BMED 2210
Fall 2015, Midterm II
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.

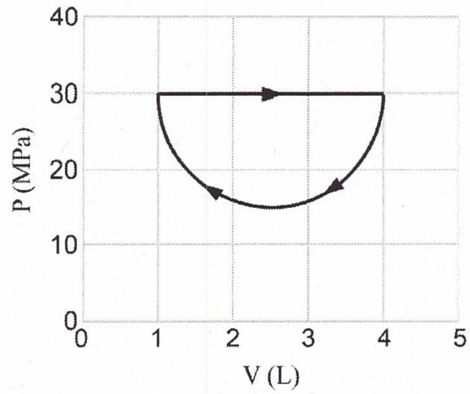
Good luck!

Question #1	____________	/25
Question #2	____________	/25
Question #3	____________	/25
Question #4	____________	/25
Total	____________	/100

$\bar{x} = 52.2$

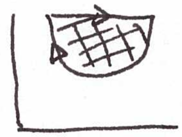
$\sigma = 12.2$

1. **[25 pts]** Gas within a chamber undergoes the complete cycle shown in the PV diagram below. If the cycle is operated at 20 Hz, calculate the net heat added to the system in one hour.



$W = \int P\,dV$ = area under curve of PV diagram

+5 for recognizing that Work is area under curve

$\Rightarrow W_{cycle}$ =  +  = 

$W_1 > 0$ $\quad$ $W_2 < 0$ $\quad$ $W_{cycle} > 0$ (since $W_1 > W_2$)

Area of half circle : $\frac{1}{2}\pi r^2 = \frac{1}{2}\pi\left(\frac{3}{2}\right)^2$

$= \frac{9\pi}{8}$ area units

+5 for recognizing area under curve is a half circle (+3 for other functions)

Each unit square has units of energy given by:

$(10\text{ MPa})(1\text{ L}) = (10^7\text{ Pa})(0.001\text{ m}^3) = 10^4\text{ J}$

This means the work done per cycle is:

$\left(\frac{9\pi}{8}\right)(10^4\text{ J}) = W_{cycle}$

+5 for correct W_{cycle} (+3 for correct idea; $W = W_1 + W_2$)

For a cycle we know $\boxed{\Delta E_{sys} = 0 \Rightarrow Q_{cycle} = W_{cycle}}$

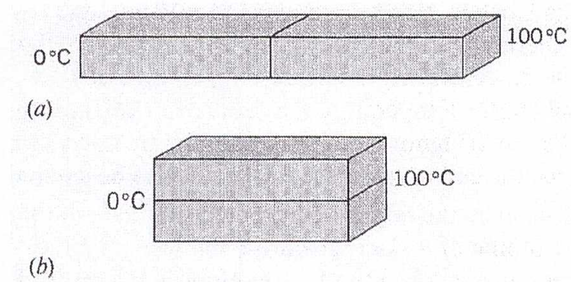
+5 for cons. of energy for closed system

$\Rightarrow$ Total heat added to system in one hour:

$Q_{TOTAL} = (20\text{Hz})\left(\frac{60\text{ sec}}{1\text{ min}}\right)\left(\frac{60\text{ min}}{1\text{ hr}}\right) Q_{cycle}$

$\boxed{Q_{TOTAL} = 2.5 \times 10^9\text{ J}}$ +5 for correct answer (+3 for propagating error)

2a. [**18 pts**] Two identical rectangular rods of metal are welded end to end as shown in (*a*), and 10 J of heat flows through the rods in 2.0 min. How long would it take 30 J to flow through the rods if they are welded as shown in (*b*)?



1-D heat flow:

$$\dot{Q} = -\frac{kA}{L}\Delta T$$

For (a) : $\dot{Q}_a = -\frac{kA}{L}\Delta T = \frac{10\text{ J}}{2.0\text{ min}}$

+5 for recognizing area of (b) is twice that of (a)

For (b) : $\dot{Q}_b = -\frac{k(2A)}{(\frac{1}{2}L)}\Delta T = -4\frac{kA}{L}\Delta T = 4\dot{Q}_a$

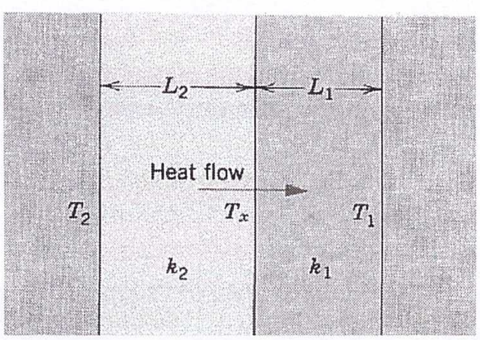
+5 for recognizing that length of (a) is 2 times that of (b)

$$\Rightarrow \dot{Q}_b = \frac{30\text{ J}}{x\text{ min}} = 4\left(\frac{10\text{ J}}{2.0\text{ min}}\right)$$

$$\Rightarrow x = \frac{30\text{ J}}{20\text{ J/min}} = \boxed{1.5\text{ min}}$$

+8 for correct answer
(+6 for right expression but wrong math)

b. [**7 pts**] The heat that flows across the wet suit of a scuba diver may be modeled as a compound slab where T_2 is the core body temperature, L_2 is the average thickness of skin, L_1 is the thickness of the wet suit, and T_1 is the temperature of the ocean. *Circle* one equation that correctly expresses the outer surface temperature T_x of the skin (Hint: use reasoning, not math).



a. $T_x = \frac{R_1T_1+R_2T_2}{R_1+R_2}$

c. $T_x = \frac{R_1T_1+R_2T_2}{R_1R_2}$

b. $T_x = \frac{R_1T_2+R_2T_1}{R_1+R_2}$

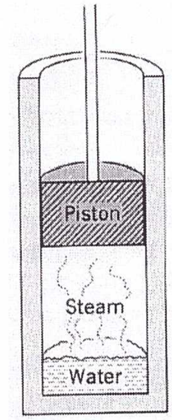
d. $T_x = \frac{R_1T_2+R_2T_1}{R_1R_2}$

When $R_1 = 0$, then $T_x = T_1$
& when $R_2 = 0$, then $T_x = T_2$

+3.5 if ~~(a) or~~ (a) circled
+7 if (b) circled

(c and d doesn't make sense when R_1 or $R_2 = 0$ since dividing by 0)

3. **[25 pts total]** A cylinder has a well-fitted 2.0-kg metal piston whose cross-sectional area is 2.0 cm^2. The cylinder contains water and steam at constant temperature. The piston is observed to fall slowly at a rate of 0.30 cm/s because heat flows out of the cylinder through the cylinder walls. As this happens, some steam condenses in the chamber. The density of the steam inside the chamber is 6.0×10^{-4} g/cm^3 and the atmospheric pressure is 1.0 atm.



a. **[10 pts]** Calculate the rate of condensation of steam (Hint: What properties of the steam, which behaves like an ideal gas, are not changing?).

For the steam, we know that

$$PV = nRT$$

here the pressure is constant (since piston falls slowly, i.e. reversible process $\Rightarrow P_{int} = P_{ext}$) and temperature is constant from the problem statement.

+5 for $\left(\frac{n}{V}\right)$ = constant

$$\Rightarrow \left(\frac{n}{V}\right) = \frac{P}{RT} = \text{constant}$$ (+3 for noticing P and T are constant)

since $$\rho_{steam} = \frac{m_{steam}}{V} = \frac{M_{H_2O}\, n_s}{V} = M_{H_2O}\left(\frac{n_s}{V}\right)$$

then the ρ_{steam} inside chamber is constant, during conversion to water.

$$\Rightarrow m_{steam} = \rho_{steam} V$$

cross section of piston

+3 for expression of $\frac{dm_s}{dt}$

$$\Rightarrow \frac{dm_s}{dt} = \frac{d}{dt}(\rho_s V) = -\rho_s A \frac{dx}{dt}$$

speed at which piston falls

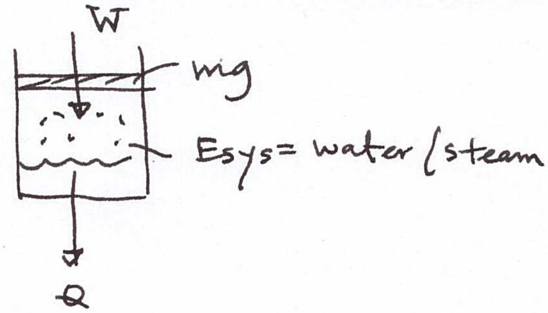
piston falling down

$$\frac{dm_s}{dt} = -(6.0 \times 10^{-4}\ g/cm^3)(2.0\ cm^2)(0.30\ cm/s)$$

$$= \boxed{-3.6 \times 10^{-4}\ \frac{g\ steam}{s}}$$

+2 for correct answer

a. **[15 pts]** At what rate is heat leaving the chamber?



<u>cons. of energy</u> +5 for energy balance

$$\Delta \dot{E}_{sys} = \dot{Q} - \dot{W}$$ — constant pressure work

$\Delta \dot{E}_{sys}$: internal energy of steam/water

$\dot{Q}$: heat flowing out of system

$$\Delta \dot{E}_{sys} = (\text{heat of condensation})\left(\frac{dm_s}{dt}\right)$$

$$= (2256\ \text{kJ/kg})(-3.6\times10^{-4}\ \text{g/s})\left(\frac{1\,\text{kg}}{1000\,\text{g}}\right)$$

$$= \boxed{-8.1\times10^{-4}\ \text{kJ/s}}$$ + 2 for $\Delta \dot{E}_{sys}$

$$\dot{W} = -PA\frac{dx}{dt} \quad (\text{volume contracting})$$

$$= -\left(1\ \text{atm} + \frac{mg}{A}\right)(A)\frac{dx}{dt}$$

$$= -\left(1.01\times10^{5}\ \text{Pa} + \frac{(2\,\text{kg})(9.8\ \text{m/s}^2)}{(2\,\text{cm}^2)\left(\frac{1\,\text{m}}{100\,\text{cm}}\right)^2}\right)\left(2\,\text{cm}^2\left(\frac{1\,\text{m}}{100\,\text{cm}}\right)^2\right)\left(\frac{0.003\,\text{m}}{\text{s}}\right)$$

$$= -(1.99\times10^{5}\ \text{Pa})(6\times10^{-7}\ \text{m}^3/\text{s})$$

$$= \boxed{-0.12\ \text{J/s}}$$

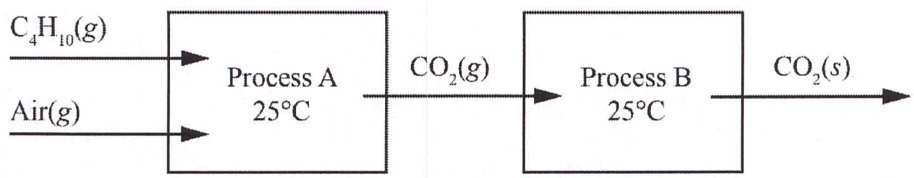
+ 6 for $\dot{W}$
(+4 for correct approach but wrong values)

$$\dot{Q} = \Delta \dot{E}_{sys} + \dot{W} = (-8.1\times10^{-4}\ \text{kJ/s}) - 0.12\ \text{J/s}$$

$$= \boxed{-0.93\ \text{J/s}}$$ (i.e. vast majority of heat flow out is used to lower piston)

+ 2 for $\dot{Q}$

4. **[25 pts total]** An industrial two-step process to make dry ice starts with the combustion of *n*-Butane with dry air (79.0% nitrogen and 21.0% oxygen by volume) to form $CO_2(g)$ in Process A, which is then converted to $CO_2(s)$ in a second Process B. *n*-Butane is fed at 10 kg per second and dry air at 200.0 kg per second, and *n*-Butane flows out at Process A at 1.2 kg per second. The standard heat of formation of dry ice is –427.4 kJ/mol. Both processes are conducted at 25°C.



a. **[15 pts]** Find the reaction rate R for Process A.

First balance stoichiometry for the combustion process in A:

+5 for correct stoichiometry

$$C_4H_{10}(g) + \frac{13}{2}O_2(g) \longrightarrow 4CO_2(g) + 5H_2O(l)$$

Find limiting reagent:

$$\min\left\{\frac{\dot{n}_{i,s}}{\sigma_s}\right\} \Rightarrow \dot{n}_{i\,butane} = \left(\frac{10{,}000\text{ g}}{\text{s}}\right)\left(\frac{1\text{ mol}}{58\text{ g/mol}}\right) = \boxed{172.4\frac{\text{mol}}{\text{s}}}$$

for $O_2(g)$, need w_{O_2} +5 for calculating w_{O_2}

$$\Rightarrow w_{O_2} = \frac{(0.21)(32\text{ g/mol})}{(0.21)(32\text{ g/mol}) + (0.79)(28\text{ g/mol})} = 0.233$$

$$\Rightarrow \dot{n}_{O_2} = w_{O_2}\,\dot{m}_{air}/M_{O_2} = (0.233)\left(\frac{200{,}000\text{ kg}}{\text{s}}\right)\left(\frac{1\text{ mol }O_2}{32\text{ g/mol}}\right)$$

$$= 1.46\times10^3\text{ mol/s}$$

$$\Rightarrow \left\{\frac{\dot{n}_{i,O_2}}{\sigma_{O_2}}\right\} = \frac{1.46\times10^3\frac{\text{mol}}{\text{s}}}{13/2} = 224$$

$$\left\{\frac{\dot{n}_{i,butane}}{\sigma_{butane}}\right\} = \frac{172.4\text{ mol/s}}{1} = 172.4 \Rightarrow \text{butane limiting reagent.}$$

$$\Rightarrow R = \frac{\dot{n}_{i,butane} - \dot{n}_{e,butane}}{-\sigma_{butane}} = \frac{(172.4\text{ mol/s}) - (1.2\text{ kg})/58\text{ g/mol}}{-(-1)}$$

$$\boxed{R = 151.7\text{ mol/s}}$$

+5 for R
(+3 for correct expression but wrong values)

b. **[10 pts]** Determine the heat released into the environment every hour for the entire process.

Process A:

$\Delta H_{rxn} = \Delta \hat{H}^{o}_{c,\text{butane}} R$

$= (-2878.52\ kJ/mol)(151.7\ mol/s)$

$= \boxed{-4.4 \times 10^5\ kJ/s}$ +3 for ΔH_{rxn} (Process A) (+1.5 for incorrect values but correct approach)

Process B:

$\Delta \hat{H}_{rxn} = \Delta \hat{H}^{o}_{f\,CO_2(s)} - \Delta \hat{H}^{o}_{f\,CO_2(g)}$

$= (-427.4\ kJ/mol) - (-393.51\ kJ/mol)$

$= -33.89\ kJ/mol\ CO_2(g)$

$\Rightarrow \Delta H_{rxn} = (4\ mol\ CO_2)(-33.89\ kJ/mol)\dot{n}_{e,CO_2(g)}$

$= (4)(-33.89\ kJ/mol)(151.7\ mol/s)$

$= \boxed{-2.1 \times 10^4\ kJ/s}$ +3 for ΔH_{rxn} (process B) (+1.5 for correct approach)

$\Delta H_{rxn\,\text{total}} = -4.4 \times 10^5 - 2.1 \times 10^4 = \boxed{-4.6 \times 10^5\ kJ/s}$

+2 for $\Delta H_{rxn} = \Delta H_A + \Delta H_B$

$\Rightarrow$ Every hour:

$\left(-4.6 \times 10^5 \frac{kJ}{s}\right)\left(\frac{60\ s}{1\ min}\right)\left(\frac{60\ min}{1\ hr}\right) = \boxed{-1.7 \times 10^9\ J/hr}$

+2 for final answer

END OF EXAM

Reference Tables

Factors for Unit Conversion

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

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

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	Noble Gases
1 **H** 1.00794														The Nonmetals			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					Transition Elements						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)												

Compound	Formula	Mol. wt.	State	$\Delta\hat{H}^{\circ}_{f}$ (kJ/g mol)	$\Delta\hat{H}^{\circ}_{c}$ (kJ/g mol)
n-Butane	C_4H_{10}	58.12	l	−147.6	−2855.6
			g	−124.73	−2878.52
Isobutane	C_4H_{10}	58.12	l	−158.5	−2849.0
			g	−134.5	−2868.8
1-Butene	C_4H_8	56.104	g	1.172	−2718.58
Calcium arsenate	$Ca_3(AsO_4)_2$	398.06	c	−3330.5	
Calcium carbide	CaC_2	64.10	c	−62.7	
Calcium carbonate	$CaCO_3$	100.09	c	−1206.9	
Calcium chloride	$CaCl_2$	110.99	c	−794.9	
Calcium cyanamide	$CaCN_2$	80.11	c	−352	
Calcium hydroxide	$Ca(OH)_2$	74.10	c	−986.56	
Calcium oxide	CaO	56.08	c	−635.6	
Calcium phosphate	$Ca_3(PO_4)_2$	310.19	c	−4137.6	
Calcium silicate	$CaSiO_3$	116.17	c	−1584	
Calcium sulfate	$CaSO_4$	136.15	c	−1432.7	
			aq	−1450.5	
Calcium sulfate (gypsum)	$CaSO_4 \cdot 2H_2O$	172.18	c	−2021.1	
Carbon	C	12.01	c Graphite (β)	0	−393.51
Carbon dioxide	CO_2	44.01	g	−393.51	
			l	−412.92	
Carbon disulfide	CS_2	76.14	l	87.86	−1075.2

TABLE 2 SOME HEATS OF TRANSFORMATION

Substance[a]	*Melting Point* (K)	*Heat of Fusion* (kJ/kg)	*Boiling Point* (K)	*Heat of Vaporization* (kJ/kg)
Hydrogen	14.0	58.6	20.3	452
Oxygen	54.8	13.8	90.2	213
Mercury	234	11.3	630	296
Water	273	333	373	2256
Lead	601	24.7	2013	858
Silver	1235	105	2485	2336
Copper	1356	205	2840	4730