BMED 2210
Fall 2015, Midterm I
Instructor: G. Kwong

Name: ANSWER KEY

This is a closed book exam. Paper notes are allowed as well as calculators. Show ALL work and express numeric answers using the correct number of significant figures. Reference tables are found on the last page of the exam.

Good luck!

Question #1		/15
Question #2		/15
Question #3		/15
Question #4		/15
Question #5		/20
Question #6		/20
Total		/100

$\bar{x} = 56.1$

$\sigma = 9.7$

1a. **[10 pts]** A light-year is a measure of length (not a measure of time) equal to the distance that light travels in 1 year. Compute the conversion factor between light-years and meters if the speed of light is 3.00×10^8 m/s.

$$1 \text{ light year} = \left(\frac{3.00 \times 10^8 \text{ m}}{\text{s}}\right)\left(\frac{60 \text{ s}}{1 \text{ min}}\right)\left(\frac{60 \text{ min}}{1 \text{ hr}}\right)\left(\frac{24 \text{ hr}}{1 \text{ day}}\right)\left(\frac{365 \text{ day}}{1 \text{ yr}}\right)$$

$$= \boxed{9.46 \times 10^{15} \text{ m}}$$

(+5 pts) for setting equation up properly

(+5 pts) for correct answer w/ sig. figs.
or +3 pts for correct answer w/o sig. figs.

b. **[5 pts]** Find the distance to the star *Proxima Centauri,* which is 4.0×10^{16} m away, in light-years.

$$\# \text{ of light years} = \left(\frac{4.0 \times 10^{16} \text{ m}}{9.46 \times 10^{15} \text{ m/light year}}\right) = \boxed{4.2}$$

(+5 pts) for correct answer w/ sig. figs.
or +3 pts for correct answer w/o sig. figs.

2. **[15 pts]** Label the following properties as intensive (I) or extensive (E). (2.5 pts each)

a. Temperature	I	d. Mass	E
b. Energy	E	e. Moles of a species	E
c. Energy per unit mass	I	f. Mole fraction	I

3. **[15 pts]** Label the following statements as True (T) or False (F). (3 pts each)

a. The total mass of a system is always conserved in biological systems. T

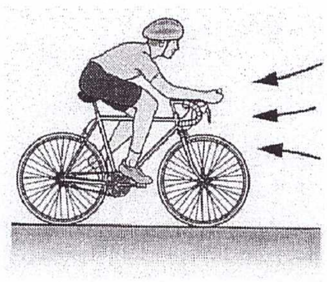
b. The moles of each species in a system is always conserved. F
not in systems w/ chemical reactions

c. In a system with chemical reactions, the limiting reagent is not always consumed entirely. T
The reaction rate R tells you whether a reaction (i.e. the limiting reagent) is 100% efficient

d. The sum of the inlet flow rates minus the sum of the exit flow rates of a system at steady state is equal to zero. F
s.s: $\dot{m}_i - \dot{m}_e + \dot{m}_{gen} - \dot{m}_{cons} = 0$

e. The basis of a system is expressed either in units of mass or moles. F
could be $\frac{kg}{s}$, $\frac{n}{s}$, etc...

4. [**15 pts**] A bicyclist traveling against the wind feels a *drag force* imposed by the surrounding air. Perform dimensional analysis to propose an equation for the drag force F_d opposing the rider.



We first notice that the units for Force is:

$$F_d \Rightarrow N \Rightarrow \left[kg \cdot \frac{m}{s^2}\right]$$ +5 for units of force

Now we consider what potential variables are in the system:

Variable	Unit	Rationale
Velocity (V)	$[m/s]$	– higher velocity, more drag
air density (ρ)	$[kg/m^3]$	– harder to move in ~~water~~ molasses than water than air
Surface Area (A_s)	$[m^2]$	kites / parachutes have large surface area

+ 5/3 per variable

To match units, we notice that a $\left[\frac{1}{s^2}\right]$ term is required for F_d.

$$\Rightarrow [F_d] = \left[kg \cdot \frac{m}{s^2}\right] \propto A_s \rho V^2 = [m^2]\left[\frac{kg}{m^3}\right]\left[\frac{m^2}{s^2}\right]$$

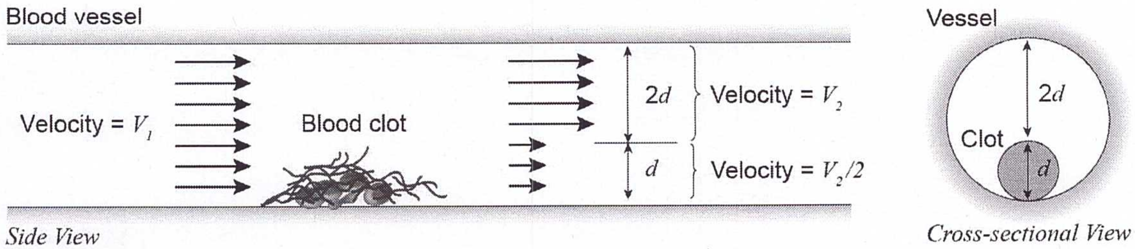
$$= \left[kg \cdot \frac{m}{s^2}\right]$$

$$\Rightarrow \boxed{F_d \propto A_s \rho V^2}$$

↳ +5 pts for correct expression

or +2 pts if another combination of variables w/ correct units

5a. **[12 pts]** A thrombus is a blood clot that obstructs the flow of blood in a vessel. Suppose a thrombus of diameter d is blocking the blood flow in a vessel of diameter $3d$. If the blood flow velocity before the thrombus is V_1, and the velocity immediately downstream of the clot is $V_2/2$ (but V_2 everywhere else), find the magnitude of V_2 in terms of V_1.



At steady state:

$$\frac{dm_{cv}}{dt} = \dot{m}_i - \dot{m}_e + \cancel{\dot{m}_{gen}} - \cancel{\dot{m}_{cons}} = 0$$

→ +3 pts for correct use of steady state cons. of mass

For the inlet:

$$\dot{m}_i = \rho A_1 V_1 = \rho\left(\pi\left(\frac{3d}{2}\right)^2\right)V_1 = \underline{\frac{9}{4}\pi\rho d^2 V_1}$$

+3 for $\dot{m}_i$

For the exit, we have two parts:

$$\dot{m}_e = \rho\left(\pi\left(\frac{d}{2}\right)^2\right)\frac{V_2}{2} + \rho\left[\pi\left(\frac{3d}{2}\right)^2 - \pi\left(\frac{d}{2}\right)^2\right]V_2$$

$$= \rho\pi d^2 V_2\left[\frac{1}{8} + \frac{9}{4} - \frac{1}{4}\right]$$

$$= \underline{\frac{17}{8}\rho\pi d^2 V_2}$$

+3 for $\dot{m}_e$ (~~+1.5~~ +1.5 for each component)

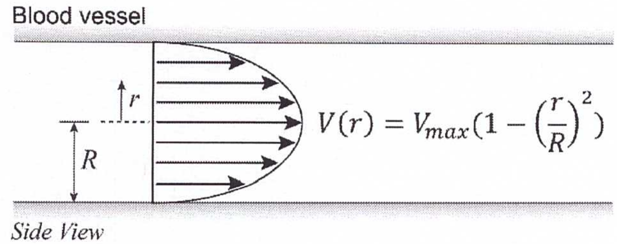
$$\Rightarrow \dot{m}_i = \dot{m}_e$$

$$\frac{9}{4}\pi\cancel{\rho}\cancel{d^2}V_1 = \frac{17}{8}\cancel{\rho}\cancel{\pi}\cancel{d^2}V_2$$

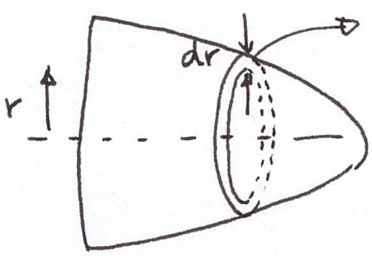
$$\boxed{V_2 = \frac{72}{68}V_1}$$

+3 for correct answer

5b. [**8 pts**] In reality, the velocity profile of blood $V(r)$ is not constant but parabolic, with a maximum velocity V_{max} at the center of the vessel ($r = 0$) and no blood flow at the walls ($r = R$). Determine the mass flow rate. (Hint: Choose a surface area dA such that the mass flow rate $d\dot{m}$ is approximately constant)



Let's consider a surface area dA that looks like a ring with radius (inner) r, and outer radius r+dr.



surface area $dA = 2\pi r\,dr$

velocity at point $r = V_{max}\left(1 - \frac{r^2}{R^2}\right)$

$$\Rightarrow d\dot{m} = \rho\, dA\, V$$

+ 3 pts for $d\dot{m}$

$$= \cancel{\rho(2\pi r dr)}\ \rho(2\pi r\,dr)\left[V_{max}\left(1 - \frac{r^2}{R^2}\right)\right]$$

This is mass flow rate across this small control volume. To find $\dot{m}$, we integrate from r=0 to R

$$\Rightarrow \dot{m} = \int_0^R \rho\,(2\pi r\,dr)\left(V_{max}\left(1 - \frac{r^2}{R^2}\right)\right)$$

+ 3 pts for correct integral or +1 for recognizing need to integrate

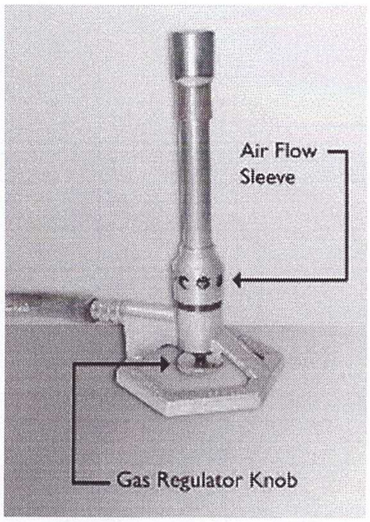
$$= \rho\, 2\pi\, V_{max}\left[\frac{1}{2}r^2 - \frac{1}{4}\frac{r^4}{R^2}\right]_0^R$$

$$= \rho\, 2\pi\, V_{max}\left[\frac{1}{2}R^2 - \frac{1}{4}R^2\right]$$

$$\boxed{\dot{m} = \rho\,\frac{1}{2}\pi R^2 V_{max}}$$

+2 pts for correct answer

6. **[20 pts total]** A Bunsen burner takes propane gas and combines it with atmospheric oxygen to produce carbon dioxide, water, heat and light. Propane is delivered to the Bunsen burner from a gas line that can be regulated to deliver propane at rates ranging from 0.00–10.0 g per second. Air holes on the side of the burner maintain the intake flow of dry air (79.0% nitrogen and 21.0% oxygen) at 50.0 g per second. Nitrogen gas is inert and does not participate in the reaction.



a. **[5 pts]** Find the stoichiometric coefficients *a, b, p* and *q* for the chemical reaction.

$$aC_3H_8 + bO_2 \rightarrow pCO_2 + qH_2O + \text{heat} + \text{light}$$

C: $\boxed{3a = p}$

H: $8a = 2q \Rightarrow \boxed{4a = q}$

O: $2b = 2p + q$

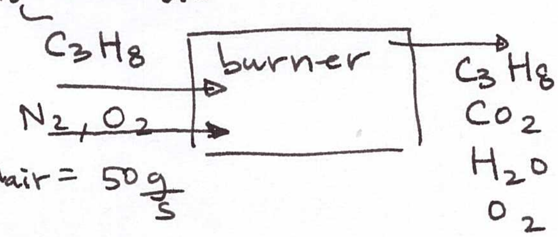
$= 2(3a) + 4a = 10a \Rightarrow \boxed{b = 5a}$

$$\boxed{C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O}$$

+5 for correct equation

b. **[5 pts]** By what fraction should the gas regulator be turned on (0 = closed, 1 = fully open) to ensure that the reactants are fed in stoichiometric proportions? Assume the regulator position is linearly proportional to the mass flow rate.

$\dot{m} = 0-10\ g/s$



$\dot{m}_{air} = 50\frac{g}{s}$

We first need to calculate molar flow rates, so find molecular weights of compounds:

$M_{C_3H_8} = 44\ g/mol$ $\quad M_{N_2} = 28\ \frac{g}{mol}$

$M_{O_2} = 32\ \frac{g}{mol}$ $\quad M_{CO_2} = 44\ \frac{g}{mol}$

+1 for molecular weights

Calculate flow rates:

$\dot{n}_{i,C_3H_8} = f\ \dot{m}_{C_3H_8} / M_{C_3H_8} = f\left(\frac{10\ g\ propane}{1\ s}\right)\left(\frac{1\ mol}{44\ g\ propane}\right)$

f → gas regulator

$$\boxed{\dot{n}_{i,C_3H_8} = f\left(0.227\ \frac{mol\ propane}{s}\right)}$$

+1 for $\dot{n}_{i,C_3H_8}$

Oxygen: $\dot{n}_{i,O_2} = w_{O_2} \dot{m}_{air} / M_{O_2}$

To calculate w_{O_2}, take 100 moles of dry air

$$\Rightarrow w_{O_2} = \frac{(21 \text{ mol } O_2)(32 \text{ g/mol})}{(21 \text{ mol } O_2)(32 \text{ g/mol}) + (79 \text{ mol } N_2)(28 \frac{\text{g}}{\text{mol}})} = 0.233$$

plug in to find molar flow rate:

$$\dot{n}_{i,O_2} = (0.233)\left(50 \frac{\text{g air}}{\text{s}}\right)\left(\frac{1 \text{ mol}}{32 \text{ g } O_2}\right) = \boxed{0.364 \frac{\text{mol } O_2}{\text{s}}}$$

+1 for $\dot{n}_{i,O_2}$

When stoichiometry is balanced:

$$\frac{\dot{n}_{i,O_2}}{\sigma_{O_2}} = \frac{f \, \dot{n}_{i,C_3H_8}}{\sigma_{C_3H_8}}$$

$$f = \left(\frac{\sigma_{C_3H_8}}{\sigma_{O_2}}\right)\left(\frac{\dot{n}_{i,O_2}}{\dot{n}_{i,C_3H_8}}\right) = \left(\frac{1}{5}\right)\left(\frac{0.364}{0.227}\right) = \boxed{0.32}$$

+2 for correct fraction

i.e. valve should be ~ 32% open.

(+1 for correct expression

+1 for correct value)

c. **[5 pts]** You adjust the regulator so that it is half open (i.e., propane flow rate at 5 g per second). If the reaction is 100% efficient, find the CO_2 volume fraction of the air flow that exits the burner.

When regulator is half open, oxygen is now the limiting reagent.

$$O_2 : \quad \dot{n}_i - \underbrace{\cancel{\dot{n}_e}}_{0 \text{ (100\% efficient reaction)}} + \sigma R = 0$$

$$\left(0.364 \frac{mol}{s}\right) + (-5) R = 0$$

$$\boxed{R = 7.28 \times 10^{-2}\ mol/s}$$ +3 for R

In the exit flow, we have:

$$\% CO_2 = 100\% \left[\frac{\dot{n}_{e,CO_2}}{\dot{n}_{e,CO_2} + \dot{n}_{e,N_2} + \dot{n}_{e,H_2O} + \dot{n}_{e,C_3H_8}} \right]$$

For N_2:

In the inlet, we know $w_{O_2} = 0.233 \Rightarrow w_{N_2} = 1 - 0.233 = 0.767$

$$\dot{n}_i = \dot{n}_e = w_{N_2} \dot{m}_{air} / M_{N_2} = \frac{(0.767)(50\ g/s)}{28\ g/mol} = \boxed{1.37 \frac{mol}{s}}$$

For CO_2:

$$\cancel{\dot{n}_i}^{\,0} - \dot{n}_e + \sigma R = 0 \Rightarrow \dot{n}_e = (3)\left(7.28 \times 10^{-2} \frac{mol}{s}\right) = \boxed{0.218 \frac{mol}{s}}$$

For H_2O:

$$\cancel{\dot{n}_i} - \dot{n}_e + \sigma R = 0 \Rightarrow \dot{n}_e = (4)(7.28 \times 10^{-2}\ mol/s) = \boxed{0.291 \frac{mol}{s}}$$

For C_3H_8:

$$\dot{n}_i - \dot{n}_e + \sigma R = 0 \Rightarrow \dot{n}_e = \left(0.114 \frac{mol}{s}\right) + (-1)\left(7.28 \times 10^{-2} \frac{mol}{s}\right)$$

$$= \boxed{4.12 \times 10^{-2}\ mol/s}$$

$$\Rightarrow \% CO_2 = 100\% \left(\frac{0.218}{0.218 + 1.37 + 0.291 + 4.12 \times 10^{-2}} \right)$$

$$= \boxed{11.4\%}$$

→ +2 for correct answer (+1 for CO_2 molar flow fraction)

d. **[5 pts]** What fraction of the propane is consumed by the Bunsen burner when the regulator is half open?

$$f = \frac{\dot{n}_i - \dot{n}_e}{\dot{n}_i} = \frac{0.114 - 0.0412}{0.114} = \boxed{0.64}$$

(+5)

+2 for the right expression

+3 for the correct numerial value

END OF EXAM

Reference Tables

Factors for Unit Conversion

Quantity	Equivalent Values
Mass	$1 \text{ kg} = 1000 \text{ g} = 0.001 \text{ metric ton} = 2.20462 \text{ lb}_m = 35.27392 \text{ oz}$ $1 \text{ lb}_m = 16 \text{ oz} = 5 \times 10^{-4} \text{ ton} = 453.593 \text{ g} = 0.453593 \text{ kg}$
Length	$1 \text{ m} = 100 \text{ cm} = 1000 \text{ mm} = 10^6 \text{ microns } (\mu\text{m})$ $= 39.37 \text{ in} = 3.2808 \text{ ft} = 1.0936 \text{ yd} = 0.0006214 \text{ mile}$ $1 \text{ ft} = 12 \text{ in} = 1/3 \text{ yd} = 0.3048 \text{ m} = 30.48 \text{ cm}$
Volume	$1 \text{ m}^3 = 1000 \text{ L} = 10^6 \text{ cm}^3 = 10^6 \text{ mL}$ $= 35.3145 \text{ ft}^3 = 220.83 \text{ imperial gallons} = 264.17 \text{ gal}$ $= 1056.68 \text{ qt}$ $1 \text{ ft}^3 = 1728 \text{ in}^3 = 7.4805 \text{ gal} = 0.028317 \text{ m}^3 = 28.317 \text{ L}$ $= 28{,}317 \text{ cm}^3$
Force	$1 \text{ N} = 1 \text{ kg}\cdot\text{m/s}^2 = 10^5 \text{ dynes} = 10^5 \text{ g}\cdot\text{cm/s}^2 = 0.22481 \text{ lb}_f$ $1 \text{ lb}_f = 32.174 \text{ lb}_m\cdot\text{ft/s}^2 = 4.4482 \text{ N} = 4.4482 \times 10^5 \text{ dynes}$
Pressure	$1 \text{ atm} = 1.01325 \times 10^5 \text{ N/m}^2 \text{ (Pa)} = 101.325 \text{ kPa} = 1.01325 \text{ bar}$ $= 1.01325 \times 10^6 \text{ dynes/cm}^2$ $= 760 \text{ mmHg at } 0°\text{C (torr)} = 10.333 \text{ m } H_2O \text{ at } 4°\text{C}$ $= 14.696 \text{ lb}_f/\text{in}^2 \text{ (psi)} = 33.9 \text{ ft } H_2O \text{ at } 4°\text{C}$ $= 29.921 \text{ in Hg at } 0°\text{C}$
Energy	$1 \text{ J} = 1 \text{ N}\cdot\text{m} = 10^7 \text{ ergs} = 10^7 \text{ dyne}\cdot\text{cm}$ $= 2.778 \times 10^{-7} \text{ kW}\cdot\text{hr} = 0.23901 \text{ cal}$ $= 0.7376 \text{ ft-lb}_f = 9.486 \times 10^{-4} \text{ Btu}$
Power	$1 \text{ W} = 1 \text{ J/s} = 0.23901 \text{ cal/s} = 0.7376 \text{ ft}\cdot\text{lb}_f/\text{s}$ $= 9.486 \times 10^{-4} \text{ Btu/s} = 1.341 \times 10^{-3} \text{ hp}$

Example: The factor to convert grams to lb_m is $\left(\dfrac{2.20462 \text{ lb}_m}{1000 \text{ g}}\right)$.

The Nonmetals

Transition Elements

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	Noble Gases
1 **H** 1.00794																	2 **He** 4.00260
3 **Li** 6.941	4 **Be** 9.01218											5 **B** 10.81	6 **C** 12.011	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.9984	10 **Ne** 20.1797
11 **Na** 22.98977	12 **Mg** 24.305											13 **Al** 26.98154	14 **Si** 28.0855	15 **P** 30.9738	16 **S** 32.066	17 **Cl** 35.4527	18 **Ar** 39.948
19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.9559	22 **Ti** 47.88	23 **V** 50.9415	24 **Cr** 51.996	25 **Mn** 54.9380	26 **Fe** 55.847	27 **Co** 58.9332	28 **Ni** 58.69	29 **Cu** 63.546	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.9216	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.9059	40 **Zr** 91.224	41 **Nb** 92.9064	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.9055	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.710	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.9045	54 **Xe** 131.29
55 **Cs** 132.9054	56 **Ba** 137.33	57* **La** 138.9055	72 **Hf** 178.49	73 **Ta** 180.9479	74 **W** 183.85	75 **Re** 186.207	76 **Os** 190.2	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.9665	80 **Hg** 200.59	81 **Ti** 204.383	82 **Pb** 207.2	83 **Bi** 208.9804	84 **Po** (209)	85 **At** (210)	86 **Rn** (~222)
87 **Fr** (223)	88 **Ra** 226.0254	89† **Ac** 227.0278	104 **Unq** (261)	105 **Unp** (262)	106 **Unh** (263)												