac{\partial T}{\partial \theta}\right) + \frac{\partial}{\partial z}\left(\alpha \frac{\partial T}{\partial z}\right) \quad (B)$$

Incompressible media, spherical coordinates

$$\frac{\partial T}{\partial t} + U_r \frac{\partial T}{\partial r} + \frac{U_\theta}{r}\frac{\partial T}{\partial \theta} + \frac{U_\phi}{r \sin\theta}\frac{\partial T}{\partial \phi} = \frac{\dot{T}_G}{\rho c_p} + \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \alpha \frac{\partial T}{\partial r}\right)$$
$$+ \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\alpha \sin\theta \frac{\partial T}{\partial \theta}\right) + \frac{1}{r^2 \sin^2\theta}\frac{\partial}{\partial \phi}\left(\alpha \frac{\partial T}{\partial \phi}\right) \quad (C)$$

Table 4: The continuity equation for species *A*[4]

General equation

$$\frac{\partial C_A}{\partial t} + (U \cdot \nabla)C_A = \dot{C}_{A,G} + (\nabla \cdot D\nabla C_A) - (C_A)(\nabla \cdot U) \quad (5.8)$$

Incompressible media, rectangular coordinates

$$\frac{\partial C_A}{\partial t} + U_x \frac{\partial C_A}{\partial x} + U_y \frac{\partial C_A}{\partial y} + U_z \frac{\partial C_A}{\partial z} = \dot{C}_{A,G} + \frac{\partial}{\partial x}\left(D \frac{\partial C_A}{\partial x}\right) + \frac{\partial}{\partial y}\left(D \frac{\partial C_A}{\partial y}\right) + \frac{\partial}{\partial z}\left(D \frac{\partial C_A}{\partial z}\right) \quad (A)$$

Incompressible media, cylindrical coordinates

$$\frac{\partial C_A}{\partial t} + U_r \frac{\partial C_A}{\partial r} + \frac{U_\theta}{r}\frac{\partial C_A}{\partial \theta} + U_z \frac{\partial C_A}{\partial z} = \dot{C}_{A,G} + \frac{1}{r}\frac{\partial}{\partial r}\left(rD \frac{\partial C_A}{\partial r}\right) + \frac{1}{r^2}\frac{\partial}{\partial \theta}\left(D \frac{\partial C_A}{\partial \theta}\right) + \frac{\partial}{\partial z}\left(D \frac{\partial C_A}{\partial z}\right) \quad (B)$$

Incompressible media, spherical coordinates

$$\frac{\partial C_A}{\partial t} + U_r \frac{\partial C_A}{\partial r} + \frac{U_\theta}{r}\frac{\partial C_A}{\partial \theta} + \frac{U_\phi}{r \sin\theta}\frac{\partial C_A}{\partial \phi} = \dot{C}_{A,G} + \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 D \frac{\partial C_A}{\partial r}\right)$$
$$+ \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(D \sin\theta \frac{\partial C_A}{\partial \theta}\right) + \frac{1}{r^2 \sin^2\theta}\frac{\partial}{\partial \phi}\left(D \frac{\partial C_A}{\partial \phi}\right) \quad (C)$$

[3] B&H *ibid* Table 5.6 p143.

[4] B&H *ibid* Table 5.4 p142.

Table 5: Collision Integrals

FUNCTIONS FOR PREDICTION OF TRANSPORT PROPERTIES OF GASES AT LOW DENSITIES[a]

$\kappa T/\epsilon$ or $\kappa T/\epsilon_{AB}$	$\Omega_\mu = \Omega_k$ (For viscosity and thermal conductivity)	$\Omega_{\mathcal{D},AB}$ (For mass diffusivity)	$\kappa T/\epsilon$ or $\kappa T/\epsilon_{AB}$	$\Omega_\mu = \Omega_k$ (For viscosity and thermal conductivity)	$\Omega_{\mathcal{D},AB}$ (For mass diffusivity)
			2.50	1.093	0.9996
0.30	2.785	2.662	2.60	1.081	0.9878
0.35	2.628	2.476	2.70	1.069	0.9770
0.40	2.492	2.318	2.80	1.058	0.9672
0.45	2.368	2.184	2.90	1.048	0.9576
0.50	2.257	2.066	3.00	1.039	0.9490
0.55	2.156	1.966	3.10	1.030	0.9406
0.60	2.065	1.877	3.20	1.022	0.9328
0.65	1.982	1.798	3.30	1.014	0.9256
0.70	1.908	1.729	3.40	1.007	0.9186
0.75	1.841	1.667	3.50	0.9999	0.9120
0.80	1.780	1.612	3.60	0.9932	0.9058
0.85	1.725	1.562	3.70	0.9870	0.8998
0.90	1.675	1.517	3.80	0.9811	0.8942
0.95	1.629	1.476	3.90	0.9755	0.8888
1.00	1.587	1.439	4.00	0.9700	0.8836
1.05	1.549	1.406	4.10	0.9649	0.8788
1.10	1.514	1.375	4.20	0.9600	0.8740
1.15	1.482	1.346	4.30	0.9553	0.8694
1.20	1.452	1.320	4.40	0.9507	0.8652
1.25	1.424	1.296	4.50	0.9464	0.8610
1.30	1.399	1.273	4.60	0.9422	0.8568
1.35	1.375	1.253	4.70	0.9382	0.8530
1.40	1.353	1.233	4.80	0.9343	0.8492
1.45	1.333	1.215	4.90	0.9305	0.8456
1.50	1.314	1.198	5.0	0.9269	0.8422
1.55	1.296	1.182	6.0	0.8963	0.8124
1.60	1.279	1.167	7.0	0.8727	0.7896
1.65	1.264	1.153	8.0	0.8538	0.7712
1.70	1.248	1.140	9.0	0.8379	0.7556
1.75	1.234	1.128	10.0	0.8242	0.7424
1.80	1.221	1.116	20.0	0.7432	0.6640
1.85	1.209	1.105	30.0	0.7005	0.6232
1.90	1.197	1.094	40.0	0.6718	0.5960
1.95	1.186	1.084	50.0	0.6504	0.5756
2.00	1.175	1.075	60.0	0.6335	0.5596
2.10	1.156	1.057	70.0	0.6194	0.5464
2.20	1.138	1.041	80.0	0.6076	0.5352
2.30	1.122	1.026	90.0	0.5973	0.5256
2.40	1.107	1.012	100.0	0.5882	0.5170

[a] Taken from J. O. Hirschfelder, R. B. Bird, and E. L. Spotz, *Chem. Revs.*, 44, 205 (1949).