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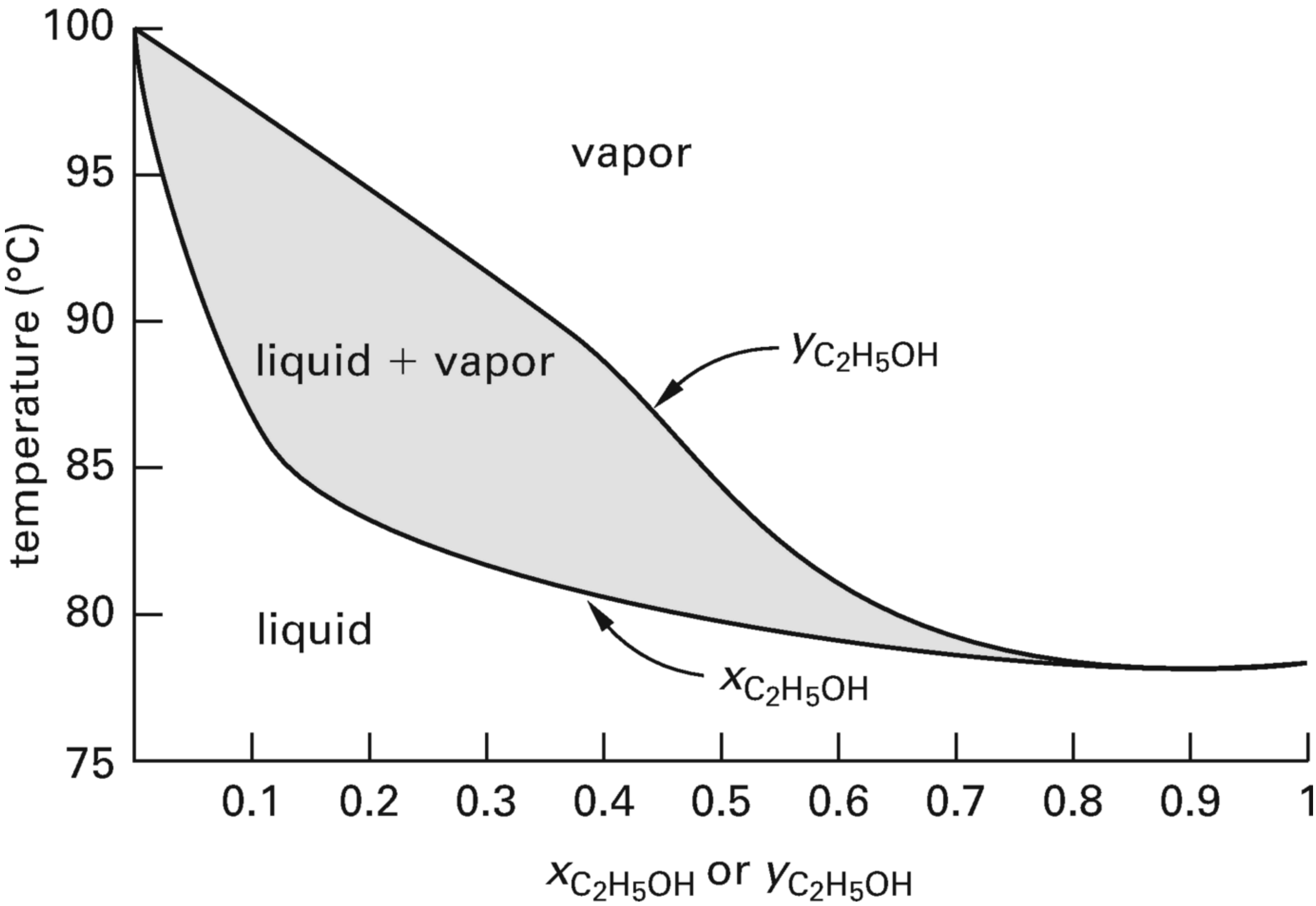
Topic V: Mass Transfer

Chapter 23. Basic Principles of Mass Transfer

Practice Problems

1.

An ethanol-water mixture at 1 atm total pressure and 95.5°C contains 10% ethanol (mole basis).



Using the *Txy* diagram provided, the amount of vapor in 1000 mol of the mixture at equilibrium is

(A)

83.3 mol

(B)

100 mol

(C)

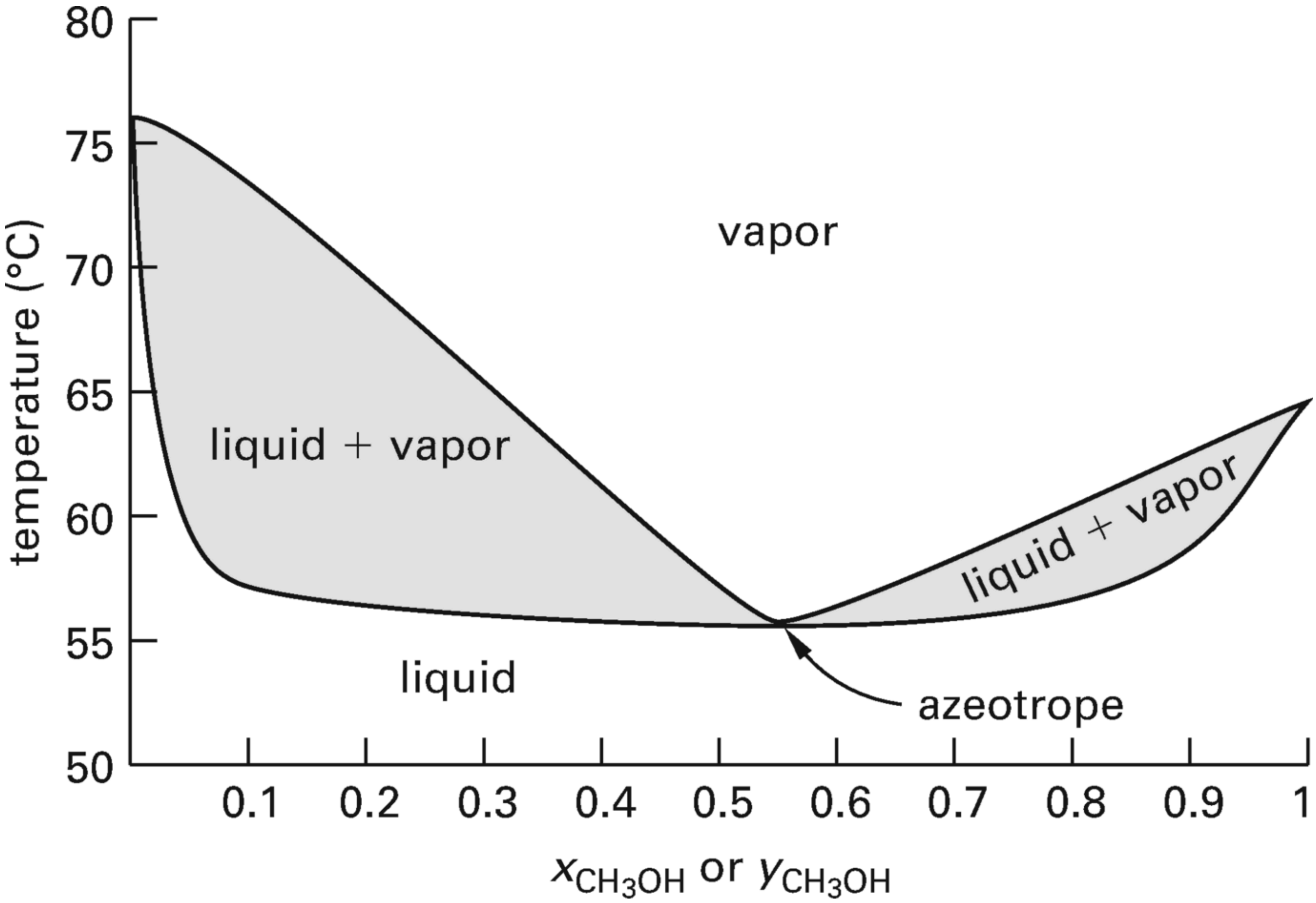
467 mol

(D)

533 mol

2.

A *Txy* diagram is provided for a methanol-carbon tetrachloride mixture consisting of 845 mol of mixture with 10% methanol (mole basis) at 60°C and 1 atm total pressure.



At equilibrium, the amount of vapor is

(A)

55.1 mol

(B)

84.5 mol

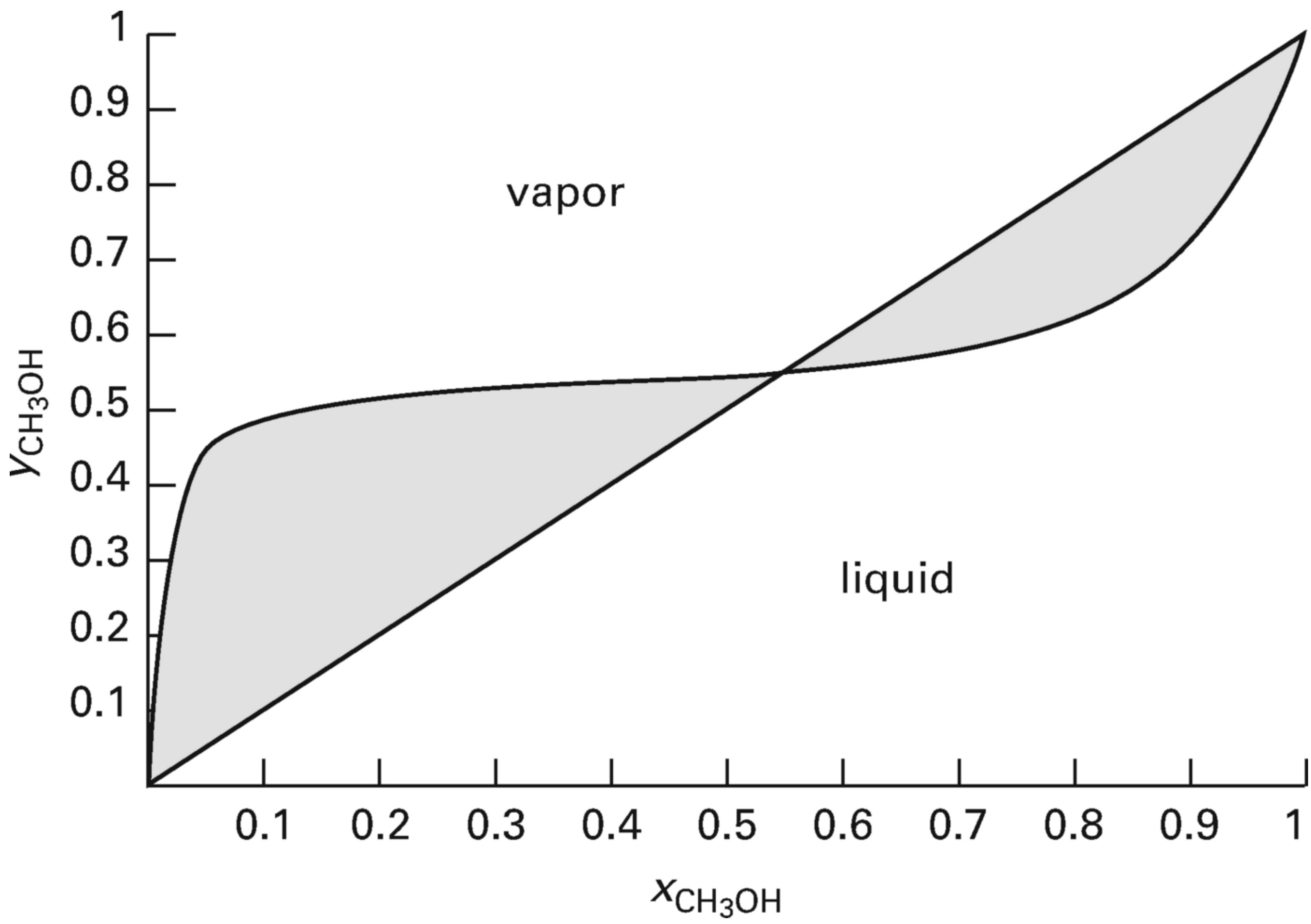
(C)

130 mol

(D)

715 mol
3.

The equilibrium data in the *xy* diagram provided describe a methanol-carbon tetrachloride mixture.



What is the relative volatility of methanol to carbon tetrachloride at the azeotropic composition?

(A)

0.55

(B)

0.67

(C)

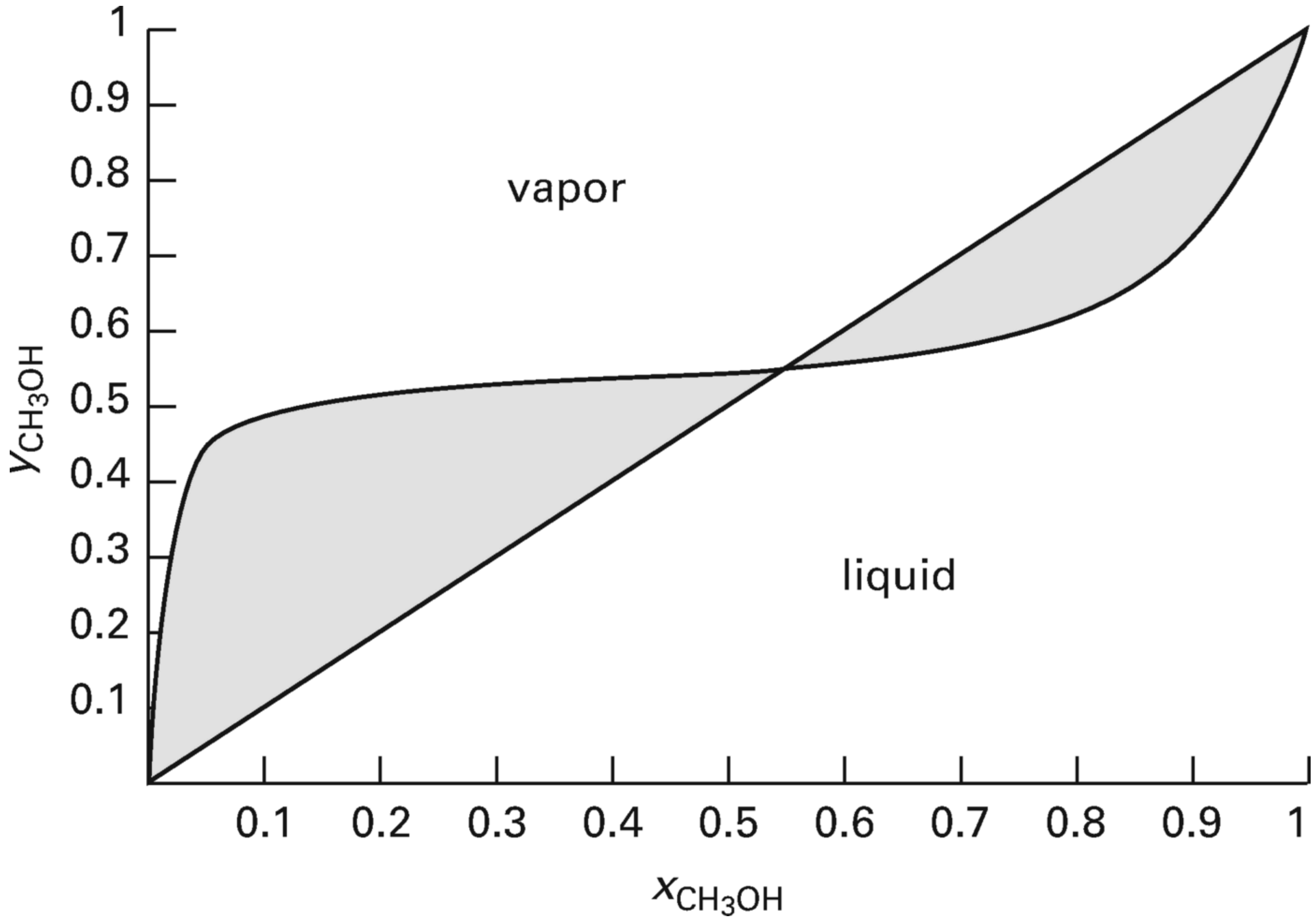
1

(D)

1.49

4.

An equilibrium methanol-carbon tetrachloride mixture with a liquid mole fraction, $x_{CH_3OH} = 0.40$ is described by the plotted data shown.



What is the relative volatility of methanol to carbon tetrachloride?

(A)

0.57

(B)

0.78

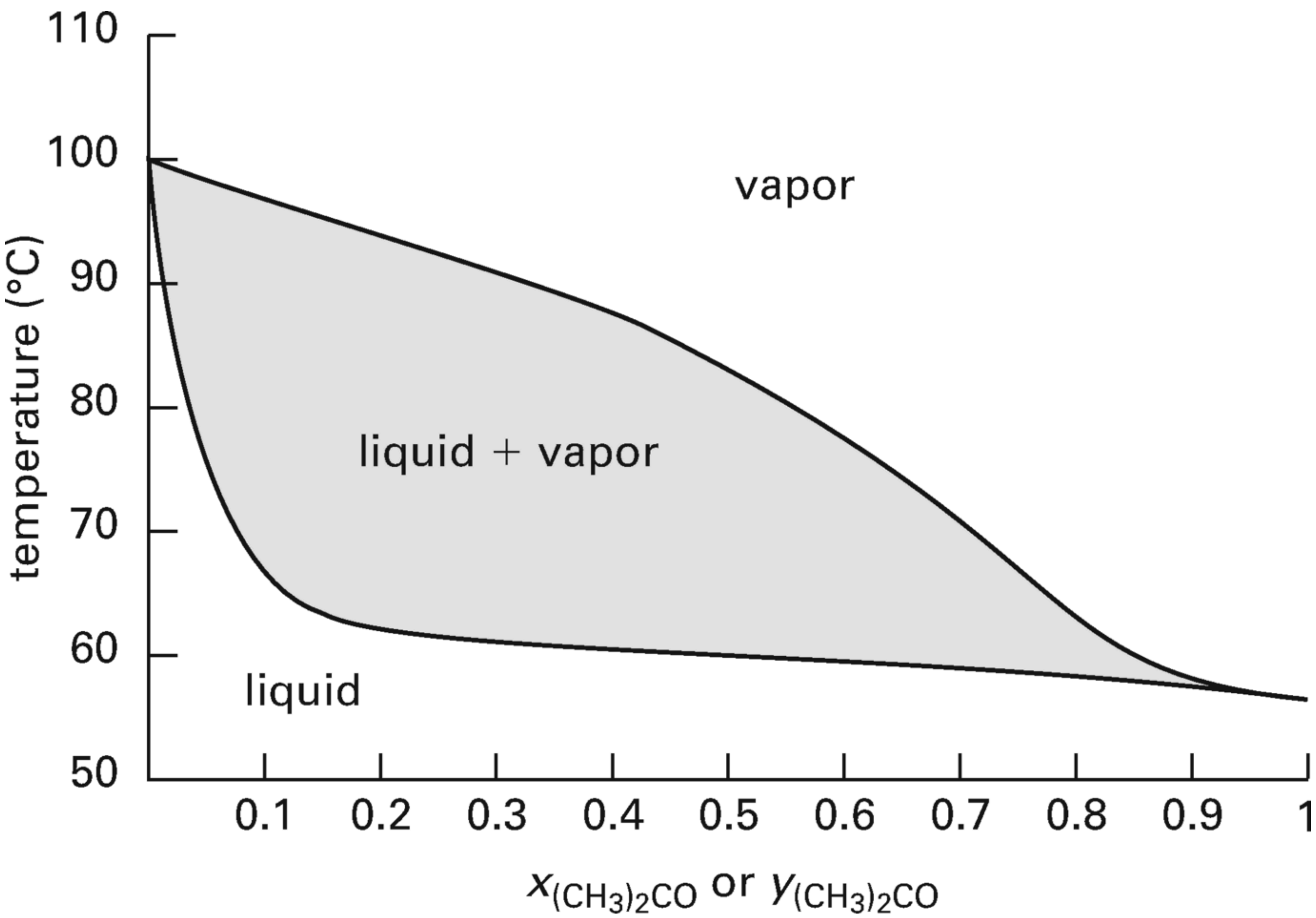
(C)

1.28

(D)

1.75
5.

800 mol of a liquid mixture contain 40 mol% acetone ($(CH_3)_2CO$) in water at 62°C and 1 atm total pressure. The following *Txy* diagram presents the equilibrium data for the acetone-water system at 1 atm total pressure.



At equilibrium, how many moles of vapor are there?

(A)

$V = 270$ mol

(B)

$V = 250$ mol

(C)

$V = 230$ mol

(D)

$V = 210$ mol
6.

An aqueous solution of methanol in water contains 24.4 wt% water. The solution follows Raoult's law. The flash point of methanol is 54°F, and the vapor pressure of methanol at this temperature is 62 mm Hg. The saturation vapor pressure of methanol at different temperatures is shown.

temperature(°F)	saturation pressure(mm Hg)
54.00	62.00
59.00	73.91
66.16	92.10
67.96	97.58
69.75	103.1
73.33	114.0
80.49	140.2

87.66	171.5
94.82	208.4

The molecular weight of water is 18 lbm/lbmol, and that of methanol is 32 lbm/lbmol. Most nearly, the flash point of the aqueous mixture is

(A)

54°F

(B)

59°F

(C)

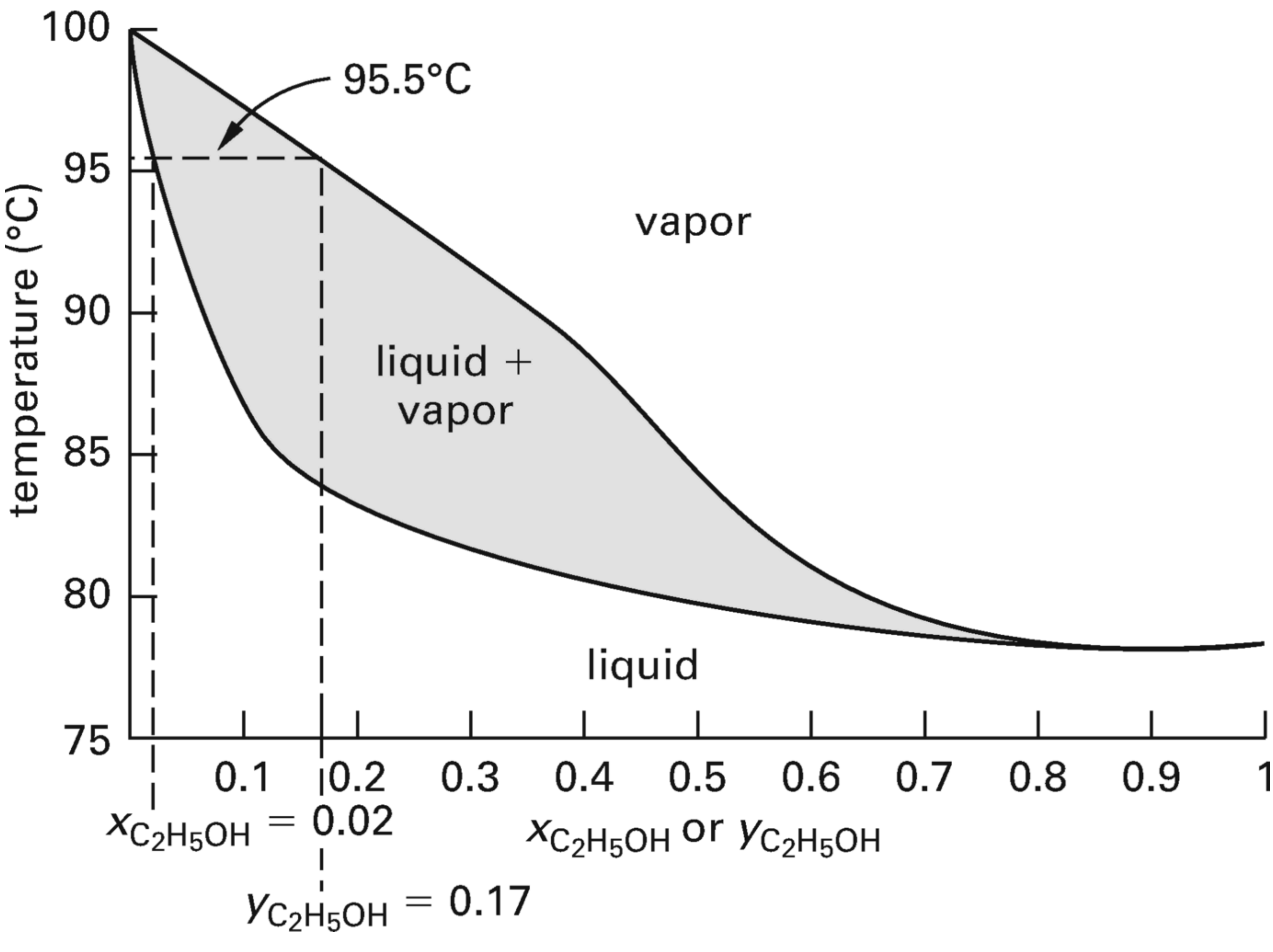
68°F

(D)

80°F

Solutions

1.



For an equilibrium liquid and vapor mixture at 95.5°C, the isotherm's intersection with the saturated liquid line indicates that the equilibrium composition of the liquid phase, $x_{C_2H_5OH}$, is 0.02. The isotherm's intersection with the saturated vapor line gives the equilibrium composition of the vapor phase, $y_{C_2H_5OH}$, as 0.17. The mole fraction of water in each phase is calculated using equationCHRM43004 and equationCHRM43005 (also *NCEES Handbook:* Fractions).

$$
\begin{aligned}
x_{C_2H_5OH} + x_{H_2O} &= 1 \\
x_{H_2O} &= 1 - x_{C_2H_5OH} = 1 - 0.02 = 0.98 \\
y_{C_2H_5OH} + y_{H_2O} &= 1 \\
y_{H_2O} &= 1 - y_{C_2H_5OH} = 1 - 0.17 = 0.83
\end{aligned}
$$

From the problem statement,

$$
\begin{aligned}
F &= 1000 \text{ mol} \\
z_{C_2H_5OH} &= 0.10
\end{aligned}
$$

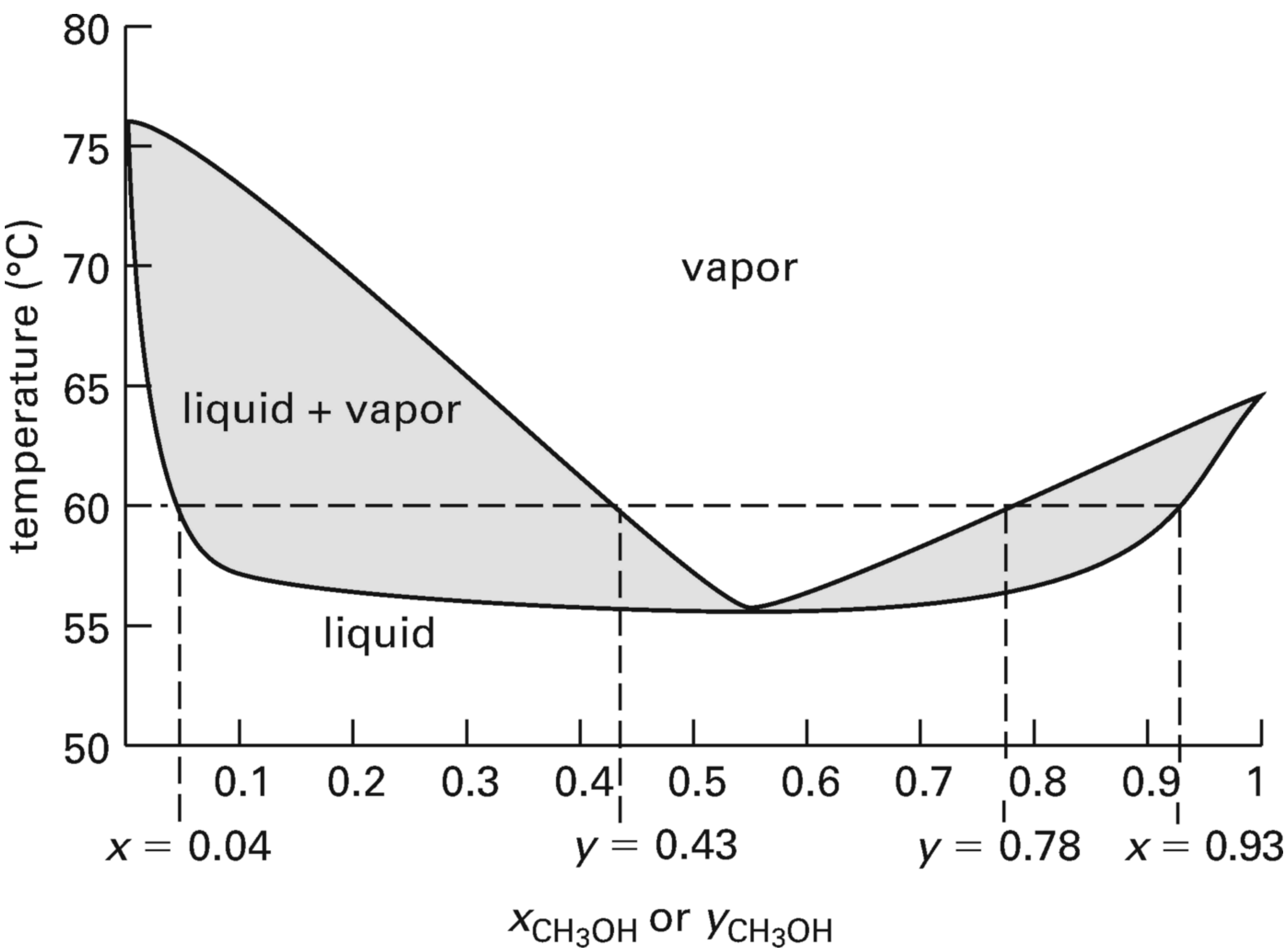
As in *NCEES Handbook:* Single-Stage Flash,

$$
\begin{aligned}
\tfrac{V}{F} &= A_v = \frac{x_F - x_A}{y_A - x_A} \\
&= \tfrac{0.1-0.02}{0.17-0.02} \\
&= 0.533
\end{aligned}
$$

$$
V = A_v F = (0.533)\,(1000 \text{ mol}) = 533 \text{ mol}
$$

The answer is (D).

2.



Draw the isotherm at 60°C and read the equilibrium composition of the liquid and the vapor phases. There are two possible equilibrium compositions. These are

$$
\begin{aligned}
x_{CH_3OH} &= 0.04 \\
y_{CH_3OH} &= 0.43
\end{aligned}
$$

and

$$
\begin{aligned}
x_{CH_3OH} &= 0.93 \\
y_{CH_3OH} &= 0.78
\end{aligned}
$$

The feed composition is given as $z_{CH_3OH} = 0.10$. Plotting the feed composition on the equilibrium diagram reveals that the equilibrium composition of the liquid and the vapor phases lies on the left side of the two-phase envelope. So,

$$x_{CH_3OH} = 0.04$$
$$y_{CH_3OH} = 0.43$$

From the problem statement,

$$F = 845 \text{ mol}$$

As in *NCEES Handbook:* Single-Stage Flash,

$$\begin{aligned}\tfrac{V}{F} = A_v &= \frac{x_F - x_A}{y_A - x_A} \\ &= \tfrac{0.1-0.04}{0.43-0.04} \\ &= 0.154\end{aligned}$$

$$V = A_v F = (0.154)(845 \text{ mol}) = 130 \text{ mol}$$

The answer is (C).
3.

From the *xy* diagram, at the azeotrope, $x_{CH_3OH} = 0.55$, $y_{CH_3OH} = 0.55$. From equationCHRM43007, the equilibrium ratio for methanol is

$$K_{CH_3OH} = \frac{y_{CH_3OH}}{x_{CH_3OH}} = \frac{0.55}{0.55} = 1.0$$

The mole fractions for carbon tetrachloride are calculated by using equationCHRM43004 and equationCHRM43005 (also *NCEES Handbook:* Fractions).

$$\begin{aligned}x_{CCl_4} + x_{CH_3OH} &= 1 \\ x_{CCl_4} &= 1 - x_{CH_3OH} = 1 - 0.55 = 0.45 \\ y_{CCl_4} + y_{CH_3OH} &= 1 \\ y_{CCl_4} &= 1 - y_{CH_3OH} = 1 - 0.55 = 0.45\end{aligned}$$

The equilibrium ratio from *NCEES Handbook:* Distribution of Components Between Phases in a Vapor/Liquid Equilibrium for carbon tetrachloride is

$$K_{CCl_4} = \frac{y_{CCl_4}}{x_{CCl_4}} = \frac{0.45}{0.45} = 1.0$$

The relative volatility from *NCEES Handbook:* Distribution of Components Between Phases in a Vapor/Liquid Equilibrium of methanol to carbon tetrachloride is

$$\alpha_{CH_3OH-CCl_4} = \frac{K_{CH_3OH}}{K_{CCl_4}} = \frac{1.0}{1.0} = 1$$

The relative volatility of carbon tetrachloride to methanol is also equal to 1.

The answer is (C).

4.

From the *xy* diagram, at $x_{CH_3OH} = 0.40$, $y_{CH_3OH} = 0.54$. The equilibrium ratio is

$$\begin{aligned}K_{CH_3OH} &= \frac{y_{CH_3OH}}{x_{CH_3OH}} \\ &= \frac{0.54}{0.40} \\ &= 1.35\end{aligned}$$

Using equationCHRM43004 and equationCHRM43005 (also *NCEES Handbook:* Fractions), the mole fractions of carbon tetrachloride are

$$\begin{aligned} x_{CCl_4} + x_{CH_3OH} &= 1 \\ x_{CCl_4} &= 1 - x_{CH_3OH} = 1 - 0.40 = 0.60 \\ y_{CCl_4} + y_{CH_3OH} &= 1 \\ y_{CCl_4} &= 1 - y_{CH_3OH} = 1 - 0.54 = 0.46 \end{aligned}$$

The equilibrium ratio from *NCEES Handbook:* Distribution of Components Between Phases in a Vapor/Liquid Equilibrium for carbon tetrachloride is

$$K_{CCl_4} = \frac{y_{CCl_4}}{x_{CCl_4}} = \frac{0.46}{0.60} = 0.77$$

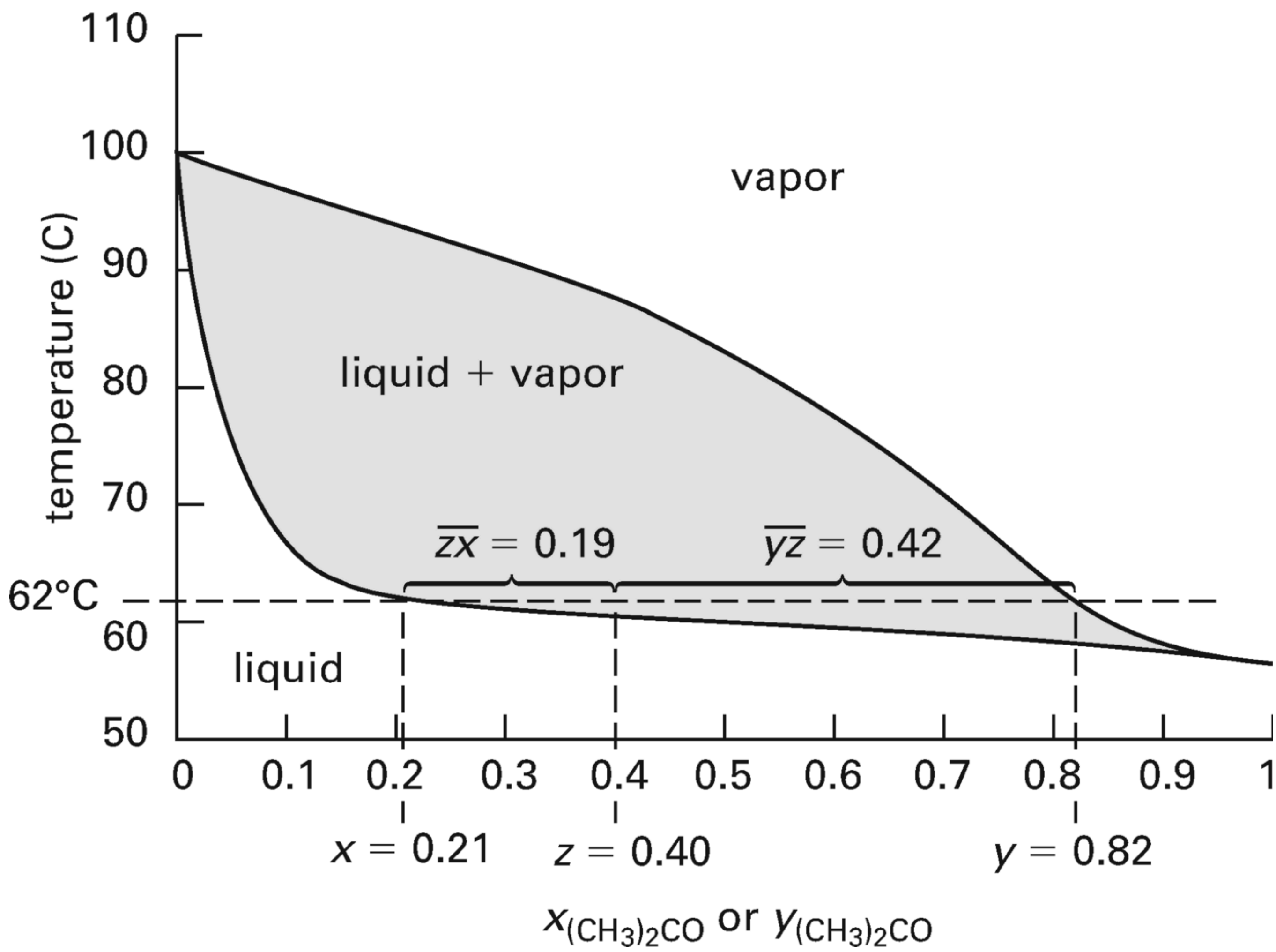
The relative volatility from *NCEES Handbook:* Distribution of Components Between Phases in a Vapor/Liquid Equilibrium of methanol to carbon tetrachloride is

$$\alpha_{CH_3OH-CCl_4} = \frac{K_{CH_3OH}}{K_{CCl_4}} = \frac{1.35}{0.77} = 1.75$$

The answer is (D).

5.

The vapor equilibrium composition is found from the points where the 62°C isotherm intersects the liquid and the vapor equilibrium lines.



For a 40 mol% acetone solution, $z_{(CH_3)_2CO} = 0.40$. The equilibrium compositions of acetone are $x_{(CH_3)_2CO} = 0.21$ and $y_{(CH_3)_2CO} = 0.82$.

As in *NCEES Handbook:* Single-Stage Flash,

$$\frac{V}{F} = A_v = \frac{x_F - x_A}{y_A - x_A} = \frac{0.4 - 0.21}{0.82 - 0.21} = 0.311$$

$$V = A_v F = (0.311)(800 \text{ mol}) = 250 \text{ mol}$$

The answer is (B).
6.

Let the basis of calculation, w, be 100 lbm of aqueous solution. The weight of water in the solution, w_{water}, is given as 24.4 lbm. The weight of methanol in the aqueous solution is

$$\begin{aligned} w_{\text{methanol}} &= w - w_{\text{water}} = 100 \text{ lbm} - 24.4 \text{ lbm} \\ &= 75.6 \text{ lbm} \end{aligned}$$

The number of moles of water in the solution is

$$n_{\text{water}} = \frac{w_{\text{water}}}{\text{MW}_{\text{water}}} = \frac{24.4 \text{ lbm}}{18 \dfrac{\text{lbm}}{\text{lbmol}}} = 1.36 \text{ lbmol}$$

The number of moles of methanol in the solution is

$$n_{\text{methanol}} = \frac{w_{\text{methanol}}}{\text{MW}_{\text{methanol}}} = \frac{75.6 \text{ lbm}}{32 \dfrac{\text{lbm}}{\text{lbmol}}} = 2.36 \text{ lbmol}$$

The total number of moles in the aqueous solution is

$$\begin{aligned} n_{\text{total}} &= n_{\text{water}} + n_{\text{methanol}} = 1.36 \text{ lbmol} + 2.36 \text{ lbmol} \\ &= 3.72 \text{ lbmol} \end{aligned}$$

The fraction mole of methanol in the aqueous solution is

$$x_{\text{methanol}} = \frac{n_{\text{methanol}}}{n_{\text{total}}} = \frac{2.36 \text{ lbmol}}{3.72 \text{ lbmol}} = 0.63$$

The pressure of methanol at the flash point, $p°$, is given as 62 mm Hg. Raoult's law gives the saturation pressure of methanol in the aqueous solution.

$$p = \frac{p^{\circ}}{x_{\text{methanol}}} = \frac{62 \text{ mm Hg}}{0.63} = 98 \text{ mm Hg}$$

From the data given about saturation pressure versus temperature, the flash point temperature of the aqueous solution is approximately 68°F.

The answer is (C).