

CHAPTER TWO

$$2.1 \text{ (a)} \quad \frac{3 \text{ wk} \mid 7 \text{ d} \mid 24 \text{ h} \mid 3600 \text{ s} \mid 1000 \text{ ms}}{1 \text{ wk} \mid 1 \text{ d} \mid 1 \text{ h} \mid 1 \text{ s}} = \underline{\underline{1.8144 \times 10^9 \text{ ms}}}$$

$$(b) \quad \frac{38.1 \text{ ft/s} \mid 0.0006214 \text{ mi} \mid 3600 \text{ s}}{3.2808 \text{ ft} \mid 1 \text{ h}} = 25.98 \text{ mi/h} \Rightarrow \underline{\underline{26.0 \text{ mi/h}}}$$

$$(c) \quad \frac{554 \text{ m}^4 \mid 1 \text{ d} \mid 1 \text{ h} \mid 1 \text{ kg} \mid 10^8 \text{ cm}^4}{\text{d} \cdot \text{kg} \mid 24 \text{ h} \mid 60 \text{ min} \mid 1000 \text{ g} \mid 1 \text{ m}^4} = \underline{\underline{3.85 \times 10^4 \text{ cm}^4 / \text{min} \cdot \text{g}}}$$

$$2.2 \text{ (a)} \quad \frac{760 \text{ mi} \mid 1 \text{ m} \mid 1 \text{ h}}{\text{h} \mid 0.0006214 \text{ mi} \mid 3600 \text{ s}} = \underline{\underline{340 \text{ m/s}}}$$

$$(b) \quad \frac{921 \text{ kg} \mid 2.20462 \text{ lb}_m \mid 1 \text{ m}^3}{\text{m}^3 \mid 1 \text{ kg} \mid 35.3145 \text{ ft}^3} = \underline{\underline{57.5 \text{ lb}_m / \text{ft}^3}}$$

$$(c) \quad \frac{5.37 \times 10^3 \text{ kJ} \mid 1 \text{ min} \mid 1000 \text{ J} \mid 1.34 \times 10^{-3} \text{ hp}}{\text{min} \mid 60 \text{ s} \mid 1 \text{ kJ} \mid 1 \text{ J/s}} = 119.93 \text{ hp} \Rightarrow \underline{\underline{120 \text{ hp}}}$$

2.3 Assume that a golf ball occupies the space equivalent to a 2 in $\times$ 2 in $\times$ 2 in cube. For a classroom with dimensions 40 ft $\times$ 40 ft $\times$ 15 ft :

$$n_{\text{balls}} = \frac{40 \times 40 \times 15 \text{ ft}^3 \mid (12)^3 \text{ in}^3 \mid 1 \text{ ball}}{\text{ft}^3 \mid 2^3 \text{ in}^3} = 5.18 \times 10^6 \approx \underline{\underline{5 \text{ million balls}}}$$

The estimate could vary by an order of magnitude or more, depending on the assumptions made.

$$2.4 \quad \frac{4.3 \text{ light yr} \mid 365 \text{ d} \mid 24 \text{ h} \mid 3600 \text{ s} \mid 1.86 \times 10^5 \text{ mi} \mid 3.2808 \text{ ft} \mid 1 \text{ step}}{1 \text{ yr} \mid 1 \text{ d} \mid 1 \text{ h} \mid 1 \text{ s} \mid 0.0006214 \text{ mi} \mid 2 \text{ ft}} = \underline{\underline{7 \times 10^{16} \text{ steps}}}$$

2.5 Distance from the earth to the moon = 238857 miles

$$\frac{238857 \text{ mi} \mid 1 \text{ m} \mid 1 \text{ report}}{0.0006214 \text{ mi} \mid 0.001 \text{ m}} = \underline{\underline{4 \times 10^{11} \text{ reports}}}$$

2.6

$$\frac{19 \text{ km} \mid 1000 \text{ m} \mid 0.0006214 \text{ mi} \mid 1000 \text{ L}}{1 \text{ L} \mid 1 \text{ km} \mid 1 \text{ m} \mid 264.17 \text{ gal}} = 44.7 \text{ mi/gal}$$

Calculate the total cost to travel x miles.

$$\text{Total Cost}_{\text{American}} = \$14,500 + \frac{\$1.25 \mid 1 \text{ gal} \mid x \text{ (mi)}}{\text{gal} \mid 28 \text{ mi}} = 14,500 + 0.04464x$$

$$\text{Total Cost}_{\text{European}} = \$21,700 + \frac{\$1.25 \mid 1 \text{ gal} \mid x \text{ (mi)}}{\text{gal} \mid 44.7 \text{ mi}} = 21,700 + 0.02796x$$

$$\text{Equate the two costs} \Rightarrow x = \underline{\underline{4.3 \times 10^5 \text{ miles}}}$$

2.7

$$\begin{array}{c}
 \begin{array}{|c|c|c|c|c|c|c|}
 \hline
 5320 \text{ imp. gal} & 14 \text{ h} & 365 \text{ d} & 10^6 \text{ cm}^3 & 0.965 \text{ g} & 1 \text{ kg} & 1 \text{ tonne} \\
 \hline
 \text{plane} \cdot \text{h} & 1 \text{ d} & 1 \text{ yr} & 220.83 \text{ imp. gal} & 1 \text{ cm}^3 & 1000 \text{ g} & 1000 \text{ kg} \\
 \hline
 \end{array} \\
 = 1.188 \times 10^5 \frac{\text{tonne kerosene}}{\text{plane} \cdot \text{yr}} \\
 \begin{array}{|c|c|c|}
 \hline
 4.02 \times 10^9 \text{ tonne crude oil} & 1 \text{ tonne kerosene} & \text{plane} \cdot \text{yr} \\
 \hline
 \text{yr} & 7 \text{ tonne crude oil} & 1.188 \times 10^5 \text{ tonne kerosene} \\
 \hline
 \end{array} \\
 = 4834 \text{ planes} \Rightarrow \underline{\underline{5000 \text{ planes}}}
 \end{array}$$

2.8 (a) $\frac{25.0 \text{ lb}_m}{32.1714 \text{ ft} / \text{s}^2} \cdot \frac{1 \text{ lb}_f}{32.1714 \text{ lb}_m \cdot \text{ft} / \text{s}^2} = \underline{\underline{25.0 \text{ lb}_f}}$

(b) $\frac{25 \text{ N}}{9.8066 \text{ m} / \text{s}^2} \cdot \frac{1 \text{ kg} \cdot \text{m} / \text{s}^2}{1 \text{ N}} = 2.55 \text{ kg} \Rightarrow \underline{\underline{2.6 \text{ kg}}}$

(c) $\frac{10 \text{ ton}}{5 \times 10^{-4} \text{ ton}} \cdot \frac{1 \text{ lb}_m}{2.20462 \text{ lb}_m} \cdot \frac{1000 \text{ g}}{980.66 \text{ cm} / \text{s}^2} \cdot \frac{1 \text{ dyne}}{1 \text{ g} \cdot \text{cm} / \text{s}^2} = \underline{\underline{9 \times 10^9 \text{ dynes}}}$

2.9 $\frac{50 \times 15 \times 2 \text{ m}^3}{1 \text{ m}^3} \cdot \frac{35.3145 \text{ ft}^3}{1 \text{ ft}^3} \cdot \frac{85.3 \text{ lb}_m}{1 \text{ s}^2} \cdot \frac{32.174 \text{ ft}}{32.174 \text{ lb}_m / \text{ft} \cdot \text{s}^2} = \underline{\underline{4.5 \times 10^6 \text{ lb}_f}}$

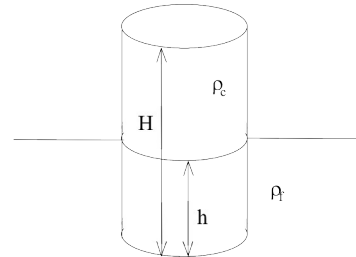
2.10 $\frac{500 \text{ lb}_m}{2.20462 \text{ lb}_m} \cdot \frac{1 \text{ kg}}{11.5 \text{ kg}} \cdot \frac{1 \text{ m}^3}{22.7 \text{ m}^3} \approx 5 \times 10^2 \text{ kg} \approx \underline{\underline{25 \text{ m}^3}}$

2.11 (a)

$$m_{\text{displaced fluid}} = m_{\text{cylinder}} \Rightarrow \rho_f V_f = \rho_c V_c \Rightarrow \rho_f h \pi r^2 = \rho_c H \pi r^2$$

$$\rho_c = \frac{\rho_f h}{H} = \frac{(30 \text{ cm} - 14.1 \text{ cm})(1.00 \text{ g} / \text{cm}^3)}{30 \text{ cm}} = \underline{\underline{0.53 \text{ g} / \text{cm}^3}}$$

(b) $\rho_f = \frac{\rho_c H}{h} = \frac{(30 \text{ cm})(0.53 \text{ g} / \text{cm}^3)}{(30 \text{ cm} - 20.7 \text{ cm})} = \underline{\underline{1.71 \text{ g} / \text{cm}^3}}$



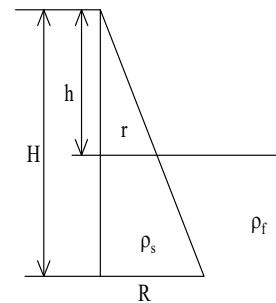
2.12

$$V_s = \frac{\pi R^2 H}{3}; V_f = \frac{\pi R^2 H}{3} - \frac{\pi r^2 h}{3}; \frac{R}{H} = \frac{r}{h} \Rightarrow r = \frac{R}{H} h$$

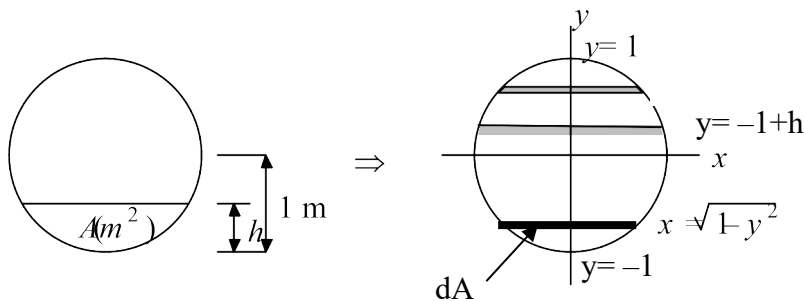
$$\Rightarrow V_f = \frac{\pi R^2 H}{3} - \frac{\pi h^3}{3} \frac{R^2}{H^2} = \frac{\pi R^2}{3} \left(H - \frac{h^3}{H^2} \right)$$

$$\rho_f V_f = \rho_s V_s \Rightarrow \rho_f \frac{\pi R^2}{3} \left(H - \frac{h^3}{H^2} \right) = \rho_s \frac{\pi R^2 H}{3}$$

$$\Rightarrow \rho_f = \rho_s \frac{H}{H - \frac{h^3}{H^2}} = \rho_s \frac{H^3}{H^3 - h^3} = \rho_s \frac{1}{1 - \frac{h^3}{H^3}}$$



2.13 Say $h(m)$ = depth of liquid



$$dA = dy \cdot \int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}} dx = 2\sqrt{1-y^2} dy$$

$$\Rightarrow A(h) = 2 \int_{-1}^{-1+h} \sqrt{1-y^2} dy$$

E Table of integrals or trigonometric substitution

$$A(h) = \left[y\sqrt{1-y^2} + \sin^{-1} y \right]_{-1}^{-1+h} = (-1+h)\sqrt{1-(-1+h)^2} + \sin^{-1}(-1+h) - \left(-1\sqrt{1-1} + \sin^{-1}(-1) \right) = (-1+h)\sqrt{1-(-1+h)^2} + \sin^{-1}(-1+h) + \frac{\pi}{2}$$

$$W(h) = \frac{4 \text{ m} \times A(h)}{g/g_0} = \frac{4 \text{ m} \times A(h)}{0.879 \text{ g/cm}^3 \times 1 \text{ m}^3 \times 10^3 \text{ g/kg} \times 9.81 \text{ N/kg}} = 3.45 \times 10^4 A$$

E Substitute for A

$$W(h) = 3.45 \times 10^4 \left[(-1+h)\sqrt{1-(-1+h)^2} + \sin^{-1}(-1+h) + \frac{\pi}{2} \right]$$

$$1 \text{ lb}_f = 1 \text{ slug} \cdot \text{ft} / \text{s}^2 = 32.174 \text{ lb}_m \cdot \text{ft} / \text{s}^2 \Rightarrow 1 \text{ slug} = 32.174 \text{ lb}_m$$

2.14 $1 \text{ poundal} = 1 \text{ lb}_m \cdot \text{ft} / \text{s}^2 = \frac{1}{32.174} \text{ lb}_f$

2.14(cont'd)

(a) (i) On the earth:

$$M = \frac{175 \text{ lb}_m}{32.174 \text{ lb}_m} = 5.44 \text{ slugs}$$

$$W = \frac{175 \text{ lb}_m}{\text{s}^2} \times \frac{32.174 \text{ ft}}{1 \text{ lb}_m \cdot \text{ft} / \text{s}^2} = 5.63 \times 10^3 \text{ poundals}$$

(ii) On the moon

$$M = \frac{175 \text{ lb}_m}{32.174 \text{ lb}_m} \left| \frac{1 \text{ slug}}{32.174 \text{ lb}_m} \right| = \underline{\underline{5.44 \text{ slugs}}}$$

$$W = \frac{175 \text{ lb}_m}{6 \text{ s}^2} \left| \frac{32.174 \text{ ft}}{1 \text{ lb}_m \cdot \text{ft} / \text{s}^2} \right| = \underline{\underline{938 \text{ poundals}}}$$

$$\text{(b)} \quad F = ma \Rightarrow a = F / m = \frac{355 \text{ poundals}}{25.0 \text{ slugs}} \left| \frac{1 \text{ lb}_m \cdot \text{ft} / \text{s}^2}{1 \text{ poundal}} \right| \left| \frac{1 \text{ slug}}{32.174 \text{ lb}_m} \right| \left| \frac{1 \text{ m}}{3.2808 \text{ ft}} \right|$$

$$= \underline{\underline{0.135 \text{ m} / \text{s}^2}}$$

$$\text{2.15 (a)} \quad F = ma \Rightarrow 1 \text{ fern} = (1 \text{ bung})(32.174 \text{ ft} / \text{s}^2) \left(\frac{1 \text{ lb}_m \cdot \text{ft} / \text{s}^2}{1 \text{ poundal}} \right) \left(\frac{1 \text{ slug}}{32.174 \text{ lb}_m} \right) \left(\frac{1 \text{ m}}{3.2808 \text{ ft}} \right) = \underline{\underline{5.3623 \text{ bung} \cdot \text{ft} / \text{s}^2}}$$

$$\Rightarrow \frac{1 \text{ fern}}{5.3623 \text{ bung} \cdot \text{ft} / \text{s}^2}$$

$$\text{(b)} \quad \text{On the moon: } W = \frac{3 \text{ bung}}{6 \text{ s}^2} \left| \frac{32.174 \text{ ft}}{1 \text{ lb}_m \cdot \text{ft} / \text{s}^2} \right| \left| \frac{1 \text{ fern}}{5.3623 \text{ bung} \cdot \text{ft} / \text{s}^2} \right| = \underline{\underline{3 \text{ fern}}}$$

$$\text{On the earth: } W = (3)(32.174) / 5.3623 = \underline{\underline{18 \text{ fern}}}$$

$$\text{2.16 (a)} \quad \approx (3)(9) = \underline{\underline{27}} \quad \text{(b)} \quad \approx \frac{4.0 \times 10^{-4}}{40} \approx \underline{\underline{1 \times 10^{-5}}}$$

$$(2.7)(8.632) = \underline{\underline{23}} \quad (3.600 \times 10^{-4}) / 45 = \underline{\underline{8.0 \times 10^{-6}}}$$

$$\text{(c)} \quad \approx 2 + 125 = \underline{\underline{127}} \quad \text{(d)} \quad \approx 50 \times 10^3 - 1 \times 10^3 \approx 49 \times 10^3 \approx \underline{\underline{5 \times 10^4}}$$

$$2.365 + 125.2 = \underline{\underline{127.5}} \quad 4.753 \times 10^4 - 9 \times 10^2 = \underline{\underline{5 \times 10^4}}$$

$$\text{2.17} \quad R \approx \frac{(7 \times 10^{-1})(3 \times 10^5)(6)(5 \times 10^4)}{(3)(5 \times 10^6)} \approx 42 \times 10^2 \approx \underline{\underline{4 \times 10^3}} \quad (\text{Any digit in range 2-6 is acceptable})$$

$$R_{\text{exact}} = 3812.5 \Rightarrow \underline{\underline{3810}} \Rightarrow \underline{\underline{3.81 \times 10^3}}$$

2.18 (a)

$$\text{A: } R = 73.1 - 72.4 = \underline{\underline{0.7^\circ \text{C}}}$$

$$\bar{X} = \frac{72.4 + 73.1 + 72.6 + 72.8 + 73.0}{5} = \underline{\underline{72.8^\circ \text{C}}}$$

$$s = \sqrt{\frac{(72.4 - 72.8)^2 + (73.1 - 72.8)^2 + (72.6 - 72.8)^2 + (72.8 - 72.8)^2 + (73.0 - 72.8)^2}{5 - 1}}$$

$$= \underline{\underline{0.3^\circ \text{C}}}$$

$$B: R = 103.1 - 97.3 = \underline{5.8^{\circ}\text{C}}$$

$$\bar{X} = \frac{97.3 + 101.4 + 98.7 + 103.1 + 100.4}{5} = \underline{100.2^{\circ}\text{C}}$$

$$s = \sqrt{\frac{(97.3 - 100.2)^2 + (101.4 - 100.2)^2 + (98.7 - 100.2)^2 + (103.1 - 100.2)^2 + (100.4 - 100.2)^2}{5 - 1}} \\ = \underline{2.3^{\circ}\text{C}}$$

(b) Thermocouple B exhibits a higher degree of scatter and is also more accurate.

$$2.19 \text{ (a)} \quad \bar{X} = \frac{\sum_{i=1}^{12} X_i}{12} = 73.5 \quad s = \sqrt{\frac{\sum_{i=1}^{12} (X - 73.5)^2}{12 - 1}} = 1.2$$

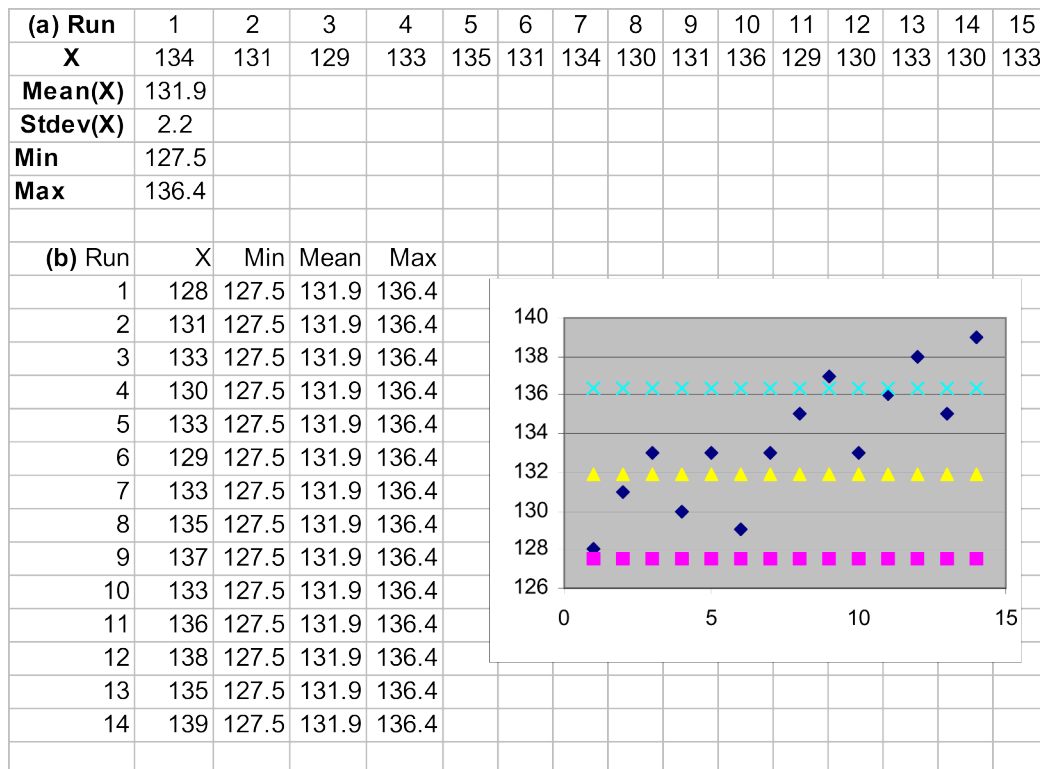
$$C_{\min} = \bar{X} - 2s = 73.5 - 2(1.2) = \underline{71.1}$$

$$C_{\max} = \bar{X} + 2s = 73.5 + 2(1.2) = \underline{75.9}$$

(b) Joanne is more likely to be the statistician, because she wants to make the control limits stricter.

(c) Inadequate cleaning between batches, impurities in raw materials, variations in reactor temperature (failure of reactor control system), problems with the color measurement system, operator carelessness

2.20 (a),(b)



(c) Beginning with Run 11, the process has been near or well over the upper quality assurance limit. An overhaul would have been reasonable after Run 12.

$$2.21 \text{ (a)} \quad Q' = \frac{2.36 \times 10^{-4} \text{ kg} \cdot \text{m}^2}{\text{h}} \left| \frac{2.10462 \text{ lb}}{\text{kg}} \right| \left| \frac{3.2808^2 \text{ ft}^2}{\text{m}^2} \right| \left| \frac{1 \text{ h}}{3600 \text{ s}} \right|$$

$$(b) \quad Q'_{\text{approximate}} \approx \frac{(2 \times 10^{-4})(2)(9)}{3 \times 10^3} \approx 12 \times 10^{(-4-3)} \approx \underline{1.2 \times 10^{-6} \text{ lb} \cdot \text{ft}^2 / \text{s}}$$

$$Q'_{\text{exact}} = \underline{1.48 \times 10^{-6} \text{ lb} \cdot \text{ft}^2 / \text{s}} = \underline{0.00000148 \text{ lb} \cdot \text{ft}^2 / \text{s}}$$

$$2.22 \quad N_{\text{Pr}} = \frac{C_p \mu}{k} = \frac{0.583 \text{ J} / \text{g} \cdot ^\circ \text{C}}{0.286 \text{ W} / \text{m} \cdot ^\circ \text{C}} \left| \frac{1936 \text{ lb}_m}{\text{ft} \cdot \text{h}} \right| \left| \frac{1 \text{ h}}{3600 \text{ s}} \right| \left| \frac{3.2808 \text{ ft}}{\text{m}} \right| \left| \frac{1000 \text{ g}}{2.20462 \text{ lb}_m} \right|$$

$$N_{\text{Pr}} \approx \frac{(6 \times 10^{-1})(2 \times 10^3)(3 \times 10^3)}{(3 \times 10^{-1})(4 \times 10^3)(2)} \approx \frac{3 \times 10^3}{2} \approx \underline{1.5 \times 10^3}. \text{ The calculator solution is } \underline{1.63 \times 10^3}$$

2.23

$$\text{Re} = \frac{D u \rho}{\mu} = \frac{0.48 \text{ ft}}{\text{s}} \left| \frac{1 \text{ m}}{3.2808 \text{ ft}} \right| \left| \frac{2.067 \text{ in}}{0.43 \times 10^{-3} \text{ kg} / \text{m} \cdot \text{s}} \right| \left| \frac{1 \text{ m}}{39.37 \text{ in}} \right| \left| \frac{0.805 \text{ g}}{\text{cm}^3} \right| \left| \frac{1 \text{ kg}}{1000 \text{ g}} \right| \left| \frac{10^6 \text{ cm}^3}{1 \text{ m}^3} \right|$$

$$\text{Re} \approx \frac{(5 \times 10^{-1})(2)(8 \times 10^{-1})(10^6)}{(3)(4 \times 10)(10^3)(4 \times 10^{-4})} \approx \frac{5 \times 10^{1-(-3)}}{3} \approx 2 \times 10^4 \Rightarrow \underline{\text{the flow is turbulent}}$$

2.24

$$\frac{k_g d_p y}{D} = 2.00 + 0.600 \left(\frac{D}{k_g d_p} \right)^{1/3} \left(\frac{\mu}{u \rho} \right)^{1/2}$$

$$(a) = 2.00 + 0.600 \left(\frac{1.00 \times 10^{-5} \text{ N} \cdot \text{s} / \text{m}^2}{(100 \text{ kg} / \text{m}^3)(1.00 \times 10^{-5} \text{ m}^2 / \text{s})} \right)^{1/3} \left(\frac{(0.00500 \text{ m})(10.0 \text{ m} / \text{s})(1.00 \text{ kg} / \text{m}^3)}{(1.00 \times 10^{-5} \text{ N} \cdot \text{s} / \text{m}^2)} \right)^{1/2}$$

$$= 44.426 \Rightarrow \frac{k_g (0.00500 \text{ m})(0.100)}{1.00 \times 10^{-5} \text{ m}^2 / \text{s}} = 44.426 \Rightarrow k_g = \underline{0.888 \text{ m} / \text{s}}$$

(b) The diameter of the particles is not uniform, the conditions of the system used to model the equation may differ significantly from the conditions in the reactor (out of the range of empirical data), all of the other variables are subject to measurement or estimation error.

(c)

$d_p \text{ (m)}$	y	$D \text{ (m}^2/\text{s)}$	$\mu \text{ (N} \cdot \text{s/m}^2)$	$\rho \text{ (kg/m}^3)$	$u \text{ (m/s)}$	k_g
0.005	0.1	1.00E-05	1.00E-05	1	10	0.889
0.010	0.1	1.00E-05	1.00E-05	1	10	0.620
0.005	0.1	2.00E-05	1.00E-05	1	10	1.427
0.005	0.1	1.00E-05	2.00E-05	1	10	0.796
0.005	0.1	1.00E-05	1.00E-05	1	20	1.240

$$2.25 \text{ (a)} \quad \underline{200 \text{ crystals} / \text{min} \cdot \text{mm}}; \underline{10 \text{ crystals} / \text{min} \cdot \text{mm}^2}$$

$$(b) \quad r = \frac{200 \text{ crystals}}{\text{min} \cdot \text{mm}} \left| \frac{0.050 \text{ in}}{\text{in}} \right| \left| \frac{25.4 \text{ mm}}{\text{in}} \right| - \frac{10 \text{ crystals}}{\text{min} \cdot \text{mm}^2} \left| \frac{0.050^2 \text{ in}^2}{\text{in}^2} \right| \left| \frac{(25.4)^2 \text{ mm}^2}{\text{in}^2} \right|$$

$$= 238 \text{ crystals} / \text{min} \Rightarrow \frac{238 \text{ crystals}}{\text{min}} \left| \frac{1 \text{ min}}{60 \text{ s}} \right| = \underline{4.0 \text{ crystals} / \text{s}}$$

$$(c) \quad D_{\text{nm}} \frac{D' \text{ ft}}{1 \text{ in}} \frac{25.4 \text{ mm}}{1 \text{ in}} = 25.4 D'; \quad r_{\text{min}} \frac{\text{crystals}}{s} \frac{60 \text{ s}}{1 \text{ min}} = 60 r' \\ \Rightarrow 60 r' = 200 \text{ crystals} \Rightarrow r' = 84.7 D' - 108 \text{ crystals}$$

2.26 (a) $\underline{70.5 \text{ lb}_m / \text{ft}^3}; \underline{8.27 \times 10^{-7} \text{ in}^2 / \text{lb}_f}$

$$(b) \quad \rho = (70.5 \text{ lb}_m / \text{ft}^3) \exp \left[\frac{8.27 \times 10^{-7} \text{ in}^2}{\text{lb}_f} \left| \frac{9 \times 10^6 \text{ N}}{\text{m}^2} \right| \frac{14.696 \text{ lb}_f / \text{in}^2}{1.01325 \times 10^5 \text{ N/m}^2} \right] \\ = \frac{70.57 \text{ lb}_m}{\text{ft}^3} \left| \frac{35.3145 \text{ ft}^3}{\text{m}^3} \right| \frac{1 \text{ m}^3}{10^6 \text{ cm}^3} \left| \frac{1000 \text{ g}}{2.20462 \text{ lb}_m} \right| = \underline{1.13 \text{ g/cm}^3} \\ (c) \quad \rho \frac{\text{lb}_m}{\text{ft}^3} = \rho' \frac{\text{g}}{\text{cm}^3} \left| \frac{1 \text{ lb}_m}{453.593 \text{ g}} \right| \frac{28,317 \text{ cm}^3}{1 \text{ ft}^3} = 62.43 \rho' \\ P \frac{\text{lb}_f}{\text{in}^2} = P' \frac{\text{N}}{\text{m}^2} \left| \frac{0.2248 \text{ lb}_f}{1 \text{ N}} \right| \frac{1^2 \text{ m}^2}{39.37^2 \text{ in}^2} = 1.45 \times 10^{-4} P' \\ \Rightarrow 62.43 \rho' = 70.5 \exp \left[8.27 \times 10^{-7} \text{ in}^2 \left| \frac{1.45 \times 10^{-4} P'}{1 \text{ N}} \right| \right] \Rightarrow \rho' = 1.13 \exp \left[1.20 \times 10^{-10} P' \right] \\ P' = 9.00 \times 10^6 \text{ N} / \text{m}^2 \Rightarrow \rho' = 1.13 \exp \left[(1.20 \times 10^{-10})(9.00 \times 10^6) \right] = \underline{1.13 \text{ g/cm}^3}$$

2.27 (a) $V_{\text{cm}^3} = \frac{V' \text{ ft}^3}{1728 \text{ in}^3} = 16.39 V'; \quad t_{\text{sec}} = 3600 t' \text{ h} \\ \Rightarrow 16.39 V' = \exp(3600 t') \Rightarrow V' = 0.06102 \exp(3600 t') \text{ h}$

(b) The t in the exponent has a coefficient of s⁻¹.

2.28 (a) $\underline{3.00 \text{ mol} / \text{L}}, \underline{2.00 \text{ min}^{-1}}$

(b) $t = 0 \Rightarrow C = 3.00 \exp[(-2.00)(0)] = 3.00 \text{ mol} / \text{L} \\ t = 1 \Rightarrow C = 3.00 \exp[(-2.00)(1)] = 0.406 \text{ mol} / \text{L}$

For t=0.6 min: $C_{\text{int}} = \frac{0.406 - 3.00}{1 - 0} (0.6 - 0) + 3.00 = \underline{1.4 \text{ mol} / \text{L}}$

$$C_{\text{exact}} = 3.00 \exp[(-2.00)(0.6)] = \underline{0.9 \text{ mol} / \text{L}}$$

$$t_{\text{int}} = \frac{1 - 0}{0.406 - 3} (0.10 - 3.00) + 0 = \underline{1.12 \text{ min}}$$

For C=0.10 mol/L:

$$t_{\text{exact}} = -\frac{1}{2.00} \ln \frac{C}{3.00} = -\frac{1}{2} \ln \frac{0.10}{3.00} = \underline{1.70 \text{ min}}$$

(c)

$$\ln y = \ln a + bx \Rightarrow y = ae^{bx}$$

$$\mathbf{2.30 (b)} \quad b = (\ln y_2 - \ln y_1) / (x_2 - x_1) = (\ln 2 - \ln 1) / (1 - 2) = -0.693$$

$$\ln a = \ln y - bx = \ln 2 + 0.693(1) \Rightarrow a = 4.00 \Rightarrow \underline{\underline{y = 4.00e^{-0.693x}}}$$

$$\ln y = \ln a + b \ln x \Rightarrow y = ax^b$$

$$\mathbf{(c)} \quad b = (\ln y_2 - \ln y_1) / (\ln x_2 - \ln x_1) = (\ln 2 - \ln 1) / (\ln 1 - \ln 2) = -1$$

$$\ln a = \ln y - b \ln x = \ln 2 - (-1) \ln(1) \Rightarrow a = 2 \Rightarrow \underline{\underline{y = 2 / x}}$$

$$\ln(xy) = \ln a + b(y/x) \Rightarrow xy = ae^{by/x} \Rightarrow y = (a/x)e^{by/x} \quad [\text{can't get } y = f(x)]$$

$$\mathbf{(d)} \quad b = [\ln(xy)_2 - \ln(xy)_1] / [(y/x)_2 - (y/x)_1] = (\ln 807.0 - \ln 40.2) / (2.0 - 1.0) = 3$$

$$\ln a = \ln(xy) - b(y/x) = \ln 807.0 - 3 \ln(2.0) \Rightarrow a = 2 \Rightarrow xy = 2e^{3y/x} \Rightarrow \underline{\underline{y = (2/x)e^{3y/x}}}$$

$$\ln(y^2/x) = \ln a + b \ln(x-2) \Rightarrow y^2/x = a(x-2)^b \Rightarrow y = [ax(x-2)^b]^{1/2}$$

$$b = [\ln(y^2/x)_2 - \ln(y^2/x)_1] / [\ln(x-2)_2 - \ln(x-2)_1]$$

$$\mathbf{(e)} \quad = (\ln 807.0 - \ln 40.2) / (\ln 2.0 - \ln 1.0) = 4.33$$

$$\ln a = \ln(y^2/x) - b \ln(x-2) = \ln 807.0 - 4.33 \ln(2.0) \Rightarrow a = 40.2$$

$$\Rightarrow y^2/x = 40.2(x-2)^{4.33} \Rightarrow \underline{\underline{y = 6.34x^{1/2}(x-2)^{2.165}}}$$

$$\mathbf{2.31 (b)} \quad \underline{\underline{\text{Plot } y^2 \text{ vs. } x^3 \text{ on rectangular axes. Slope} = m, \text{Intcpt} = -n}}$$

$$\mathbf{(c)} \quad \frac{1}{\ln(y-3)} = \frac{1}{b} + \frac{a}{b}\sqrt{x} \Rightarrow \underline{\underline{\text{Plot } \frac{1}{\ln(y-3)} \text{ vs. } \sqrt{x} \text{ [rect. axes], slope} = \frac{a}{b}, \text{intercept} = \frac{1}{b}}}}$$

$$\mathbf{(d)} \quad \frac{1}{(y+1)^2} = a(x-3)^3 \Rightarrow \underline{\underline{\text{Plot } \frac{1}{(y+1)^2} \text{ vs. } (x-3)^3 \text{ [rect. axes], slope} = a, \text{intercept} = 0}}}$$

OR

2.31 (cont'd)

$$2 \ln(y+1) = -\ln a - 3 \ln(x-3)$$

$$\underline{\underline{\text{Plot } \ln(y+1) \text{ vs. } \ln(x-3) \text{ [rect.]} \text{ or } (y+1) \text{ vs. } (x-3) \text{ [log]}}}}$$

$$\Rightarrow \text{slope} = -\frac{3}{2}, \text{intercept} = -\frac{\ln a}{2}$$

$$\mathbf{(e)} \quad \ln y = a\sqrt{x} + b$$

$$\underline{\underline{\text{Plot } \ln y \text{ vs. } \sqrt{x} \text{ [rect.]} \text{ or } y \text{ vs. } \sqrt{x} \text{ [semilog]}, \text{slope} = a, \text{intercept} = b}}}$$

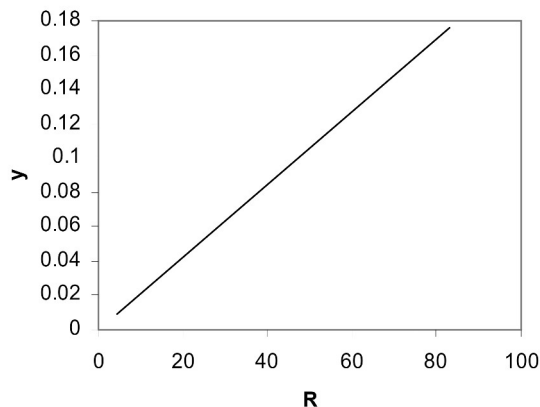
$$\mathbf{(f)} \quad \log_{10}(xy) = a(x^2 + y^2) + b$$

$$\underline{\underline{\text{Plot } \log_{10}(xy) \text{ vs. } (x^2 + y^2) \text{ [rect.]} \Rightarrow \text{slope} = a, \text{intercept} = b}}}$$

(g) $\frac{1}{y} = ax + \frac{b}{x} \Rightarrow \frac{x}{y} = ax^2 + b \Rightarrow \text{Plot } \frac{x}{y} \text{ vs. } x^2 \text{ [rect.], slope} = a, \text{ intercept} = b$

OR $\frac{1}{y} = ax + \frac{b}{x} \Rightarrow \frac{1}{xy} = a + \frac{b}{x^2} \Rightarrow \text{Plot } \frac{1}{xy} \text{ vs. } \frac{1}{x^2} \text{ [rect.], slope} = b, \text{ intercept} = a$

2.32 (a) A plot of y vs. R is a line through $(R = 5, y = 0.011)$ and $(R = 80, y = 0.169)$.



$$y = aR + b \quad a = \frac{0.169 - 0.011}{80 - 5} = 2.11 \times 10^{-3} \quad b = 0.011 - 2.11 \times 10^{-3} \times 5 = 4.50 \times 10^{-4} \Rightarrow y = 2.11 \times 10^{-3} R + 4.50 \times 10^{-4}$$

(b) $R = 43 \Rightarrow y = 2.11 \times 10^{-3} \times 43 + 4.50 \times 10^{-4} = 0.092 \text{ kg H}_2\text{O/kg}$

$1200 \text{ kg/h} \times 0.092 \text{ kg H}_2\text{O/kg} = 110 \text{ kg H}_2\text{O/h}$

$\ln T = \ln a + b \ln \phi \Rightarrow T = a\phi^b$

2.33 (a) $b = (\ln T_2 - \ln T_1) / (\ln \phi_2 - \ln \phi_1) = (\ln 120 - \ln 210) / (\ln 40 - \ln 25) = -1.19$

$\ln a = \ln T - b \ln \phi = \ln 210 - (-1.19) \ln(25) \Rightarrow a = 9677.6 \Rightarrow T = 9677.6 \phi^{-1.19}$

$T = 9677.6 \phi^{-1.19} \Rightarrow \phi = 9677.6 / T^{0.403}$

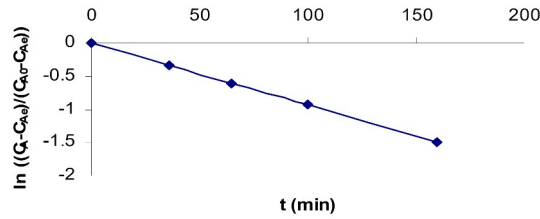
$T = 85^\circ \text{C} \Rightarrow \phi = 9677.6 / 85^{0.403} = 53.5 \text{ L/s}$

(b) $T = 175^\circ \text{C} \Rightarrow \phi = 9677.6 / 175^{0.403} = 29.1 \text{ L/s}$

$T = 290^\circ \text{C} \Rightarrow \phi = 9677.6 / 290^{0.403} = 19.0 \text{ L/s}$

(c) The estimate for $T=175^\circ\text{C}$ is probably closest to the real value, because the value of temperature is in the range of the data originally taken to fit the line. The value of $T=290^\circ\text{C}$ is probably the least likely to be correct, because it is farthest away from the date range.

- 2.34 (a)** Yes, because when $\ln[(C_A - C_{Ae}) / (C_{A0} - C_{Ae})]$ is plotted vs. t in rectangular coordinates, the plot is a straight line.



$$\text{Slope} = -0.0093 \Rightarrow k = 9.3 \times 10^{-3} \text{ min}^{-1}$$

$$\ln[(C_A - C_{Ae}) / (C_{A0} - C_{Ae})] = -kt \Rightarrow C_A = (C_{A0} - C_{Ae})e^{-kt} + C_{Ae}$$

$$C_A = (0.1823 - 0.0495)e^{-(9.3 \times 10^{-3})(120)} + 0.0495 = 9.300 \times 10^{-2} \text{ g/L}$$

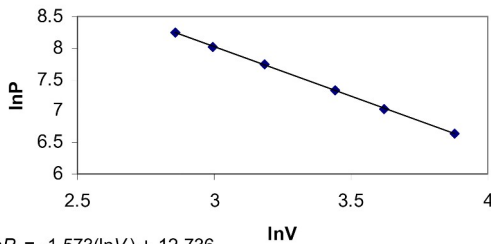
(b) $C = m/V \Rightarrow m = CV = \frac{9.300 \times 10^{-2} \text{ g}}{\text{L}} \left| \frac{30.5 \text{ gal}}{\text{L}} \right| \frac{28.317 \text{ L}}{7.4805 \text{ gal}} = \underline{\underline{10.7 \text{ g}}}$

- 2.35 (a)** ft^3 and h^{-2} , respectively

- (b)** $\ln(V)$ vs. t^2 in rectangular coordinates, slope=2 and intercept= $\ln(3.53 \times 10^{-2})$; or V (logarithmic axis) vs. t^2 in semilog coordinates, slope=2, intercept= 3.53×10^{-2}

(c) $\underline{\underline{V(\text{m}^3) = 1.00 \times 10^{-3} \exp(1.5 \times 10^{-7} t^2)}}$

2.36 $PV^k = C \Rightarrow P = C/V^k \Rightarrow \ln P = \ln C - k \ln V$

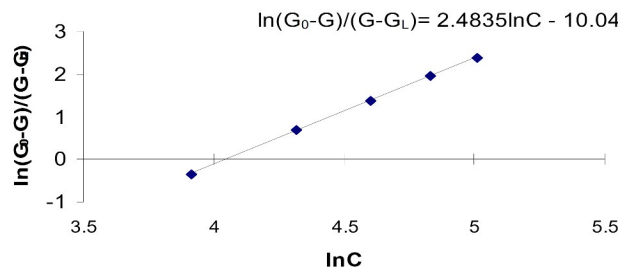


$$\ln P = -1.573(\ln V) + 12.736$$

$$k = -\text{slope} = -(-1.573) = \underline{\underline{1.573}} \text{ (dimensionless)}$$

$$\text{Intercept} = \ln C = 12.736 \Rightarrow C = e^{12.736} = \underline{\underline{3.40 \times 10^5 \text{ mm Hg} \cdot \text{cm}^{4.719}}}$$

2.37 (a) $\frac{G - G_L}{G_0 - G} = \frac{1}{K_L C^m} \Rightarrow \frac{G_0 - G}{G - G_L} = K_L C^m \Rightarrow \ln \frac{G_0 - G}{G - G_L} = \ln K_L + m \ln C$



2.37 (cont'd)

$$m = \text{slope} = \underline{2.483} \text{ (dimensionless)}$$

$$\text{Intercept} = \ln K_L = -10.045 \Rightarrow K_L = \underline{4.340 \times 10^{-5} \text{ ppm}^{-2.483}}$$

$$(b) C = 475 \Rightarrow \frac{G - 1.80 \times 10^{-3}}{3.00 \times 10^{-3} - G} = 4.340 \times 10^{-5} (475)^{2.483} \Rightarrow G = \underline{1.806 \times 10^{-3}}$$

$C=475$ ppm is well beyond the range of the data.

2.38 (a) For runs 2, 3 and 4:

$$Z = a \dot{V}^b p^c \Rightarrow \ln Z = \ln a + b \ln \dot{V} + c \ln p$$

$$\ln(3.5) = \ln a + b \ln(1.02) + c \ln(9.1)$$

$$\ln(2.58) = \ln a + b \ln(1.02) + c \ln(11.2)$$

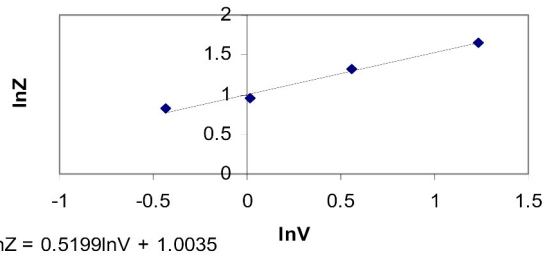
$$\ln(3.72) = \ln a + b \ln(1.75) + c \ln(11.2)$$

$$b = \underline{0.68}$$

$$\Rightarrow c = \underline{-1.46}$$

$$a = \underline{86.7 \text{ volts} \cdot \text{kPa}^{1.46} / (\text{L} / \text{s})^{0.678}}$$

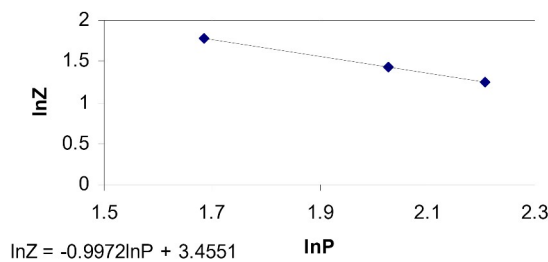
(b) When P is constant (runs 1 to 4), plot $\ln Z$ vs. $\ln \dot{V}$. Slope= b , Intercept= $\ln a + c \ln p$



$$b = \text{slope} = \underline{0.52}$$

$$\text{Intercept} = \ln a + c \ln P = 1.0035$$

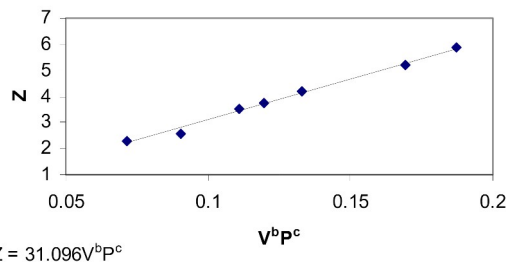
When $\dot{V}$ is constant (runs 5 to 7), plot $\ln Z$ vs. $\ln P$. Slope= c , Intercept= $\ln a + b \ln \dot{V}$



$$c = \text{slope} = -0.997 \Rightarrow \underline{1.0}$$

$$\text{Intercept} = \ln a + b \ln \dot{V} = 3.4551$$

Plot Z vs $\dot{V}^b P^c$. Slope= a (no intercept)



$$a = \text{slope} = \underline{31.1 \text{ volt} \cdot \text{kPa} / (\text{L} / \text{s})^{.52}}$$

The results in part (b) are more reliable, because more data were used to obtain them.

2.39 (a)

$$s_{xy} = \frac{1}{n} \sum_{i=1}^n x_i y_i = [(0.4)(0.3) + (2.1)(1.9) + (3.1)(3.2)] / 3 = 4.677$$

$$s_{xx} = \frac{1}{n} \sum_{i=1}^n x_i^2 = (0.3^2 + 1.9^2 + 3.2^2) / 3 = 4.647$$

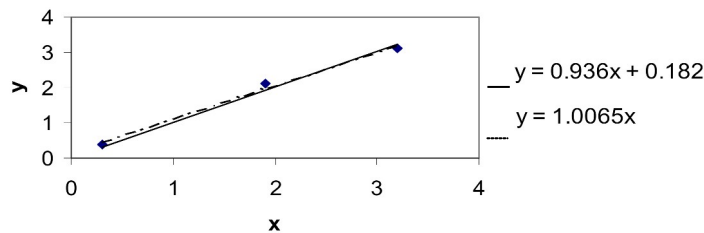
$$s_x = \frac{1}{n} \sum_{i=1}^n x_i = (0.3 + 1.9 + 3.2) / 3 = 1.8; \quad s_y = \frac{1}{n} \sum_{i=1}^n y_i = (0.4 + 2.1 + 3.1) / 3 = 1.867$$

$$a = \frac{s_{xy} - s_x s_y}{s_{xx} - s_x^2} = \frac{4.677 - (1.8)(1.867)}{4.647 - (1.8)^2} = 0.936$$

$$b = \frac{s_{xx} s_y - s_{xy} s_x}{s_{xx} - s_x^2} = \frac{(4.647)(1.867) - (4.677)(1.8)}{4.647 - (1.8)^2} = 0.182$$

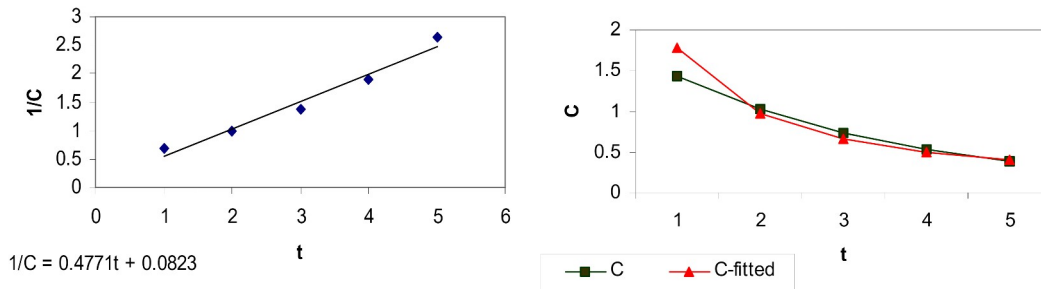
$$y = 0.936x + 0.182$$

(b) $a = \frac{s_{xy}}{s_{xx}} = \frac{4.677}{4.647} = 1.0065 \Rightarrow y = 1.0065x$



2.40 (a) 1/C vs. t. Slope=b, intercept=a

(b) $b = \text{slope} = 0.477 \text{ L} / \text{g} \cdot \text{h}; \quad a = \text{Intercept} = 0.082 \text{ L} / \text{g}$



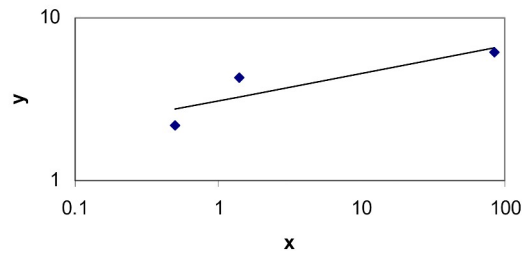
$$C = 1 / (a + bt) \Rightarrow 1 / [0.082 + 0.477(0)] = 12.2 \text{ g} / \text{L}$$

(c) $t = (1 / C - a) / b = (1 / 0.01 - 0.082) / 0.477 = 209.5 \text{ h}$

(d) $t=0$ and $C=0.01$ are out of the range of the experimental data.

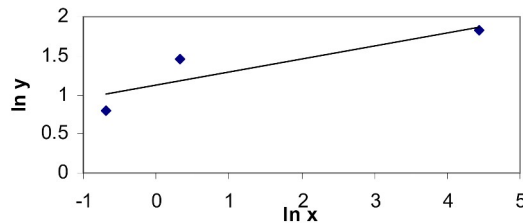
(e) The concentration of the hazardous substance could be enough to cause damage to the biotic resources in the river; the treatment requires an extremely large period of time; some of the hazardous substances might remain in the tank instead of being converted; the decomposition products might not be harmless.

2.41 (a) and (c)



(b) $y = ax^b \Rightarrow \ln y = \ln a + b \ln x$; Slope = b , Intercept = $\ln a$

$$\ln y = 0.1684 \ln x + 1.1258$$

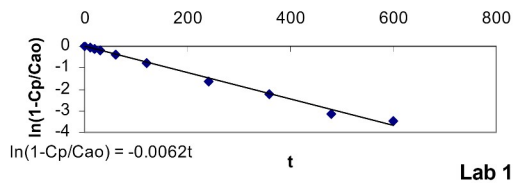


$$b = \text{slope} = \underline{\underline{0.168}}$$

$$\text{Intercept} = \ln a = 1.1258 \Rightarrow a = \underline{\underline{3.08}}$$

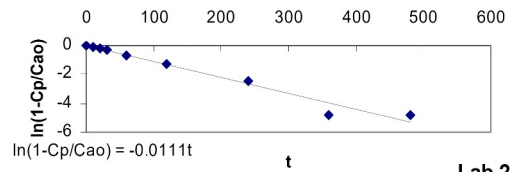
2.42 (a) $\ln(1-C_p/C_{A0})$ vs. t in rectangular coordinates. Slope = $-k$, intercept = 0

(b)



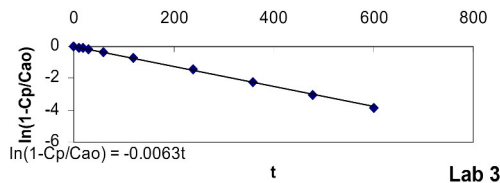
Lab 1

$$k = \underline{\underline{0.0062 \text{ s}^{-1}}}$$



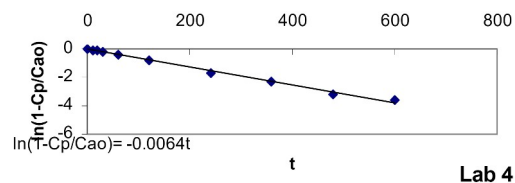
Lab 2

$$k = \underline{\underline{0.0111 \text{ s}^{-1}}}$$



Lab 3

$$k = \underline{\underline{0.0063 \text{ s}^{-1}}}$$



Lab 4

$$k = \underline{\underline{0.0064 \text{ s}^{-1}}}$$

(c) Disregarding the value of k that is very different from the other three, k is estimated with the average of the calculated k 's. $k = \underline{\underline{0.0063 \text{ s}^{-1}}}$

(d) Errors in measurement of concentration, poor temperature control, errors in time measurements, delays in taking the samples, impure reactants, impurities acting as

catalysts, inadequate mixing, poor sample handling, clerical errors in the reports, dirty reactor.

$$2.43 \quad y_i = ax_i \Rightarrow \phi(a) = \sum_{i=1}^n d_i^2 = \sum_{i=1}^n (y_i - ax_i)^2 \Rightarrow \frac{d\phi}{da} = 0 = \sum_{i=1}^n 2(y_i - ax_i)(-x_i) \Rightarrow \sum_{i=1}^n y_i x_i - a \sum_{i=1}^n x_i^2 = 0$$

$$\Rightarrow a = \frac{\sum_{i=1}^n y_i x_i}{\sum_{i=1}^n x_i^2}$$

```

2.44      DIMENSION X(100), Y(100)
          READ (5, 1) N
C      N = NUMBER OF DATA POINTS
          1FORMAT (I10)
          READ (5, 2) (X(J), Y(J), J = 1, N
          2FORMAT (8F 10.2)
          SX = 0.0
          SY = 0.0
          SXX = 0.0
          SXY = 0.0
          DO 100J = 1, N
            SX = SX + X(J)
            SY = SY + Y(J)
            SXX = SXX + X(J) ** 2
            100SXY = SXY + X(J) * Y(J)
          AN = N
          SX = SX/AN
          SY = SY/AN
          SXX = SXX/AN
          SXY = SXY/AN
          CALCULATE SLOPE AND INTERCEPT
          A = (SXY - SX * SY)/(SXX - SX ** 2)
          B = SY - A * SX
          WRITE (6, 3)
          3FORMAT (1H1, 20X 'PROBLEM 2-39'/)
          WRITE (6, 4) A, B
          4FORMAT (1H0, 'SLOPEb -- bAb =', F6.3, 3X 'INTERCEPTb -- b8b =', F7.3/)
C      CALCULATE FITTED VALUES OF Y, AND SUM OF SQUARES OF
          RESIDUALS
          SSQ = 0.0
          DO 200J = 1, N
            YC = A * X(J) + B
            RES = Y(J) - YC
            WRITE (6, 5) X(J), Y(J), YC, RES
            5FORMAT (3X 'Xb =', F5.2, 5X 'Yb =', F7.2, 5X 'Y(FITTED)b =', F7.2, 5X
              * 'RESIDUALb =', F6.3)
            200SSQ = SSQ + RES ** 2
          WRITE (6, 6) SSQ
          6FORMAT (1H0, 'SUM OF SQUARES OF RESIDUALSb =', E10.3)
          STOP
          END
$DATA
      5
      1.0  2.35  1.5   5.53  2.0   8.92  2.5   12.15
      3.0  15.38

```

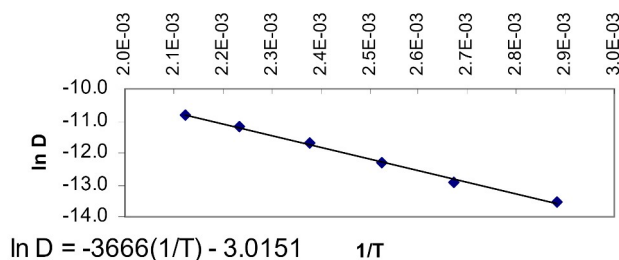
SOLUTION: $a = 6.536, b = -4.206$

2.45 (a) E (cal/mol), D_0 (cm²/s)

(b) $\ln D$ vs. $1/T$, Slope= $-E/R$, intercept= $\ln D_0$.

(c) Intercept = $\ln D_0 = -3.0151 \Rightarrow D_0 = 0.05 \text{ cm}^2 / \text{s}$.

Slope = $-E / R = -3666 \text{ K} \Rightarrow E = (3666 \text{ K})(1.987 \text{ cal} / \text{mol} \cdot \text{K}) = 7284 \text{ cal} / \text{mol}$



(d) Spreadsheet

T	D	1/T	lnD	(1/T)*(lnD)	(1/T)**2
347	1.34E-06	2.88E-03	-13.5	-0.03897	8.31E-06
374.2	2.50E-06	2.67E-03	-12.9	-0.03447	7.14E-06
396.2	4.55E-06	2.52E-03	-12.3	-0.03105	6.37E-06
420.7	8.52E-06	2.38E-03	-11.7	-0.02775	5.65E-06
447.7	1.41E-05	2.23E-03	-11.2	-0.02495	4.99E-06
471.2	2.00E-05	2.12E-03	-10.8	-0.02296	4.50E-06

Sx	2.47E-03
Sy	-12.1
Syx	-3.00E-02
Sxx	6.16E-06
-E/R	-3666
$\ln D_0$	-3.0151
D_0	7284
E	0.05