CHAPTER TWO

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

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

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

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

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

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

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

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

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

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

2.5 Distance from the earth to the moon = 238857 miles

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

2.6

$$\frac{19\text{ km}}{1\text{ L}} \left| \frac{1000\text{ m}}{1\text{ km}} \right| \frac{0.0006214\text{ mi}}{1\text{ m}} \left| \frac{1000\text{ L}}{264.17\text{ gal}} \right. = 44.7\text{ mi/gal}$$

Calculate the total cost to travel x miles.

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

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

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

2.7

$$\frac{5320\text{ imp. gal}}{\text{plane}\cdot\text{h}}\left|\frac{14\text{ h}}{1\text{ d}}\right|\frac{365\text{ d}}{1\text{ yr}}\left|\frac{10^6\text{ cm}^3}{220.83\text{ imp. gal}}\right|\frac{0.965\text{ g}}{1\text{ cm}^3}\left|\frac{1\text{ kg}}{1000\text{ g}}\right|\frac{1\text{ tonne}}{1000\text{ kg}}$$

$$=1.188\times10^5\ \frac{\text{tonne kerosene}}{\text{plane}\cdot\text{yr}}$$

$$\frac{4.02\times10^9\text{ tonne crude oil}}{\text{yr}}\left|\frac{1\text{ tonne kerosene}}{7\text{ tonne crude oil}}\right|\frac{\text{plane}\cdot\text{yr}}{1.188\times10^5\text{ tonne kerosene}}$$

$$=4834\text{ planes}\Rightarrow\underline{\underline{5000\text{ planes}}}$$

2.8 (a)

$$\frac{25.0\text{ lb}_\text{m}}{}\left|\frac{32.1714\text{ ft/s}^2}{}\right|\frac{1\text{ lb}_\text{f}}{32.1714\text{ lb}_\text{m}\cdot\text{ft/s}^2}=\underline{\underline{25.0\text{ lb}_\text{f}}}$$

(b)

$$\frac{25\text{ N}}{}\left|\frac{1}{9.8066\text{ m/s}^2}\right|\frac{1\text{ kg}\cdot\text{m/s}^2}{1\text{ N}}=2.5493\text{ kg}\Rightarrow\underline{\underline{2.5\text{ kg}}}$$

(c)

$$\frac{10\text{ ton}}{}\left|\frac{1\text{ lb}_\text{m}}{5\times10^{-4}\text{ ton}}\right|\frac{1000\text{ g}}{2.20462\text{ lb}_\text{m}}\left|\frac{980.66\text{ cm/s}^2}{}\right|\frac{1\text{ dyne}}{1\text{ g}\cdot\text{cm/s}^2}=\underline{\underline{9\times10^9\text{ dynes}}}$$

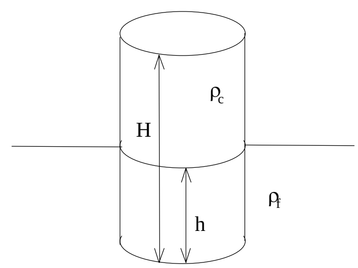
2.9

$$\frac{50\times15\times2\text{ m}^3}{}\left|\frac{35.3145\text{ ft}^3}{1\text{ m}^3}\right|\frac{85.3\text{ lb}_\text{m}}{1\text{ ft}^3}\left|\frac{32.174\text{ ft}}{1\text{ s}^2}\right|\frac{1\text{ lb}_\text{f}}{32.174\text{ lb}_\text{m}/\text{ft}\cdot\text{s}^2}=\underline{\underline{4.5\times10^6\text{ lb}_\text{f}}}$$

2.10

$$\frac{500\text{ lb}_\text{m}}{}\left|\frac{1\text{ kg}}{2.20462\text{ lb}_\text{m}}\right|\frac{1\text{ m}^3}{11.5\text{ kg}}\approx5\times10^2\left(\frac{1}{2}\right)\left(\frac{1}{10}\right)\approx\underline{\underline{25\text{ m}^3}}$$

2.11 **(a)**

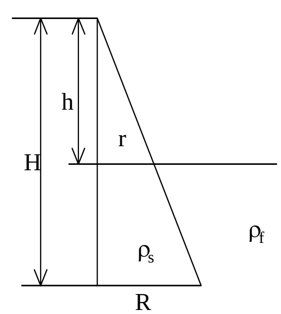


$$m_\text{displaced fluid}=m_\text{cylinder}\Rightarrow\rho_fV_f=\rho_cV_c\Rightarrow\rho_fh\pi r^2=\rho_cH\pi r^2$$

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

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

2.12



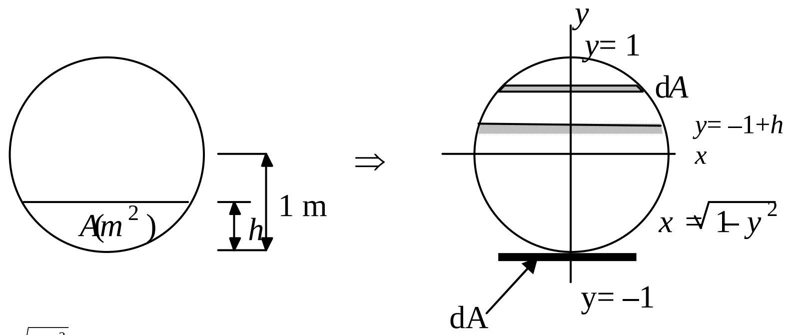
$$V_s=\frac{\pi R^2H}{3};\quad V_f=\frac{\pi R^2H}{3}-\frac{\pi r^2h}{3};\quad\frac{R}{H}=\frac{r}{h}\Rightarrow r=\frac{R}{H}h$$

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

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

$$\Rightarrow\rho_f=\rho_s\frac{H}{H-\dfrac{h^3}{H^2}}=\rho_s\frac{H^3}{H^3-h^3}=\underline{\underline{\rho_s\frac{1}{1-\left(\dfrac{h}{H}\right)^3}}}$$

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



$$dA = dy \cdot \int_{-\sqrt{1-y^2}}^{\sqrt{1-y^2}} dx = 2\sqrt{1-y^2}\,dy \Rightarrow A\left(m^2\right) = 2\int_{-1}^{-1+h} \sqrt{1-y^2}\,dy$$

$\Downarrow$ Table of integrals or trigonometric substitution

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

$$W(N) = \frac{4\ \mathrm{m} \times A(\mathrm{m}^2)}{} \left| \frac{0.879\ \mathrm{g}}{\mathrm{cm}^3} \right| \frac{10^6\ \mathrm{cm}^2}{1\ \mathrm{m}^3} \left| \frac{1\ \mathrm{kg}}{10^3\ \mathrm{g}} \right| \frac{9.81\ \mathrm{N}}{\underbrace{\mathrm{kg}}_{g/g_0}} = 3.45 \times 10^4 A$$

$\Downarrow$ Substitute for A

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

2.14 $1\ \mathrm{lb_f} = 1\ \mathrm{slug} \cdot \mathrm{ft/s^2} = 32.174\ \mathrm{lb_m} \cdot \mathrm{ft/s^2} \Rightarrow 1\ \mathrm{slug} = 32.174\ \mathrm{lb_m}$

$1\ \mathrm{poundal} = 1\ \mathrm{lb_m} \cdot \mathrm{ft/s^2} = \dfrac{1}{32.174}\ \mathrm{lb_f}$

(a) (i) On the earth:

$$M = \frac{175\ \mathrm{lb_m}}{} \left| \frac{1\ \mathrm{slug}}{32.174\ \mathrm{lb_m}} \right. = \underline{\underline{5.44\ \mathrm{slugs}}}$$

$$W = \frac{175\ \mathrm{lb_m}}{} \left| \frac{32.174\ \mathrm{ft}}{\mathrm{s}^2} \right| \frac{1\ \mathrm{poundal}}{1\ \mathrm{lb_m} \cdot \mathrm{ft/s^2}} = \underline{\underline{5.63 \times 10^3\ \mathrm{poundals}}}$$

(ii) On the moon

$$M = \frac{175\ \mathrm{lb_m}}{} \left| \frac{1\ \mathrm{slug}}{32.174\ \mathrm{lb_m}} \right. = \underline{\underline{5.44\ \mathrm{slugs}}}$$

$$W = \frac{175\ \mathrm{lb_m}}{} \left| \frac{32.174\ \mathrm{ft}}{6\quad \mathrm{s}^2} \right| \frac{1\ \mathrm{poundal}}{1\ \mathrm{lb_m} \cdot \mathrm{ft/s^2}} = \underline{\underline{938\ \mathrm{poundals}}}$$

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

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

2.15 (a) $F = ma \Rightarrow 1 \text{ fern} = (1 \text{ bung})(32.174 \text{ ft / s}^2)\left(\frac{1}{6}\right) = \underline{\underline{5.3623 \text{ bung} \cdot \text{ft / s}^2}}$

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

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

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

2.16 (a) $\approx (3)(9) = \underline{\underline{27}}$

$(2.7)(8.632) = \underline{\underline{23}}$

(b) $\approx \frac{4.0 \times 10^{-4}}{40} \approx \underline{\underline{1 \times 10^{-5}}}$

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

(c) $\approx 2 + 125 = \underline{\underline{127}}$

$2.365 + 125.2 = \underline{\underline{127.5}}$

(d) $\approx 50 \times 10^3 - 1 \times 10^3 \approx 49 \times 10^3 \approx \underline{\underline{5 \times 10^4}}$

$4.753 \times 10^4 - 9 \times 10^2 = \underline{\underline{5 \times 10^4}}$

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

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

2.18 (a)

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

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

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

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

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

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

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

$$= \underline{\underline{2.3^\circ \text{C}}}$$

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

2.19 (a)

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

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

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

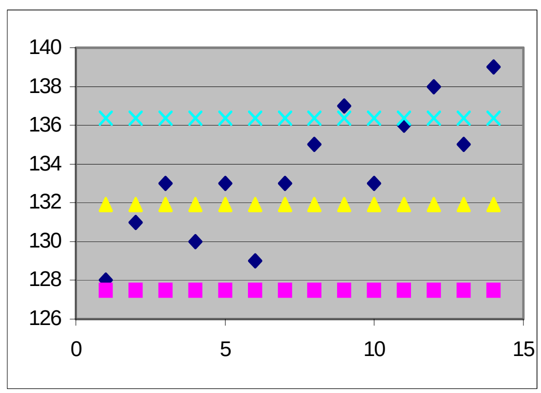
(b) Joanne is more likely to be the statistician, because she wants to make the control limits stricter.

(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)

(a) Run	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
X	134	131	129	133	135	131	134	130	131	136	129	130	133	130	133
Mean(X)	131.9														
Stdev(X)	2.2														
Min	127.5														
Max	136.4														

(b) Run	X	Min	Mean	Max
1	128	127.5	131.9	136.4
2	131	127.5	131.9	136.4
3	133	127.5	131.9	136.4
4	130	127.5	131.9	136.4
5	133	127.5	131.9	136.4
6	129	127.5	131.9	136.4
7	133	127.5	131.9	136.4
8	135	127.5	131.9	136.4
9	137	127.5	131.9	136.4
10	133	127.5	131.9	136.4
11	136	127.5	131.9	136.4
12	138	127.5	131.9	136.4
13	135	127.5	131.9	136.4
14	139	127.5	131.9	136.4



(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 (a) $Q' = \dfrac{2.36\times10^{-4}\ \text{kg}\cdot\text{m}^2}{\text{h}} \left| \dfrac{2.20462\ \text{lb}}{\text{kg}} \right| \dfrac{3.2808^2\ \text{ft}^2}{\text{m}^2} \left| \dfrac{1\quad \text{h}}{3600\ \text{s}} \right.$

(b) $Q'_{\text{approximate}} \approx \dfrac{(2\times10^{-4})(2)(9)}{3\times10^3} \approx 12\times10^{(-4-3)} \approx \underline{\underline{1.2\times10^{-6}\ \text{lb}\cdot\text{ft}^2/\text{s}}}$

$Q'_{\text{exact}} = \underline{\underline{1.56\times10^{-6}\ \text{lb}\cdot\text{ft}^2/\text{s}}} = \underline{\underline{0.00000156\ \text{lb}\cdot\text{ft}^2/\text{s}}}$

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

$N_{\text{Pr}} \approx \dfrac{(6\times10^{-1})(2\times10^3)(3\times10^3)}{(3\times10^{-1})(4\times10^3)(2)} \approx \dfrac{3\times10^3}{2} \approx \underline{\underline{1.5\times10^3}}$. The calculator solution is $\underline{\underline{1.63\times10^3}}$

2.23

$\text{Re} = \dfrac{Du\rho}{\mu} = \dfrac{0.48\ \text{ft}}{\text{s}}\left|\dfrac{1\ \text{m}}{3.2808\ \text{ft}}\right|\dfrac{2.067\ \text{in}}{0.43\times10^{-3}\ \text{kg/m}\cdot\text{s}}\left|\dfrac{1\ \text{m}}{39.37\ \text{in}}\right|\dfrac{0.805\ \text{g}}{\text{cm}^3}\left|\dfrac{1\ \text{kg}}{1000\ \text{g}}\right|\dfrac{10^6\ \text{cm}^3}{1\ \text{m}^3}$

$\text{Re} \approx \dfrac{(5\times10^{-1})(2)(8\times10^{-1})(10^6)}{(3)(4\times10)(10^3)(4\times10^{-4})} \approx \dfrac{5\times10^{1-(-3)}}{3} \approx 2\times10^4 \Rightarrow$ $\underline{\underline{\text{the flow is turbulent}}}$

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

$= 2.00 + 0.600\left[\dfrac{1.00\times10^{-5}\ \text{N}\cdot\text{s/m}^2}{(1.00\ \text{kg/m}^3)(1.00\times10^{-5}\ \text{m}^2/\text{s})}\right]^{1/3}\left[\dfrac{(0.00500\ \text{m})(10.0\ \text{m/s})(1.00\ \text{kg/m}^3)}{(1.00\times10^{-5}\ \text{N}\cdot\text{s/m}^2)}\right]^{1/2}$

$= 44.426 \Rightarrow \dfrac{\boldsymbol{k_g}(0.00500\ \text{m})(0.100)}{1.00\times10^{-5}\ \text{m}^2/\text{s}} = 44.426 \Rightarrow \boldsymbol{k_g} = \underline{\underline{0.888\ \text{m/s}}}$

(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 (m)	y	D (m^2/s)	μ (N-s/m^2)	ρ (kg/m^3)	u (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 (a) $\underline{\underline{200\ \text{crystals/min}\cdot\text{mm}}}$; $\underline{\underline{10\ \text{crystals/min}\cdot\text{mm}^2}}$

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

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

(c) $D(\text{mm}) = \dfrac{D'(\text{in})}{}\left|\dfrac{25.4\ \text{mm}}{1\ \text{in}}\right. = 25.4D'$; $r\left(\dfrac{\text{crystals}}{\text{min}}\right) = r'\dfrac{\text{crystals}}{\text{s}}\left|\dfrac{60\ \text{s}}{1\ \text{min}}\right. = 60r'$

$\Rightarrow 60r' = 200(25.4D') - 10(25.4D')^2 \Rightarrow \underline{\underline{r' = 84.7D' - 108(D')^2}}$

2.26 (a) $\underline{\underline{70.5\ \text{lb}_m / \text{ft}^3}}$; $\underline{\underline{8.27\times10^{-7}\ \text{in}^2 / \text{lb}_f}}$

(b) $\rho = (70.5\ \text{lb}_m/\text{ft}^3)\exp\left[\dfrac{8.27\times10^{-7}\ \text{in}^2}{\text{lb}_f}\left|\dfrac{9\times10^6\ \text{N}}{\text{m}^2}\right|\dfrac{14.696\ \text{lb}_f/\text{in}^2}{1.01325\times10^5\ \text{N/m}^2}\right]$

$$= \frac{70.57\ \text{lb}_m}{\text{ft}^3}\left|\frac{35.3145\ \text{ft}^3}{\text{m}^3}\right|\frac{1\quad \text{m}^3}{10^6\ \text{cm}^3}\left|\frac{1000\ \text{g}}{2.20462\ \text{lb}_m}\right. = \underline{\underline{1.13\ \text{g/cm}^3}}$$

(c) $\rho\left(\dfrac{\text{lb}_m}{\text{ft}^3}\right) = \rho'\dfrac{\text{g}}{\text{cm}^3}\left|\dfrac{1\ \text{lb}_m}{453.593\ \text{g}}\right|\dfrac{28{,}317\ \text{cm}^3}{1\ \text{ft}^3} = 62.43\rho'$

$$P\left(\frac{\text{lb}_f}{\text{in}^2}\right) = P'\frac{\text{N}}{\text{m}^2}\left|\frac{0.2248\ \text{lb}_f}{1\ \text{N}}\right|\frac{1^2\quad \text{m}^2}{39.37^2\ \text{in}^2} = 1.45\times10^{-4}\,P'$$

$$\Rightarrow 62.43\rho' = 70.5\exp\left[\left(8.27\times10^{-7}\right)\left(1.45\times10^{-4}\,P'\right)\right] \Rightarrow \underline{\underline{\rho' = 1.13\exp\left(1.20\times10^{-10}\,P'\right)}}$$

$$P' = 9.00\times10^6\ \text{N/m}^2 \Rightarrow \rho' = 1.13\exp[(1.20\times10^{-10})(9.00\times10^6)] = \underline{\underline{1.13\ \text{g/cm}^3}}$$

2.27 (a) $V\left(\text{cm}^3\right) = \dfrac{V'\left(\text{in}^3\right)}{}\left|\dfrac{28{,}317\ \text{cm}^3}{1728\ \text{in}^3}\right. = 16.39V'$; $t(\text{s}) = 3600t'(\text{hr})$

$$\Rightarrow 16.39V' = \exp\left(3600t'\right) \Rightarrow \underline{\underline{V' = 0.06102\exp\left(3600t'\right)}}$$

(b) The t in the exponent has a coefficient of s^{-1}.

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

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

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

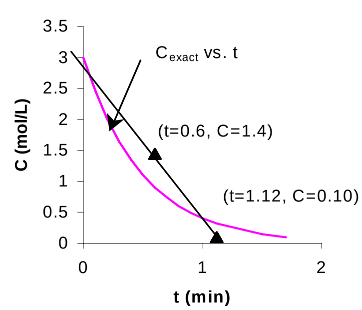
For t=0.6 min: $C_{\text{int}} = \dfrac{0.406-3.00}{1-0}(0.6-0)+3.00 = \underline{\underline{1.4\ \text{mol/L}}}$

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

For C=0.10 mol/L: $t_{\text{int}} = \dfrac{1-0}{0.406-3}(0.10-3.00)+0 = \underline{\underline{1.12\ \text{min}}}$

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

(c)



2.29 (a) $p^* = \dfrac{60-20}{199.8-166.2}(185-166.2)+20 = \underline{\underline{42 \text{ mm Hg}}}$

(b)

```
c     MAIN PROGRAM FOR PROBLEM 2.29
      IMPLICIT REAL*4(A–H, 0–Z)
      DIMENSION TD(6), PD(6)
      DO 1 I = 1, 6
            READ (5, *) TD(I), PD(I)
1     CONTINUE
      WRITE (5, 902)
902   FORMAT (‘0’, 5X, ‘TEMPERATURE     VAPOR PRESSURE’/6X,
*                 ‘        (C)                  (MM HG)’/)
      DO 2 I = 0, 115, 5
      T = 100 + I
      CALL VAP (T, P, TD, PD)
      WRITE (6, 903)   T, P
903   FORMAT (10X, F5.1, 10X, F5.1)
2     CONTINUE
      END
      SUBROUTINE VAP (T, P, TD, PD)
      DIMENSION TD(6), PD(6)
      I = 1
1     IF (TD(I).LE.T.AND.T.LT.TD(I + 1)) GO TO 2
      I = I + 1
      IF (I.EQ.6) STOP
      GO TO 1
2     P = PD(I) + (T – TD(I))/(TD(I + 1) – TD(I)) * (PD(I + 1) – PD(I))
      RETURN
      END
```

<u>DATA</u>

98.5	1.0
131.8	5.0
⋮	⋮
215.5	100.0

<u>OUTPUT</u>

TEMPERATURE (C)	VAPOR PRESSURE (MM HG)
100.0	1.2
105.0	1.8
⋮	⋮
215.0	98.7

2.30 (b) $\ln y = \ln a + bx \Rightarrow y = ae^{bx}$

$b = (\ln y_2 - \ln y_1)/(x_2 - x_1) = (\ln 2 - \ln 1)/(1-2) = -0.693$

$\ln a = \ln y - bx = \ln 2 + 0.63(1) \Rightarrow a = 4.00 \Rightarrow \underline{\underline{y = 4.00e^{-0.693x}}}$

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

$b = (\ln y_2 - \ln y_1)/(\ln x_2 - \ln x_1) = (\ln 2 - \ln 1)/(\ln 1 - \ln 2) = -1$

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

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

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

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

[can't solve explicitly for $y(x)$]

2.30 (cont'd)

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

$$b = [\ln(y^2/x)_2 - \ln(y^2/x)_1]/[\ln(x-2)_2 - \ln(x-2)_1]$$
$$= (\ln 807.0 - \ln 40.2)/(\ln 2.0 - \ln 1.0) = 4.33$$
$$\ln a = \ln(y^2/x) - b(x-2) = \ln 807.0 - 4.33\ln(2.0) \Rightarrow a = 40.2$$
$$\Rightarrow y^2/x = 40.2(x-2)^{4.33} \Rightarrow \underline{\underline{y = 6.34x^{1/2}(x-2)^{2.165}}}$$

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

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

(d)

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

OR

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

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

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

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

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

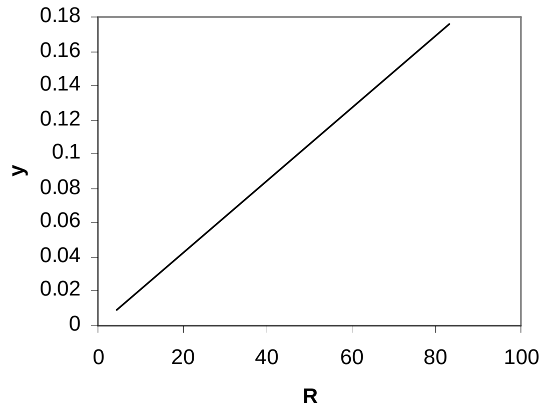
(f) $\log_{10}(xy) = a(x^2+y^2) + b$

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

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

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

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



$$y = a\,R + b \qquad \left.\begin{array}{l} a = \dfrac{0.169 - 0.011}{80-5} = 2.11\times10^{-3} \\ b = 0.011 - \left(2.11\times10^{-3}\right)(5) = 4.50\times10^{-4} \end{array}\right\} \Rightarrow \underline{\underline{y = 2.11\times10^{-3} R + 4.50\times10^{-4}}}$$

(b) $R = 43 \Rightarrow y = \left(2.11\times10^{-3}\right)(43) + 4.50\times10^{-4} = 0.092 \text{ kg } \mathrm{H_2O/kg}$

$$(1200 \text{ kg/h})(0.092 \text{ kg } \mathrm{H_2O/kg}) = \underline{\underline{110 \text{ kg } \mathrm{H_2O/h}}}$$

2.33 (a) $\ln T = \ln a + b\ln\phi \Rightarrow T = a\phi^b$

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

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

(b) $T = 9677.6\phi^{-1.19} \Rightarrow \phi = (9677.6/T)^{0.8403}$

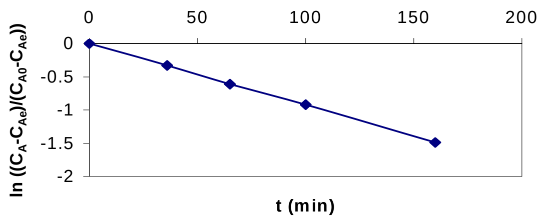
$$T = 85^{\circ} C \Rightarrow \phi = (9677.6/85)^{0.8403} = \underline{\underline{53.5 \text{ L/s}}}$$

$$T = 175^{\circ} C \Rightarrow \phi = (9677.6/175)^{0.8403} = \underline{\underline{29.1 \text{ L/s}}}$$

$$T = 290^{\circ} C \Rightarrow \phi = (9677.6/290)^{0.8403} = \underline{\underline{19.0 \text{ L/s}}}$$

(c) The estimate for *T*=175°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°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.



$$\text{Slope} = -0.0093 \Rightarrow \underline{\underline{k = 9.3\times10^{-3}\ \text{min}^{-1}}}$$

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

$$C_A = (0.1823 - 0.0495)e^{-(9.3\times10^{-3})(120)} + 0.0495 = 9.300\times10^{-2}\ \text{g/L}$$

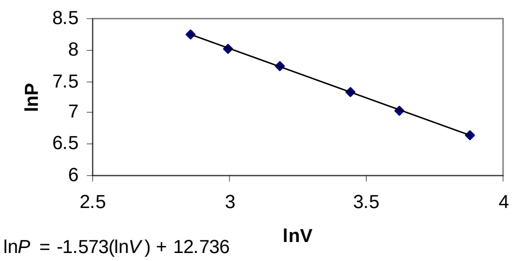
$$C = m/V \Rightarrow m = CV = \frac{9.300\times10^{-2}\ \text{g}}{\text{L}}\left|\frac{30.5\ \text{gal}}{}\right|\frac{28.317\ \text{L}}{7.4805\ \text{gal}} = \underline{\underline{10.7\ \text{g}}}$$

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

(b) $\ln(V)$ vs. t^2 in rectangular coordinates, slope=2 and intercept= $\ln(3.53\times10^{-2})$; or V(logarithmic axis) vs. t^2 in semilog coordinates, slope=2, intercept= 3.53×10^{-2}

(c) $\underline{\underline{V(\text{m}^3) = 1.00\times10^{-3}\exp(1.5\times10^{-7}\,\text{t}^2)}}$

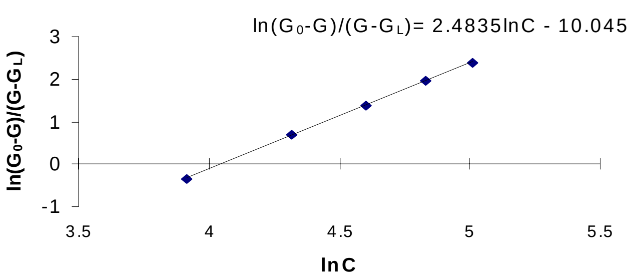
2.36 $PV^k = C \Rightarrow P = C/V^k \Rightarrow \ln P = \ln C - k\ln V$



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

$$\text{Intercept} = \ln C = 12.736 \Rightarrow C = e^{12.736} = \underline{\underline{3.40\times10^5\ \text{mm Hg}\cdot\text{cm}^{4.719}}}$$

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



2.37 (cont'd)

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

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

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

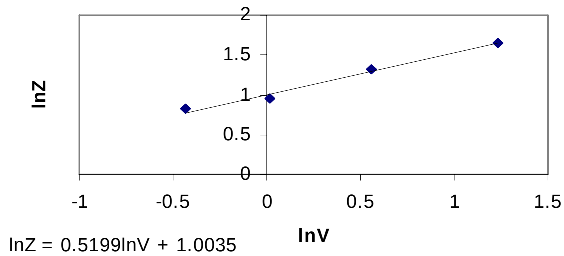
C=475 ppm is well beyond the range of the data.

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

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

$$\left.\begin{aligned} \ln(3.5) &= \ln a + b\ln(1.02) + c\ln(9.1) \\ \ln(2.58) &= \ln a + b\ln(1.02) + c\ln(11.2) \\ \ln(3.72) &= \ln a + b\ln(1.75) + c\ln(11.2) \end{aligned}\right\} \Rightarrow \begin{aligned} b &= \underline{\underline{0.68}} \\ c &= \underline{\underline{-1.46}} \\ \text{a} &= \underline{\underline{86.7\ \text{volts} \cdot \text{kPa}^{1.46} / (\text{L/s})^{0.678}}} \end{aligned}$$

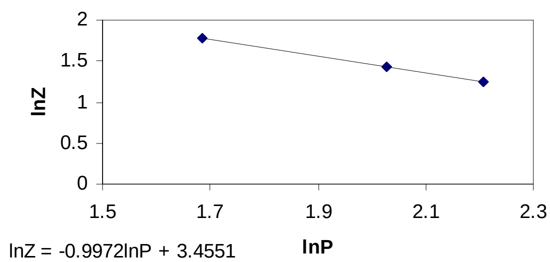
(b) When P is constant (runs 1 to 4), plot $\ln Z$ vs. $\ln \dot{\text{V}}$. Slope=b, Intercept= $\ln a + c \ln p$



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

Intercept $= \ln a + c \ln P = 1.0035$

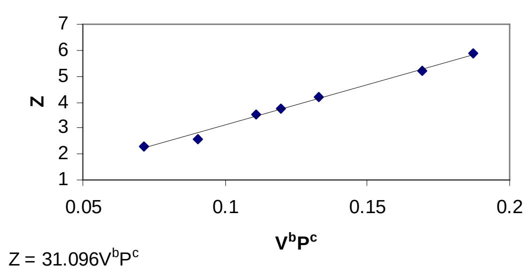
When $\dot{V}$ is constant (runs 5 to 7), plot ln$Z$ vs. ln$P$. Slope=c, Intercept= $\ln a + c \ln \dot{V}$



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

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

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



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

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

2.39 (a)

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

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

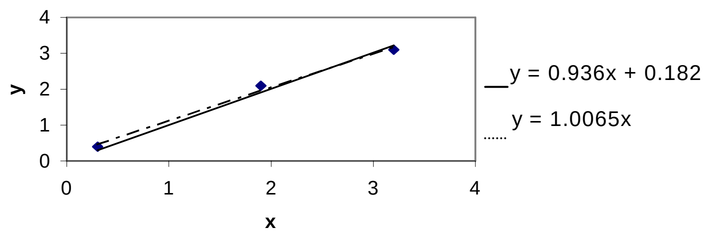
$$s_x = \frac{1}{n}\sum_{i=1}^{n} x_i = (0.3 + 1.9 + 3.2)/3 = 1.8; \quad s_y = \frac{1}{n}\sum_{i=1}^{n} y_i = (0.4 + 2.1 + 3.1)/3 = 1.867$$

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

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

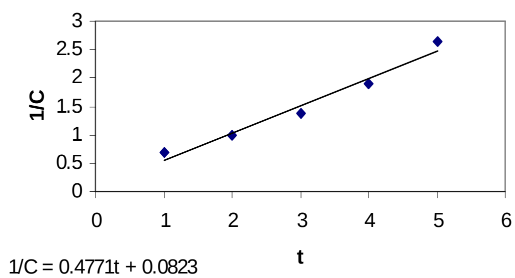
$$\underline{\underline{y = 0.936x + 0.182}}$$

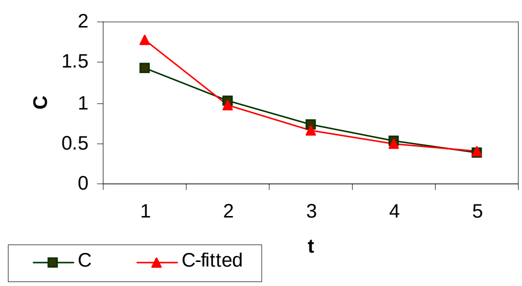
(b) $a = \dfrac{s_{xy}}{s_{xx}} = \dfrac{4.677}{4.647} = 1.0065 \Rightarrow \underline{\underline{y = 1.0065x}}$



2.40 (a) <u>*1/C* vs. t</u>. <u>Slope= b, intercept</u>=a

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





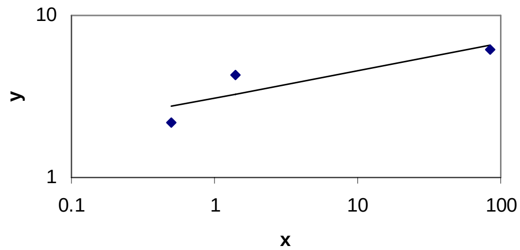
(c) $C = 1/(a + bt) \Rightarrow 1/[0.082 + 0.477(0)] = \underline{\underline{12.2\ \text{g/L}}}$

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

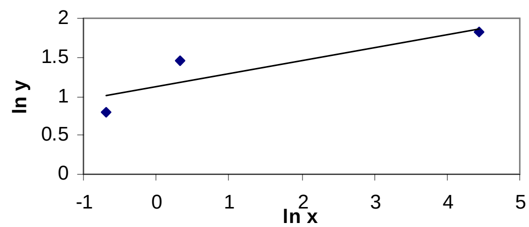
(d) t=0 and C=0.01 are out of the range of the experimental data.

(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*

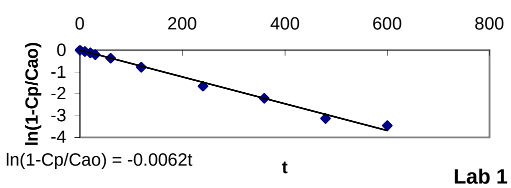


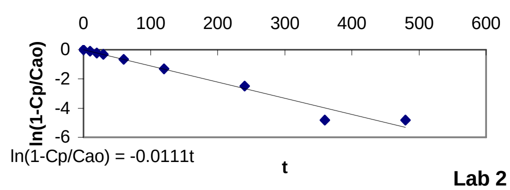
$b = \text{slope} = \underline{\underline{0.168}}$

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

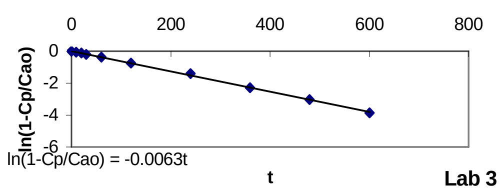
2.42 (a) $\ln(1-C_p/C_{A0})$ vs. t in rectangular coordinates. Slope=-k, intercept=0

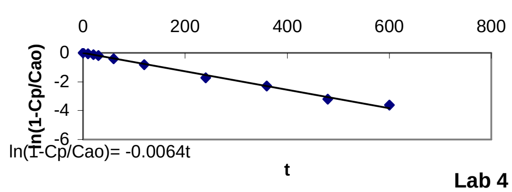
(b)





$k = \underline{\underline{0.0062 \text{ s}^{-1}}}$ $k = \underline{\underline{0.0111 \text{ s}^{-1}}}$





$k = \underline{\underline{0.0063 \text{ s}^{-1}}}$ $k = \underline{\underline{0.0064 \text{ s}^{-1}}}$

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

$$\Rightarrow \underline{\underline{a = \sum_{i=1}^{n} y_i x_i \bigg/ \sum_{i=1}^{n} x_i^2}}$$

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 (IH0, '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
```

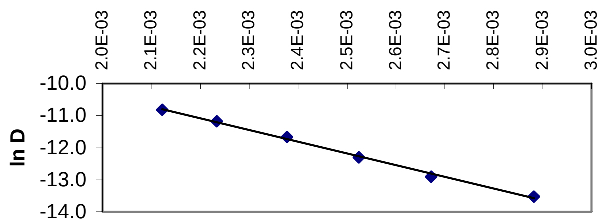
<u>SOLUTION:</u> $\underline{\underline{a = 6.536, b = -4.206}}$

2.45 (a) E(cal/mol), D_0 (cm^2/s)

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

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

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



(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