Ref. No. Ex/PG/PE/T/111A/2018

M. POWER ENGINEERING FIRST SEMESTER EXAMINATION 2018

SUBJECT: ***APPLIED THERMODYNAMICS I***

Time: Three Hours **Full Marks 100**

Answer Question No. 1 and any three from the rest

1. Answer any 4 **(10×4 = 40 marks)**

(a) Answer if the following statements are true or false, and explain in one sentence:

(i) A PMMII obeys the First Law of Thermodynamics
(ii) Theoretically, a cooling tower can cool the CW below the ambient dry bulb temperature
(iii) The entropy of a fixed amount of an ideal gas decreases during an isothermal compression
(iv) Heat transfer during a nonflow process is always denoted by $Q = \int_1^2 Tds$.
(v) For a gas mixture comprising of CO_2, O_2 and N_2 one would need at least three properties to uniquely determine the state of the mixture.

5×2 = 10 marks

(b) Two insulated chambers A and B contain n_A and n_B kmol of two different ideal gases that are at the same temperature T and pressure p, and are initially separated by a thin membrane. The gases mix as the membrane is ruptured. Find out the change of entropy of the system. Is the process of mixing reversible, or irreversible? Justify. **10 marks**

(c) An ideal gas of molecular weight 100 executes an internally reversible cycle as described in Fig 1c. Find (i) The heat addition to the cycle, (ii) The net work done, (iii) Efficiency/ COP, (iv) $\oint Tds$, and (v) ΔH during process 1 -2. Assume γ=1.5. **10 marks**

(d) A district heating plant uses hot flue gas at 900 K to produce 180 liter per minute of hot water at 57°C (the water enters the heating plant at 7°C). Assuming that the gas temperature in the furnace is nearly constant and the temperature in the water line rises linearly with its length in the furnace, find the exergy destroyed in the heating process. **10 marks**

(e) Estimate the value of Joule Thomson Coefficient for steam at 360° and 30 bar from the Mollier chart/ steam table. **10 marks**

2.

(a) Write down the Kelvin Planck and Clausius statements, and show that they are equivalent. **6 marks**

(b) A fully reversible cycle receives 2500 kJ of heat at a mean temperature of 900 K. What would be the mean temperature of heat rejection if it rejects 1500 kJ of heat? **4 marks**

(c) A Carnot heat engine receives heat from a reservoir at 927°C at a rate of 800 kJ/min and rejects the waste heat to the ambient air at 27°C. The entire work output of the heat engine is used to drive a refrigerator that removes heat from the refrigerated space at -5°C and transfers it to the same ambient air at 27°C. Determine (a) the maximum rate of heat removal from the refrigerated space and (b) the corresponding total rate of heat rejection to the ambient air. **10 marks**

3.

(a) Explain why it is important to match the heat source temperature and the heat utilization temperature for any thermal application. **5 marks**

(b) An insulated piston–cylinder device contains 2 L of saturated liquid water at a constant pressure of 150 kPa. An electric resistance heater inside the cylinder is turned on, and electrical work is done on the water in the amount of 2200 kJ. Determine (a) the minimum work with which this process could be accomplished and (b) the exergy destroyed during the actual process. See Fig. P3b. **15 marks**

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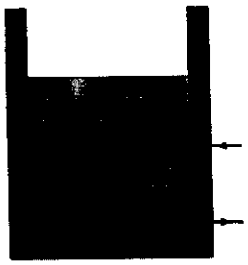


Fig P3b

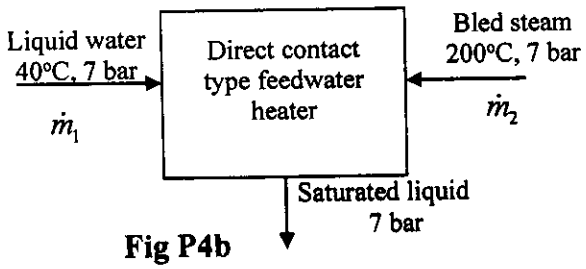


Fig P4b

4.

(a) Write the availability balance equation for an open system and identify what each term means. **5 marks**

(b) An direct contact type feedwater heater in a regenerative vapor power plant operates at steady state with liquid entering at inlet 1 with T_1 = 40°C and p_1 = 7.0 bar. Bled steam from turbine is taken at T_2=200°C and p_2=7.0 bar enters at inlet 2 to heat the feedwater. Saturated liquid water exits with a pressure of p_3 = 7.0 bar. Ignoring heat transfer with the surroundings and all kinetic and potential energy effects, (a) determine the ratio of mass flow rates $\dot{m}_1/\dot{m}_2$, (b) the rate of exergy destruction, in kJ per kg of liquid exiting, and (c) the Second Law efficiency. See Fig. P4b. **15 marks**

5.

(a) An insulated tank has two compartments connected by a valve. Initially, one compartment contains 0.7 kg of CO_2 at 500 K, 6.0 bar and the other contains 0.3 kg of N_2 at 300 K, 6.0 bar. The valve is opened and the gases are allowed to mix until equilibrium is achieved. Determine (a) the final temperature, in K. (b) the final pressure, in bar. (c) the amount of entropy produced, in kJ/K. **10 marks**

(b) Air at 35°C, 1 atm, and 50% relative humidity enters a dehumidifier operating at steady state. Saturated moist air and condensate exit in separate streams, each at 15°C. Neglecting kinetic and potential energy effects, determine (a) the heat transfer from the moist air, in kJ per kg of dry air. (b) the amount of water condensed, in kg per kg of dry air. **10 marks**

6.

(a) Derive the four Maxwell relations from the definitions of *u*, *h*, *a*, and *g*. **5 marks**

(b) Show that, for a pure fluid,

$$\left(\frac{\partial u}{\partial v}\right)_T = T^2\left(\frac{\partial (p/T)}{\partial T}\right)_v \quad \text{and} \quad \left(\frac{\partial h}{\partial p}\right)_T = -T^2\left(\frac{\partial (v/T)}{\partial T}\right)_p$$

Hence, show that, for a pure fluid, whose internal energy and enthalpy are functions of temperature only, (p/T) and (v/T) are sole functions of volume and pressure respective. **Do not assume the ideal gas equation of state.**

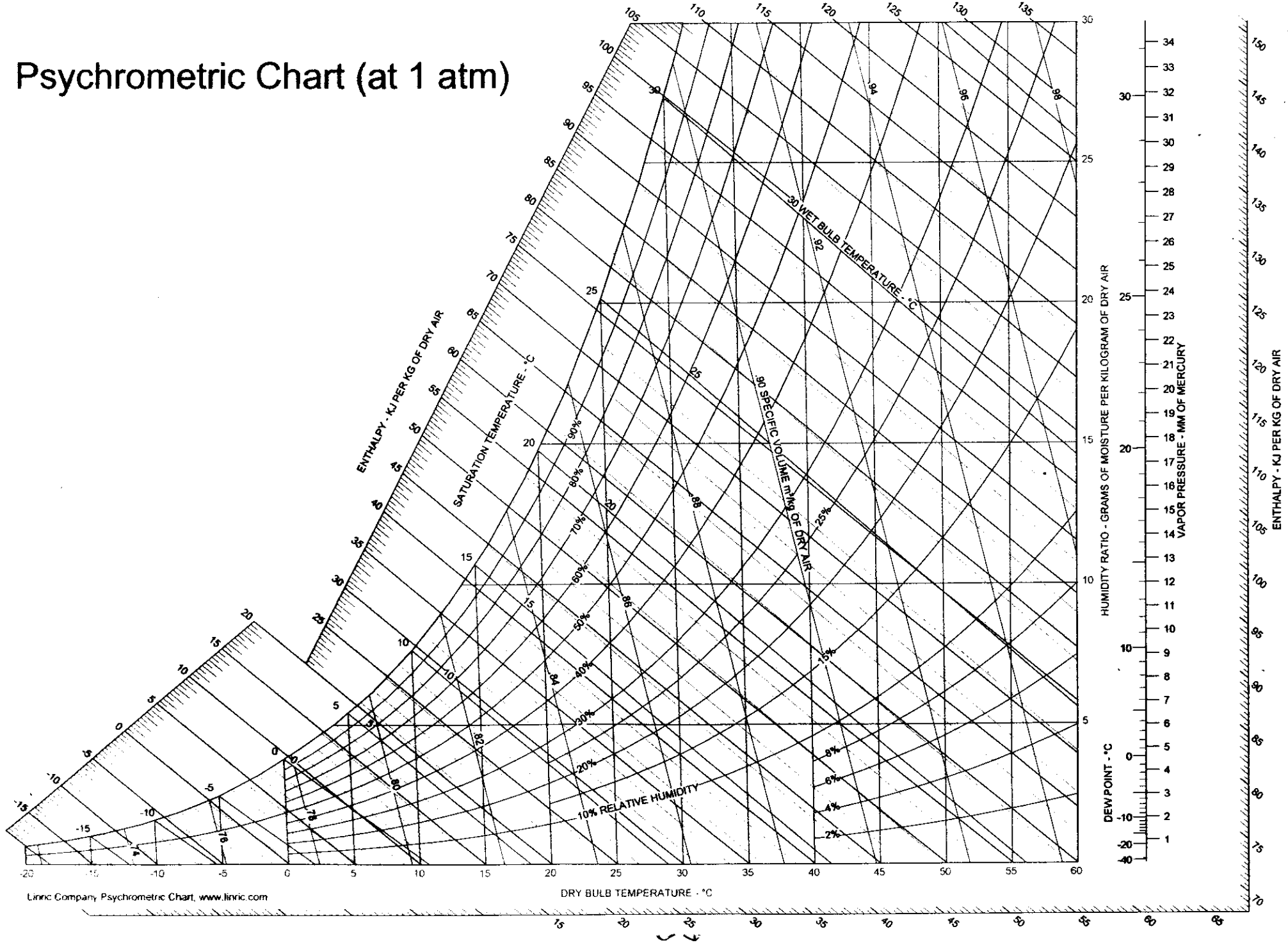
Use this result to show that pv/T = Constant is a necessary condition for internal energy and enthalpy to be functions of temperature only. **8 + 4 + 3 = 15 marks**

TABLE A-23 Ideal Gas Properties of Selected Gases

T(K), $\bar{h}$ and $\bar{u}$(kJ/kmol), $\bar{s}°$(kJ/kmol K)

	Carbon Dioxide, CO_2 ($\bar{h}_f^\circ$ = −393,520 kJ/kmol)			Carbon Monoxide, CO ($\bar{h}_f^\circ$ = −110,530 kJ/kmol)			Water Vapor, H_2O ($\bar{h}_f^\circ$ = −241,820 kJ/kmol)			Oxygen, O_2 ($\bar{h}_f^\circ$ = 0 kJ/kmol)			Nitrogen, N_2 ($\bar{h}_f^\circ$ = 0 kJ/kmol)			
T	$\bar{h}$	$\bar{u}$	$\bar{s}°$	$\bar{h}$	$\bar{u}$	$\bar{s}°$	$\bar{h}$	$\bar{u}$	$\bar{s}°$	$\bar{h}$	$\bar{u}$	$\bar{s}°$	$\bar{h}$	$\bar{u}$	$\bar{s}°$	T
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
220	6,601	4,772	202.966	6,391	4,562	188.683	7,295	5,466	178.576	6,404	4,575	196.171	6,391	4,562	182.638	220
230	6,938	5,026	204.464	6,683	4,771	189.980	7,628	5,715	180.054	6,694	4,782	197.461	6,683	4,770	183.938	230
240	7,280	5,285	205.920	6,975	4,979	191.221	7,961	5,965	181.471	6,984	4,989	198.696	6,975	4,979	185.180	240
250	7,627	5,548	207.337	7,266	5,188	192.411	8,294	6,215	182.831	7,275	5,197	199.885	7,266	5,188	186.370	250
260	7,979	5,817	208.717	7,558	5,396	193.554	8,627	6,466	184.139	7,566	5,405	201.027	7,558	5,396	187.514	260
270	8,335	6,091	210.062	7,849	5,604	194.654	8,961	6,716	185.399	7,858	5,613	202.128	7,849	5,604	188.614	270
280	8,697	6,369	211.376	8,140	5,812	195.173	9,296	6,968	186.616	8,150	5,822	203.191	8,141	5,813	189.673	280
290	9,063	6,651	212.660	8,432	6,020	196.735	9,631	7,219	187.791	8,443	6,032	204.218	8,432	6,021	190.695	290
298	9,364	6,885	213.685	8,669	6,190	197.543	9,904	7,425	188.720	8,682	6,203	205.033	8,669	6,190	191.502	298
300	9,431	6,939	213.915	8,723	6,229	197.723	9,966	7,472	188.928	8,736	6,242	205.213	8,723	6,229	191.682	300
310	9,807	7,230	215.146	9,014	6,437	198.678	10,302	7,725	190.030	9,030	6,453	206.177	9,014	6,437	192.638	310
320	10,186	7,526	216.351	9,306	6,645	199.603	10,639	7,978	191.098	9,325	6,664	207.112	9,306	6,645	193.562	320
330	10,570	7,826	217.534	9,597	6,854	200.500	10,976	8,232	192.136	9,620	6,877	208.020	9,597	6,853	194.459	330
340	10,959	8,131	218.694	9,889	7,062	201.371	11,314	8,487	193.144	9,916	7,090	208.904	9,888	7,061	195.328	340
350	11,351	8,439	219.831	10,181	7,271	202.217	11,652	8,742	194.125	10,213	7,303	209.765	10,180	7,270	196.173	350
360	11,748	8,752	220.948	10,473	7,480	203.040	11,992	8,998	195.081	10,511	7,518	210.604	10,471	7,478	196.995	360
370	12,148	9,068	222.044	10,765	7,689	203.842	12,331	9,255	196.012	10,809	7,733	211.423	10,763	7,687	197.794	370
380	12,552	9,392	223.122	11,058	7,899	204.622	12,672	9,513	196.920	11,109	7,949	212.222	11,055	7,895	198.572	380
390	12,960	9,718	224.182	11,351	8,108	205.383	13,014	9,771	197.807	11,409	8,166	213.002	11,347	8,104	199.331	390
400	13,372	10,046	225.225	11,644	8,319	206.125	13,356	10,030	198.673	11,711	8,384	213.765	11,640	8,314	200.071	400
410	13,787	10,378	226.250	11,938	8,529	206.850	13,699	10,290	199.521	12,012	8,603	214.510	11,932	8,523	200.794	410
420	14,206	10,714	227.258	12,232	8,740	207.549	14,043	10,551	200.350	12,314	8,822	215.241	12,225	8,733	201.499	420
430	14,628	11,053	228.252	12,526	8,951	208.252	14,388	10,813	201.160	12,618	9,043	215.955	12,518	8,943	202.189	430
440	15,054	11,393	229.230	12,821	9,163	208.929	14,734	11,075	201.955	12,923	9,264	216.656	12,811	9,153	202.863	440
450	15,483	11,742	230.194	13,116	9,375	209.593	15,080	11,339	202.734	13,228	9,487	217.342	13,105	9,363	203.523	450
460	15,916	12,091	231.144	13,412	9,587	210.243	15,428	11,603	203.497	13,535	9,710	218.016	13,399	9,574	204.170	460
470	16,351	12,444	232.080	13,708	9,800	210.880	15,777	11,869	204.247	13,842	9,935	218.676	13,693	9,786	204.803	470
480	16,791	12,800	233.004	14,005	10,014	211.504	16,126	12,135	204.982	14,151	10,160	219.326	13,988	9,997	205.424	480
490	17,232	13,158	233.916	14,302	10,228	212.117	16,477	12,403	205.705	14,460	10,386	219.963	14,285	10,210	206.033	490
500	17,678	13,521	234.814	14,600	10,443	212.719	16,828	12,671	206.413	14,770	10,614	220.589	14,581	10,423	206.630	500
510	18,126	13,885	235.700	14,898	10,658	213.310	17,181	12,940	207.112	15,082	10,842	221.206	14,876	10,635	207.216	510
520	18,576	14,253	236.575	15,197	10,874	213.890	17,534	13,211	207.799	15,395	11,071	221.812	15,172	10,848	207.792	520
530	19,029	14,622	237.439	15,497	11,090	214.460	17,889	13,482	208.475	15,708	11,301	222.409	15,469	11,062	208.358	530
540	19,485	14,996	238.292	15,797	11,307	215.020	18,245	13,755	209.139	16,022	11,533	222.997	15,766	11,277	208.914	540
550	19,945	15,372	239.135	16,097	11,524	215.572	18,601	14,028	209.795	16,338	11,765	223.576	16,064	11,492	209.461	550
560	20,407	15,751	239.962	16,399	11,743	216.115	18,959	14,303	210.440	16,654	11,998	224.146	16,363	11,707	209.999	560
570	20,870	16,131	240.789	16,701	11,961	216.649	19,318	14,579	211.075	16,971	12,232	224.708	16,662	11,923	210.528	570
580	21,337	16,515	241.602	17,003	12,181	217.175	19.678	14,856	211.702	17,290	12,467	225.262	16,962	12,139	211.049	580
590	21,807	16,902	242.405	17,307	12,401	217.693	20,039	15,134	212.320	17,609	12,703	225.808	17,262	12,356	211.562	590

Psychrometric Chart (at 1 atm)



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