

Solutions Manual

to accompany

AIR POLLUTION: Its Origin and Control

Third Edition

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Solutions Manual to accompany Wark/Warner/Davis AIR POLLUTION: Its Origin and Control,
Third Edition

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1-1 Using Equation 1-1 M_w of CO = 12 + 16 = 28

$$\mu\text{g}/\text{m}^3 = \frac{\text{ppm} (M_w) (10^3)}{24.5}$$

$$= \frac{(35)(28)(10^3)}{24.5} = 40,000 \mu\text{g}/\text{m}^3$$

or 40 mg/m³

1-2 Eg. 1-1

$$\text{ppm} = \frac{(\mu\text{g}/\text{m}^3)(24.5)}{M_w (10^3)}$$

$$= \frac{(80)(24.5)}{64 \times 10^3} = 0.0306 \text{ ppm}$$

1-3 7000 grains = 1 lb.

$$\text{Conc} = 150 \frac{\mu\text{g}}{\text{m}^3} \times \frac{1 \text{ m}^3}{35.3 \text{ ft}^3} \times \frac{1 \text{ g}}{10^6 \mu\text{g}} \times \frac{1 \text{ lb}}{453.6 \text{ g}} \times \frac{7000 \text{ gr}}{\text{lb}}$$

$$= 6.5 \times 10^{-5} \text{ grains}/\text{ft}^3$$

1-4 Eg 1-1

$$\mu\text{g}/\text{m}^3 = \frac{0.25 \times 48 \times 10^3}{24.5} = 490$$

$$\% \text{ exceeded} = \frac{490 - 240}{240} = 104\%$$

1-5 % by volume = ppm $\times 10^{-4} = 400 \times 10^{-4}$

$$= 0.04$$

Using Eg. 1-1 $\mu\text{g}/\text{m}^3 = \frac{400 \times 28 \times 10^3}{24.5}$

$$\text{Conc} = 457 \times 10^{-3} \mu\text{g}/\text{m}^3 = 457 \text{ mg}/\text{m}^3$$

(1)

1-6. Rewriting of 1-1.

$$\begin{aligned} \text{ppm} &= \frac{(\mu\text{g}/\text{m}^3)(24.5)}{(10)^3 (2\text{nd } \text{m}^2)} \\ &= \frac{(100)(24.5)}{(10)^3 (46)} = 0.05326 \end{aligned}$$

1-7. (a) $C = 160 \mu\text{g}/\text{m}^3$

$$C = (160 \mu\text{g}/\text{m}^3) \left(\frac{1 \text{ grain}/\text{ft}^3}{2.29 \text{ g}/\text{m}^3} \right) \times \frac{\text{g}}{10^6 \mu\text{g}} = 6.99 \times 10^{-5} \text{ grains}/\text{ft}^3$$

(b) $C = 10 \text{ grains}/\text{ft}^3$

$$C = \left(\frac{10 \text{ grains}}{1 \text{ ft}^3} \right) \left(\frac{2.29 \text{ g}/\text{m}^3}{1 \text{ grain}/\text{ft}^3} \right) \left(\frac{10^6 \mu\text{g}}{\text{g}} \right) = 22.9 \times 10^6 \frac{\mu\text{g}}{\text{m}^3}$$

1-8. (a) Cf. 1-7. $L_v = \frac{3.9}{\sigma}$ $\sigma = \left(\frac{3.9}{2} \right) \text{mi}$

$$\text{and } \left(\frac{I}{I_0} \right)_{0.2 \text{ mi}} = \exp \left[\left(-\frac{3.9}{2} \right) (0.2) \right] = 0.677 \text{ or } 67.7\%$$

(b) When 99% is used, $\ln I/I_0 = -\sigma d$

$$\ln(0.01) = -\sigma L_v \quad L_v = 4.605/\sigma$$

$$\therefore \sigma = \left(\frac{4.605}{2} \right) \text{mi}^{-1}$$

$$\begin{aligned} \text{and } \left(\frac{I}{I_0} \right)_{0.2 \text{ mi}} &= \exp \left[\left(-\frac{4.605}{2} \right) (0.2) \right] \\ &= .631 \text{ or } 63.1\% \end{aligned}$$

1-9.

$$I/I_0 = \exp(-\sigma d)$$

$$0.02 = \exp(-\sigma L_v)$$

$$\sigma = \frac{\ln 0.02}{-L_v} = 3.912/L_v$$

$$(a) \left(\frac{I}{I_0}\right)_{10\% \text{ path}} = \exp\left(\frac{-3.912 \times 0.1 L_v}{L_v}\right) = 0.676$$

$$\% \text{ extinc} = 32.4\%$$

$$(b) \left(\frac{I}{I_0}\right)_{20\% \text{ path}} = \exp\left(\frac{-3.912 \times 0.2 L_v}{L_v}\right) = 0.457$$

$$\% \text{ extinc} = 54.3\%$$

$$(c) \left(\frac{I}{I_0}\right)_{50\% \text{ path}} = \exp(-3.912 \times 5) = 0.141$$

$$\% \text{ extinc} = 85.9\%$$

1-10

(a)	$N_2 = 78\%$ by volume	M_w 28
	$O_2 = 21\%$ by volume	32
	MEK = 0.05%	72

$$M_w \text{ MEK} = (\text{CH}_3\text{CH}_2\text{COCH}_3) = 4(12) + 8(1) + 16 = 72$$

$$1\% \equiv 10^4 \text{ ppm}$$

$$\therefore N_2 = 78\% \times 10^4 = 780,000 \text{ ppm}$$

$$O_2 = 21\% \times 10^4 = 210,000 \text{ ppm}$$

$$\text{MEK} = 0.05\% \times 10^4 = 500 \text{ ppm}$$

$$(b) \text{ Eg. 1-1 } \mu\text{g}/\text{m}^3 = \frac{\text{ppm} \times M_w \times 10^3}{24.5}$$

$$N_2 = \frac{780,000(28)10^3}{24.5} = 8.91 \times 10^8 \mu\text{g}/\text{m}^3$$

$$O_2 = \frac{210,000(32)(10^3)}{24.5} = 2.7 \times 10^8 \mu\text{g}/\text{m}^3$$

$$\text{MEK} = \frac{500(72)10^3}{24.5} = 1.47 \times 10^6 \mu\text{g}/\text{m}^3$$

(3)

1.11 Can use the ideal gas law or start with the equation at 25°C & 1 atm:

(a) use $\frac{\mu\text{g}}{\text{m}^3} = \frac{\text{ppm}(\text{Mw})(10^3)}{24.5}$ and adjust 24.5.

$$\begin{aligned} \text{NO:} \quad \frac{\mu\text{g}}{\text{m}^3} &= \frac{\text{ppm}(\text{Mw})10^3}{24.5 \left(\frac{300+460}{77+460} \right) \left(\frac{29.92}{30.20} \right)} = \frac{(450)(30)10^3}{24.5 \left(\frac{760}{537} \right) (.991)} \\ \text{Mw} &= 30 \\ &= 392,870 \mu\text{g}/\text{m}^3 = \boxed{0.393 \text{ g}/\text{m}^3} \end{aligned}$$

$$\begin{aligned} \text{NO}_2 \quad \frac{\mu\text{g}}{\text{m}^3} &= \frac{(30)(46)10^3}{24.5 \left(\frac{760}{537} \right) (.991)} = 40,160 \mu\text{g}/\text{m}^3 \\ \text{Mw} &= 46 \\ &= \boxed{0.04 \text{ g}/\text{m}^3} \end{aligned}$$

(b) Concentration in ppm remains unchanged unless condensation occurs.

$$\therefore \text{NO}_2 = \boxed{450 \text{ ppm}} \quad \text{NO}_2 = \boxed{30 \text{ ppm}}$$

(c) As in part a, except correct to 20°C & 29.92 "Hg

$$\begin{aligned} \therefore \text{NO} &= \frac{(450)(30)10^3}{24.5 \left(\frac{293}{298} \right) \left(\frac{29.92}{29.92} \right)} = 560,423 \mu\text{g}/\text{m}^3 \\ &\approx \boxed{0.56 \text{ g}/\text{m}^3} \end{aligned}$$

$$\begin{aligned} \text{NO}_2 &= \frac{(30)(46)10^3}{24.5 \left(\frac{293}{298} \right)} = 57288 \mu\text{g}/\text{m}^3 \\ &\approx \boxed{0.057 \text{ g}/\text{m}^3} \end{aligned}$$

$$1-12 \quad (a) \quad I = I_0 e^{-\sigma_{\text{scat}} d}$$

$$-\sigma_{\text{scat}} d = \ln(0.08) = -2.526$$

$$\therefore \sigma_{\text{scat}} = \frac{2.526}{1,000} = 2.53 \times 10^{-3} \text{ m}^{-1}$$

$$(b) \quad \sigma_{\text{scat}} = N K \pi r^2 \quad N m_p = C \quad \text{and} \quad \left(\frac{4\pi r^3}{3}\right) \rho_p = m_p$$

$$\therefore N = \frac{C}{\frac{4}{3}\pi r^3 \rho_p} = 745 \frac{\mu\text{g}}{\text{m}^3} \times \frac{3}{4\pi(0.4 \times 10^{-6})^3} \frac{1}{\text{m}^3}$$

$$\times \frac{\text{cm}^3}{1.15 \text{g}} \times \frac{\text{m}^3}{10^6 \text{cm}^3} \times \frac{\text{g}}{10^6 \mu\text{g}} =$$

$$\frac{(745)(3)}{4\pi} \times \frac{1}{1.15} \times \left(\frac{1}{0.4}\right)^3 \times \frac{1}{10^{-6}} = 2.416 \times 10^9$$

$$= 2,420 \text{ parts/cm}^3$$

$$K = \frac{\sigma_{\text{scat}}}{N \pi r^2} = \frac{2.53 \times 10^{-3}}{\text{m}} \times \frac{\text{cm}^3}{2420} \times \frac{1}{\pi} \times$$

$$\frac{1}{(0.4 \times 10^{-6})^2 \text{m}^2} \times \frac{\text{m}^3}{10^6 \text{cm}^3} = 2.08$$

$$(c) \quad L_v = \frac{5.2 \rho_p r}{K C} = \frac{3.9}{\sigma_{\text{scat}}}$$

$$= \frac{3.9 \text{ m}}{2.53 \times 10^{-3}} \times \frac{\text{km}}{10^3 \text{ m}} = 1.54 \text{ km}$$

or

$$L_v = \frac{5.2 \times 1.15 \times 0.4 \times 10^{-6} \text{ g}}{(2.08)(745)} \times \text{m} \times \frac{\text{m}^3}{\text{Mg}} \times \frac{10^6 \text{ cm}^3}{\text{m}^3}$$

$$\times \frac{10^6 \mu\text{g}}{\text{g}} = 1,544 \text{ m} = 1.54 \text{ km}$$

(5)

1-13 Droplets are $0.5 \mu\text{m}$ in diameter
 $r = 0.25 \mu\text{m}$, refraction index = 1.5
 $\rho_p = 1.1 \text{ g/cm}^3$, $\lambda = 0.48 \mu\text{m}$
 Visibility = 2 miles = 3220 m

Use Eq. 1-8 $C = \frac{5.2 \rho_p r}{K L_v}$

Use Fig 1-6 to determine K

$$\frac{4\pi r |m-1|}{\lambda} = \frac{4(3.14)(0.25)(1.5-1)}{0.48}$$

$$= 3.27$$

From Fig 1-6, $K \sim 3.7$

$$\therefore C = \frac{(5.2)(1.1 \frac{\text{g}}{\text{cm}^3})(10^6 \frac{\text{cm}^3}{\text{m}^3})(0.25 \times 10^{-6} \text{ m})}{3.7(3220 \text{ m})}$$

$$= 120 \times 10^{-6} \text{ g/m}^3 = 1.2 \times 10^{-4} \text{ g/m}^3$$

or $120 \mu\text{g/m}^3$

1-14 Eq 1-7

$$\sigma = \frac{3.9}{L_v} = \frac{3.9}{3} = 1.3 \text{ mi}^{-1}$$

Using Eq 1-3 for a length of 0.5 mi

$$\frac{I}{I_0} = \exp(-1.3 \text{ mi}^{-1} \times 0.5 \text{ mi}) = 0.522$$

∴ 52.2% will pass through 0.5 mi

1-15 From Eq. 1-5, $L_v = \frac{3.9}{\sigma_{ext}}$

From Eq. 1-6, $\sigma = NK\pi r^2$

$\therefore L_v = \frac{3.9}{NK\pi r^2}$

$C = N\left(\frac{4\pi r^3}{3}\right)(\rho_p)$ or $N = \frac{3C}{4\pi r^3 \rho_p}$

$\therefore L_v = \frac{3.9}{\left(\frac{3C}{4\pi r^3 \rho_p}\right)K\pi r^2} = \frac{5.2 r \rho_p}{KC}$

1-16

(a) From Fig. 1-5,

$\sigma_{abs} \approx 0.14 \text{ km}^{-1}$ for 0.1 ppm NO_2 at $0.45 \mu\text{m}$

at 30 ppm, $\sigma_{abs} = \frac{30}{0.1} \times 0.14 \text{ km}^{-1} = 42 \text{ km}^{-1}$

$\therefore I/I_0 = \exp\left(-42 \text{ km}^{-1} \times 6 \text{ m} \times \frac{\text{km}}{1000 \text{ m}}\right)$
 $= 0.78$

Opacity = $(1 - I/I_0) \times 100\%$
 $= (1 - 0.78) \times 100 = 22\%$

(b) From Fig. 1-5, $\sigma_{abs} \approx 0.025 \text{ km}^{-1}$ at 0.1 ppm

$\frac{I}{I_0} = \exp\left(-0.025 \left(\frac{30}{.1}\right) (6 \text{ m}) \left(\frac{1}{1000}\right)\right) = 0.956$

Opacity = $(1 - I/I_0) \times 100\% = 4.4\%$

(7)

$$1-17 \quad d_{aero} = d_p \left(\frac{K_c \rho_p}{K_{c,aero} \rho_{aero}} \right)^{0.5}$$

For $d_p > 1 \mu\text{m}$, $K_c \approx 1.0$

$$\therefore d_{aero} \approx d_p \left(\frac{\rho_p}{\rho_a} \right)^{0.5}$$

$$(a) \quad d_{aero} = 5 \mu\text{m} (1)^{0.5} = 5 \mu\text{m}$$

yes, it will be collected in a PM_{10} sampler

$$(b) \quad d_{aero} = 5 \mu\text{m} (7.9)^{0.5} = 14 \mu\text{m}; \text{ no}$$

$$(c) \quad d_{aero} = 10 \mu\text{m} (2)^{0.5} = 14 \mu\text{m}; \text{ no}$$

$$(d) \quad d_{aero} = 2.5 \mu\text{m} (4)^{0.5} = 5 \mu\text{m}, \text{ yes}$$

1-18 From Figure 1-5 for 0.1 ppm of NO_2 :

$$\sigma_{abs, 0.45 \mu\text{m}} = 0.14, \quad \sigma_{0.5 \text{ ppm}} = \frac{0.5}{0.1} (0.14) = 0.7 \text{ km}^{-1}$$

$$\sigma_{abs, 0.55 \mu\text{m}} = 0.027, \quad \sigma_{0.5 \text{ ppm}} = \frac{0.5}{0.1} (0.027) = 0.135 \text{ km}^{-1}$$

$$\sigma_{abs, 0.65 \mu\text{m}} = 0.0046, \quad \sigma_{0.5 \text{ ppm}} = \frac{0.5}{0.1} (0.0046) = 0.023 \text{ km}^{-1}$$

$$\sigma_{ext} = \sigma_{\text{Rayleigh}} + \sigma_{abs}$$

$$\sigma_{\text{Rayleigh}} = 0.026 \text{ km}^{-1} \text{ at } 0.45 \mu\text{m}$$

$$0.011 \text{ km}^{-1} \text{ at } 0.55 \mu\text{m}$$

$$0.006 \text{ km}^{-1} \text{ at } 0.65 \mu\text{m}$$

$$(a) \quad \frac{I}{I_0} = \exp(-\sigma d) = \exp(-(0.7 + 0.026)(3)) = 0.11$$

attenuation = 0.89 or 89%

$$(b) \quad \frac{I}{I_0} = \exp(-(.135 + .011)(3)) = 0.65, \text{ attenuation} = 35\%$$

$$(c) \quad \frac{I}{I_0} = \exp(-(.023 + .006)(3)) = 0.917, \text{ attenuation} = 8.3\%$$

(8)

1-19 $I/I_0 = \exp(-kCd)$ for NO_2

$$k = \text{ppm}^{-1}(\text{km}^{-1})$$

(a) Using Figure 1-5, determine k at $\lambda = 0.5 \mu\text{m}$

Based on the above equation, $\sigma = kC = k\text{km}^{-1}$

$$k_{0.5\mu\text{m}} = \frac{\sigma}{C} = \frac{0.06 \text{ km}^{-1}}{0.1 \text{ ppm NO}_2} = 0.6 \text{ ppm}^{-1} \text{ km}^{-1}$$

(b) neglecting Rayleigh scattering & particles,

$$\text{For } I/I_0 = 0.40 = \exp(-kCd)$$

$$C = -\frac{\ln(0.40)}{kd} = -\frac{\ln(0.40)}{0.6(2)} = 0.76 \text{ ppm}$$

$$\text{For } I/I_0 = 0.75 \quad C = -\frac{\ln(0.75)}{0.6(2)} = 0.23 \text{ ppm}$$

$$\text{For } I/I_0 = 0.90 \quad C = -\frac{\ln(0.90)}{0.6(2)} = 0.087 \text{ ppm}$$

with Rayleigh scattering of 0.016 km^{-1} at $0.5 \mu\text{m}$,

$$I/I_0 = 0.40 = \exp(-kCd - .016d)$$

$$\therefore C = 0.74 \text{ ppm}$$

$$I/I_0 = 0.75 : C = 0.21 \text{ ppm}$$

$$I/I_0 = 0.90 : C = 0.06 \text{ ppm}$$

1-20 Note $K = K_{\text{scatt.}}$; Using Eq 1-8,

$$L_v = 5.2 \left(\frac{1.49}{\text{cm}^3} \right) \left(\frac{0.7 \times 10^{-4} \text{ cm}}{(2.2) \left(\frac{200 \times 10^{-6} \text{ g} \times 10^{-4} \text{ cm}}{\text{m}^3 \times \text{cm}^2} \right)} \right)$$

$$= 0.01158 \times 10^{-6} \text{ m} = 11.58 \text{ km}$$

1-21

$$\text{Conc.} = \frac{0.53 \text{ g/day}}{1.7 \frac{\text{m}^3}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}}} = 2.17 \times 10^{-4} \text{ g/m}^3$$

$$\text{or } 217 \mu\text{g/m}^3$$

(9)

1-22

$$\frac{COHb}{O_2Hb} = \frac{(240)(450)}{190,000} = 0.568$$

$$\frac{0.568}{1 + 0.568} \times 100\% = 36.2\%$$

1-23 (a). O_2 capacity = $(4800 \text{ ml blood}) \left(\frac{20 \text{ ml } O_2}{100 \text{ ml blood}} \right)$
 $= 960 \text{ ml } O_2$

$$CO \text{ breathed} = \left(\frac{4.2 \times 10^3 \text{ ml air}}{\text{min}} \right) \left(\frac{100 \times 10^{-6} \text{ CO}}{\text{air}} \right)$$

$$= 0.42 \text{ ml CO/min}$$

$$t = \frac{0.7 \times 960}{0.42} = 160 \text{ min.}$$

(b) $t = 160 \times \frac{0.25}{0.07} = 114 \text{ min.}$

1-24 $\frac{COHb}{O_2Hb} = \frac{m P_{CO}}{P_{O_2}}$ where $m = 200 - 250$

$$P_{O_2} = 17.5\% O_2 \times \frac{1 \text{ atm}}{10^{-4} \%} = 17.5 \times 10^4 \text{ ppm}$$

If $m = 200$

$$\frac{COHb}{O_2Hb} = 200 \left(\frac{220}{17.5 \times 10^4} \right) = 0.251$$

$$\% COHb = \frac{0.251}{1.251} (100) = 20.1\%$$

If $m = 250$

$$\frac{COHb}{O_2Hb} = 250 \left(\frac{220}{17.5 \times 10^4} \right) = 0.314$$

$$\% COHb = \frac{0.314}{1.314} \times 100 = 23.9\%$$

(10)

1-25

- (a) Based on Figure 1-8, the value of 1.5% COHb is created by a 1 hr exposure at a concentration of about 40 ppm.
- (b) The value of 1.5% is off of the graph slightly, but is estimated to be about 8-9 ppm for an 8-hr exposure.