SOLUTIONS TO EXAM 2

PROBLEM 1 (40 pts):

Estimate the added cancer risk for a 50-kg individual who is exposed to 0.3 mg m^{-3} formaldehyde (CH_2O) in her workplace's air, and determine whether the risk is acceptable. Assume that exposure occurs 8 hours per day, 5 days per week, 50 weeks per year, for 10 years. The potency factor for inhaled formaldehyde is thought to be 0.2 kg day mg^{-1}.

Chronic daily intake:

$$CDI = \frac{0.3\,\text{mg CH}_2\text{O/m}^3\,\text{air} \times 20\,\text{m}^3\,\text{air/day} \times 8\,\text{hr}/24\,\text{hr} \times 5\,\text{day/wk} \times 50\,\text{wk/yr} \times 10\,\text{yr}}{50\,\text{kg} \times 365\,\text{day/yr} \times 70\,\text{yr}}$$

$$= 3.9 \times 10^{-3}\,\text{mg CH}_2\text{O}\,\text{kg}^{-1}\,\text{day}^{-1}$$

Added cancer risk:

$$CDI \times PF = 7.8 \times 10^{-4} = 783\,\text{per million}$$

The risk is higher than 1 per million and therefore not acceptable.

Assumptions: EPA default values for inhalation rate and person's lifetime; linear toxicity with given slope factor.

PROBLEM 2 (25 pts):
How many liters of pure oxygen at 30°C and a pressure of 1 atm are required to burn 1 kg methane (CH_4)? The reaction stoichiometry is $CH_4 + 2\,O_2 \rightarrow 2\,H_2O + CO_2$.

Determine number of moles of methane:

$$1\,\text{kg CH}_4 \times \text{mol CH}_4/16\text{ g CH}_4 \times 1000\,\text{g}/\text{kg} = 62.5\,\text{mol CH}_4$$

Determine number of moles of oxygen required:

$$62.5\,\text{mol CH}_4 \times 2\text{ mol O}_2/\text{mol CH}_4 = 125\,\text{mol O}_2$$

Determine volume of 1 mol of oxygen under given conditions (approximate as ideal gas):

$$v = RT/P = 0.08206\,\text{L atm mol}^{-1}\,\text{K}^{-1} \times 303.15\,\text{K}/1\,\text{atm} = 24.88\,\text{L}/\text{mol}$$

Determine the total volume required:

$$V = nv = 24.88\,\text{L}/\text{mol} \times 125\,\text{mol} = 3110\,\text{L}$$

PROBLEM 3 (25 pts):
A river channel has a half-circle cross-section with diameter 2 m. The velocity profile in the river channel is radial and given as $v(r) = v_0(1 - r/R)$, where $v_0 = 4$ m s^{-1}.
(a) How many kg of water are in a 100-m length of the river?

The cross-sectional area is
$$A = \pi R^2/2 = 1.57\ m^2$$
The volume in this length of river is
$$V = LA = 157\ m^3$$
Assuming a typical density for liquid water, the mass of water in the river is
$$m = \rho V = 1000\ kg\ m^{-3} \times 157\ m^3 = 1.57 \times 10^5\ kg$$

(b) What is the volume flow rate of the river?

This requires integrating the velocity profile over the half-circle cross-sectional area:
$$Q = \int_0^R \pi\, v(r)\, r\, dr$$
$$= \pi v_0 \int_0^R (1 - r/R)\, r\, dr$$
$$= \pi v_0 \left[\frac{r^2}{2} - \frac{r^3}{3R} \right]_{r=0}^{R}$$
$$= \frac{\pi v_0 R^2}{6}$$
$$= 2.09\ m^3\ s^{-1}$$

PROBLEM 4 (10 pts):
In what category is each of the following chemical reactions?
(a) $CaCO_3(s) \leftrightharpoons Ca^{+2} + CO_3^{-2}$
Solubility/precipitation

(b) $SO_2(g) \leftrightharpoons SO_2(aq)$
Volatilization/condensation

(c) $HI(aq) \leftrightharpoons H^{+} + I^{-}$
Dissociation/association

(d) $C_6H_{14}(aq) \leftrightharpoons C_6H_{14}(ads)$
Desorption/adsorption

What do these reactions all have in common?
These are all reversible reaction types, where the equilibrium constant is important in determining the relative concentration of the reactants versus products.

GIVEN INFORMATION

1 m^3 = 1000 L, 1 mg = 10^{-3} g, 1 µg = 10^{-6} g

T(degK) = T(degC) + 273.15, 1 atm = 101325 Pa

$$\mathrm{MW}_i=\frac{\text{mass i}}{\text{mols i}}=\sum_{k=1,K} n_k \mathrm{AW}_k, \quad \mathrm{FW}=\sum_{k=1,K} y_i \mathrm{MW}_i$$

PV=nRT where R=0.08206 L atm mol^{-1} K^{-1}

$$\rho_{air}=\frac{mass\ air}{volume\ air}=\frac{n_{air}\times MW_{air}}{V_{air}}=\frac{n_{air}}{V_{air}}\times MW_{air}=\frac{P}{RT}\times MW_{air}$$

$$M_i=\frac{\text{mols i}}{\text{L m}}=\frac{\text{mass}_i/\text{MW}_i}{V_w}=\frac{m_i}{\text{MW}_i}$$

$$\text{pH}=-\log(M_{H^+}),\ \text{pOH}=-\log(M_{OH^+}),\ \text{pH}+\text{pOH}=14 \text{ at } 25°\text{C}$$

$$y_i=\frac{mols\ i}{mols\ t}\approx\frac{mass_i/MW_i}{\rho_m\times V_m / MW_m} \quad \textbf{and} \quad \sum_{i=1,I} y_i=1$$

$$\mathrm{P}_i=y_i\mathrm{P} \quad \textbf{and} \quad \sum_{i=1,I} P_i=P$$

AW of elements in g/mol: 1 for H, 12 for C, 14 for N, 16 for O, 31 for P, 32 for S
Density of pure water at 1 atm and 4°C = 1000 kg/m^3

$$\text{Lifetime risk of death}=\text{Chronic Daily Intake}\times\text{Potency Factor}$$

$$\text{Chronic Daily Intake}=\frac{\text{Exposure concentration}\times\text{Intake rate}\times\text{Exposure duration}}{\text{Body weight}\times\text{Lifetime}}$$

$$0.5\times C(0)=C(0)e^{-kt_{1/2}} \text{ and } k=-\ln(0.5)/t_{1/2}$$

$$\text{Exposure concentration }=C(0)\times e^{-kt}\times\text{Bioconcentration factor}$$

$$\text{Lifetime hazard quotient}=\frac{\text{Chronic Daily Intake}}{\text{Reference Dose}}$$

$$\frac{d}{dt}\int_{cv}\rho\, d\forall=-\int_{cs}\rho\, V(A)\cdot n\, dA \quad \text{and} \quad \frac{d}{dt}\int_{cv}\rho\, d\forall=\frac{dm}{dt}$$

$$\int_{cs}\rho\, V(A)\cdot n\, dA=-\int_{cs,in}\rho\, V(A)\, dA+\int_{cs,out}\rho\, V(A)\, dA=\sum_{cs,in}\rho\,\bar{V}A-\sum_{cs,out}\rho\,\bar{V}A=\sum_{cs,in}\dot{m}-\sum_{cs,out}\dot{m}$$

Land use	Exposure pathway	Intake rate (amount/day)	Exposure frequency (day/year)	Exposure duration (year)
Residential	Ingestion of potable water	2 L	350	30
	Ingestion of homegrown produce	42 g (fruit) 80 g (veg.)	350	30
	Ingestion of locally caught fish	54 g	350	30
	Ingestion of soil or dust	200 mg	350	30
	Inhalation of air	20 m^3	350	30
Industrial or commercial	Ingestion of potable water	1 L	250	25
	Ingestion of soil or dust	50 mg	250	25
	Inhalation of air	20 m^3	250	25