2.1 (a) $\frac{2\text{ wk}}{} \left| \frac{7\text{ d}}{1\text{ wk}} \right| \frac{24\text{ h}}{1\text{ d}} \left| \frac{3600\text{ s}}{1\text{ h}} \right| \frac{10^6\ \mu\text{s}}{1\text{ s}} = 1.2096\times 10^{12}\ \mu\text{s} = \underline{\underline{1\times 10^{12}\ \mu\text{s}}}$

(b) $\frac{38.1\text{ ft/s}}{} \left| \frac{0.3048\text{ m}}{1\text{ ft}} \right| \frac{1\text{ km}}{1000\text{ m}} \left| \frac{3600\text{ s}}{1\text{ h}} \right. = \underline{\underline{41.8\text{ km/h}}}$

(c) $\frac{554\text{ m}^4}{\text{d}\cdot\text{kg}} \left| \frac{1\text{ d}}{24\text{ h}} \right| \frac{1\text{ h}}{60\text{ min}} \left| \frac{0.453593\text{ kg}}{1\text{ lb}_\text{m}} \right| \frac{1\text{ ft}^4}{(0.3048\text{ m})^4} = \underline{\underline{20.2\text{ ft}^4/\text{min}\cdot\text{lb}_\text{m}}}$

2.2 (a) $\dfrac{1760\ \text{mi}}{\text{h}}\left|\dfrac{0.001\ \text{km}}{0.0006214\ \text{mi}}\right|\dfrac{1\ \ \text{h}}{3600\ \text{s}} = \underline{\underline{0.787\ \text{km/s}}}$

(b) $\dfrac{1400\ \text{kg}}{\text{m}^3}\left|\dfrac{2.20462\ \text{lb}_\text{m}}{1\ \text{kg}}\right|\dfrac{1\ \ \text{m}^3}{35.3145\ \text{ft}^3} = \underline{\underline{87.4\ \text{lb}_\text{m}/\text{ft}^3}}$

(c) $\dfrac{5.37\times10^3\ \text{kJ}}{\text{s}}\left|\dfrac{1000\ \text{J}}{1\ \text{kJ}}\right|\dfrac{1.34\times10^{-3}\ \text{hp}}{1\ \text{J/s}} = 7195.8\ \text{hp} \Rightarrow \underline{\underline{7200\ \text{hp}}}$

2.3 Assume that a baseball occupies the space equivalent to a $3 \text{ in} \times 3 \text{ in} \times 3 \text{ in}$ cube. For a classroom with dimensions $40 \text{ ft} \times 40 \text{ ft} \times 15 \text{ ft}$:

$$n_{\text{balls}} = \frac{40 \times 40 \times 15 \text{ ft}^3}{} \left| \frac{(12)^3 \text{ in}^3}{\text{ft}^3} \right| \frac{1 \text{ ball}}{3^3 \text{ in}^3} = 1.536 \times 10^6 \approx \underline{\underline{1.5 \text{ million baseballs}}}$$

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

Site A: $\dfrac{50 \text{ microns } (\mu m) \;|\; 100 \text{ cm}}{\;|\; 10^6 \;\mu m} = 0.005 \text{ cm}$

Site B: $\dfrac{3 \text{ mil} \;|\; 10^{-3} \text{ in} \;|\; 30.48 \text{ cm}}{\;|\; 1 \text{ mil} \;|\; 12 \text{ in}} = 0.00762 \text{ cm}$

$0.005 \text{ cm} < 0.00762 \text{ cm} \Rightarrow$ Site B is selling the thicker liner.

2.6 Distance from the earth to the moon = 238857 miles

$$\frac{238857 \text{ mi}}{} \left| \frac{1 \quad \text{m}}{0.0006214 \text{ mi}} \right| \frac{1 \text{ report}}{0.001 \text{ m}} = \underline{\underline{4\times10^{11} \text{ reports}}}$$

2.7 $$\frac{19\text{ km}}{1\text{ L}}\left|\frac{1000\text{ m}}{1\text{ km}}\right|\frac{0.0006214\text{ mi}}{1\text{ m}}\left|\frac{1000\text{ L}}{264.17\text{ gal}}\right.=44.7\text{ mi/gal}$$

Calculate the total cost to travel x miles:

$$\text{Total Cost}_{\text{American}}=\$28,500+\frac{\$3.25}{\text{gal}}\left|\frac{1\text{ gal}}{28\text{ mi}}\right|\frac{x\text{ (mi)}}{}=28,500+0.1161x$$

$$\text{Total Cost}_{\text{European}}=\$35,700+\frac{\$3.25}{\text{gal}}\left|\frac{1\text{ gal}}{44.7\text{ mi}}\right|\frac{x\text{ (mi)}}{}=35,700+0.07271x$$

Equate the two costs: $x=\underline{\underline{1.7\times10^{5}\text{ miles}}}$

2.8 (a) $$\frac{100\times10^6\text{ J}}{\text{s}}\left|\frac{3600\text{ s}}{1\text{ hr}}\right|\frac{24\text{ hr}}{1\text{ d}}\left|\frac{365\text{ d}}{1\text{ yr}}\right.=\underline{\underline{3.15\times10^{15}\text{ J/yr}}}$$

(b) The question asks "how much power does a 100 MW plant generate annually?" The answer is implied in the units. The question should ask, "How much energy does a 100 MW plant generate annually?", e.g. in units of J/yr.

(c) The unit of MW is equivalent to J/s; power is energy/time, so MW is already a rate-based unit. We know that 100MW = 100MJ/s.

2.9 **(a)**

$$\frac{25.0\ \text{lb}_m \;\Big|\; 32.1714\ \text{ft/s}^2 \;\Big|\; 1\ \text{lb}_f}{\;\Big|\; \;\Big|\; 32.1714\ \text{lb}_m\cdot\text{ft/s}^2} = \underline{\underline{25.0\ \text{lb}_f}}$$

(b)

$$\frac{25\ \text{N} \;\Big|\; 1 \;\Big|\; 1\ \text{kg}\cdot\text{m/s}^2}{\;\Big|\; 9.8066\ \text{m/s}^2 \;\Big|\; 1\ \text{N}} = 2.55\ \text{kg} \Rightarrow \underline{\underline{2.6\ \text{kg}}}$$

(c)

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

2.10

$$\frac{50\times 25\times 2\ \text{m}^3}{} \left| \frac{35.3145\ \text{ft}^3}{1\ \text{m}^3} \right| \frac{75.3\ \text{lb}_\text{m}}{1\ \text{ft}^3} \left| \frac{32.174\ \text{ft}}{1\ \text{s}^2} \right| \frac{1\ \text{lb}_\text{f}}{32.174\ \text{lb}_\text{m}/\text{ft}\cdot\text{s}^2} = \underline{\underline{6.6\times 10^6\ \text{lb}_\text{f}}}$$

2.11

$$\frac{500\ \text{lb}_m \,\Big|\, 1\ \text{kg} \,\Big|\, 1\ \text{m}^3 \,\Big|\, 35.3145\ \text{ft}^3}{\Big|\, 2.20462\ \text{lb}_m \,\Big|\, 12.5\ \text{kg} \,\Big|\, 1\ \text{m}^3} \approx 500\left(\frac{1}{2}\right)\left(\frac{1}{10}\right)\left(\frac{40}{1}\right) \approx \underline{\underline{1000\ \text{ft}^3}}$$

2.12

$$\frac{31{,}000\text{ tons}}{1\text{ day}}\left|\frac{1\text{ lb}_\text{m}}{5\times10^{-4}\text{ tons}}\right|\frac{0.453593\text{ kg}}{1\text{ lb}_\text{m}}\left|\frac{0.012\text{ m}^3}{\text{kg}}\right|\frac{365\text{ days}}{1\text{ yr}}=1.2318\times10^{8}\text{ m}^3/\text{yr}\Rightarrow\underline{\underline{1.2\times10^{8}\text{ m}^3}}$$

2.13 **(a)**

(i) Electricity generated in a month by one panel :

$$= \frac{140 \text{ J}}{\text{s}} \left| \frac{3600 \text{ s}}{1 \text{ hr}} \right| \frac{5 \text{ hrs}}{1 \text{ day}} \left| \frac{30 \text{ days}}{1 \text{ month}} \right| \frac{2.778\times10^{-7} \text{ kWh}}{1 \text{ J}}$$

$= 21 \text{ kWh}$

The number of panels needed $= 948\text{kWh} / 21\text{kWh} / \text{panel} = 45.11 \text{ panels} \rightarrow \underline{\underline{46 \text{ panels}}}$

Cost $= 46 \text{ panels } \times \$210 / \text{panel} = \underline{\underline{\$9660}}$

(ii) Electricity generated in a month by one panel :

$$= \frac{240 \text{ J}}{\text{s}} \left| \frac{3600 \text{ s}}{1 \text{ hr}} \right| \frac{5 \text{ hrs}}{1 \text{ day}} \left| \frac{30 \text{ days}}{1 \text{ month}} \right| \frac{2.778\times10^{-7} \text{ kWh}}{1 \text{ J}}$$

$= 36 \text{ kWh}$

The number of panels needed $= 948\text{kWh} / 36\text{kWh} / \text{panel} = 26.33 \text{ panels} \rightarrow \underline{\underline{27 \text{ panels}}}$

Cost $= 27 \text{ panels } \times \$260 / \text{panel} = \underline{\underline{\$7020}}$

240W panel will be more beneficial.

(b) The amount of excess electricity in a month:

$= 27 \text{ panels } \times 36 \text{ kWh} / \text{panel} - 948 \text{ kWh} = 24 \text{ kWh}$

$$\text{Total cost savings} = \frac{24 \text{ kWh}}{\text{month}} \left| \frac{12 \text{ months}}{1 \text{ yr}} \right| \frac{3 \text{ yr}}{} \left| \frac{\$ \ 0.15}{1 \text{ kWh}} \right. = \underline{\underline{\$129.6}}$$

Student Response

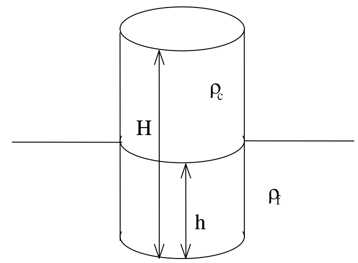
(c) Student Response

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

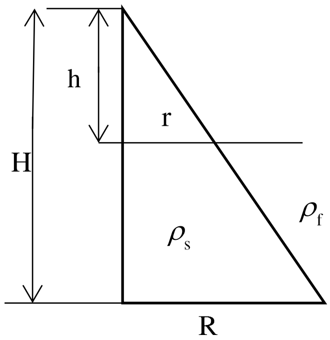
$$\rho_c = \frac{\rho_f h}{H} = \frac{(30 \text{ cm} - 13.5 \text{ cm})(1.00 \text{ g/cm}^3)}{30 \text{ cm}} = \underline{\underline{0.55 \text{ g/cm}^3}}$$

(b) $\rho_f = \dfrac{\rho_c H}{h} = \dfrac{(30 \text{ cm})(0.55 \text{ g/cm}^3)}{(30 \text{ cm} - 18.9 \text{ cm})} = \underline{\underline{1.49 \text{ g/cm}^3}}$

(c) Student Response



2.15



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

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

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

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

2.16 **(a)** $\underline{h = 0}$, the drum is empty:

$$V = L\left[r^2\cos^{-1}\left(\frac{r-0}{r}\right)-(r-0)\sqrt{r^2-(r-0)^2}\right]=\underline{\underline{0}}$$

$\underline{h = r}$, the drum is half full/empty:

$$V = L\left[r^2\cos^{-1}\left(\frac{r-r}{r}\right)-(r-r)\sqrt{r^2-(r-r)^2}\right]=L\left[r^2\cos^{-1}(0)\right]=\underline{\underline{\frac{\pi}{2}Lr^2}}$$

$\underline{h = 2r}$, the drum is full:

$$V = L\left[r^2\cos^{-1}\left(\frac{r-2r}{r}\right)-(r-2r)\sqrt{r^2-(r-2r)^2}\right]=L\left[r^2\cos^{-1}(-1)\right]=\underline{\underline{\pi Lr^2}}$$

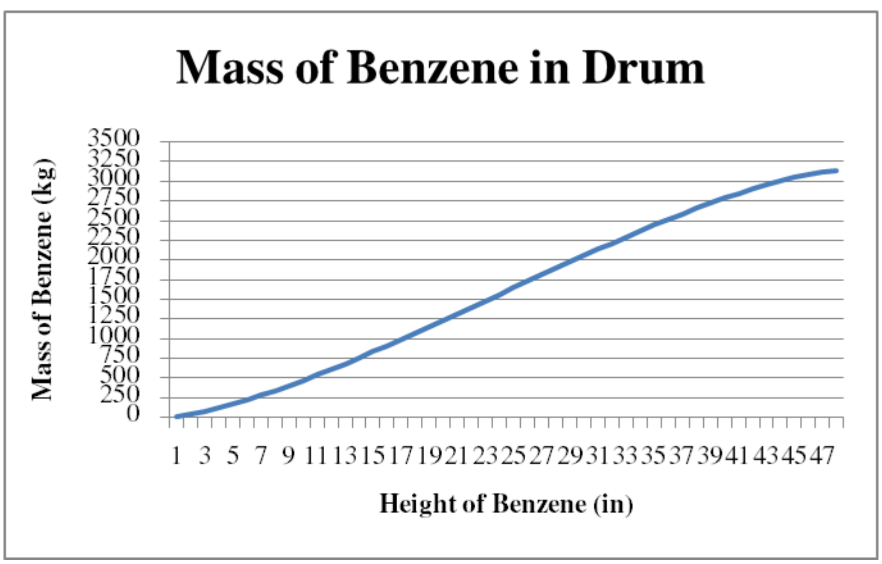
(b) $L = 10$ ft, $r = 2$ ft, $h = 4$ in, $\cos^{-1}$ found in radians

$$h = \frac{4\text{ in}}{}\left|\frac{1\text{ ft}}{12\text{ in}}\right. = 0.333\text{ ft}$$

$$V=(10)\left[(2\text{ ft})^2\cos^{-1}\left(\frac{2\text{ ft}-0.333\text{ ft}}{2\text{ ft}}\right)-(2\text{ ft}-0.333\text{ ft})\sqrt{(2\text{ ft})^2-(2\text{ ft}-0.333\text{ ft})^2}\right]=4.99435\text{ ft}^3$$

$$m=\frac{4.99435\text{ ft}^3}{}\left|\frac{10^6\text{ cm}^3}{35.3145\text{ ft}^3}\right|\frac{0.879\text{ g}}{1\text{ cm}^3}\left|\frac{1\text{ kg}}{10^3\text{ g}}\right.=124.313\text{ kg}\Rightarrow\underline{\underline{124\text{ kg}}}$$

(c)



2.17 $1\ \text{lb}_f = 1\ \text{slug}\cdot\text{ft/s}^2 = 32.174\ \text{lb}_m\cdot\text{ft/s}^2 \Rightarrow 1\ \text{slug}=32.174\ \text{lb}_m$

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

(a) (i) On the earth:

$$M = \frac{135\ \text{lb}_m}{} \left| \frac{1\ \text{slug}}{32.174\ \text{lb}_m} \right. = \underline{\underline{4.20\ \text{slugs}}}$$

$$W = \frac{135\ \text{lb}_m}{} \left| \frac{32.174\ \text{ft}}{\text{s}^2} \right| \frac{1\ \text{poundal}}{1\ \text{lb}_m\cdot\text{ft/s}^2} = \underline{\underline{4.34\times 10^3\ \text{poundals}}}$$

(ii) On the moon

$$M = \frac{135\ \text{lb}_m}{} \left| \frac{1\ \text{slug}}{32.174\ \text{lb}_m} \right. = \underline{\underline{4.20\ \text{slugs}}}$$

$$W = \frac{135\ \text{lb}_m}{} \left| \frac{32.174\ \text{ft}}{6\ \text{s}^2} \right| \frac{1\ \text{poundal}}{1\ \text{lb}_m\cdot\text{ft/s}^2} = \underline{\underline{724\ \text{poundals}}}$$

(b)

$$F = ma \Rightarrow a = F/m = \frac{405\ \text{poundals}}{35.0\ \text{slugs}} \left| \frac{1\ \text{lb}_m\cdot\text{ft/s}^2}{1\ \text{poundal}} \right| \frac{1\ \text{slug}}{32.174\ \text{lb}_m} \left| \frac{1\ \text{m}}{3.2808\ \text{ft}} \right.$$

$$= 0.1096\ \text{m/s}^2 \Rightarrow \underline{\underline{0.110\ \text{m/s}^2}}$$

2.18 **(a)**

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

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

(b) On the moon: $W = \frac{3 \text{ cuz}}{} \Big| \frac{32.174 \text{ ft}}{6 \quad \text{s}^2} \Big| \frac{1 \text{ doozy}}{5.3623 \text{ cuz}\cdot\text{ft/s}^2} = \underline{\underline{3 \text{ doozies}}}$

In Lizard Lick, NC: $W = (3)(32.174)/5.3623 = \underline{\underline{17 \text{ doozies}}}$

2.19 (a) First we need to make assumptions about how many doses were taken per day by a patient. While there are 6 four hour periods in one calendar day, it is unlikely a patient would wake up at 4 in the morning to take a dose. If a person was awake for 16 hours, they would take, at most, 4 doses (Waking, mid-day, before sleep):

$$V_D = 4 \text{ doses} \times \frac{3 \text{ teaspoon}}{\text{dose}} = 12 \text{ teaspoons}$$

The volume of a teaspoon is roughly 5 mL/teaspoon:

$$V_D = 12 \text{ teaspoon} \times \frac{5 \text{ mL}}{\text{teaspoon}} = \underline{\underline{60 \text{ mL}}} \text{ consumed in a day}$$

(b)

$$m_{\text{patient, max}} = \frac{60 \text{ mL}}{} \left| \frac{\text{kg body mass}}{1.4 \text{ mL}} \right| \frac{2.20462 \text{ lb}_m}{\text{kg}} = 94.5 \text{ lb}_m \approx \underline{\underline{95 \text{ lb}_m}}$$

Anyone under 95 lb_m would be fatally poisoned. The intuitive answer is that a highly poisonous substance should not be taken even if the quantities are supposedly below a lethal level. Glycol (antifreeze) poisoning is attended with severe symptoms even if death is not the ultimate result. If the lethal dose is in error or has some variability, then even those above that body mass are at risk.

(c)

$$N_p = \frac{V}{V_d} = \frac{240 \text{ gal}}{60 \text{ mL}} \times \frac{10^6 \text{ mL}}{264.17 \text{ gal}} = \underline{\underline{15{,}141 \text{ people}}}$$

(d)

- Research chemist might have turned up a possible alternate solvent. Definitely would have discovered DEG's poisonous qualities.
- Product made with almost nonexistent testing for quality, storage life, toxicity, etc. Proper testing would have prevented the poisoning and otherwise improved the product.
- Product released unrestricted without initial clinical field testing. Send out a test batch or two and see what the results are.

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

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

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

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

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

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

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

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

2.21 $R \approx \dfrac{(7\times10^{-1})(3\times10^{5})(6)(5\times10^{4})}{(3)(5\times10^{6})} \approx 42\times10^{2} \approx \underline{\underline{4\times10^{3}}}$ (Any digit in range 2-6 is acceptable)

$R_{\text{exact}} = 3812.5 \Rightarrow \underline{\underline{3810}} \Rightarrow \underline{\underline{3.81\times10^{3}}}$

2.22 **(a)** 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: $R = 103.1 - 97.3 = \underline{\underline{5.8^\circ\text{C}}}$

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

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

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

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

2.23

(a)

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

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

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

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

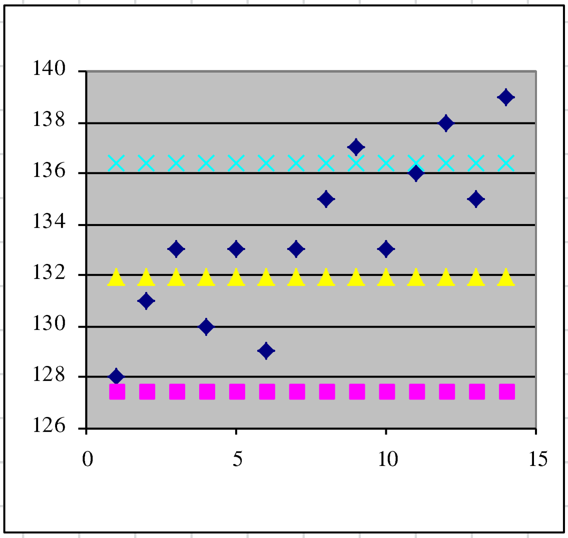
(c) Inadequate cleaning between batches, impurities in raw materials, variations in reactor temperature (failure of reactor control system), problems with the color measurement system, operator carelessness

2.24

(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.

2.25 **(a)** $Q' = \dfrac{2.36\times10^{-4}\ \text{kg}\cdot\text{m}^2}{\text{h}} \left| \dfrac{2.10462\ \text{lb}}{\text{kg}} \right| \dfrac{3.2808^2\ \text{ft}^2}{\text{m}^2} \left| \dfrac{1\ \ \text{h}}{3600\ \text{s}} \right.$

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

$Q'_{\text{exact}} = \underline{\underline{1.48\times10^{-6}\ \text{lb}\cdot\text{ft}^2/\text{s}}} = \underline{\underline{0.00000148\ \text{lb}\cdot\text{ft}^2/\text{s}}}$

2.26

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

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

2.27 $\text{Re} = \dfrac{Du\rho}{\mu} = \dfrac{0.48\ \text{ft}}{\text{s}}\left|\dfrac{1\ \ \text{m}}{3.2808\ \text{ft}}\right|\dfrac{2.067\ \text{in}}{0.43\times10^{-3}\ \text{kg/m}\cdot\text{s}}\left|\dfrac{1\ \ \text{m}}{39.37\ \text{in}}\right|\dfrac{0.805\ \text{g}}{\text{cm}^3}\left|\dfrac{1\ \text{kg}}{1000\ \text{g}}\right|\dfrac{10^6\ \text{cm}^3}{1\ \ \text{m}^3}$

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

2.28

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

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

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

(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)	(N-s/m^2)	(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

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

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

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

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

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

(d) The equation predicts that the diameter of the crystals will increase with the size of the crystals. This corresponds to an empirical formula since, as the rate is faster, the duration time is smaller, leaving less time for mixing and larger crystals.

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

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

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

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

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

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

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

2.31

(a)

$$\frac{t\ (\text{hr})\ \Big|\ 60\ \text{min}\ \Big|\ 60\ \text{s}}{\quad\ \Big|\ 1\ \text{hr}\ \Big|\ 1\ \text{min}} = 3600t\ \text{s}$$

$$V\left(\text{in}^3\right) = \frac{V\ \text{cm}^3\ \Big|\ 1728\ \text{in}^3}{\quad\ \Big|\ 28317\ \text{cm}^3} = 0.06102V\left(\text{cm}^3\right)$$

$$\Rightarrow \underline{\underline{V\left(\text{in}^3\right) = 0.061a \cdot e^{3600b \cdot t(\text{hr})}}}$$

(b) $a = \text{cm}^3$, $b = \text{s}^{-1}$

2.32 (a) 3.00 mol/L, 2.00 min^{-1}

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

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

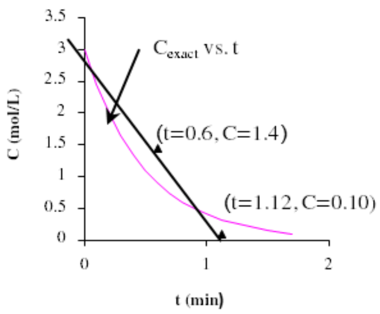
For t=0.6 min: $$C_{int} = \frac{0.406 - 3.00}{1 - 0}(0.6 - 0) + 3.00 = \underline{\underline{1.4 \text{ mol/L}}}$$

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

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

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

(c)

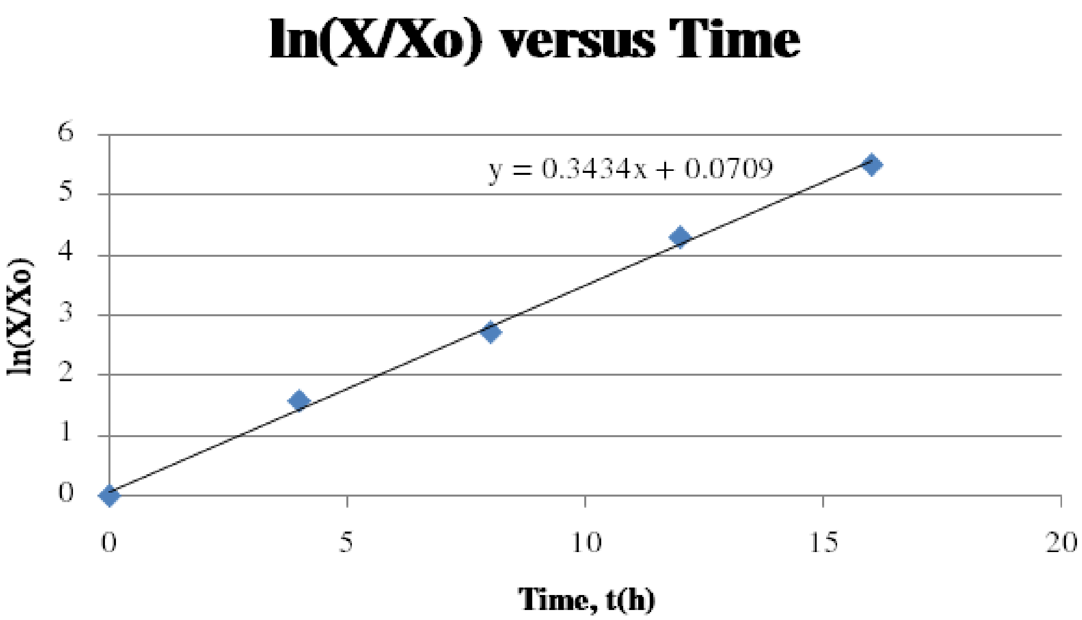


2.33 **(a)** $\mu = \text{h}^{-1}$

(b) i. $\ln\left(X/X_0\right)$ vs. t on rectangular axes.

ii. X/X_0 vs. t on semi-log axes.

(c)



μ is a slope of the graph, so $\mu = \underline{\underline{0.3434\ \text{h}^{-1}}}$

(d)

For doubling the ratio $X/X_0 = 2$

$\ln\left(X/X_0\right) = \mu t + b$

$t = (\ln(2) - 0.0709)/0.3434 \Rightarrow \underline{\underline{t = 1.81\ \text{hr}}}$

2.34 (a)

time, t (h)	Concentration, C	ln C
0 (8am)	x	ln x
3 (11am)	3850	8.2558
9 (5am)	36530	10.5059

i) exponential growth: $C = C_0 e^{kt} \Rightarrow \ln C = \ln C_0 + kt$

$$\begin{cases} 8.2558 = \ln C_0 + 3k \\ 10.5059 = \ln C_0 + 9k \end{cases} \Rightarrow \begin{array}{l} \underline{\underline{k = 0.375}} \\ \ln C_0 = 7.13075 \Rightarrow \underline{\underline{C_0 = 1250}} \end{array}$$

ii) linear growth: $C = C_0 + kt$

$$\begin{cases} 3850 = C_0 + 3k \\ 36530 = C_0 + 9k \end{cases} \Rightarrow \begin{array}{l} \underline{\underline{k = 5446.7}} \\ \underline{\underline{C_0 = -12490}} \end{array}$$

C_0 becomes negative, so linear relationship is not reasonable.

iii) power-law growth: $C = kt^b \Rightarrow \ln C = \ln k + b \ln t$

$$\begin{cases} 8.2558 = \ln k + b \ln 3 \\ 10.5059 = \ln k + b \ln 9 \end{cases} \Rightarrow \begin{array}{l} \ln k = 6.0057 \\ b = 2.048 \end{array}$$

$\underline{\underline{k = 405.7}}$

C_0 cannot be determined, so power-law relationship is not reasonable.

(b) exponential growth: $C = C_0 e^{kt}$ (see calculations below in Part (a) to verify)

(c) At $t = 0$, using the exponential growth relationship, $C = kt^b \Rightarrow \ln C = \ln k + b \ln t$

$\underline{\underline{C = C_0 = 1250}}$ -- Assumptions: Student response.

(d)

$C = 2$ million cells $= 2 \times 10^6$ cells

$\ln C = \ln C_0 + kt$

$\ln(2 \times 10^6) = 7.131 + 0.375t$

$\Rightarrow t = 19.67$ hr ≈ 20 hr

$\therefore$ 4 am

In the future, you might plant to start the experiment at a more convenient time so that you don't have to make late night trips to the lab.

2.35

(a) Since the bacteria catalyze the production reaction, we would like to have an abundant population as soon as possible, which means we want a high bacterial growth rate, dC/dt. For a given concentration, C, the growth rate is μC, so a high value of μ is desirable.

(b) To integrate this expression, separate the variables (bring all functions of C to one side and all functions of t to the other), and then integrate each side from the initial condition ($t=0$, $C=C_o$):

$$\frac{dC}{dt} = \mu C \Rightarrow \frac{dC}{C} = \mu dt \Rightarrow \int_{C_o}^{C} \frac{dC}{C} = \mu \int_0^t dt \Rightarrow \underline{\underline{\ln C - \ln C_o = \mu t}}$$

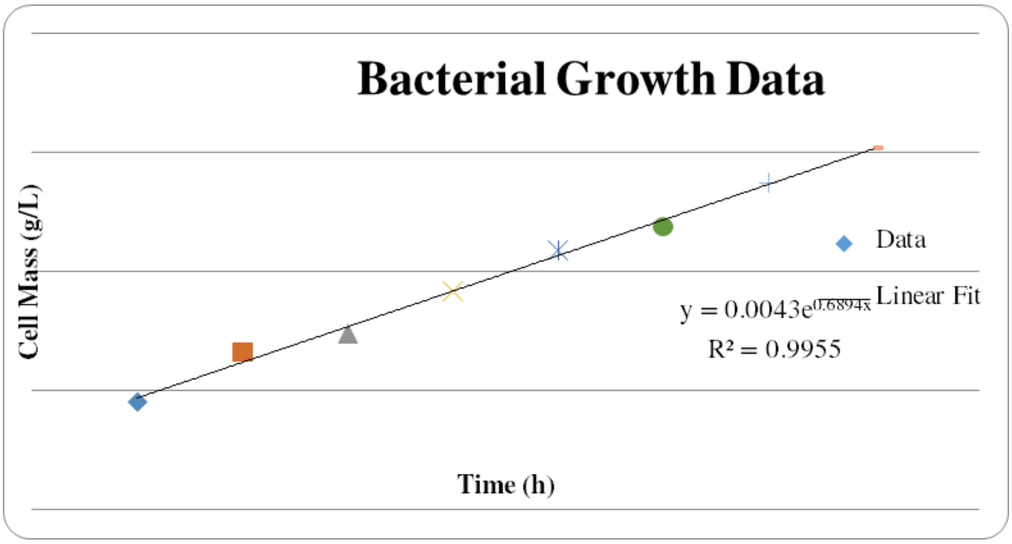
(Note: Since dC/C is dimensionless, $\mu(dt)$ must be as well, which means that μ must have units of inverse time. If t is in hours, then μ has units of h^{-1}.)

If the given expression is rewritten to $\ln C = \mu t + \ln(C_o)$, it follows that

($\ln C$) vs. t on rectangular coordinates → straight line, slope μ, intercept $\ln(C_o)$

C vs. t on semilog coordinates → straight line, slope μ, intercept C_o

(c) A semilog plot of the data in the table is shown below. The linearity of the plot indicates that balanced growth applies over the period of data collection.



From the slope of the plot, the specific growth rate is $\underline{\underline{\mu=0.689\ \text{h}^{-1}}}$.

(d) To determine the doubling time, we can find the value of t for a value of $C = 2C_0$.

$$\ln C - \ln C_0 = \ln\frac{C}{C_0} = \mu t \xrightarrow[t=t_{1/2}]{C=2C_0} \ln 2 = \mu t_{1/2} \Rightarrow \underline{\underline{t_{1/2} = \frac{\ln 2}{\mu} = \frac{\ln 2}{0.689\ \text{h}^{-1}} = 1.0\ \text{h}}}$$

2.36 **(a)** This is a power law relationship: $y = a\,(x^b)$

(b) Express the equation as ln(y) = ln (a) + b (ln(x))

$$\text{Slope } (=b) = \frac{\ln(C_{D2}) - \ln(C_{D1})}{\ln(C_{C2}) - \ln(C_{C1})} = \frac{\ln(2.27) - \ln(1.4)}{\ln(10) - \ln(2.8)} = 0.379$$

ln(2.95) = ln (a) + 0.379 ln (20)

ln(a) = -0.054

a = 0.948

$$C_D = 0.948 C_c^{0.379}$$

(c) When $C_D = 10$,

$$10 = 0.948\, C_C^{0.379}$$

Concentration of C_C = 502.25 mol/L

(d) Arguments for **not** stopping the reaction until C_D = 13 mol/L: More product C would be produced.

Arguments for **stopping** the reaction prior to C_D = 13 mol/L: Too close to the explosive limit of 15 mol/L, more hazardous product D to deal with.

2.37 (a)

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

(b)

$$p^*_{148.2} = 1+(100-1)\frac{148.2-98.5}{215.5-98.5} = \underline{\underline{43.05 \text{ mm Hg}}}$$

$$\left|\frac{10-43.05}{10}\right| \times 100 = \underline{\underline{330.5\%}}\ \underline{\underline{\text{error}}}$$

Student Response

2.38 (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 $y = f(x)$]

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

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

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

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

$$= (\ln 807.0 - \ln 40.2)/(\ln 2.0 - \ln 1.0) = 4.33$$

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

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

2.39 **(b)** Plot y^2 vs. x^3 on rectangular axes. Slope $= m$, Intcpt $= -n$

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

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

OR

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

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

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

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

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

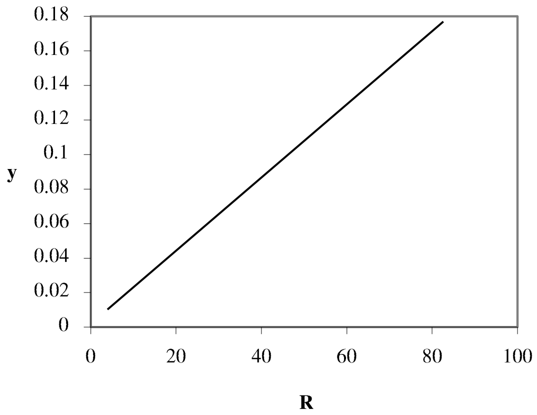
(f) $\log_{10}(xy) = a(x^2 + y^2) + b$

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

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

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

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

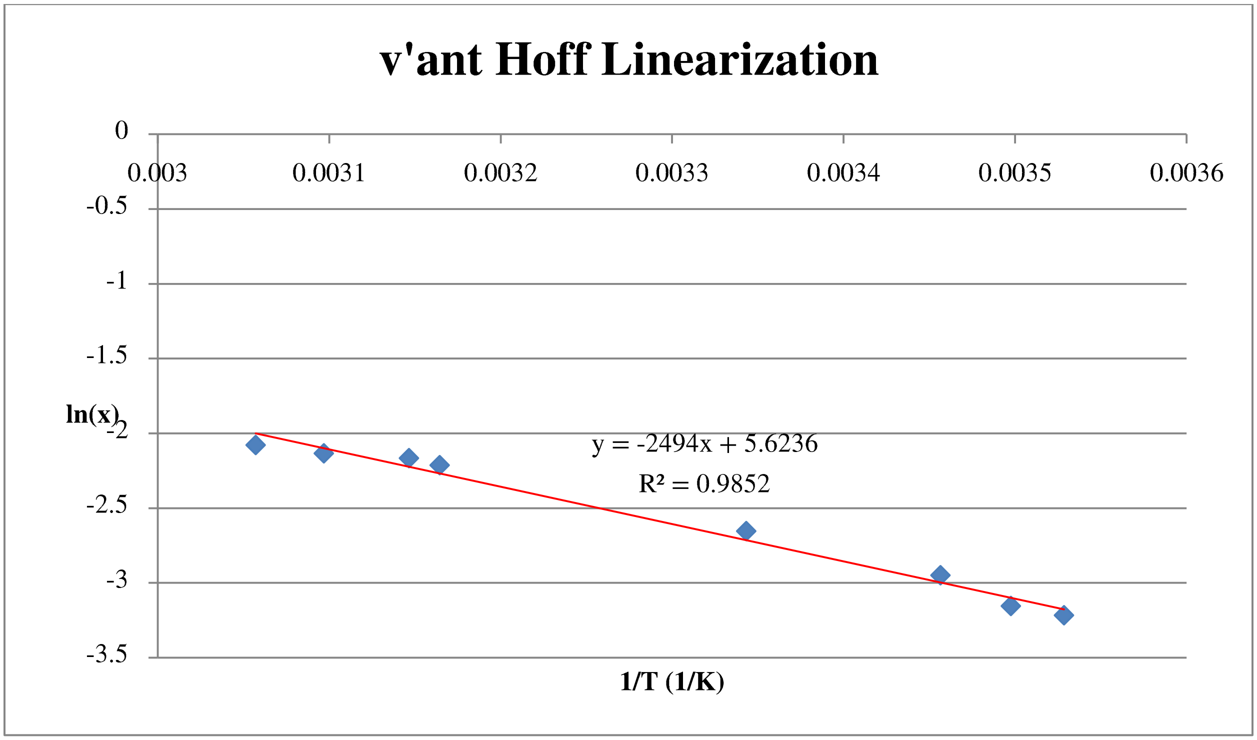


$$y = aR + b \qquad \left.\begin{aligned} a &= \frac{0.169-0.011}{80-5} = 2.11\times10^{-3} \\ b &= 0.011-\left(2.11\times10^{-3}\right)\left(5\right) = 4.50\times10^{-4} \end{aligned}\right\} \Rightarrow \underline{\underline{y = 2.11\times10^{-3}R + 4.50\times10^{-4}}}$$

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

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

2.41



a = -2494 ˚K, *b* = 5.624 (unitless)

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

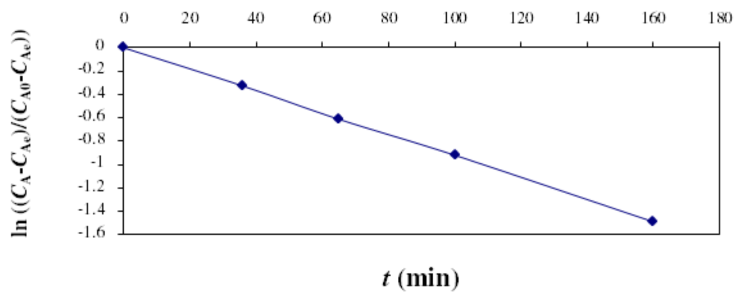
$$T = 85^\circ C \Rightarrow \phi = \left(9677.6/85\right)^{0.8403} = \underline{\underline{53.5 \text{ L/s}}}$$

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

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

(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*=85°C is probably the least likely to be correct, because it is farthest away from the date range.

2.43 **(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.



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

(b)

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

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

C_A(t = 120 min) $= m/V \Rightarrow m_A = CV = (9.300\times 10^{-2}\ \text{g/L})(125\ \text{L}) = 11.625$ g A

$m_{A0} = C_{A0}V = (0.1823\ \text{g/L})(125\ \text{L}) = 22.787$ g A

This means that (22.787 - 11.625) = 11.16g of A have been consumed at t = 120 min.
Since the reaction is 1:1, $\underline{\underline{11.16\ \text{g B}}}$ have been generated.

(c) $\ln\left(\frac{C_A - C_{Ae}}{C_{A0} - C_{Ae}}\right) = -kt \Rightarrow t = \frac{-1}{k}\ln\left(\frac{C_A - C_{Ae}}{C_{A0} - C_{Ae}}\right)$

$\rightarrow C_A = 1.1C_{Ae} = 1.1(0.0495\ \text{g/L}) = 0.05445\ \text{g/L}$

$$t = \frac{-1}{0.0093\ \text{min}^{-1}}\ln\left(\frac{0.05445\ \text{g/L} - 0.0495\ \text{g/L}}{0.1823\ \text{g/L} - 0.0495\text{g/L}}\right) = 353.705\ \text{min} \Rightarrow \underline{\underline{354\ \text{min}}}$$

$m_A = (0.05445\ \text{g/L})(125\ \text{L}) = 6.80625$ g A

As in part (b), $m_B = 22.787 - 6.80625 = \underline{\underline{15.98\ \text{g B}}}$

$\rightarrow C_A = 1.05C_{Ae} = 1.1(0.0495\ \text{g/L}) = 0.051975\ \text{g/L}$

$$t = \frac{-1}{0.0093\ \text{min}^{-1}}\ln\left(\frac{0.051975\ \text{g/L} - 0.0495\ \text{g/L}}{0.1823\ \text{g/L} - 0.0495\text{g/L}}\right) = 428.237\ \text{min} \Rightarrow \underline{\underline{428\ \text{min}}}$$

$m_A = (0.051975\ \text{g/L})(125\ \text{L}) = 6.49875$ g A

$m_B = 22.787 - 6.49875 = \underline{\underline{16.29\ \text{g B}}}$

$$\rightarrow C_A = 1.01C_{Ae} = 1.1(0.0495 \text{ g/L}) = 0.049995 \text{ g/L}$$

$$t = \frac{-1}{0.0093 \text{ min}^{-1}} \ln\left(\frac{0.049995 \text{ g/L} - 0.0495 \text{ g/L}}{0.1823 \text{ g/L} - 0.0495\text{g/L}}\right) = 601.2948 \text{ min} \Rightarrow \underline{\underline{601 \text{ min}}}$$

$$m_A = (0.049995 \text{ g/L})(125 \text{ L}) = 6.249375 \text{ g A}$$

$$m_B = 22.787 - 6.249375 = \underline{\underline{16.54 \text{ g B}}}$$

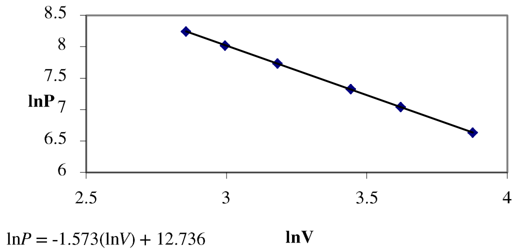
2.44 (a) ft^3 and h^{-2}, respectively

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

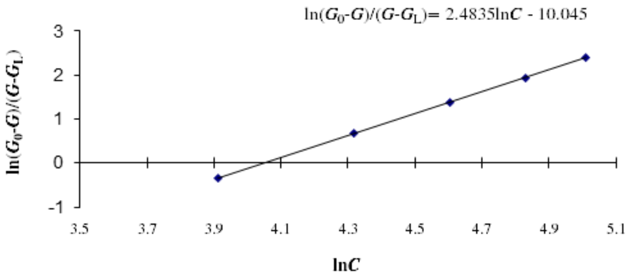
2.45 $PV^k = C \Rightarrow P = C / V^k \Rightarrow \ln P = \ln C - k \ln V$



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

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

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



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

Intercept=ln $K_L=-10.045\Rightarrow K_L=\underline{\underline{4.340\times10^{-5}\ \text{ppm}^{-2.483}}}$

(b) $C=475\Rightarrow\frac{G-1.80\times10^{-3}}{3.00\times10^{-3}-G}=4.340\times10^{-5}(475)^{2.483}\Rightarrow G=\underline{\underline{1.806\times10^{-3}}}$

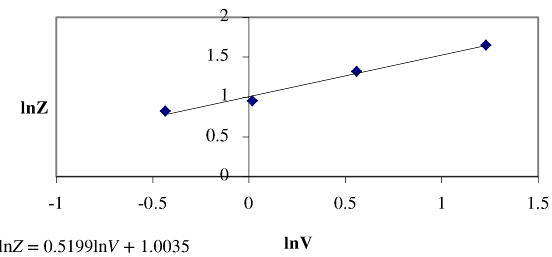
C=475 ppm is well beyond the range of the data.

2.47 **(a)** For runs 2, 3 and 4:

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

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

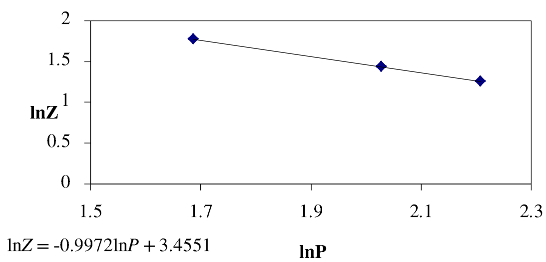
(b) When P is constant (runs 1 to 4), plot $\ln Z$ vs. $\ln\dot{V}$. Slope=b, Intercept= $\ln a + c\ln p$



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

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

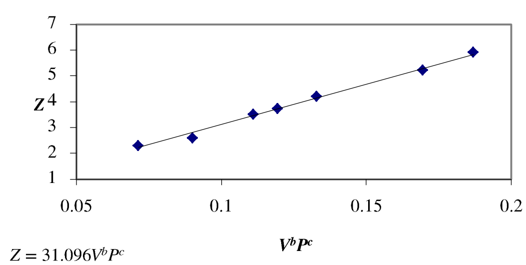
When $\dot{V}$ is constant (runs 5 to 7), plot ln$Z$ vs. ln$P$. Slope=c, Intercept= $\ln a + c\ln\dot{V}$



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

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

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



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

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

2.48 (a)

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

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

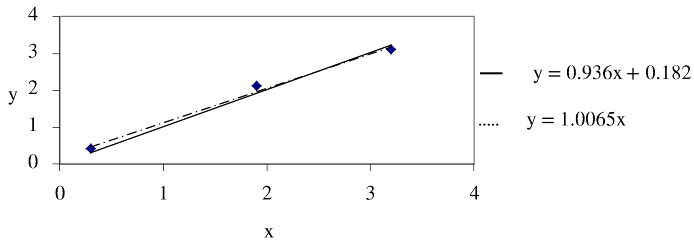
$$s_x=\frac{1}{n}\sum_{i=1}^{n}x_i=(0.3+1.9+3.2)/3=1.8;\quad s_y=\frac{1}{n}\sum_{i=1}^{n}y_i=(0.4+2.1+3.1)/3=1.867$$

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

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

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

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



2.49 (a)

$<t> =$	5.0
$<T> =$	32.9
$<t^2> =$	36.667
$<t>^2 =$	25
$<t*T> =$	182.933

$T = mt + b$

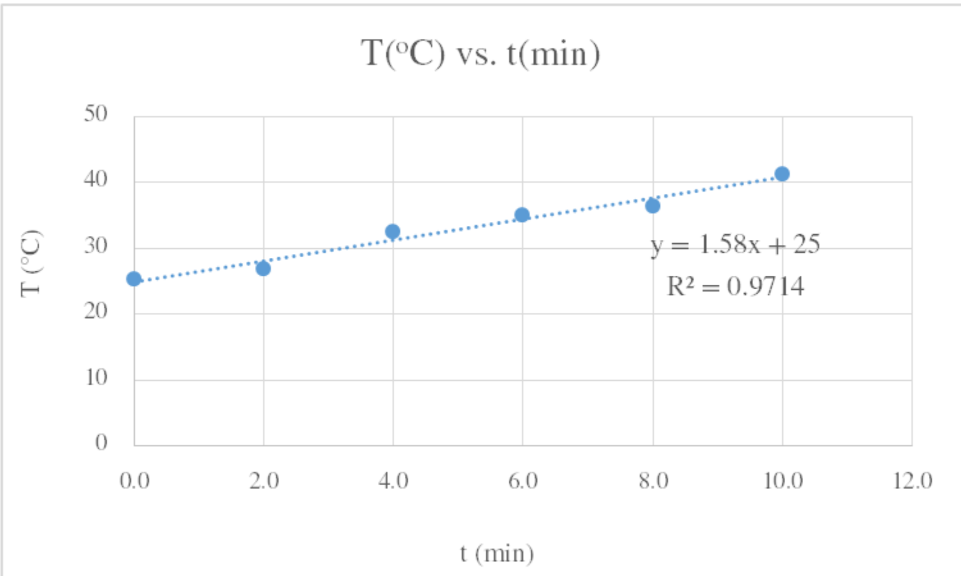
$$m = \frac{<tT> - <t><T>}{<t^2> - <t>^2} = 1.56$$

$$b = <T> - m<t> = 25$$

$$\Rightarrow \underline{\underline{T = 1.56t + 25}}$$

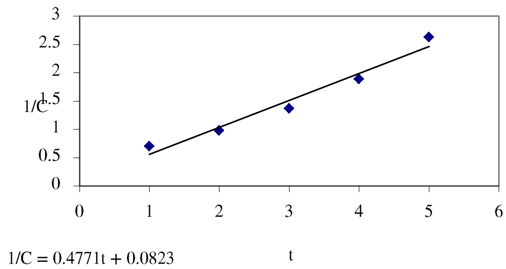
Convert it to a formula for $t(T)$: $t = \dfrac{T-25}{1.56} = \underline{\underline{0.641T - 16.03}}$

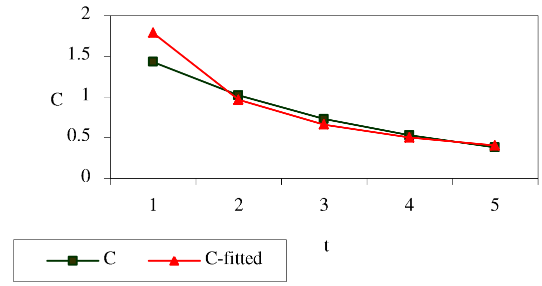
(b)



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

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





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

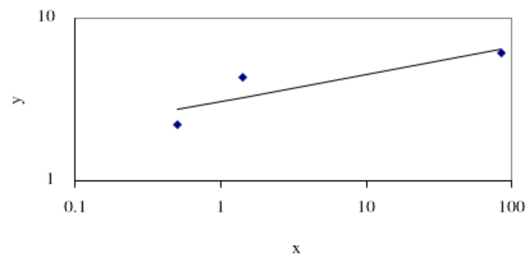
$$t = (1/C - a)/b = (1/0.01 - 0.082)/0.477 = \underline{\underline{209.5\ \text{h}}}$$

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

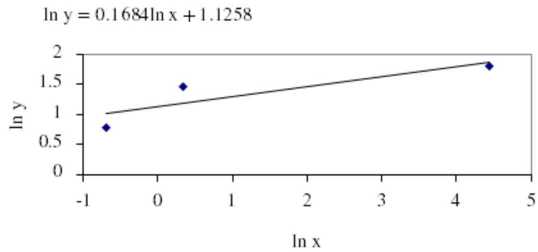
(e) The concentration of the hazardous substance could be enough to cause damage to the biotic resources in the river; the treatment requires an extremely large period of time; some of the hazardous substances might remain in the tank instead of being converted; the decomposition products might not be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

(f) Student Response

2.51 (a) and (c)



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

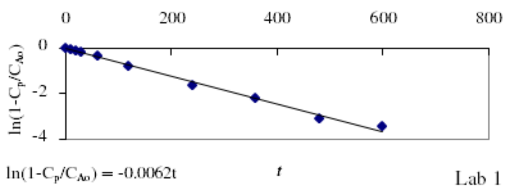


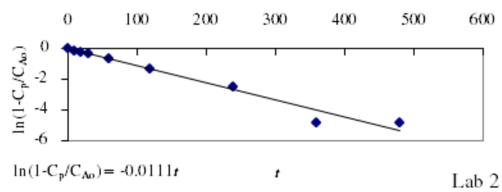
$b = \text{slope} = \underline{\underline{0.168}}$

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

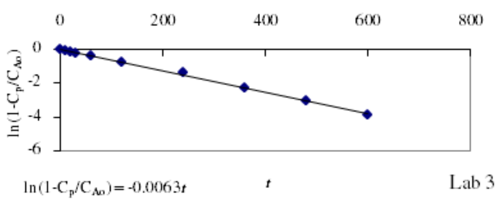
2.52 (a) $\ln(1-C_p/C_{A0})$ vs. t in rectangular coordinates. Slope=$-k$, intercept=0

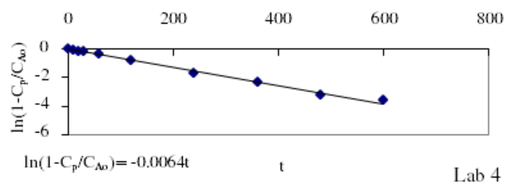
(b)





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





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

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

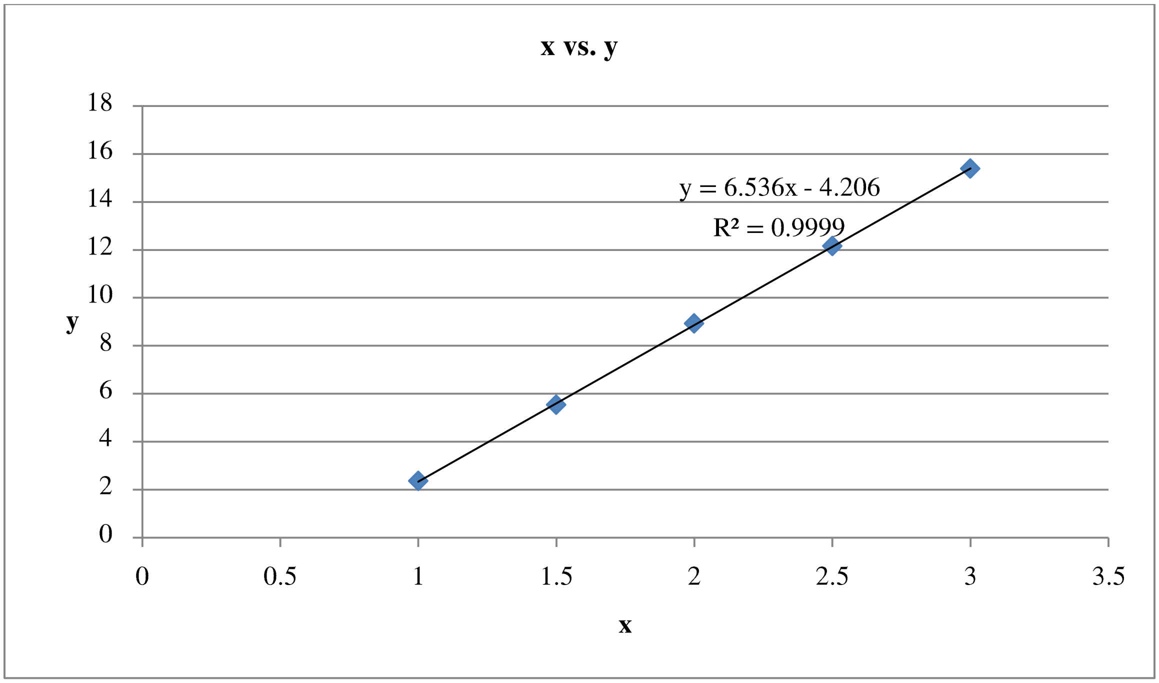
(d) Errors in measurement of concentration, poor temperature control, errors in time measurements, delays in taking the samples, impure reactants, impurities acting as catalysts, inadequate mixing, poor sample handling, clerical errors in the reports, dirty reactor.

2.53

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

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

2.54



x	y	y=ax+b (Excel)	Deviation	Absolute Deviation
1	2.35	2.33	0.02	0.02
1.5	5.53	5.598	-0.068	0.068
2	8.92	8.866	0.054	0.054
2.5	12.15	12.134	0.016	0.016
3	15.38	15.402	-0.022	0.022

The average deviation is 0.036, which indicates a good fit (consistent with the $R^2 = 0.999$). The linear parameters are obtained from Excel: $a = 6.536 \quad b = -4.206$

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

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

(c)

T(K)	D(cm2/s)		$1/T$	ln D
347.0	1.34E-06		0.0028818	-13.52284
374.2	2.50E-06		0.0026724	-12.89922
396.2	4.55E-06		0.002524	-12.30038
420.7	8.52E-06		0.002377	-11.67309
447.7	1.407E-05		0.0022336	-11.17147
471.2	1.999E-05		0.0021222	-10.82028

Use points (0.02882, -13.523) and (0.002672, -12.899)

$$\begin{cases} -13.523 = 0.002882a + b \\ -12.899 = 0.002672a + b \end{cases}$$

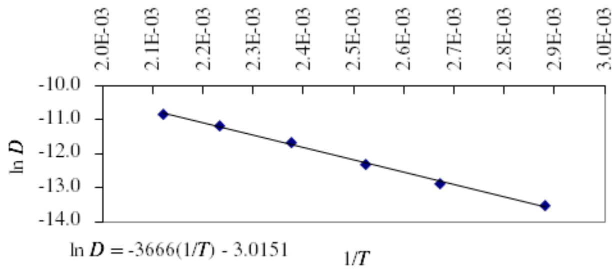
solve these equations for a and b

$$a = -2971.43 = -\frac{E}{R} \Rightarrow E = (2971.43\text{ K})(1.987\text{ cal/mol}\cdot\text{K}) = \underline{\underline{5904\text{ cal/mol}}}$$

$$b = -4.959 = \ln D_0 \Rightarrow D_0 = \exp(-4.959) = \underline{\underline{0.00702\text{ cm}^2/\text{s}}}$$

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

(d) Using a spreadsheet:



$$\ln D_0 = -3.0151$$

$$D_0 = \exp(-3.0151) = \underline{\underline{0.0490 \text{ cm}^2/\text{s}}}$$

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