L-4/T-II/ME **Date : 29/04/2023**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-II B. Sc. Engineering Examinations 2020-2021

Sub : **ME 407** (Advanced Thermodynamics)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

Symbols indicate their usual meaning. An equation sheet is provided with this manuscript.

1. One *kmol* of gaseous *AB* (fractious molecule) is contained in a rigid tank at a pressure of 10 kPa and temperature of 100 K (state 1). The temperature of the tank is raised to 2000 K (state 2) by heat transfer. Assume that *AB* exhibits ideal gas behavior at both states 1 and 2, and *AB* does not dissociate at state 2. Assuming that AB is rigid-rotator and harmonic oscillator, Calculate the internal energy change ($U_2 - U_1$) in kJ and entropy change ($S_2 - S_1$) in kJ/K for the constant volume heating process. **(35)**

For *AB*:

θ_{rot}(K)	θ_{vib}(K)	m (amu)
3	2800	34

Consider the following electronic levels:

Level 0: $g_{0,elec} = 2$ $(E_{0,elec}/k_B) = 0$ k

Level 1: $g_{0,elec} = 4$ $(E_{0,elec}/k_B) = 172$ K

Level 2: $g_{0,elec} = 6$ $(E_{0,elec}/k_B) = 374$ K

2. (a) A diatomic molecule has values of characteristic rotational and vibrational temperatures of 100 K and 7000 K. Show the trend of the temperature behavior of the normalized constant volume specific heat (Cv/Nk_B) for the ideal gas at very low pressure from a temperature of 1 K to 10,000 K. **(10)**

(b) Two low lying, but closely spaced, excited energy levels of calcium have the configuration $1s^2 2s^2 2p^6 3s^2 3p^6 4s3d$. For both levels, determine the term symbol, and the degeneracy of each member of the multiplet. **(25)**

3. (a) A beam of infrared laser light passes through a cell filled with *CO* (carbon monoxide). A series of *P*- and *R*-branch absorption lines are observed when the laser frequency matches a vibration-rotation transition in *CO*. The laser excites the molecules from the v″ lower level to the v′=v″+1 upper vibrational level. For R-branch lines, $J'=J''+1$, where J' is the rotational quantum number of the upper level and J'' is the rotational quantum number of the lower level. For P-branch lines, $J'=J''-1$. **(28)**

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(i) Develop general expressions for *P*-and *R*-branch lines for $v'=v''+1$ vibrational transitions considering first-order corrections for vibrational anharmonicity, vibration-rotation interaction, and centrifugal stretching. In your expressions, let $J = J''$ and $v = v''$. Assume $D_{v'} = D_{v''} = D_e$.

(ii) Calculate the actual frequency (in cm^{-1}) of the R ($J'' = 8$) rotational transitions in the $v''=1 \rightarrow v' = 2$ vibrational bands, accounting for anharmonicity, centrifugal stretching, and the dependence of the rotational constant *B* on vibrational level. Neglect the dependence of *D* on vibrational level.

(b) Write a short note on "dilute limit". **(7)**

4. A system has available energy levels of 0, βk_B, $2\beta k_B$, and $3\beta k_B$, units, where = 800 K. The degeneracy of each of the four levels is given by $g_J = 100{,}000 + 50{,}000\, j$ (j = 0, 1, 2 and 3). The thermodynamic assembly has 10,000 particles (N = 10,000) and the temperature of the assembly is 600 K. For this dilute assembly, the population distribution for the most probable macrostate is given by the Boltzmann distribution law. **(35)**

(a) Using the Boltzmann distribution law, calculate the most probable macrostate $\{N_{0mp}, N_{1mp}, N_{2mp}, N_{3mp}\}$. Round the populations to the nearest integer.

(b) What is the entropy (J/K) of the assembly?

(c) What is the energy (J) of the assembly?

(d) Calculate the number of microstates associated with two macrostates that are very similar to the most probable macrostate. Macrostate A is given by $\{N_{0mp}+150, N_{1mp}-300, N_{2mp}+150, N_{3mp}\}$. Mactrostate B is given by $\{N_{0mp}-150, N_{1mp}+300, N_{2mp}-150, N_{3mp}\}$ Comment on the results. Note that the most probable macrostate, Macrostate A, and Macrostate B, all have the same total energy $E = \sum_j N_j E_j$.

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

Data tales will be supplied and assume any reasonable value. All the symbols have their usual meanings.

5. (a) Show that, for steady-flow steady state process. **(20)**

$$\Delta(\dot{m}\Psi) = \sum(\dot{m}\Psi)_e - \sum(\dot{m}\Psi)_i = \dot{\phi}_Q - \dot{W}_{u,act} - j_{cv.}$$

(b) In a counterflow heat exchanger saturated water vapour enters at atmospheric pressure and leaves as saturated liquid at 1 kg/s rate. Air at atmospheric pressure and at 25°C enters the system which leaves at 50°C. Estimate the effectiveness of the system. **(15)**

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6. (a) Estimate the relative humidity and moisture context of atmospheric air at T_{db} = 35°C & T_{wb} = 27°C without using the psychrometric chart, **(10)**

(b) Moist air at 35°C & 75% RH is compressed to 5atm pressure. Estimate the psychrometric condition of compressed air. **(5)**

(c) Explain the physical meaning of Joule-Thomson coefficient. Show that, for Van-der Waals gas:

$$\mu_{JT} = \frac{1}{C_P} \cdot \left[\frac{RT}{\left(P + \frac{q}{v^2}\right) - (v-b)\frac{29}{v^3}} - v \right]$$

Estimate the pressure and temperature limits for a fluid to achieve cooling during expansion. **(20)**

7. (a) Explain Clapeyron Equation. Using only P-V-T data for water, estimate h_{fg} of water at 100°C. and compare the results with tabulated data table. **(15)**

(b) Steam enters a nozzle at 520°C, 3MPa and 2 m/s and leaves at 100 kPa and 300 m/s. Estimate the energy destruction in the process. **(5)**

(c) One mole of CO is mixed with 2 mole of O_2 and temperature is raised to 2500 k at 1 atm pressure. Using Gibb's function, estimate the equilibrium composition of the gaseous mixture. **(15)**

8. A simple power plant uses steam at 520°C, 15 MPa and condenser pressure is 15 kPa. Cooling water supplied to the condenser is at 20°C which experiences 10°C temperature rise. If isentropic efficiencies of the turbine and the pump are same at 75%. With suitable assumptions, make energy and energy balance of the basic Rankine cycle. **(35)**

Equation Sheet

Specific Heats: $c_P = \left(\frac{\partial h}{\partial T}\right)_P = T\left(\frac{\partial s}{\partial T}\right)_P$; $c_V = \left(\frac{\partial u}{\partial T}\right)_v = T\left(\frac{\partial s}{\partial T}\right)_v$

Degeneracies: $g_{rot} = 2J+1$ $\quad g_{vib} = 1$

Rigid Rotator, Harmonic Oscillator

$\frac{\varepsilon_{rot}}{hc} = F(J) = B_e J(J+1)$ $\quad \frac{\varepsilon_{rot}}{k_B} = \theta_{rot} J(J+1)$ $\quad \frac{\varepsilon_{vib}}{hc} = G(\mathrm{v}) = \omega_e\left(\mathrm{v}+\frac{1}{2}\right)$

$\frac{\varepsilon_{vib}}{hc} = G(\mathrm{v}) = \omega_e\left(\mathrm{v}+\frac{1}{2}\right)$ $\quad \frac{\varepsilon_{vib}}{k_B} = \theta_{vib}\left(\mathrm{v}+\frac{1}{2}\right)$ *ZPE included*

$\frac{\varepsilon_{vib}}{hc} = G(\mathrm{v}) = \omega_e \mathrm{v}$ $\quad \frac{\varepsilon_{vib}}{k_B} = \theta_{vib}\mathrm{v}$ *ZPE **not** included*

Characteristic Temperatures:

$\theta_{rot} = \frac{hc}{k_B} B_e$ $\quad \theta_{vib} = \frac{hc}{k_B}\omega_e$ $\quad \frac{hc}{k_B} = 1.439 \frac{K}{cm^{-1}}$

Boltzmann Relation: $S = k_B \ln(W_{tot}) \cong k_B \ln(W_{mp})$

Number of Particle Arrangements

$W_{j,FD} = \frac{g_j!}{N_j!\,(g_j - N_j)!}$ $\quad W_{j,BE} = \frac{(N_j + g_j - 1)!}{N_j!(g_j - 1)!}$

Number of Microstates in a Macrostate

$$\ln(W_{m,CMB}) = \sum_j \left[N_j \ln\left(\frac{g_j}{N_j}\right) + N_j\right] = N + \sum_j N_j \ln\left(\frac{g_j}{N_j}\right)$$

$$\ln W_{m,FD} = \sum_j \left[N_j \ln\left(\frac{g_j - N_j}{N_j}\right) - g_j \ln\left(\frac{g_j - N_j}{g_j}\right)\right]$$

$$\ln W_{m,BE} = \sum_j \left[N_j \ln\left(\frac{g_j + N_j}{N_j}\right) + g_j \ln\left(\frac{g_j + N_j}{g_j}\right)\right]$$

Partition Function, Boltzmann Distribution Relations (Microcanonical Ensemble)

$$Z = \sum_j g_j \exp\left(-\varepsilon_j / k_B T\right) \quad , \quad N_j = N \frac{g_j \exp\left(-\varepsilon_j / k_B T\right)}{Z} \quad , \quad g_j = \textit{level degeneracy}$$

$$N = \sum_j N_j \quad , \quad E = \sum_j N_j \varepsilon_j$$

$$Z_{trans} = \forall \left(\frac{2\pi m k_B T}{h^2} \right)^{3/2}$$

$$Z_{rot} = \frac{1}{\sigma}\left(\frac{\mathrm{T}}{\theta_{rot}}\right)$$ *for rigid rotator*, $T >> \theta_{rot}$, $\sigma = 2$ *for homonuclear molecule*,

$\sigma = 1$ *for heteronuclear molecule*,

$$Z_{vib} = \frac{\exp\left(-\theta_{vib}/2T\right)}{1 - \exp\left(-\theta_{vib}/T\right)}$$ [with zero-point energy included in G(v)]

$$Z_{vib} = \frac{1}{1 - \exp\left(-\theta_{vib}/T\right)}$$ [without zero-point energy included in G(v)]

$Z_{nuc} = (2I_A + 1)(2I_B + 1)$ molecule AB, nuclear spins I_A , I_B

$Z_{nuc} = (2I_A + 1)$ atom A, nuclear spin I_A

Statistical Thermodynamic Property Calculations: CMB Statistics

$$E = U = N k_B T^2 \left[\frac{\partial (\ln Z)}{\partial T} \right]_{\forall}$$

$$E_{trans} = U_{trans} = \frac{3}{2} N k_B T$$

$$E_{rot} = U_{rot} = N k_B T$$ *for rigid rotator*, $T >> \theta_{rot}$

$$E_{vib} = U_{vib} = N k_B \left[\frac{\theta_{vib}}{2} + \frac{\theta_{vib}}{\exp(\theta_{vib}/T) - 1} \right]$$ zero-point energy included

$$E_{vib} = U_{vib} = \frac{N k_B \theta_{vib}}{\exp(\theta_{vib}/T) - 1}$$ zero-point energy not included

$$P = N k_B T \left[\frac{\partial (\ln Z)}{\partial \forall} \right]_T$$

for an ideal gas: $P\forall = N k_B T, \quad P\overline{\forall} = R_u T, \quad R_u = N_{Avogadro}\, k_B$

$$S = k_B \ln(W_{tot}) \cong k_B \ln(W_{mp})$$

$$S = N k_B \left[\ln\left(\frac{Z}{N}\right) + T\left(\frac{\partial(\ln Z)}{\partial T}\right)_{\forall} + 1 \right] = N k_B \left[\ln\left(\frac{Z}{N}\right) + 1 \right] + \frac{E}{T}$$

$$S_{trans} = N k_B \left[\ln\left(\frac{Z_{tr}}{N}\right) + T\left(\frac{\partial(\ln Z_{tr})}{\partial T}\right)_{\forall} + 1 \right] = N k_B \left[\ln\left(\frac{Z_{tr}}{N}\right) + 1 \right] + \frac{E_{tr}}{T}$$

$$= N k_B \left\{ \frac{5}{2}\ln T - \ln P + \ln\left[\left(\frac{2\pi m}{h^2}\right)^{3/2} k_B^{5/2} \right] + \frac{5}{2} \right\}$$

$$S_{int} = N k_B \left[\ln Z_{int} + T\left(\frac{\partial(\ln Z)}{\partial T}\right)_{\forall} \right] = N k_B \ln Z_{int} + \frac{E_{int}}{T}$$

Constants and Conversion Factors

Universal gas constant $R_u = 8.314 \frac{N-m}{(gmol)(K)} = 8.314 \frac{J}{(gmol)(K)} = 8314 \frac{J}{(kmol)(K)}$

Pressure $1\ atm = 1.01325\ bars = 1.01325\times10^5 \frac{N}{m^2} = 1.01325\times10^5 \frac{J}{m^3} = 0.101325\ MPa$

Speed of light $c = 2.998\times10^8 \frac{m}{sec} = 2.998\times10^{10} \frac{cm}{sec}$

Electron charge $e = 1.602\times10^{-19}\ coul$

Electron mass $m_e = 9.109\times10^{-31}\ kg$

Atomic mass unit $amu = 1.661\times10^{-27}\ kg$

Planck's constant $h = 6.626\times10^{-34}\ J-sec \quad ; \quad \hbar = \frac{h}{2\pi} = 1.055\times10^{-34}\ J-sec$

Dielectric permittivity $\varepsilon_0 = 8.854\times10^{-12} \frac{coul^2}{J-m}$

Avogadro constant $N_{Av} = 6.022\times10^{23}\ gmol^{-1}$ or $N_{Av} = 6.022\times10^{26}\ kmol^{-1}$

Boltzmann constant $k_B = 1.381\times10^{-23} \frac{J}{K}$

1 J = 1 kg-m^2/sec^2

K.1 Diatomic Molecules in Ground Electronic State

Molecule	Term symbol	ω_e (cm^{-1})	$\omega_e x_e$ (cm^{-1})	B_e (cm^{-1})	α_e (cm^{-1})	D_e (cm^{-1})	r_e (10^{-8} cm)	D_o (eV)
Br_2	$^1\Sigma_g^+$	325.32	1.077	0.0821	0.00032	2.09×10^{-8}	2.281	1.971
CH	$^2\Pi$	2858.50	63.020	14.457	0.534	14.5×10^{-4}	1.120	3.465
Cl_2	$^1\Sigma_g^+$	559.72	2.675	0.2440	0.0015	18.6×10^{-8}	1.988	2.479
CO	$^1\Sigma^+$	2169.81	13.288	1.9313	0.0175	6.12×10^{-6}	1.128	11.09
H_2	$^1\Sigma_g^+$	4401.21	121.336	60.853	3.062	4.71×10^{-2}	0.741	4.478
HBr	$^1\Sigma^+$	2648.98	45.218	8.4649	0.2333	3.46×10^{-4}	1.414	3.758
HCl	$^1\Sigma^+$	2990.95	52.819	10.593	0.3072	5.32×10^{-4}	1.275	4.434
HF	$^1\Sigma^+$	4138.32	89.880	20.956	0.798	21.5×10^{-4}	0.917	5.869
N_2	$^1\Sigma_g^+$	2358.57	14.324	1.9982	0.0173	5.76×10^{-6}	1.098	9.759
NO	$^2\Pi_{1/2}$	1904.20	14.075	1.6720	0.0171	0.54×10^{-6}	1.151	6.497
O_2	$^3\Sigma_g^-$	1580.19	11.981	1.4456	0.0159	4.84×10^{-6}	1.208	5.116
OH	$^2\Pi$	3737.76	84.881	18.911	0.7242	19.4×10^{-4}	0.970	4.392

TABLE A-2

Properties of Saturated Water (Liquid–Vapor): Temperature Table

Pressure Conversions: 1 bar = 0.1 MPa = 10^2 kPa

H_2O

Temp. °C	Press. bar	Specific Volume m³/kg: Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Internal Energy kJ/kg: Sat. Liquid u_f	Sat. Vapor u_g	Enthalpy kJ/kg: Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Entropy kJ/kg · K: Sat. Liquid s_f	Sat. Vapor s_g	Temp. °C
.01	0.00611	1.0002	206.136	0.00	2375.3	0.01	2501.3	2501.4	0.0000	9.1562	.01
4	0.00813	1.0001	157.232	16.77	2380.9	16.78	2491.9	2508.7	0.0610	9.0514	4
5	0.00872	1.0001	147.120	20.97	2382.3	20.98	2489.6	2510.6	0.0761	9.0257	5
6	0.00935	1.0001	137.734	25.19	2383.6	25.20	2487.2	2512.4	0.0912	9.0003	6
8	0.01072	1.0002	120.917	33.59	2386.4	33.60	2482.5	2516.1	0.1212	8.9501	8
10	0.01228	1.0004	106.379	42.00	2389.2	42.01	2477.7	2519.8	0.1510	8.9008	10
11	0.01312	1.0004	99.857	46.20	2390.5	46.20	2475.4	2521.6	0.1658	8.8765	11
12	0.01402	1.0005	93.784	50.41	2391.9	50.41	2473.0	2523.4	0.1806	8.8524	12
13	0.01497	1.0007	88.124	54.60	2393.3	54.60	2470.7	2525.3	0.1953	8.8285	13
14	0.01598	1.0008	82.848	58.79	2394.7	58.80	2468.3	2527.1	0.2099	8.8048	14
15	0.01705	1.0009	77.926	62.99	2396.1	62.99	2465.9	2528.9	0.2245	8.7814	15
16	0.01818	1.0011	73.333	67.18	2397.4	67.19	2463.6	2530.8	0.2390	8.7582	16
17	0.01938	1.0012	69.044	71.38	2398.8	71.38	2461.2	2532.6	0.2535	8.7351	17
18	0.02064	1.0014	65.038	75.57	2400.2	75.58	2458.8	2534.4	0.2679	8.7123	18
19	0.02198	1.0016	61.293	79.76	2401.6	79.77	2456.5	2536.2	0.2823	8.6897	19
20	0.02339	1.0018	57.791	83.95	2402.9	83.96	2454.1	2538.1	0.2966	8.6672	20
21	0.02487	1.0020	54.514	88.14	2404.3	88.14	2451.8	2539.9	0.3109	8.6450	21
22	0.02645	1.0022	51.447	92.32	2405.7	92.33	2449.4	2541.7	0.3251	8.6229	22
23	0.02810	1.0024	48.574	96.51	2407.0	96.52	2447.0	2543.5	0.3393	8.6011	23
24	0.02985	1.0027	45.883	100.70	2408.4	100.70	2444.7	2545.4	0.3534	8.5794	24
25	0.03169	1.0029	43.360	104.88	2409.8	104.89	2442.3	2547.2	0.3674	8.5580	25
26	0.03363	1.0032	40.994	109.06	2411.1	109.07	2439.9	2549.0	0.3814	8.5367	26
27	0.03567	1.0035	38.774	113.25	2412.5	113.25	2437.6	2550.8	0.3954	8.5156	27
28	0.03782	1.0037	36.690	117.42	2413.9	117.43	2435.2	2552.6	0.4093	8.4946	28
29	0.04008	1.0040	34.733	121.60	2415.2	121.61	2432.8	2554.5	0.4231	8.4739	29
30	0.04246	1.0043	32.894	125.78	2416.6	125.79	2430.5	2556.3	0.4369	8.4533	30
31	0.04496	1.0046	31.165	129.96	2418.0	129.97	2428.1	2558.1	0.4507	8.4329	31
32	0.04759	1.0050	29.540	134.14	2419.3	134.15	2425.7	2559.9	0.4644	8.4127	32
33	0.05034	1.0053	28.011	138.32	2420.7	138.33	2423.4	2561.7	0.4781	8.3927	33
34	0.05324	1.0056	26.571	142.50	2422.0	142.50	2421.0	2563.5	0.4917	8.3728	34
35	0.05628	1.0060	25.216	146.67	2423.4	146.68	2418.6	2565.3	0.5053	8.3531	35
36	0.05947	1.0063	23.940	150.85	2424.7	150.86	2416.2	2567.1	0.5188	8.3336	36
38	0.06632	1.0071	21.602	159.20	2427.4	159.21	2411.5	2570.7	0.5458	8.2950	38
40	0.07384	1.0078	19.523	167.56	2430.1	167.57	2406.7	2574.3	0.5725	8.2570	40
45	0.09593	1.0099	15.258	188.44	2436.8	188.45	2394.8	2583.2	0.6387	8.1648	45

H_2O

TABLE A-2

(Continued)

Temp. °C	Press. bar	Specific Volume m³/kg: Sat. Liquid $v_f \times 10^3$	Specific Volume m³/kg: Sat. Vapor v_g	Internal Energy kJ/kg: Sat. Liquid u_f	Internal Energy kJ/kg: Sat. Vapor u_g	Enthalpy kJ/kg: Sat. Liquid h_f	Enthalpy kJ/kg: Evap. h_{fg}	Enthalpy kJ/kg: Sat. Vapor h_g	Entropy kJ/kg · K: Sat. Liquid s_f	Entropy kJ/kg · K: Sat. Vapor s_g	Temp. °C
50	.1235	1.0121	12.032	209.32	2443.5	209.33	2382.7	2592.1	.7038	8.0763	50
55	.1576	1.0146	9.568	230.21	2450.1	230.23	2370.7	2600.9	.7679	7.9913	55
60	.1994	1.0172	7.671	251.11	2456.6	251.13	2358.5	2609.6	.8312	7.9096	60
65	.2503	1.0199	6.197	272.02	2463.1	272.06	2346.2	2618.3	.8935	7.8310	65
70	.3119	1.0228	5.042	292.95	2469.6	292.98	2333.8	2626.8	.9549	7.7553	70
75	.3858	1.0259	4.131	313.90	2475.9	313.93	2321.4	2635.3	1.0155	7.6824	75
80	.4739	1.0291	3.407	334.86	2482.2	334.91	2308.8	2643.7	1.0753	7.6122	80
85	.5783	1.0325	2.828	355.84	2488.4	355.90	2296.0	2651.9	1.1343	7.5445	85
90	.7014	1.0360	2.361	376.85	2494.5	376.92	2283.2	2660.1	1.1925	7.4791	90
95	.8455	1.0397	1.982	397.88	2500.6	397.96	2270.2	2668.1	1.2500	7.4159	95
100	1.014	1.0435	1.673	418.94	2506.5	419.04	2257.0	2676.1	1.3069	7.3549	100
110	1.433	1.0516	1.210	461.14	2518.1	461.30	2230.2	2691.5	1.4185	7.2387	110
120	1.985	1.0603	0.8919	503.50	2529.3	503.71	2202.6	2706.3	1.5276	7.1296	120
130	2.701	1.0697	0.6685	546.02	2539.9	546.31	2174.2	2720.5	1.6344	7.0269	130
140	3.613	1.0797	0.5089	588.74	2550.0	589.13	2144.7	2733.9	1.7391	6.9299	140
150	4.758	1.0905	0.3928	631.68	2559.5	632.20	2114.3	2746.5	1.8418	6.8379	150
160	6.178	1.1020	0.3071	674.86	2568.4	675.55	2082.6	2758.1	1.9427	6.7502	160
170	7.917	1.1143	0.2428	718.33	2576.5	719.21	2049.5	2768.7	2.0419	6.6663	170
180	10.02	1.1274	0.1941	762.09	2583.7	763.22	2015.0	2778.2	2.1396	6.5857	180
190	12.54	1.1414	0.1565	806.19	2590.0	807.62	1978.8	2786.4	2.2359	6.5079	190
200	15.54	1.1565	0.1274	850.65	2595.3	852.45	1940.7	2793.2	2.3309	6.4323	200
210	19.06	1.1726	0.1044	895.53	2599.5	897.76	1900.7	2798.5	2.4248	6.3585	210
220	23.18	1.1900	0.08619	940.87	2602.4	943.62	1858.5	2802.1	2.5178	6.2861	220
230	27.95	1.2088	0.07158	986.74	2603.9	990.12	1813.8	2804.0	2.6099	6.2146	230
240	33.44	1.2291	0.05976	1033.2	2604.0	1037.3	1766.5	2803.8	2.7015	6.1437	240
250	39.73	1.2512	0.05013	1080.4	2602.4	1085.4	1716.2	2801.5	2.7927	6.0730	250
260	46.88	1.2755	0.04221	1128.4	2599.0	1134.4	1662.5	2796.6	2.8838	6.0019	260
270	54.99	1.3023	0.03564	1177.4	2593.7	1184.5	1605.2	2789.7	2.9751	5.9301	270
280	64.12	1.3321	0.03017	1227.5	2586.1	1236.0	1543.6	2779.6	3.0668	5.8571	280
290	74.36	1.3656	0.02557	1278.9	2576.0	1289.1	1477.1	2766.2	3.1594	5.7821	290
300	85.81	1.4036	0.02167	1332.0	2563.0	1344.0	1404.9	2749.0	3.2534	5.7045	300
320	112.7	1.4988	0.01549	1444.6	2525.5	1461.5	1238.6	2700.1	3.4480	5.5362	320
340	145.9	1.6379	0.01080	1570.3	2464.6	1594.2	1027.9	2622.0	3.6594	5.3357	340
360	186.5	1.8925	0.006945	1725.2	2351.5	1760.5	720.5	2481.0	3.9147	5.0526	360
374.14	220.9	3.155	0.003155	2029.6	2029.6	2099.3	0	2099.3	4.4298	4.4298	374.14

Source: Tables A-2 through A-5 are extracted from J. H. Keenan, F. G. Keyes, P. G. Hill, and J. G. Moore, *Steam Tables*, Wiley, New York, 1969.

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TABLE A-3

Properties of Saturated Water (Liquid–Vapor): Pressure Table

Pressure Conversions:
1 bar = 0.1 MPa
= 10^2 kPa

H_2O

Press. bar	Temp. °C	Specific Volume m^3/kg Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Internal Energy kJ/kg Sat. Liquid u_f	Sat. Vapor u_g	Enthalpy kJ/kg Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Entropy kJ/kg · K Sat. Liquid s_f	Sat. Vapor s_g	Press. bar
0.04	28.96	1.0040	34.800	121.45	2415.2	121.46	2432.9	2554.4	0.4226	8.4746	0.04
0.06	36.16	1.0064	23.739	151.53	2425.0	151.53	2415.9	2567.4	0.5210	8.3304	0.06
0.08	41.51	1.0084	18.103	173.87	2432.2	173.88	2403.1	2577.0	0.5926	8.2287	0.08
0.10	45.81	1.0102	14.674	191.82	2437.9	191.83	2392.8	2584.7	0.6493	8.1502	0.10
0.20	60.06	1.0172	7.649	251.38	2456.7	251.40	2358.3	2609.7	0.8320	7.9085	0.20
0.30	69.10	1.0223	5.229	289.20	2468.4	289.23	2336.1	2625.3	0.9439	7.7686	0.30
0.40	75.87	1.0265	3.993	317.53	2477.0	317.58	2319.2	2636.8	1.0259	7.6700	0.40
0.50	81.33	1.0300	3.240	340.44	2483.9	340.49	2305.4	2645.9	1.0910	7.5939	0.50
0.60	85.94	1.0331	2.732	359.79	2489.6	359.86	2293.6	2653.5	1.1453	7.5320	0.60
0.70	89.95	1.0360	2.365	376.63	2494.5	376.70	2283.3	2660.0	1.1919	7.4797	0.70
0.80	93.50	1.0380	2.087	391.58	2498.8	391.66	2274.1	2665.8	1.2329	7.4346	0.80
0.90	96.71	1.0410	1.869	405.06	2502.6	405.15	2265.7	2670.9	1.2695	7.3949	0.90
1.00	99.63	1.0432	1.694	417.36	2506.1	417.46	2258.0	2675.5	1.3026	7.3594	1.00
1.50	111.4	1.0528	1.159	466.94	2519.7	467.11	2226.5	2693.6	1.4336	7.2233	1.50
2.00	120.2	1.0605	0.8857	504.49	2529.5	504.70	2201.9	2706.7	1.5301	7.1271	2.00
2.50	127.4	1.0672	0.7187	535.10	2537.2	535.37	2181.5	2716.9	1.6072	7.0527	2.50
3.00	133.6	1.0732	0.6058	561.15	2543.6	561.47	2163.8	2725.3	1.6718	6.9919	3.00
3.50	138.9	1.0786	0.5243	583.95	2546.9	584.33	2148.1	2732.4	1.7275	6.9405	3.50
4.00	143.6	1.0836	0.4625	604.31	2553.6	604.74	2133.8	2738.6	1.7766	6.8959	4.00
4.50	147.9	1.0882	0.4140	622.25	2557.6	623.25	2120.7	2743.9	1.8207	6.8565	4.50
5.00	151.9	1.0926	0.3749	639.68	2561.2	640.23	2108.5	2748.7	1.8607	6.8212	5.00
6.00	158.9	1.1006	0.3157	669.90	2567.4	670.56	2086.3	2756.8	1.9312	6.7600	6.00
7.00	165.0	1.1080	0.2729	696.44	2572.5	697.22	2066.3	2763.5	1.9922	6.7080	7.00
8.00	170.4	1.1148	0.2404	720.22	2576.8	721.11	2048.0	2769.1	2.0462	6.6628	8.00
9.00	175.4	1.1212	0.2150	741.83	2580.5	742.83	2031.1	2773.9	2.0946	6.6226	9.00
10.0	179.9	1.1273	0.1944	761.68	2583.6	762.81	2015.3	2778.1	2.1387	6.5863	10.0
15.0	198.3	1.1539	0.1318	843.16	2594.5	844.84	1947.3	2792.2	2.3150	6.4448	15.0
20.0	212.4	1.1767	0.09963	906.44	2600.3	908.79	1890.7	2799.5	2.4474	6.3409	20.0
25.0	224.0	1.1973	0.07998	959.11	2603.1	962.11	1841.0	2803.1	2.5547	6.2575	25.0
30.0	233.9	1.2165	0.06668	1004.8	2604.1	1008.4	1795.7	2804.2	2.6457	6.1869	30.0
35.0	242.6	1.2347	0.05707	1045.4	2603.7	1049.8	1753.7	2803.4	2.7253	6.1253	35.0
40.0	250.4	1.2522	0.04978	1082.3	2602.3	1087.3	1714.1	2801.4	2.7964	6.0701	40.0
45.0	257.5	1.2692	0.04406	1116.2	2600.1	1121.9	1676.4	2798.3	2.8610	6.0199	45.0
50.0	264.0	1.2859	0.03944	1147.8	2597.1	1154.2	1640.1	2794.3	2.9202	5.9734	50.0
60.0	275.6	1.3187	0.03244	1205.4	2589.7	1213.4	1571.0	2784.3	3.0267	5.8892	60.0
70.0	285.9	1.3513	0.02737	1257.6	2580.5	1267.0	1505.1	2772.1	3.1211	5.8133	70.0
80.0	295.1	1.3842	0.02352	1305.6	2569.8	1316.6	1441.3	2758.0	3.2068	5.7432	80.0
90.0	303.4	1.4178	0.02048	1350.5	2557.8	1363.3	1378.9	2742.1	3.2858	5.6772	90.0
100.	311.1	1.4524	0.01803	1393.0	2544.4	1407.6	1317.1	2724.7	3.3596	5.6141	100.
110.	318.2	1.4886	0.01599	1433.7	2529.8	1450.1	1255.5	2705.6	3.4295	5.5527	110.

TABLE A-3

(Continued)

H_2O

Press. bar	Temp. °C	Specific Volume m^3/kg Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Internal Energy kJ/kg Sat. Liquid u_f	Sat. Vapor u_g	Enthalpy kJ/kg Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Entropy kJ/kg · K Sat. Liquid s_f	Sat. Vapor s_g	Press. bar
120.	324.8	1.5267	0.01426	1473.0	2513.7	1491.3	1193.6	2684.9	3.4962	5.4924	120.
130.	330.9	1.5671	0.01278	1511.1	2496.1	1531.5	1130.7	2662.2	3.5606	5.4323	130.
140.	336.8	1.6107	0.01149	1548.6	2476.8	1571.1	1066.5	2637.6	3.6232	5.3717	140.
150.	342.2	1.6581	0.01034	1585.6	2455.5	1610.5	1000.0	2610.5	3.6848	5.3098	150.
160.	347.4	1.7107	0.009306	1622.7	2431.7	1650.1	930.6	2580.6	3.7461	5.2455	160.
170.	352.4	1.7702	0.008364	1660.2	2405.0	1690.3	856.9	2547.2	3.8079	5.1777	170.
180.	357.1	1.8397	0.007489	1698.9	2374.3	1732.0	777.1	2509.1	3.8715	5.1044	180.
190.	361.5	1.9243	0.006657	1739.9	2338.1	1776.5	688.0	2464.5	3.9388	5.0228	190.
200.	365.8	2.036	0.005834	1785.6	2293.0	1826.3	583.4	2409.7	4.0139	4.9269	200.
220.9	374.1	3.155	0.003155	2029.6	2029.6	2099.3	0	2099.3	4.4298	4.4298	220.9

TABLE A-4

Properties of Superheated Water Vapor

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 0.06 bar = 0.006 MPa (T_{sat} = 36.16°C)				p = 0.35 bar = 0.035 MPa (T_{sat} = 72.69°C)			
Sat.	23.739	2425.0	2567.4	8.3304	4.526	2473.0	2631.4	7.7158
80	27.132	2487.3	2650.1	8.5804	4.625	2483.7	2645.6	7.7564
120	30.219	2544.7	2726.0	8.7840	5.163	2542.4	2723.1	7.9644
160	33.302	2602.7	2802.5	8.9693	5.696	2601.2	2800.6	8.1519
200	36.383	2661.4	2879.7	9.1398	6.228	2660.4	2878.4	8.3237
240	39.462	2721.0	2957.8	9.2982	6.758	2720.3	2956.8	8.4828
280	42.540	2781.5	3036.8	9.4464	7.287	2780.9	3036.0	8.6314
320	45.618	2843.0	3116.7	9.5859	7.815	2842.5	3116.1	8.7712
360	48.696	2905.5	3197.7	9.7180	8.344	2905.1	3197.1	8.9034
400	51.774	2969.0	3279.6	9.8435	8.872	2968.6	3279.2	9.0291
440	54.851	3033.5	3362.6	9.9633	9.400	3033.2	3362.2	9.1490
500	59.467	3132.3	3489.1	10.1336	10.192	3132.1	3488.8	9.3194
	p = 0.70 bar = 0.07 MPa (T_{sat} = 89.95°C)				p = 1.0 bar = 0.10 MPa (T_{sat} = 99.63°C)			
Sat.	2.365	2494.5	2660.0	7.4797	1.694	2506.1	2675.5	7.3594
100	2.434	2509.7	2680.0	7.5341	1.696	2506.7	2676.2	7.3614
120	2.571	2539.7	2719.6	7.6375	1.793	2537.3	2716.6	7.4668
160	2.841	2599.4	2798.2	7.8279	1.984	2597.8	2796.2	7.6597
200	3.108	2659.1	2876.7	8.0012	2.172	2658.1	2875.3	7.8343
240	3.374	2719.3	2955.5	8.1611	2.359	2718.5	2954.5	7.9949
280	3.640	2780.2	3035.0	8.3162	2.546	2779.6	3034.2	8.1445
320	3.905	2842.0	3115.3	8.4504	2.732	2841.5	3114.6	8.2849
360	4.170	2904.6	3196.5	8.5828	2.917	2904.2	3195.9	8.4175
400	4.434	2968.2	3278.6	8.7086	3.103	2967.9	3278.2	8.5435
440	4.698	3032.9	3361.8	8.8286	3.288	3032.6	3361.4	8.6636
500	5.095	3131.8	3488.5	8.9991	3.565	3131.6	3488.1	8.8342
	p = 1.5 bar = 0.15 MPa (T_{sat} = 111.37°C)				p = 3.0 bar = 0.30 MPa (T_{sat} = 133.55°C)			
Sat.	1.159	2519.7	2693.6	7.2233	0.606	2543.6	2725.3	6.9919
120	1.188	2533.3	2711.4	7.2693				
160	1.317	2595.2	2792.8	7.4665	0.651	2587.1	2782.3	7.1276
200	1.444	2656.2	2872.9	7.6433	0.716	2650.7	2865.5	7.3115
240	1.570	2717.2	2952.7	7.8052	0.781	2713.1	2947.3	7.4774
280	1.695	2778.6	3032.8	7.9555	0.844	2775.4	3028.6	7.6299
320	1.819	2840.6	3113.5	8.0964	0.907	2838.1	3110.1	7.7722
360	1.943	2903.5	3195.0	8.2293	0.969	2901.4	3192.2	7.9061
400	2.067	2967.3	3277.4	8.3555	1.032	2965.6	3275.0	8.0330
440	2.191	3032.1	3360.7	8.4757	1.094	3030.6	3358.7	8.1538
500	2.376	3131.2	3487.6	8.6466	1.187	3130.0	3486.0	8.3251
600	2.685	3301.7	3704.3	8.9101	1.341	3300.8	3703.2	8.5892

Pressure Conversions:
1 bar = 0.1 MPa
= 10^2 kPa

H_2O

H_2O

TABLE A-4

(Continued)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 5.0 bar = 0.50 MPa (T_{sat} = 151.86°C)				p = 7.0 bar = 0.70 MPa (T_{sat} = 164.97°C)			
Sat.	0.3749	2561.2	2748.7	6.8213	0.2729	2572.5	2763.5	6.7080
180	0.4045	2609.7	2812.0	6.9656	0.2847	2599.8	2799.1	6.7880
200	0.4249	2642.9	2855.4	7.0592	0.2999	2634.8	2844.8	6.8865
240	0.4646	2707.6	2939.9	7.2307	0.3292	2701.8	2932.2	7.0641
280	0.5034	2771.2	3022.9	7.3865	0.3574	2766.9	3017.1	7.2233
320	0.5416	2834.7	3105.6	7.5308	0.3852	2831.3	3100.9	7.3697
360	0.5796	2898.7	3188.4	7.6660	0.4126	2895.8	3184.7	7.5063
400	0.6173	2963.2	3271.9	7.7938	0.4397	2960.9	3268.7	7.6350
440	0.6548	3028.6	3356.0	7.9152	0.4667	3026.6	3353.3	7.7571
500	0.7109	3128.4	3483.9	8.0873	0.5070	3126.8	3481.7	7.9299
600	0.8041	3299.6	3701.7	8.3522	0.5738	3298.5	3700.2	8.1956
700	0.8969	3477.5	3925.9	8.5952	0.6403	3476.6	3924.8	8.4391

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 10.0 bar = 1.0 MPa (T_{sat} = 179.91°C)				p = 15.0 bar = 1.5 MPa (T_{sat} = 198.32°C)			
Sat.	0.1944	2583.6	2778.1	6.5865	0.1318	2594.5	2792.2	6.4448
200	0.2060	2621.9	2827.9	6.6940	0.1325	2598.1	2796.8	6.4546
240	0.2275	2692.9	2920.4	6.8817	0.1483	2676.9	2899.3	6.6628
280	0.2480	2760.2	3008.2	7.0465	0.1627	2748.6	2992.7	6.8381
320	0.2678	2826.1	3093.9	7.1962	0.1765	2817.1	3081.9	6.9938
360	0.2873	2891.6	3178.9	7.3349	0.1899	2884.4	3169.2	7.1363
400	0.3066	2957.3	3263.9	7.4651	0.2030	2951.3	3255.8	7.2690
440	0.3257	3023.6	3349.3	7.5883	0.2160	3018.5	3342.5	7.3940
500	0.3541	3124.4	3478.5	7.7622	0.2352	3120.3	3473.1	7.5698
540	0.3729	3192.6	3565.6	7.8720	0.2478	3189.1	3560.9	7.6805
600	0.4011	3296.8	3697.9	8.0290	0.2668	3293.9	3694.0	7.8385
640	0.4198	3367.4	3787.2	8.1290	0.2793	3364.8	3783.8	7.9391

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 20.0 bar = 2.0 MPa (T_{sat} = 212.42°C)				p = 30.0 bar = 3.0 MPa (T_{sat} = 233.90°C)			
Sat.	0.0996	2600.3	2799.5	6.3409	0.0667	2604.1	2804.2	6.1869
240	0.1085	2659.6	2876.5	6.4952	0.0682	2619.7	2824.3	6.2265
280	0.1200	2736.4	2976.4	6.6828	0.0771	2709.9	2941.3	6.4462
320	0.1308	2807.9	3069.5	6.8452	0.0850	2788.4	3043.4	6.6245
360	0.1411	2877.0	3159.3	6.9917	0.0923	2861.7	3138.7	6.7801
400	0.1512	2945.2	3247.6	7.1271	0.0994	2932.8	3230.9	6.9212
440	0.1611	3013.4	3335.5	7.2540	0.1062	3002.9	3321.5	7.0520
500	0.1757	3116.2	3467.6	7.4317	0.1162	3108.0	3456.5	7.2338
540	0.1853	3185.6	3556.1	7.5434	0.1227	3178.4	3546.6	7.3474
600	0.1996	3290.9	3690.1	7.7024	0.1324	3285.0	3682.3	7.5085
640	0.2091	3362.2	3780.4	7.8035	0.1388	3357.0	3773.5	7.6106
700	0.2232	3470.9	3917.4	7.9487	0.1484	3466.5	3911.7	7.7571

TABLE A-4

(Continued)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 40 bar = 4.0 MPa (T_{sat} = 250.4°C)				p = 60 bar = 6.0 MPa (T_{sat} = 275.64°C)			
Sat.	0.04978	2602.3	2801.4	6.0701	0.03244	2589.7	2784.3	5.8892
280	0.05546	2680.0	2901.8	6.2568	0.03317	2605.2	2804.2	5.9252
320	0.06199	2767.4	3015.4	6.4553	0.03876	2720.0	2952.6	6.1846
360	0.06788	2845.7	3117.2	6.6215	0.04331	2811.2	3071.1	6.3782
400	0.07341	2919.9	3213.6	6.7690	0.04739	2892.9	3177.2	6.5408
440	0.07872	2992.2	3307.1	6.9041	0.05122	2970.0	3277.3	6.6853
500	0.08643	3099.5	3445.3	7.0901	0.05665	3082.2	3422.2	6.8803
540	0.09145	3171.1	3536.9	7.2056	0.06015	3156.1	3517.0	6.9999
600	0.09885	3279.1	3674.4	7.3688	0.06525	3266.9	3658.4	7.1677
640	0.1037	3351.8	3766.6	7.4720	0.06859	3341.0	3752.6	7.2731
700	0.1110	3462.1	3905.9	7.6198	0.07352	3453.1	3894.1	7.4234
740	0.1157	3536.6	3999.6	7.7141	0.07677	3528.3	3989.2	7.5190
	p = 80 bar = 8.0 MPa (T_{sat} = 295.06°C)				p = 100 bar = 10.0 MPa (T_{sat} = 311.06°C)			
Sat.	0.02352	2569.8	2758.0	5.7432	0.01803	2544.4	2724.7	5.6141
320	0.02682	2662.7	2877.2	5.9489	0.01925	2588.8	2781.3	5.7103
360	0.03089	2772.7	3019.8	6.1819	0.02331	2729.1	2962.1	6.0060
400	0.03432	2863.8	3138.3	6.3634	0.02641	2832.4	3096.5	6.2120
440	0.03742	2946.7	3246.1	6.5190	0.02911	2922.1	3213.2	6.3805
480	0.04034	3025.7	3348.4	6.6586	0.03160	3005.4	3321.4	6.5282
520	0.04313	3102.7	3447.7	6.7871	0.03394	3085.6	3425.1	6.6622
560	0.04582	3178.7	3545.3	6.9072	0.03619	3164.1	3526.0	6.7864
600	0.04845	3254.4	3642.0	7.0206	0.03837	3241.7	3625.3	6.9029
640	0.05102	3330.1	3738.3	7.1283	0.04048	3318.9	3723.7	7.0131
700	0.05481	3443.9	3882.4	7.2812	0.04358	3434.7	3870.5	7.1687
740	0.05729	3520.4	3978.7	7.3782	0.04560	3512.1	3968.1	7.2670
	p = 120 bar = 12.0 MPa (T_{sat} = 324.75°C)				p = 140 bar = 14.0 MPa (T_{sat} = 336.75°C)			
Sat.	0.01426	2513.7	2684.9	5.4924	0.01149	2476.8	2637.6	5.3717
360	0.01811	2678.4	2895.7	5.8361	0.01422	2617.4	2816.5	5.6602
400	0.02108	2798.3	3051.3	6.0747	0.01722	2760.9	3001.9	5.9448
440	0.02355	2896.1	3178.7	6.2586	0.01954	2868.6	3142.2	6.1474
480	0.02576	2984.4	3293.5	6.4154	0.02157	2962.5	3264.5	6.3143
520	0.02781	3068.0	3401.8	6.5555	0.02343	3049.8	3377.8	6.4610
560	0.02977	3149.0	3506.2	6.6840	0.02517	3133.6	3486.0	6.5941
600	0.03164	3228.7	3608.3	6.8037	0.02683	3215.4	3591.1	6.7172
640	0.03345	3307.5	3709.0	6.9164	0.02843	3296.0	3694.1	6.8326
700	0.03610	3425.2	3858.4	7.0749	0.03075	3415.7	3846.2	6.9939
740	0.03781	3503.7	3957.4	7.1746	0.03225	3495.2	3946.7	7.0952

H_2O

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H_2O

TABLE A-4

(Continued)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 160 bar = 16.0 MPa (T_{sat} = 347.44°C)				p = 180 bar = 18.0 MPa (T_{sat} = 357.06°C)			
Sat.	0.00931	2431.7	2580.6	5.2455	0.00749	2374.3	2509.1	5.1044
360	0.01105	2539.0	2715.8	5.4614	0.00809	2418.9	2564.5	5.1922
400	0.01426	2719.4	2947.6	5.8175	0.01190	2672.8	2887.0	5.6887
440	0.01652	2839.4	3103.7	6.0429	0.01414	2808.2	3062.8	5.9428
480	0.01842	2939.7	3234.4	6.2215	0.01596	2915.9	3203.2	6.1345
520	0.02013	3031.1	3353.3	6.3752	0.01757	3011.8	3378.0	6.2960
560	0.02172	3117.8	3465.4	6.5132	0.01904	3101.7	3444.4	6.4392
600	0.02323	3201.8	3573.5	6.6399	0.02042	3188.0	3555.6	6.5696
640	0.02467	3284.2	3678.9	6.7580	0.02174	3272.3	3663.6	6.6905
700	0.02674	3406.0	3833.9	6.9224	0.02362	3396.3	3821.5	6.8580
740	0.02808	3486.7	3935.9	7.0251	0.02483	3478.0	3925.0	6.9623

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 200 bar = 20.0 MPa (T_{sat} = 365.81°C)				p = 240 bar = 24.0 MPa			
Sat.	0.00583	2293.0	2409.7	4.9269				
400	0.00994	2619.3	2818.1	5.5540	0.00673	2477.8	2639.4	5.2393
440	0.01222	2774.9	3019.4	5.8450	0.00929	2700.6	2923.4	5.6506
480	0.01399	2891.2	3170.8	6.0518	0.01100	2838.3	3102.3	5.8950
520	0.01551	2992.0	3302.2	6.2218	0.01241	2950.5	3248.5	6.0842
560	0.01689	3085.2	3423.0	6.3705	0.01366	3051.1	3379.0	6.2448
600	0.01818	3174.0	3537.6	6.5048	0.01481	3145.2	3500.7	6.3875
640	0.01940	3260.2	3648.1	6.6286	0.01588	3235.5	3616.7	6.5174
700	0.02113	3386.4	3809.0	6.7993	0.01739	3366.4	3783.8	6.6947
740	0.02224	3469.3	3914.1	6.9052	0.01835	3451.7	3892.1	6.8038
800	0.02385	3592.7	4069.7	7.0544	0.01974	3578.0	4051.6	6.9567

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 280 bar = 28.0 MPa				p = 320 bar = 32.0 MPa			
400	0.00383	2223.5	2330.7	4.7494	0.00236	1980.4	2055.9	4.3239
440	0.00712	2613.2	2812.6	5.4494	0.00544	2509.0	2683.0	5.2327
480	0.00885	2780.8	3028.5	5.7446	0.00722	2718.1	2949.2	5.5968
520	0.01020	2906.8	3192.3	5.9566	0.00853	2860.7	3133.7	5.8357
560	0.01136	3015.7	3333.7	6.1307	0.00963	2979.0	3287.2	6.0246
600	0.01241	3115.6	3463.0	6.2823	0.01061	3085.3	3424.6	6.1858
640	0.01338	3210.3	3584.8	6.4187	0.01150	3184.5	3552.5	6.3290
700	0.01473	3346.1	3758.4	6.6029	0.01273	3325.4	3732.8	6.5203
740	0.01558	3433.9	3870.0	6.7153	0.01350	3415.9	3847.8	6.6361
800	0.01680	3563.1	4033.4	6.8720	0.01460	3548.0	4015.1	6.7966
900	0.01873	3774.3	4298.8	7.1084	0.01633	3762.7	4285.1	7.0372

TABLE A-23

Ideal Gas Properties of Selected Gases

Enthalpy $\bar{h}(T)$ and internal energy $\bar{u}(T)$, in kJ/kmol. Absolute entropy at 1 atm $\bar{s}^\circ(T)$, in 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(K)	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	T(K)
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

TABLE A-23

(Continued)

$\bar{h}$ and $\bar{u}$ in kJ/kmol. $\bar{s}^\circ$ in 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(K)	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	T(K)
600	22,280	17,291	243.199	17,611	12,622	218.204	20,402	15,413	212.920	17,929	12,940	226.346	17,563	12,574	212.066	600
610	22,754	17,683	243.983	17,915	12,843	218.708	20,765	15,693	213.529	18,250	13,178	226.877	17,864	12,792	212.564	610
620	23,231	18,076	244.758	18,221	13,066	219.205	21,130	15,975	214.122	18,572	13,417	227.400	18,166	13,011	213.055	620
630	23,709	18,471	245.524	18,527	13,289	219.695	21,495	16,257	214.707	18,895	13,657	227.918	18,468	13,230	213.541	630
640	24,190	18,869	246.282	18,833	13,512	220.179	21,862	16,541	215.285	19,219	13,898	228.429	18,772	13,450	214.018	640
650	24,674	19,270	247.032	19,141	13,736	220.656	22,230	16,826	215.856	19,544	14,140	228.932	19,075	13,671	214.489	650
660	25,160	19,672	247.773	19,449	13,962	221.127	22,600	17,112	216.419	19,870	14,383	229.430	19,380	13,892	214.954	660
670	25,648	20,078	248.507	19,758	14,187	221.592	22,970	17,399	216.976	20,197	14,626	229.920	19,685	14,114	215.413	670
680	26,138	20,484	249.233	20,068	14,414	222.052	23,342	17,688	217.527	20,524	14,871	230.405	19,991	14,337	215.866	680
690	26,631	20,894	249.952	20,378	14,641	222.505	23,714	17,978	218.071	20,854	15,116	230.885	20,297	14,560	216.314	690
700	27,125	21,305	250.663	20,690	14,870	222.953	24,088	18,268	218.610	21,184	15,364	231.358	20,604	14,784	216.756	700
710	27,622	21,719	251.368	21,002	15,099	223.396	24,464	18,561	219.142	21,514	15,611	231.827	20,912	15,008	217.192	710
720	28,121	22,134	252.065	21,315	15,328	223.833	24,840	18,854	219.668	21,845	15,859	232.291	21,220	15,234	217.624	720
730	28,622	22,552	252.755	21,628	15,558	224.265	25,218	19,148	220.189	22,177	16,107	232.748	21,529	15,460	218.059	730
740	29,124	22,972	253.439	21,943	15,789	224.692	25,597	19,444	220.707	22,510	16,357	233.201	21,839	15,686	218.472	740
750	29,629	23,393	254.117	22,258	16,022	225.115	25,977	19,741	221.215	22,844	16,607	233.649	22,149	15,913	218.889	750
760	30,135	23,817	254.787	22,573	16,255	225.533	26,358	20,039	221.720	23,178	16,859	234.091	22,460	16,141	219.301	760
770	30,644	24,242	255.452	22,890	16,488	225.947	26,741	20,339	222.221	23,513	17,111	234.528	22,772	16,370	219.709	770
780	31,154	24,669	256.110	23,208	16,723	226.357	27,125	20,639	222.717	23,850	17,364	234.960	23,085	16,599	220.113	780
790	31,665	25,097	256.762	23,526	16,957	226.762	27,510	20,941	223.207	24,186	17,618	235.387	23,398	16,830	220.512	790
800	32,179	25,527	257.408	23,844	17,193	227.162	27,896	21,245	223.693	24,523	17,872	235.810	23,714	17,061	220.907	800
810	32,694	25,959	258.048	24,164	17,429	227.559	28,284	21,549	224.174	24,861	18,126	236.230	24,027	17,292	221.298	810
820	33,212	26,394	258.682	24,483	17,665	227.952	28,672	21,855	224.651	25,199	18,382	236.644	24,342	17,524	221.684	820
830	33,730	26,829	259.311	24,803	17,902	228.339	29,062	22,162	225.123	25,537	18,637	237.055	24,658	17,757	222.067	830
840	34,251	27,267	259.934	25,124	18,140	228.724	29,454	22,470	225.592	25,877	18,893	237.462	24,974	17,990	222.447	840
850	34,773	27,706	260.551	25,446	18,379	229.106	29,846	22,779	226.057	26,218	19,150	237.864	25,292	18,224	222.822	850
860	35,296	28,125	261.164	25,768	18,617	229.482	30,240	23,090	226.517	26,559	19,408	238.264	25,610	18,459	223.194	860
870	35,821	28,588	261.770	26,091	18,858	229.856	30,635	23,402	226.973	26,899	19,666	238.660	25,928	18,695	223.562	870
880	36,347	29,031	262.371	26,415	19,099	230.227	31,032	23,715	227.426	27,242	19,925	239.051	26,248	18,931	223.927	880
890	36,876	29,476	262.968	26,740	19,341	230.593	31,429	24,029	227.875	27,584	20,185	239.439	26,568	19,168	224.288	890
900	37,405	29,922	263.559	27,066	19,583	230.957	31,828	24,345	228.321	27,928	20,445	239.823	26,890	19,407	224.647	900
910	37,935	30,369	264.146	27,392	19,826	231.317	32,228	24,662	228.763	28,272	20,706	240.203	27,210	19,644	225.002	910
920	38,467	30,818	264.728	27,719	20,070	231.674	32,629	24,980	229.202	28,616	20,967	240.580	27,532	19,883	225.353	920
930	39,000	31,268	265.304	28,046	20,314	232.028	33,032	25,300	229.637	28,960	21,228	240.953	27,854	20,122	225.701	930
940	39,535	31,719	265.877	28,375	20,559	232.379	33,436	25,621	230.070	29,306	21,491	241.323	28,178	20,362	226.047	940
950	40,070	32,171	266.444	28,703	20,805	232.727	33,841	25,943	230.499	29,652	21,754	241.689	28,501	20,603	226.389	950
960	40,607	32,625	267.007	29,033	21,051	233.072	34,247	26,265	230.924	29,999	22,017	242.052	28,826	20,844	226.728	960
970	41,145	33,081	267.566	29,362	21,298	233.413	34,653	26,588	231.347	30,345	22,280	242.411	29,151	21,086	227.064	970
980	41,685	33,537	268.119	29,693	21,545	233.752	35,061	26,913	231.767	30,692	22,544	242.768	29,476	21,328	227.398	980
990	42,226	33,995	268.670	30,024	21,793	234.088	35,472	27,240	232.184	31,041	22,809	243.120	29,803	21,571	227.728	990

TABLE A-23

(Continued)

$\bar{h}$ and $\bar{u}$ in kJ/kmol. $\bar{s}^\circ$ in 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(K)	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	T(K)
1000	42,769	34,455	269.215	30,355	22,041	234.421	35,882	27,568	232.597	31,389	23,075	243.471	30,129	21,815	228.057	1000
1020	43,859	35,378	270.293	31,020	22,540	235.079	36,709	28,228	233.415	32,088	23,607	244.164	30,784	22,304	228.706	1020
1040	44,953	36,306	271.354	31,688	23,041	235.728	37,542	28,895	234.223	32,789	24,142	244.844	31,442	22,795	229.344	1040
1060	46,051	37,238	272.400	32,357	23,544	236.364	38,380	29,567	235.020	33,490	24,677	245.513	32,101	23,288	229.973	1060
1080	47,153	38,174	273.430	33,029	24,049	236.992	39,223	30,243	235.806	34,194	25,214	246.171	32,762	23,782	230.591	1080
1100	48,258	39,112	274.445	33,702	24,557	237.609	40,071	30,925	236.584	34,899	25,753	246.818	33,426	24,280	231.199	1100
1120	49,369	40,057	275.444	34,377	25,065	238.217	40,923	31,611	237.352	35,606	26,294	247.454	34,092	24,780	231.799	1120
1140	50,484	41,006	276.430	35,054	25,575	238.817	41,780	32,301	238.110	36,314	26,836	248.081	34,760	25,282	232.391	1140
1160	51,602	41,957	277.403	35,733	26,088	239.407	42,642	32,997	238.859	37,023	27,379	248.698	35,430	25,786	232.973	1160
1180	52,724	42,913	278.362	36,406	26,602	239.989	43,509	33,698	239.600	37,734	27,923	249.307	36,104	26,291	233.549	1180
1200	53,848	43,871	279.307	37,095	27,118	240.663	44,380	34,403	240.333	38,447	28,469	249.906	36,777	26,799	234.115	1200
1220	54,977	44,834	280.238	37,780	27,637	241.128	45,256	35,112	241.057	39,162	29,018	250.497	37,452	27,308	234.673	1220
1240	56,108	45,799	281.158	38,466	28,426	241.686	46,137	35,827	241.773	39,877	29,568	251.079	38,129	27,819	235.223	1240
1260	57,244	46,768	282.066	39,154	28,678	242.236	47,022	36,546	242.482	40,594	30,118	251.653	38,807	28,331	235.766	1260
1280	58,381	47,739	282.962	39,884	29,201	242.780	47,912	37,270	243.183	41,312	30,670	252.219	39,488	28,845	236.302	1280
1300	59,522	48,713	283.847	40,534	29,725	243.316	48,807	38,000	243.877	42,033	31,224	252.776	40,170	29,361	236.831	1300
1320	60,666	49,691	284.722	41,266	30,251	243.844	49,707	38,732	244.564	42,753	31,778	253.325	40,853	29,878	237.353	1320
1340	61,813	50,672	285.586	41,919	30,778	244.366	50,612	39,470	245.243	43,475	32,334	253.868	41,539	30,398	237.867	1340
1360	62,963	51,656	286.439	42,613	31,306	244.880	51,521	40,213	245.915	44,198	32,891	254.404	42,227	30,919	238.376	1360
1380	64,116	52,643	287.283	43,309	31,836	245.388	52,434	40,960	246.582	44,923	33,449	254.932	42,915	31,441	238.878	1380
1400	65,271	53,631	288.106	44,007	32,367	245.889	53,351	41,711	247.241	45,648	34,008	255.454	43,605	31,964	239.375	1400
1420	66,427	54,621	288.934	44,707	32,900	246.385	54,273	42,466	247.895	46,374	34,567	255.968	44,295	32,489	239.865	1420
1440	67,586	55,614	289.743	45,408	33,434	246.876	55,198	43,226	248.543	47,102	35,129	256.475	44,988	33,014	240.350	1440
1460	68,748	56,609	290.542	46,110	33,971	247.360	56,128	43,989	249.185	47,831	35,692	256.978	45,682	33,543	240.827	1460
1480	69,911	57,606	291.333	46,813	34,508	247.839	57,062	44,756	249.820	48,561	36,256	257.474	46,377	34,071	241.301	1480
1500	71,078	58,606	292.114	47,517	35,046	248.312	57,999	45,528	250.450	49,292	36,821	257.965	47,073	34,601	241.768	1500
1520	72,246	59,609	292.888	48,222	35,584	248.778	58,942	46,304	251.074	50,024	37,387	258.450	47,771	35,133	242.228	1520
1540	73,417	60,613	292.654	48,928	36,124	249.240	59,888	47,084	251.693	50,756	37,952	258.928	48,470	35,665	242.685	1540
1560	74,590	61,620	294.411	49,635	36,665	249.695	60,838	47,868	252.305	51,490	38,520	259.402	49,168	36,197	243.137	1560
1580	76,767	62,630	295.161	50,344	37,207	250.147	61,792	48,655	252.912	52,224	39,088	259.870	49,869	36,732	243.585	1580
1600	76,944	63,741	295.901	51,053	37,750	250.592	62,748	49,445	253.513	52,961	39,658	260.333	50,571	37,268	244.028	1600
1620	78,123	64,653	296.632	51,763	38,293	251.033	63,709	52,240	254.111	53,696	40,227	260.791	51,275	37,806	244.464	1620
1640	79,303	65,668	297.356	52,472	38,837	251.470	64,675	51,039	254.703	54,434	40,799	261.242	51,980	38,344	244.896	1640
1660	80,486	66,592	298.072	53,184	39,382	251.901	65,643	51,841	255.290	55,172	41,370	261.690	52,686	38,884	245.324	1660
1680	81,670	67,702	298.781	53,895	39,927	252.329	66,614	52,646	255.873	55,912	41,944	262.132	53,393	39,424	245.747	1680
1700	82,856	68,721	299.482	54,609	40,474	252.751	67,589	53,455	256.450	56,652	42,517	262.571	54,099	39,965	246.166	1700
1720	84,043	69,742	300.177	55,323	41,023	253.169	68,567	54,267	257.022	57,394	43,093	263.005	54,807	40,507	246.580	1720
1740	85,231	70,764	300.863	56,039	41,572	253.582	69,550	55,083	257.589	58,136	43,669	263.435	55,516	41,049	246.990	1740

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TABLE A-23

(Continued)

$\bar{h}$ and $\bar{u}$ in kJ/kmol, $\bar{s}°$ in 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(K)	$\bar{h}$	$\bar{u}$	$\bar{s}°$	$\bar{h}$	$\bar{u}$	$\bar{s}°$	$\bar{h}$	$\bar{u}$	$\bar{s}°$	$\bar{h}$	$\bar{u}$	$\bar{s}°$	$\bar{h}$	$\bar{u}$	$\bar{s}°$	T(K)
1760	86,420	71,787	301.543	56,756	42,123	253.991	70,535	55,902	258.151	58,800	44,247	263.861	56,227	41,594	247.396	1760
1780	87,612	72,812	302.271	57,473	42,673	254.398	71,523	56,723	258.708	59,624	44,825	264.283	56,938	42,139	247.798	1780
1800	88,806	73,840	302.884	58,191	43,225	254.797	72,513	57,547	259.262	60,371	45,405	264.701	57,651	42,685	248.195	1800
1820	90,000	74,868	303.544	58,910	43,778	255.194	73,507	58,375	259.811	61,118	45,986	265.113	58,363	43,231	248.589	1820
1840	91,196	75,897	304.198	59,629	44,331	255.587	74,506	59,207	260.357	61,866	46,568	265.521	59,075	43,777	248.979	1840
1860	92,394	76,929	304.845	60,351	44,886	255.976	75,506	60,042	260.898	62,616	47,151	265.925	59,790	44,324	249.365	1860
1880	93,593	77,962	305.487	61,072	45,441	256.361	76,511	60,880	261.436	63,365	47,734	266.326	60,504	44,873	249.748	1880
1900	94,793	78,996	306.122	61,794	45,997	256.743	77,517	61,720	261.969	64,116	48,319	266.722	61,220	45,423	250.128	1900
1920	95,995	80,031	306.751	62,516	46,552	257.122	78,527	62,564	262.497	64,868	48,904	267.115	61,936	45,973	250.502	1920
1940	97,197	81,067	307.374	63,238	47,108	257.497	79,540	63,411	263.022	65,620	49,490	267.505	62,654	46,524	250.874	1940
1960	98,401	82,105	307.992	63,961	47,665	257.868	80,555	64,259	263.542	66,374	50,078	267.891	63,381	47,075	251.242	1960
1980	99,606	83,144	308.604	64,684	48,221	258.236	81,573	65,111	264.059	67,127	50,665	268.275	64,090	47,627	251.607	1980
2000	100,804	84,185	309.210	65,408	48,780	258.600	82,593	65,965	264.571	67,881	51,253	268.655	64,810	48,181	251.969	2000
2050	103,835	86,791	310.701	67,224	50,179	259.494	85,156	68,111	265.838	69,772	52,727	269.588	66,612	49,567	252.858	2050
2100	106,864	89,404	312.160	69,044	51,584	260.370	87,735	70,275	267.081	71,668	54,208	270.504	68,417	50,957	253.726	2100
2150	109,898	92,023	313.589	70,864	52,988	261.226	90,330	72,454	268.301	73,573	55,697	271.399	70,226	52,351	254.578	2150
2200	112,939	94,648	314.988	72,688	54,396	262.065	92,940	74,649	269.500	75,484	57,192	272.278	72,040	53,749	255.412	2200
2250	115,984	97,277	316.356	74,516	55,809	262.887	95,562	76,855	270.679	77,397	58,690	273.136	73,856	55,149	256.227	2250
2300	119,035	99,912	317.695	76,345	57,222	263.692	98,199	79,076	271.839	79,316	60,193	273.981	75,676	56,553	257.027	2300
2350	122,091	102,552	319.011	78,178	58,640	264.480	100,846	81,308	272.978	81,243	61,704	274.809	77,496	57,958	257.810	2350
2400	125,152	105,197	320.302	80,015	60,060	265.253	103,508	83,553	274.098	83,174	63,219	275.625	79,320	59,366	258.580	2400
2450	128,219	107,849	321.566	81,852	61,482	266.012	106,183	85,811	275.201	85,112	64,742	276.424	81,149	60,779	259.332	2450
2500	131,290	110,504	322.808	83,692	62,906	266.755	108,868	88,082	276.286	87,057	66,271	277.207	82,981	62,195	260.073	2500
2550	134,368	113,166	324.026	85,537	64,335	267.485	111,565	90,364	277.354	89,004	67,802	277.979	84,814	63,613	260.799	2550
2600	137,449	115,832	325.222	87,383	65,766	268.202	114,273	92,656	278.407	90,956	69,339	278.738	86,650	65,033	261.512	2600
2650	140,533	118,500	326.396	89,230	67,197	268.905	116,991	94,958	279.441	92,916	70,883	279.485	88,488	66,455	262.213	2650
2700	143,620	121,172	327.549	91,077	68,628	269.596	119,717	97,269	280.462	94,881	72,433	280.219	90,328	67,880	262.902	2700
2750	146,713	123,849	328.684	92,930	70,066	270.285	122,453	99,588	281.464	96,852	73,987	280.942	92,171	69,306	263.577	2750
2800	149,808	126,528	329.800	94,784	71,504	270.943	125,198	101,917	282.453	98,826	75,546	281.654	94,014	70,734	264.241	2800
2850	152,908	129,212	330.896	96,639	72,945	271.602	127,952	104,256	283.429	100,808	77,112	282.357	95,859	72,163	264.895	2850
2900	156,009	131,898	331.975	98,495	74,383	272.249	130,717	106,605	284.390	102,793	78,682	283.048	97,705	73,593	265.538	2900
2950	159,117	134,589	333.037	100,352	75,825	272.884	133,486	108,959	285.338	104,785	80,258	283.728	99,556	75,028	266.170	2950
3000	162,226	137,283	334.084	102,210	77,267	273.508	136,264	111,321	286.273	106,780	81,837	284.399	101,407	76,464	266.793	3000
3050	165,341	139,982	335.114	104,073	78,715	274.123	139,051	113,692	287.194	108,778	83,419	285.060	103,260	77,902	267.404	3050
3100	168,456	142,681	336.126	105,939	80,164	274.730	141,846	116,072	288.102	110,784	85,009	285.713	105,115	79,341	268.007	3100
3150	171,576	145,385	337.124	107,802	81,612	275.326	144,648	118,458	288.999	112,795	86,601	286.355	106,972	80,782	268.601	3150
3200	174,695	148,089	338.109	109,667	83,061	275.914	147,457	120,851	289.884	114,809	88,203	286.989	108,830	82,224	269.186	3200
3250	177,822	150,801	339.069	111,534	84,513	276.494	150,272	123,250	290.756	116,827	89,804	287.614	110,690	83,668	269.763	3250

Source: Table A-23 is based on the JANAF Thermochemical Tables, NSRDS-NBS-37, 1971

L-4/T-II/ME **Date : 29/04/2023**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-II B. Sc. Engineering Examinations 2020-2021

Sub : **ME 413** (Energy and Environment)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

1. (a) Bhutan is not just carbon neural-it is carbon negative. What are the initiatives Bhutan has taken to remain carbon neutral? Will this kind of initiatives be feasible for Bangladesh? **(10)**

(b) How much unit of energy we need to input to a power plant with an efficiency of 35% to produce 1 unit of useful energy using a conventional bulb (98% loss) as shown in the system loss diagram (Fig. 1(b)). If you have given an option to choose between a more efficient power plant (efficiency 50%) and a more efficient light bulb (90% loss), which one will save you more energy considering all other losses remain same as Fig. 1(b). **(17)**

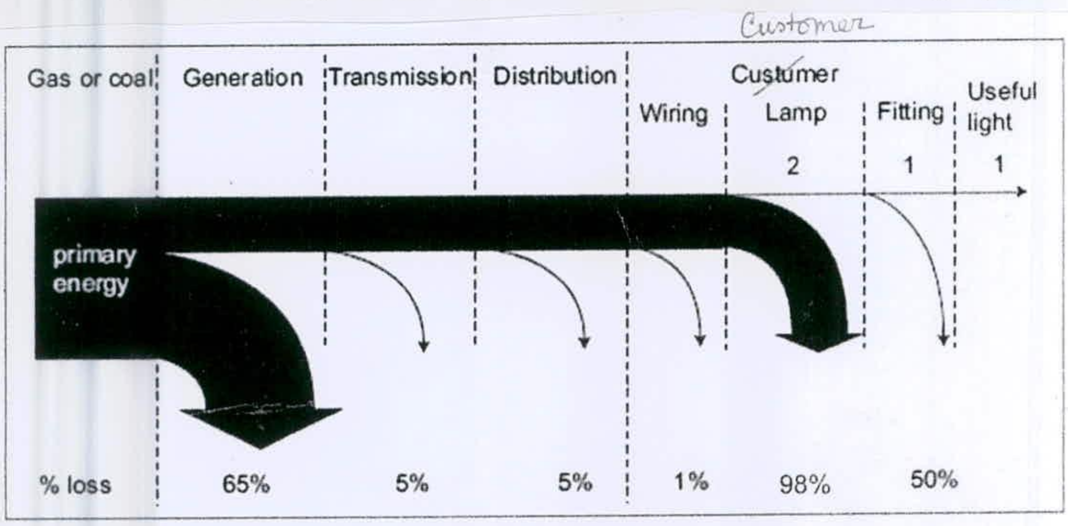

Fig. for Q. 1(b)

(c) Compressors are often referred to as power guzzlers. What are the best practices for reducing power consumption in compressed air system? **(8)**

2. (a) What is the physical meaning of Levelized Cost of Energy (LCOE)? **(5)**

(b) Infrastructure Development Company (IDCOL) reports that it takes 120 kWh/m^2 to make PV modules. Another 120 kWh/m^2 is needed for the frame and support structure for a rooftop-mounted, grid-connected system. Assume 6% conversion efficiency and 1700 kWh/m^2 per year of available sunlight energy. What is the energy payback period and Energy Return on Energy Invested (EROI) assuming a lifetime of 15 years and 30 years? **(10)**

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(c) In an oil refinery, a furnace is operated to heat 300 m^3/hr of crude oil from 250°C to 360°C by burning fuel oil at a rate of 10 ton/hour. The fuel oil has a gross calorimetric value of 9500 kcal/kg. In order to reduce the heat loss by flue gas, an air pre-heater is installed which is designed to pre-heat 300 tons/hour of combustion air from 30°C to 225°C. The following data are also provided: **(20)**

Specific heat of air = 0.24 kCal/kg°C

Specific heat of crude oil = 0.75 kCal/kg°C

Specific gravity of crude oil = 0.90

Determine the % improvement in furnace efficiency after installing the air-preheater. If % of carbon in fuel oil is 84%, determine the reduction in GHG emission after installing the air-preheater.

3. (a) What are the challenges of integrating renewable energy into the national grid? **(10)**

(b) Electric vehicles (EVs) provide a greener and more sustainable solution considering electricity supply from renewable source, but there are challenges in widespread adoption of EVs.

(i) What are the challenges of widespread adoption of electric vehicles? **(5)**

(ii) What will be the biggest environmental impact of Li-ion battery powered electric vehicle? Explain with a mitigation strategy. **(10)**

(iii) Can hydrogen powered electric vehicle be an option for rapid refueling, long range, and larger vehicles? Explain by describing the working principle of a polymer electrolyte fuel cell. **(10)**

4. (a) What is the physical meaning of life cycle impact assessment? **(5)**

(b) What is Earth's Energy Budget? What are the factors that affect Earth's Energy Budget?

(c) Write a fundamental strategy that dense urban areas can deploy on a large scale to mitigate the urban heat island effect. **(10)**

(d) What did we achieve out of Montreal Protocol? Describe background behind this treaty. **(10)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

All the symbols have their usual meaning and interpretation.

5. (a) How does energy flow in an ecosystem? With the help of diagram(s), illustrate how the energy flow is different from material flow in an ecosystem. **(8)**

(b) Classify petroleum reserves. Explain why reserve estimates are generally revised over time. **(10)**

(c) Interpret the current (as of in 2023) global energy crisis. Specify the main reasons behind this present energy crisis. **(17)**

6. (a) What do you understand by sustainability? What are the three pillars or foundations of sustainability and how do they affect each other? **(10)**

   (b) Goal 7 of SDG 2030 is "Affordable and Clean Energy". List some of the specific targets of this goal. **(10)**

   (c) "Smog disrupts domestic and international air services in Dhaka" – Why? What are the mechanism and consequence of smog formation? **(15)**

7. (a) "The density of lead in the air of Dhaka is 10 times more than the acceptable standard" – what are the sources of this lead pollution in Dhaka? Who are at most risk from this air pollution by lead in Dhaka city? **(10)**

   (b) What is the connection between the burning of fossil fuels and acid rain? How does acid precipitation affect marble and limestone buildings? **(10)**

   (c) What are different indicators that you can show to prove that global warming is real? List the major effects of global warming that have already been observed in the world. **(15)**

8. (a) Why is the value of COD higher than BOD for the same wastewater sample? **(5)**

   (b) What are the purposes of different treatment levels in effluent treatment plant (ETP)? With necessary diagram(s), explain the mechanism of secondary treatment level. **(15)**

   (c) What do you understand by Temperature Inversion? Did temperature inversion play any role in the thick fog formation during the recent winter months in Bangladesh? Justify your answer. **(15)**

L-4/T-2/ME **Date: 10/04/2023**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-2 B. Sc. Engineering Examinations 2020-2001

Sub : **ME 419** (Power Plant Engineering)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

The abbreviations have their standard meaning. Assume standard data if necessary.

1. (a) What do you understand by LCF? Briefly discuss about the share of LCF in global power generation. **(8)**

   (b) Briefly discuss regarding the "Global Footprint" and the "Energy Mix" scenario of power generation in Bangladesh. **(10)**

   (c) What do you understand by BOP of a plant? Identify the typical electrical and mechanical BOP components of a thermal power plant. **(12)**

   (d) What do you understand by color codes of Hydrogen? Identify "Blue" and "Pink" Hydrogen. **(5)**

2. (a) How can you identify a coal fired thermal power plant? Briefly discuss regarding the main technical feature of "Payra Power Plant" of Bangladesh. **(8)**

   (b) Identify the typical stages of Coal handling in a steam power plant. **(8)**

   (c) Distinguish between "Sub-critical" and Super-critical" boilers. Why SC and USC boilers are being used in modern Steam Power Plants? **(7)**

   (d) Briefly discuss the functions of –Feed water Healers, Deaerators and Economizers in a Steam Power Plant. How can you identify them? **(12)**

3. (a) What do you understand by 2×1 configuration of a CCPP? Briefly explain why this configuration is most commonly used in modern CCPP. **(12)**

   (b) Identify the components of a HRSG in a CCPP. Briefly explain how it works. **(11)**

   (c) Distinguish between "Back Pressure" and "Extraction-Condensing" turbines used in Station Power Plants. Why are they used? **(12)**

4. (a) Briefly describe the starting operation of large reciprocating engines used in DPP. **(12)**

   (b) Why does HFO require pre-processing before being used as a fuel in a DPP. What is the role of EGB in this process? Briefly discuss. **(13)**

   (c) A generator is being directly driven by a diesel engine in a plant of Bangladesh. The alternator is supporting a 3-phase electric load of 390 VAC and current in each phase of 25 kA with a power factor of 0.86. The alternator efficiency is 92% and the diesel (SG = 0.83) run engine is operating at 1000 rpm with a BSFC of 240 g/kWh. Calculate- **(10)**

   (i) Hourly diesel consumption rate in liters.

   (ii) No. of poles needed in the alternator.

Contd P/2

ME 419

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) Compare aero-derivative and heavy-duty industrial gas turbines on various aspects like performance, fuel, start-up, loading shutdown, etc. **(15)**

(b) A gas turbine power plant consists of two-stage compression with intercooling and a turbine with a regenerator. Air enters the compressor at 1 bar, 20°C and the turbine at 900°C. The turbine works on a pressure ratio of 6. The effectiveness of the regenerator is 0%. The rate of airflow through the plant is 210 kg/s and the calorific value of fuel is 40.8 MJ/kg having combustion efficiency of 0.95. Assuming perfect intercooling and neglecting friction, pressure and heat losses estimate (i) air-fuel ratio, and (ii) the cycle efficiency. Take c_p = 1.005 kJ/kgk, k = 1.4 for air and c_p = 1.08 kJ/kgk and k = 1.33 for combustion gases. Comment on the effect of turbine inlet temperature on the cycle efficiency. **(20)**

6. (a) A power station has to supply electric load as follows: **(20)**

Time (h)	0-6	6-12	12-14	14-18	18-24
Load (MW)	30	90	60	100	50

Do the following:

(i) Draw the load curve and load duration curve

(ii) Select suitable generating units to supply the loads, and hence, the station capacity

(iii) Operating schedule of different units

(iv) Calculate the load factor and capacity factor.

(b) Describe cost elements of electricity generation and use. Explain how the cost elements are recovered in the Doherty rate method. **(15)**

7. (a) Distinguish between PWR and BWR by using suitable schematics. **(10)**

(b) Briefly explain the front end of fission fuel cycle along with its associated health/environmental hazards. **(10)**

(c) Elucidate the main concept for providing fundamental safety. Explain how for these are incorporated in Rooppur Power Plant. **(15)**

8. (a) Mention salient features of Kaptai Hydel Power Plant. Also briefly explain the prospect of Hydel power in Bangladesh. **(14)**

(b) Write short notes on any there of the following: **(3×7=21)**

(i) GT blade cooling

(ii) Theory of rates and its general form

(iii) Factors for selecting hydel power plant

(iv) LOCA.

L-4/T-II/ME **Date : 29/04/2023**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-II B. Sc. Engineering Examinations 2020-2021

Sub : **ME 427** (Applied Engineering Mathematics)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

Symbols have their usual meanings.

1. (a) With reference to graphical interpretation, compare and contrast the characteristics of differential and variational operators. Discuss the laws of variations of different arithmetic operations in comparison with those of differentiation. **(18)**

(b) The variational functional of a one-dimensional heat flow problem can be expressed as **(17)**

$$I(T)=\int_0^L\left\{\dot{q}AT+HPT_\infty T+E\sigma PT_\infty^4 T-\frac{HP}{2}T^2-\tfrac{1}{5}E\sigma PT^5-\frac{KA}{2}\left(\frac{dT}{dx}\right)^2\right\}dx$$

Determine the corresponding thermal equilibrium equation. Give the physical interpretation of the problem with necessary definition of the symbols used.

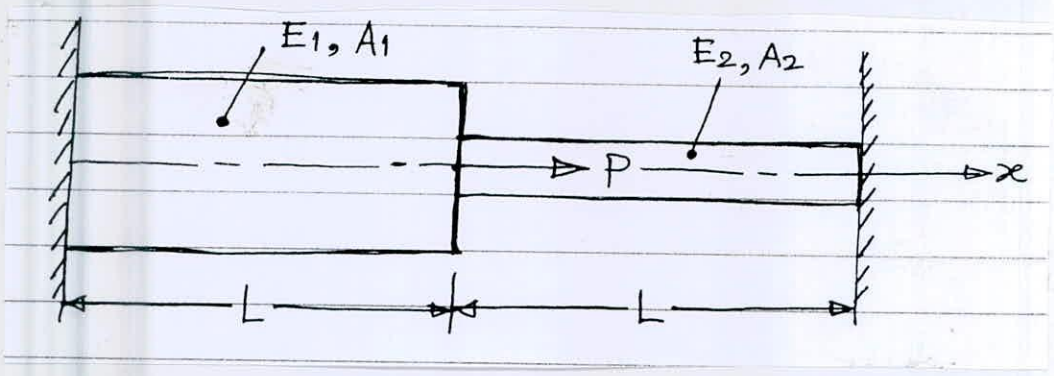
2. 

Figure for Q 2.

Find the solution of displacement and stress for the stepped composite bar shown in Figure for Q2 using Galekin's weight residual approach. Consider one-parameter approximate solution. **(35)**

Also, comment on the accuracy of the approximate solution so obtained with reference to exact analytical solutions of the bar.

3. (a) With a neat sketch, describe the details of a standard quadratic shaft element. Verify the following mathematical statements for the corresponding shape functions of the element: **(17)**

ME 427
Contd...Q. No. 3(a)

$$(i)\sum_{i=1}^{3} Ni(\xi)=1$$

$$(ii)\sum_{i=1}^{3} Ni(\xi)\xi_i=\xi$$

$$(iii)\sum_{i=1}^{3} Ni(\xi)\xi_i^2=\xi^2$$

$$(iv)\sum_{i=1}^{3} \frac{d}{dx}(N_i(\xi))=0$$

(b) Consider the bar element shown in Figure for Q. 3(b). **(18)**

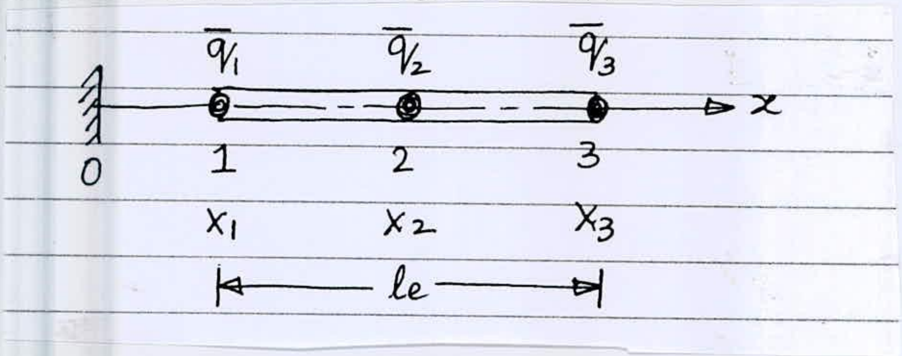


Figure for Q. 3(b)

Given:

Cross-sectional area, $A_e = 1$ in^2

Elastic modulus, $E = 30 \times 10^6$ psi

Element nodal positions: $x_1 = 10$ in, x_2, $= 20$ in, $x_3 = 30$ in

Element nodal displacement, $\{q\} = [0.02 \quad 0.024 \quad 0.03]$

For finite-element analysis determine the following:

(i) the displacement at point, x = 24 in

(ii) the element strain-displacement matrix for x = 24in

(iii) the stress at point, x = 24 in

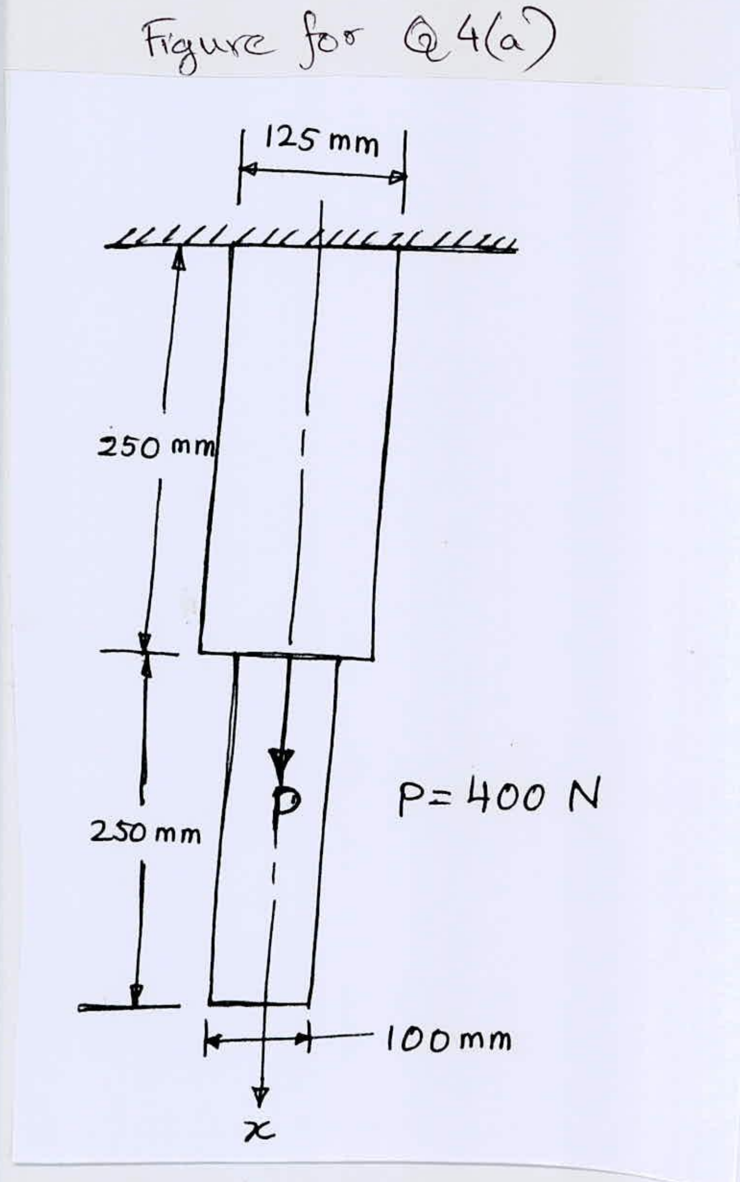
(iv) the element stiffness matrix

4. (a) Consider the thin rectangular plate of uniform thickness 20 mm (see Figure for Q4(a)). The elastic modulus and unit weight of the material are given as follows: **(18)**

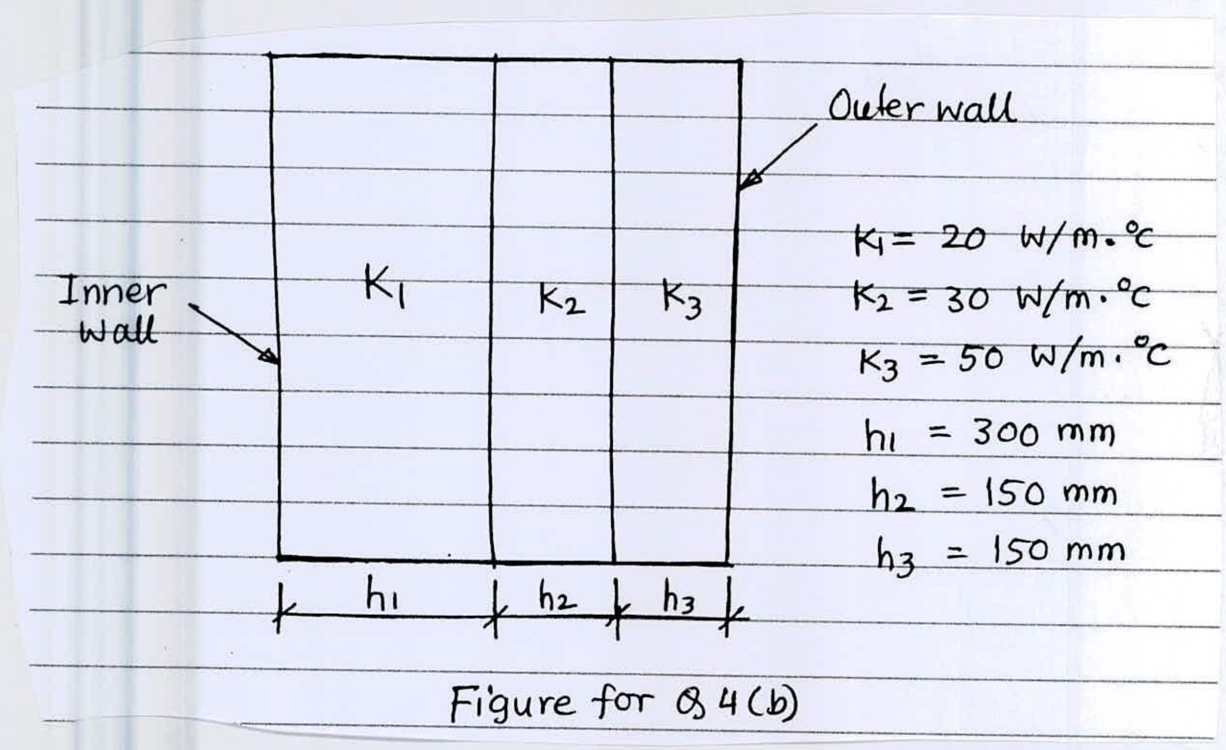
$$E = 2 \times 10^5 \text{ N/mm}^2; \gamma = 0.8 \times 10^{-4} \text{N/mm}^3$$

Using a two-element FEM model, determine the nodal displacements, element stresses and support reaction.

ME 427
Contd…Q. No. 4(a)



4. (b)



ME 427

Contd...Q. No. 4. (b)

A composite wall consists of three materials as shown in Figure for Q. 4(b). The outer wall temperature is 20°C. On the inner wall, convection heat transfer takes place with a coefficient of 25 W/m^2°C. The surrounding medium in contact with the inner wall is at 800°C. Determine the temperature distribution across the composite wall by FEM. **(17)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) Describe Robine boundary condition with a suitable sketch. **(5)**

(b) Displacement of a bar is governed by the following differential equation: **(15)**

$$AE\frac{d^2u}{dx^2} + f(x) = 0$$

Where, E is the Young's Modulus, A is the cross-sectional area and u is the axial displacement. Describe the various types of physical conditions possible for this problem.

(c) Consider the following governing differential equation for a spring-mass system, also known as the "Duffing equation":

$$\frac{d^2y}{dt^2} + \left(\alpha(y) + \beta y^2\right)y = A\cos(\phi t)$$

Discuss the degree, order, linearity, and homogeneity of the above equation. **(15)**

6. (a) Express the following 2 degrees of freedom spring-mass-damper problem (as shown in figure 6(a)) into an equivalent 1st order initial value problem. The boundary conditions are: $x_1(0) = 1,\ \dot{x}_1(0) = 0,\ x_2(0) = 0.5, \dot{x}_2(0) = 0$ **(20)**

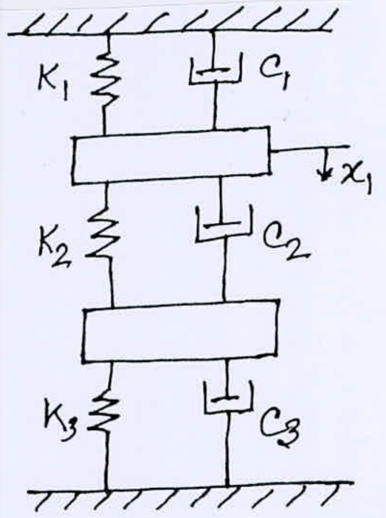


Figure 6(a)

(b) Consider the following differential equation: **(15)**

$$\frac{d^2y}{dx^2} = \frac{dy}{dx} + 2y + cos(x), \quad for\ 0 \le x \le \frac{\pi}{2}$$

Contd P/5

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Contd…Q. No. 6(b)

Where the boundary conditions are $y(0) = -0.3,\ y\left(\frac{\pi}{2}\right) = -0.1$

Implement the "Shooting Technique" to convert this boundary value problem to an initial value problem.

7. (a) Describe the L-Hospitals rule with a suitable example. **(10)**

(b) The buckling of a column as shown in figure 7(b) is governed by the following differential equation: **(25)**

$$El\frac{d^2y}{dx^2} + Py = 0$$

The boundary conditions: $\frac{dy}{dx} = 0\ at\ x = 0\ and\ y = 0\ at\ x = L.$

Find the critical value of P using finite difference method with sub-division $n = 3$.

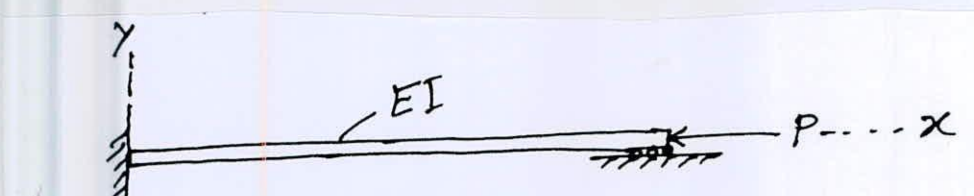


Figure 7(b)

8. (a) The governing differential equation for Couette flow with pressure gradient as shown in figure 8(a) is as following **(25)**

$$\frac{d^2u}{dy^2} = \frac{1}{\mu}\frac{dp}{dx}$$

The boundary conditions are $u(0) = 0$ and $u(1) = 2$. If the value of $\frac{1}{\mu}\frac{dp}{dx} = 2,$. determine the velocity profile ($u(y)$) using finite difference method. Use a step size of $h = 0.25$.

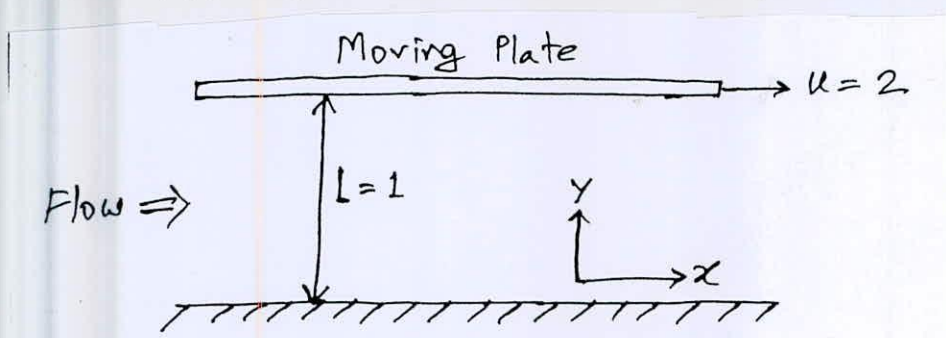


Figure 8(a)

(b) Give the physical interpretation of the mathematical model given below: **(10)**

$$u_{xx} + u_{yy} + \dot{q}/k = 0\ \left[0 < x < 1,\ 0 < y < 1\right]$$
$$u_x(0, y) = 100$$
$$u_x(1, y) = 0$$
$$u(x,1) = 50$$
$$u_y(x,0) - \beta[u(x,0) - 25] = 0$$

L-4/T-2/ME **Date: 03/04/2023**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-2 B. Sc. Engineering Examinations 2020-2021

Sub: **ME 433** (Fluidics)

Full Marks: 210 Time: 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

1. (a) Discuss two advantages and two limitations of pneumatic systems when compared to hydraulic systems. **(6)**

(b) What are the functions of an FRL unit in a pneumatic system? **(5)**

(c) Draw the symbol of a typical 3 position 4 way spring centered solenoid actuated directional control valve for pneumatic system with tandem connection in center position. Mention the key differences of this symbol if the valve was for hydraulic system. **(10)**

(d) What is the necessity of a compressor unloader system? **(5)**

(e) What happens to the cylinder of the circuit shown in Figure Q1.(e)? **(9)**

(i) when valve V3 is depressed, (ii) when valve V3 is released

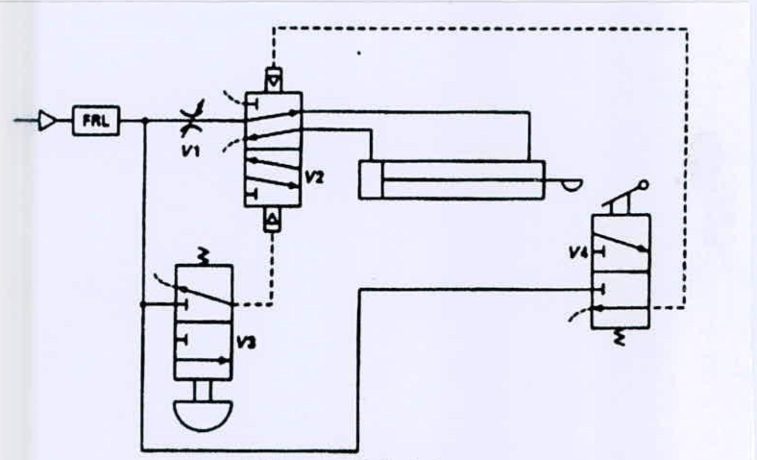


Figure Q1.(e)

2. (a) For the hydraulic system shown in Fig. Q2.a, the following data are given. Pump hydraulic horse power = 4 HP, Pump flow rate = 25 gpm, Pipe inside diameter = 0.75 inch, Specific gravity of the oil = 0.9 and the kinematic viscosity of the oil is 100 cSt. Find the pressure available at the inlet to the hydraulic motor (station 2). The pressure at station 1 in the hydraulic tank is atmospheric (0 psig). **(17)**

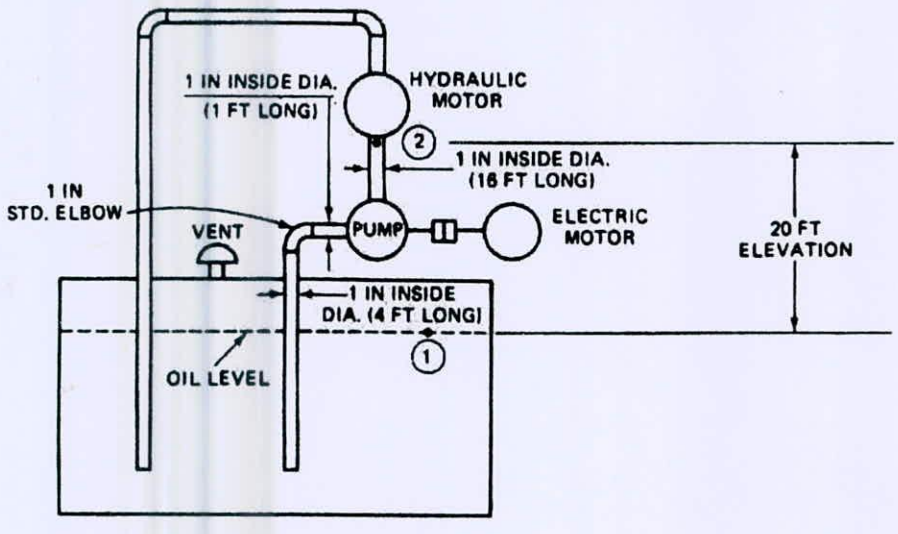


Fig. Q2.a

Contd P/2

ME 433

Contd ... Q. No. 2

(b) A hydraulic cylinder is to compress a car body down to bale size in 10 s. The operation requires a 12 ft stroke and a 8200 lb force. If a 1000 psi pump has been selected, and assuming the cylinder is 100% efficient, find **(8)**

-The required piston area

-The necessary pump flow rate

-The hydraulic horsepower (HHP) delivered to the cylinder

- The output horse power delivered by the cylinder to the load.

(c) What are the recommended velocities in the pipelines of a hydraulic system? How are these determined? **(4)**

(d) Write a short note on different type of fluid conductors used in a hydraulic system. **(6)**

3. (a) What size reservoir should be used for a hydraulic system using a 15-gpm pump? **(4)**

(b) With a neat sketch, describe the recommended orientations of the pump suction line, return line and baffle plate in a hydraulic reservoir. **(14)**

(c) A hydraulic pump operates at 140 bars and delivers oil at 0.001 m^3/s to a hydraulic actuator. Oil discharges through the pressure relief valve (PRV) during 50% of the cycle time. The pump has an overall efficiency of 80%, and 15% of the power is lost due to frictional pressure losses in the hydraulic lines. What heat exchanger rating is required to dissipate all the generated heat? **(12)**

(d) Write a short note on sealing devices for hydraulic systems. **(5)**

4. (a) What are the advantages of fluidics devices over their electrical counterparts? **(5)**

(b) Differentiate between MPL and fluidic devices. **(5)**

(c) Describe in brief the operation of the electro-pneumatic box sorting system shown in Fig. Q4.c. **(9)**

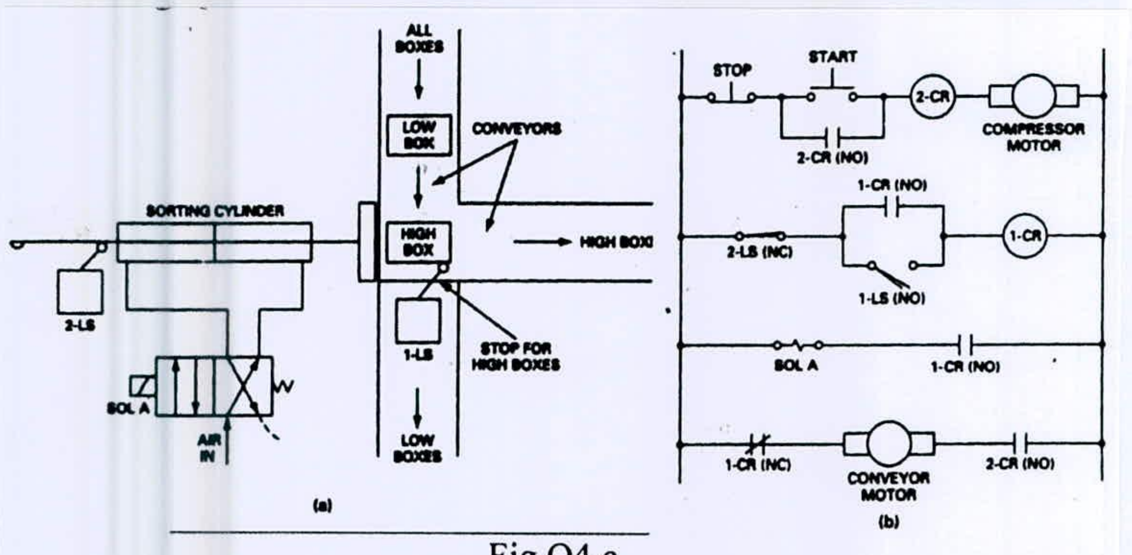


Fig Q4.c

(d) What is "Coanda Effect"? With necessary sketches explain how a wall attachment flip-flop works. **(8)**

(e) With sketches, briefly describe the working principles of Turbulence amplifier and Vortex flow amplifier. **(8)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) What are factors that you need to consider for the design of a fluid power system? Explain in brief. **(10)**

(b) Explain the working principle of a balanced vane pump with schematic diagram(s). Differentiate this pump with a pressure-compensated vane pump. **(15)**

(c) A pump supplies oil at 20 gpm to a 2 inch diameter double acting hydraulic cylinder. If the load is 1000 lb (extending and retracting) and the rod diameter is 1 inch, find the hydraulic pressure, the piston velocity and the cylinder horsepower during both the extending stroke and the retracting stroke. **(10)**

6. (a) Schematically show the second-class and third-class lever systems which are used as mechanical linkage for hydraulic cylinder loading. **(10)**

(b) How torque can be developed by a gear motor? Explain using schematic diagram. **(15)**

(c) A hydraulic motor has a 10 in^3 volume diplacemnt nad operates with a pressure of 1000 psi and a speed of 2000 rpm. The actual flow are consumed by the motor is 95 gpm and the actual torque delivered is 1500 in-lb. Find the motor (i) volumetric efficiency, (ii) mechanical efficiency, (iii) overall efficiency, and (iv) actual hp delivered by the motor. **(10)**

7. (a) A 3-position 4-way directional control valve (DCV) is connected to a hydraulic cylinder. Discuss what will happen to the cylinder if the DCV is (i) Open center type, (ii) Tandem center type, and (iii) Closed center type. **(10)**

(b) What do you mean by servo valve? Briefly explain the working principle of a mechanical type servo valve. How does it differ from electrohydraulic servo valve? **(15)**

(c) A pressure relief valve contains a poppet with a 0.75 in^2 area on which system pressure acts. During assembly a spring with a spring constant of 2500 lb/in is installed to the poppet against its seat. The adjustment mechanism is then set so that the spring is initially compressed 0.20 in from its free length condition. In order to pass full pump flow through the valve at the PRV pressure setting, the poppet must move 0.10 in. from the fully closed position. Determine the (i) cracking pressure and (ii) full pump flow pressure (PRV pressure setting). **(10)**

Contd ... P/4

8. (a) Schematically show a regenerative circuit. A double-acting cylinder is hooked in the regenerative circuit. The cracking pressure for the relief valve is 1000 psi. The piston area is 25 in^2 and the rod area is 7 in^2. The pump flow rate is 20 gpm. Find the cylinder speed, the load carrying capacity, and power delivered to the load during the (i) Extending stroke and (ii) Retracting stroke. **(10)**

   (b) What are the functions of a fail-safe circuit? Explain the working principle of a fail-safe circuit with overload protection. **(10)**

   (c) Design a hydraulic circuit for speed control of a hydraulic motor. **(8)**

   (d) Write short note on air-over-oil circuit. **(7)**

L-4/T-2/ME **Date : 03/04/2023**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-2 B. Sc. Engineering Examinations 2020-2021

Sub : **ME 449** (Composite Materials)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

1. (a) With a neat sketch, show how the stress and strain vary along the thickness of a laminate. **(5)**

(b) Show that, for a symmetric laminate, the coupling stiffness matrix is equal to zero. **(10)**

(c) There are large excursions of temperature in space and thus composites with zero or near zero thermal expansion coefficients are attractive. Find the volume fraction of the graphite fibers for which the thermal expansion coefficient is zero in the longitudinal direction of a graphite/epoxy unidirectional lamina. Use all the properties of graphite and epoxy from the supplied tables. **(12)**

(d) What is a quasi-isotropic laminate? Dose it behave like an isotropic material? Explain. **(8)**

2. (a) Derive the expression for major Poisson's ratio of a unidirectional composite lamina using the mechanics of materials approach. **(15)**

(b) The global strains at the top surface of a $[0/45/60]_s$ laminate are given as **(10)**

$$\begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix} = \begin{bmatrix} 1.686 \times 10^{-8} \\ -6.50 \times 10^{-8} \\ -2.14 \times 10^{-7} \end{bmatrix}$$

and the midplane strains in this laminate are given as:

$$\begin{bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \end{bmatrix} = \begin{bmatrix} 8.388 \times 10^{-6} \\ 4.762 \times 10^{-4} \\ -3.13 \times 10^{-3} \end{bmatrix}$$

Calculate the global strains at the top surface of the bottom ply of this laminate if each ply is 0.1 mm thick.

(c) Write an example of laminate code for the following: (i) Symmetric laminate, (ii) Antisymmetric laminate, (iii) Symmetric cross-ply laminate, (iv) Symmetric angle-ply laminate, (v) Balanced angle-ply laminate. **(5)**

(d) Do high fiber volume fractions increase the transverse strength of a unidirectional lamina? Justify your answer. **(5)**

Contd P/2

ME 449

3. (a) Briefly discuss why warpage occurs in a composite laminate. Derive an expression for calculating the residual stresses in a composite laminate. **(15)**

   (b) Find the extensional stiffness matrix [A] for a [0/60/−60] glass/epoxy laminate. Assume that the thickness of each lamina is 0.1 mm. Use properties of the glass/epoxy lamina from the supplied table. **(20)**

4. (a) Why sandwich composites are extensively used? Briefly discuss their key design aspects. **(8)**

   (b) Briefly describe the steps to be followed in failure analysis of a laminate. **(12)**

   (c) A simply supported laminated composite beam is shown in Fig. for Q. 4(c) of length 0.1 m and width 5 mm made of $[0/90]_s$ graphite/epoxy laminate. A uniform load of 200 N/m is applied to the beam. What is the maximum deflection of the beam? Find the local stresses at the top surface of the first ply from the top. Assume that each ply is 0.125 mm thick and use the properties of unidirectional graphite/epoxy from the supplied table. **(15)**

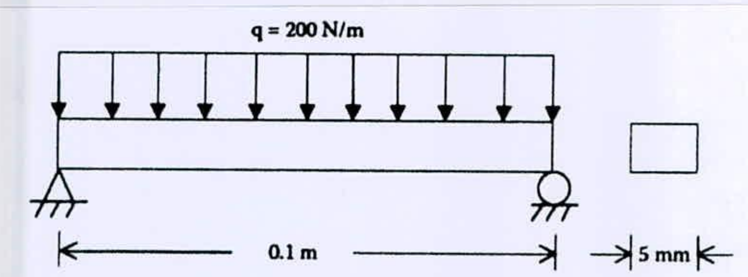


Fig. for Q 4(c)

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.
Symbols indicate their usual meanings. Assume any missing data.

5. (a) State and explain the mechanical parameters used for measuring the relative advantage of composites over metals under different loading conditions. **(10)**

   (b) Classify composite materials based on geometry of the reinforcement with necessary diagrams and examples. **(10)**

   (c) Define Polymer Matrix Composite (PMC). Explain different stages of manufacturing of a carbon fiber based PMC from PAN (polyacrylonitrile) based precursors with necessary schematic diagram. **(15)**

6. (a) A glass/epoxy lamina consists of a 70% fiber volume fraction. Use properties of glass and epoxy from Table, to determine the (i) Density of lamina; (ii) Mass fractions of the glass and epoxy; (iii) Volume of composite lamina if the mass of the lamina is 4 kg; (iv) Volume and mass of glass and epoxy in part (iii). **(18)**

Contd P/3

ME 449

Contd...Q. No. 6

(b) State the detrimental effects of void content in a composite materials. A graphite/epoxy cuboid specimen with voids has dimensions of $l \times m \times n$ and its mass is M_c. After it is put into a mixture of sulfuric acid and hydrogen peroxide, the remaining graphite fibers have a mass M_f. From independent tests, the densities of graphite and epoxy are ρ_f and ρ_m, respectively. Find the volume fraction of the voids in terms of l, m, n, M_f, M_c, ρ_f and ρ_m. **(17)**

7. (a) For a unidirectional lamina, show that the ultimate tensile strength can be expressed as, $\left(\sigma_1^T\right)_{ult} = \left(\sigma_f\right)_{ult} V_f + \left(\varepsilon_f\right)_{ult} E_m \left(1 - V_f\right)$ **(25)**

   Also, find the minimum fiber volume fraction $(F_f)_{min}$ and the critical fiber volume fraction $(V_f)_{critical}$ for a graphite/epoxy lamina with a 65% fiber volume fraction. Properties of graphite and epoxy are given in Tables.

   (b) Define hygrothermal stresses and strains in a lamina. State the hygrothermal stress-strain relationships for a unidirectional lamina. **(10)**

8. (a) State and explain the Tsai-Hill failure theory for a composite lamina. For the lamina, derive an expression of this failure criterion in terms of the ultimate tensile strengths $(\sigma_1)_{ult}$, $(\sigma_2)_{ult}$, and $(\tau_{12})_{ult}$, under plane stress condition. **(18)**

   (b) A 60° lamina of graphite/epoxy is subjected to the following stress condition. $\sigma_x = 2S$, $\sigma_y = -4S$, $\tau_{xy} = 2S$ $(S>0)$. Use the Tsai-Wu failure theory to find the maximum allowable value of S. Properties of graphite and epoxy are given in Tables. **(17)**

Table: Properties of Fibers and Matrices

Typical Properties of Fibers (SI System of Units)

Property	Units	Graphite	Glass	Aramid
Axial modulus	GPa	230	85	124
Transverse modulus	GPa	22	85	8
Axial Poisson's ratio	—	0.30	0.20	0.36
Transverse Poisson's ratio	—	0.35	0.20	0.37
Axial shear modulus	GPa	22	35.42	3
Axial coefficient of thermal expansion	μm/m/°C	−1.3	5	−5.0
Transverse coefficient of thermal expansion	μm/m/°C	7.0	5	4.1
Axial tensile strength	MPa	2067	1550	1379
Axial compressive strength	MPa	1999	1550	276
Transverse tensile strength	MPa	77	1550	7
Transverse compressive strength	MPa	42	1550	7
Shear strength	MPa	36	35	21
Specific gravity	—	1.8	2.5	1.4

Typical Properties of Matrices (SI System of Units)

Property	Units	Epoxy	Aluminum	Polyamide
Axial modulus	GPa	3.4	71	3.5
Transverse modulus	GPa	3.4	71	3.5
Axial Poisson's ratio	—	0.30	0.30	0.35
Transverse Poisson's ratio	—	0.30	0.30	0.35
Axial shear modulus	GPa	1.308	27	1.3
Coefficient of thermal expansion	μm/m/°C	63	23	90
Coefficient of moisture expansion	m/m/kg/kg	0.33	0.00	0.33
Axial tensile strength	MPa	72	276	54
Axial compressive strength	MPa	102	276	108
Transverse tensile strength	MPa	72	276	54
Transverse compressive strength	MPa	102	276	108
Shear strength	MPa	34	138	54
Specific gravity	—	1.2	2.7	1.2

Expressions for transformed reduced stiffness matrix:

$$\bar{Q}_{11} = Q_{11}c^4 + Q_{22}s^4 + 2(Q_{12} + 2Q_{66})s^2c^2$$

$$\bar{Q}_{12} = (Q_{11} + Q_{22} - 4Q_{66})s^2c^2 + Q_{12}(c^4 + s^2)$$

$$\bar{Q}_{22} = Q_{11}s^4 + Q_{22}c^4 + 2(Q_{12} + 2Q_{66})s^2c^2$$

$$\bar{Q}_{16} = (Q_{11} - Q_{12} - 2Q_{66})c^3s - (Q_{22} - Q_{12} - 2Q_{66})s^3c,$$

$$\bar{Q}_{26} = (Q_{11} - Q_{12} - 2Q_{66})cs^3 - (Q_{22} - Q_{12} - 2Q_{66})c^3s$$

$$\bar{Q}_{66} = (Q_{11} + Q_{22} - 2Q_{12} - 2Q_{66})s^2c^2 + Q_{66}(s^4 + c^4)$$

Table: Properties of Composite Lamina

Typical Mechanical Properties of a Unidirectional Lamina (SI System of Units)

Property	Symbol	Units	Glass/ epoxy	Boron/ epoxy	Graphite/ epoxy
Fiber volume fraction	V_f		0.45	0.50	0.70
Longitudinal elastic modulus	E_1	GPa	38.6	204	181
Transverse elastic modulus	E_2	GPa	8.27	18.50	10.30
Major Poisson's ratio	ν_{12}		0.26	0.23	0.28
Shear modulus	G_{12}	GPa	4.14	5.59	7.17
Ultimate longitudinal tensile strength	$(\sigma_1^T)_{ult}$	MPa	1062	1260	1500
Ultimate longitudinal compressive strength	$(\sigma_1^C)_{ult}$	MPa	610	2500	1500
Ultimate transverse tensile strength	$(\sigma_2^T)_{ult}$	MPa	31	61	40
Ultimate transverse compressive strength	$(\sigma_2^C)_{ult}$	MPa	118	202	246
Ultimate in-plane shear strength	$(\tau_{12})_{ult}$	MPa	72	67	68
Longitudinal coefficient of thermal expansion	α_1	μm/m/°C	8.6	6.1	0.02
Transverse coefficient of thermal expansion	α_2	μm/m/°C	22.1	30.3	22.5
Longitudinal coefficient of moisture expansion	β_1	m/m/kg/kg	0.00	0.00	0.00
Transverse coefficient of moisture expansion	β_2	m/m/kg/kg	0.60	0.60	0.60

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-2 B. Sc. Engineering Examinations 2020-2021

Sub: **ME 461** (Control Engineering)

Full Marks: 210 Time: 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

Symbols have their usual meaning and interpretation. Assume any missing data.

1. (a) Determine the system type, the static error constants as well as the steady-state errors for a unity feedback control system with standard step and ramp inputs when the plant transfer function is **(13)**

$$G(s)=\frac{700(s+10)(s+15)}{s(s+3)(s+7)(s+20)}$$

(b) A closed-loop system is used to track the sun to obtain the maximum power from a photo-voltaic array. The tracking system may be represented by Fig. for Q. No. 1(b) with H(s) = 1 and G(s) = 100/(τs+1), where τ = 3 seconds normally. Calculate –

(i) the sensitivity of the system for a small change in τ and

(ii) the time constant of the system response. **(10)**

(c) Design the values of k_1 and k_2 in the system shown in Fig. for Q. No. 1(c) to meet the following specifications: steady-state error component due to a unit step disturbance is – 0.000012; steady-state error component due to a unit ramp input is 0.003. **(12)**

2. (a) Describe the requirements of root locus plot. **(10)**

(b) Consider a unity feedback system with the open-loop transfer function: **(25)**

$$G(s)=\frac{K(s+10)}{s(s+1)(s+3)}$$

Do the following:

(i) Sketch the root locus

(ii) Find the asymptotes

(iii) Find the breakaway point

(iv) Find the jω crossing point

(v) Find the range of gain K that makes the system stable.

3. (a) Draw the Nyquist plot of the response of a damped spring system (τ = 0.1) as shown in Fig. for Q. No. 3(a). **(15)**

(b) Plot the asymptotic attenuation and phase angle diagram for the following open-loop transfer function: $G(s)=\dfrac{50(s+2)}{s(s+10)}$ **(20)**

Contd P/2

ME 461

Contd … Q. No. 3(b)

Determine:

(i) the gain cross-over frequency,

(ii) the phase cross-over frequency,

(iii) the gain margin,

(iv) the phase margin

(v) the nature of stability.

4. (a) Graphically show the zone of area where the roots of the characteristic equation must lie within **(10)**

$\tau \leq 0.5$ sec

$\omega_d \leq 6$ rad/sec

$\xi \leq 0.71$.

(b) What is compensator? Classify compensators according to the nature of their influence on transfer function modification. **(10)**

(c) Consider the system shown in Fig. for Q. No. 4(c). Design a lead compensator such that the dominant closed-loop poles have the damping ratio $\xi = 0.5$ and the undamped natural frequency $\omega_n = 3$ rad/sec. **(15)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

Assume reasonable values for any missing data. Symbols indicate their usual meaning.

5. (a) The motor whose torque-speed characteristics are shown in Fig. 5a drives the load shown in the diagram. Some of the gears have inertia. Find the transfer function, $G(s) = \theta_2(s)/E_a(s)$. **(15)**

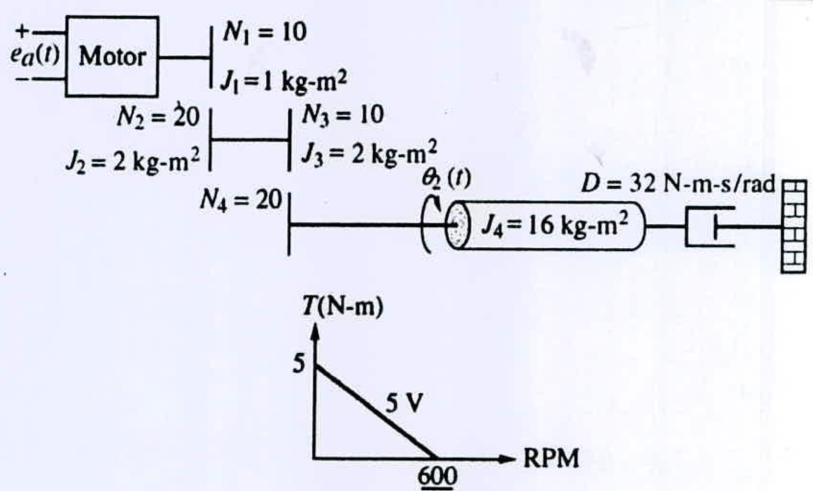


Fig. 5a

(b) Consider the inverted-pendulum system shown in Fig. 5(b). Assume that the mass of the inverted pendulum is m and is evenly distributed along the length of the rod. (The center of gravity of the pendulum is located at the center of the rod.) Assuming that u is small, derive mathematical models for the system in the forms of differential equations. **(20)**

ME 461

Contd...Q. No. 5(b)

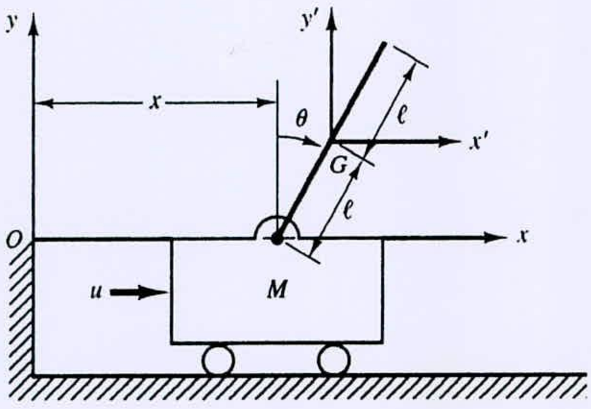


Fig. 5b

6. (a) Starting from the general response equation for an underdamped second order system, derive expressions for rise time and settling time. Also, calculate the rise time and settling time (2% criterion) in the unit-step response of a closed-loop system given by **(18)**

$$\frac{C(s)}{R(s)} = \frac{36}{s^2 + 2s + 36}$$

(b) Solve for $x(t)$ in the system shown in Fig. 6(b) if $f(t)$ is a unit step. **(17)**

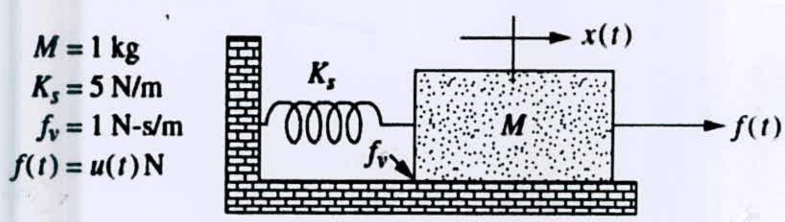


Fig. 6b

7. (a) Design the value of gain K, for the feedback control system of Fig. 7(a) below, so that the system will respond with a 15% overshoot. **(15)**

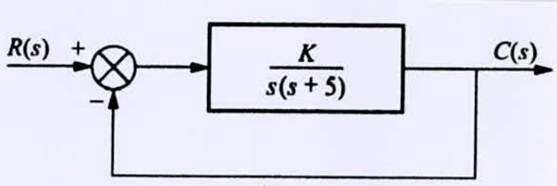


Fig. 7a

(b) Reduce the block diagram shown in Fig. 7(b) to a single block representing the transfer function, $T(s) = C(s)/R(s)$. **(20)**

Contd P/4

ME 461
Contd...Q. No. 7(b)

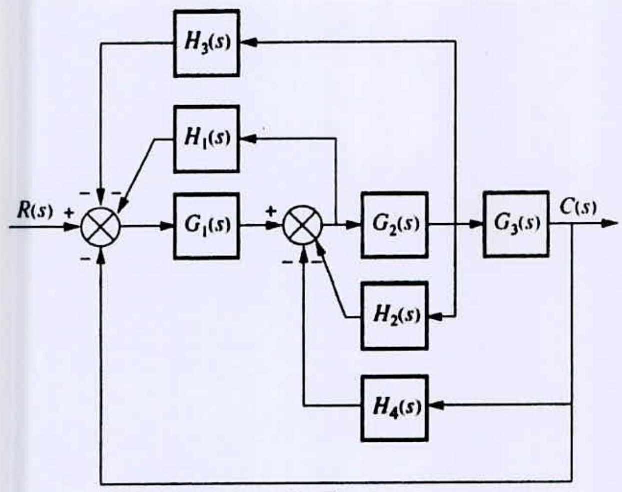


Fig. 7b

8. (a) By proper graphical representation, explain what will happen to the system response if, **(18)**

   (i) a pole is moved with a constant imaginary part,

   (ii) a pole is moved with a constant real part,

   (iii) a pole is moved along a radial line extending from the origin.

   (b) In the system of Fig. 8 (b), let, **(17)**

$$G(s) = \frac{K(s+2)}{s(s-1)(s+3)}$$

Find the range of K for closed-loop stability. Use Routh-Hurwitz Criterion for your analysis.

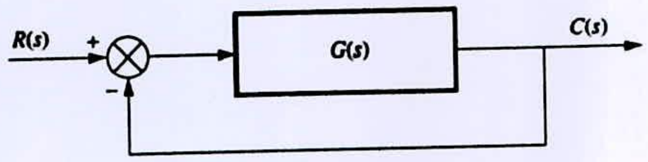


Fig. 8b

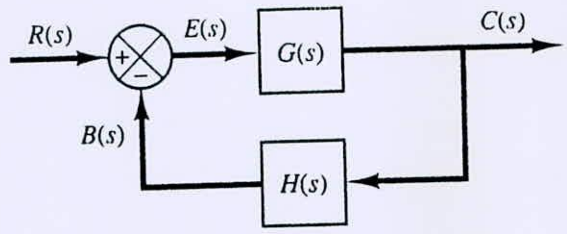


Fig. for Q. No. 1(b)

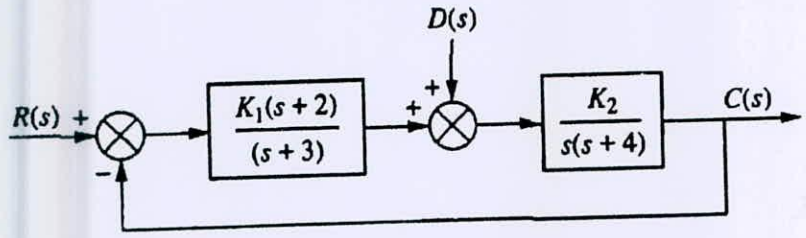


Fig. for Q. No. 1(c)

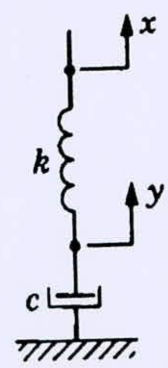


Fig. for Q. No. 3(a)

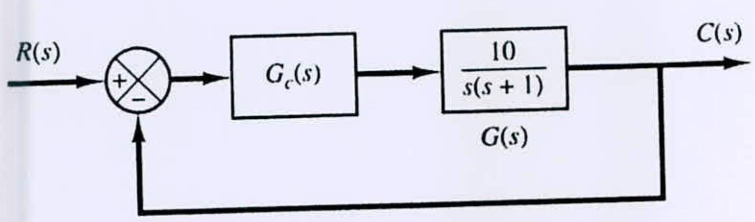


Fig. for Q. No. 4(c)

TABLE 2.2 Laplace transform theorems

Item no.	Theorem	Name
1.	$\mathscr{L}[f(t)] = F(s) \; = \int_{0-}^{\infty} f(t)e^{-st}dt$	Definition
2.	$\mathscr{L}[kf(t)] \; = kF(s)$	Linearity theorem
3.	$\mathscr{L}[f_1(t) + f_2(t)] = F_1(s) + F_2(s)$	Linearity theorem
4.	$\mathscr{L}[e^{-at}f(t)] \; = F(s+a)$	Frequency shift theorem
5.	$\mathscr{L}[f(t-T)] \; = e^{-sT}F(s)$	Time shift theorem
6.	$\mathscr{L}[f(at)] \; = \frac{1}{a}F\left(\frac{s}{a}\right)$	Scaling theorem
7.	$\mathscr{L}\left[\frac{df}{dt}\right] \; = sF(s) - f(0-)$	Differentiation theorem
8.	$\mathscr{L}\left[\frac{d^2f}{dt^2}\right] \; = s^2F(s) - sf(0-) - f'(0-)$	Differentiation theorem
9.	$\mathscr{L}\left[\frac{d^nf}{dt^n}\right] \; = s^nF(s) - \sum_{k=1}^{n} s^{n-k}f^{k-1}(0-)$	Differentiation theorem
10.	$\mathscr{L}\left[\int_{0-}^{t} f(\tau)d\tau\right] = \frac{F(s)}{s}$	Integration theorem
11.	$f(\infty) \; = \lim_{s \to 0} sF(s)$	Final value theorem[1]
12.	$f(0+) \; = \lim_{s \to \infty} sF(s)$	Initial value theorem[2]

L-4/T-2/ME **Date: 03/04/2023**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-2 B. Sc. Engineering Examinations 2020-2001

Sub : **ME 469** (Nuclear Engineering)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

Symbols used have their usual meanings and interpretation.

1. (a) What is burnup depth? Why does the burnup depth of a nuclear fuel rod need to be considered for the safer design and operation of the fuel rod? Provide the typical curves for your explanation. Briefly describe the consequences and measures due to burnup of fuel rod for efficient operation of nuclear reactor. **(17)**

   (b) Draw a schematic diagram and describe in details the cycle of reprocessing of nuclear fuel materials. Hence, compare the reprocess fuels Low Enriched Uranium (LEU), Mixed Oxide Fuel (MOX) and REMIX fuel along with their neutron multiplication factors. **(18)**

2. (a) What is "fuel pellet" used in a fuel assembly of a nuclear reactor? What are the basic parameters of a fuel pellet those need to be controlled for proper operation? Briefly describe them along with schematic diagram (if necessary). **(17)**

   (b) What are the three basic safety functions used in a III+ generation nuclear reactor? Hence, describe the parameters those are considered during designing of external events regarding safety issues in a nuclear power reactor. **(18)**

3. (a) What is reactor poisoning? Describe poison injection shutdown system of CANDU reactor with necessary schematic diagram and explain its importance during emergency situation. **(17)**

   (b) Describe a secondary side heat removal system of a nuclear reactor during emergency situation with neat sketches. Hence, explain the requirements to meet the emergency and describe the corresponding design choices. **(18)**

4. (a) What is passive safety system used in a nuclear reactor? Why is passive safety system designed for nuclear reactor though there is engineered safety system exists? Hence, describe briefly passive decay heat removal system with necessary diagrams used in a Light Water Reactor. **(17)**

   (b) Describe a passive containment spray system of a nuclear reactor. Draw a schematic diagram and mark all the major components here. Hence, show the natural draft air circulation flow path for removing heat to the outside of the containment building. **(18)**

Contd P/2

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) What do you understand by PWR? Briefly explain what order of pressure level is used in typical PWR plants? **(12)**

   (b) Briefly explain the advantages and limitations of PWR plants. **(15)**

   (c) Briefly explain the role of Boric acid used in PWR plant. **(8)**

6. (a) Deduce an expression of temperature distribution across a plate type fuel element of uniform cross-section with cladding. **(14)**

   (b) What do you understand by "Low level" radioactive wastes? Why is it important to handle them properly? **(9)**

   (c) Briefly explain the procedures for properly handling "Low level" radioactive wastes. **(12)**

7. (a) Briefly discuss the modes of heat transfer from the fuel rod to the coolant. What is different if liquid metal is used as the coolant? **(12)**

   (b) Briefly describe the bubble formation regimes as the surface temperature of a fuel rod increases in a BWR. **(13)**

   (c) What do you understand by LOCA? Briefly explain. **(10)**

8. (a) What happens to the spent fuel of a reactor? Briefly describe wet and dry spent fuel facilities. Where does the fuel finally end up? **(20)**

   (b) What is a "Fast Breeder Reactor? Briefly describe its operation. How is it different from other nuclear reactors? **(15)**

L-4/T-2/ME Date : 27/03/2023

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-2 B. Sc. Engineering Examinations 2020-2021

Sub : **ME 475** (Mechatronics)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

Assume any data if necessary. Symbols used have their usual meaning.

1. (a) What are the major disciplines that are involved in mechatronics? **(5)**

(b) Illustrate the advantages of using Mechatronics systems in contrast to separate mechanical or electrical control systems. **(12)**

(c) Using a block diagram, show the different modules/components which are used to build-up a mechatronics system. List some examples of mechatronics system. Explain one of them. **(18)**

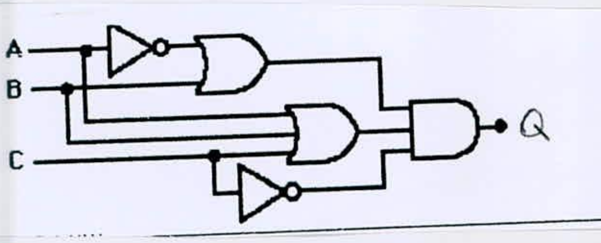
2. (a) Using SOP ro POS method, find the simplified Boolean expression for a two button door lock for the following truth table: **(9)**

B1	B2	L
0	0	1
0	1	0
1	0	1
1	1	0

(b) Give examples of static and dynamic systems. Differentiate between analog and digital systems. Using k-map, find the Boolean expression for the following motor control circuit: **(16)**

Thermal Sensor	Front Sensor	Rear Sensor	Drive Motor
OFF	OFF	OFF	ON
OFF	OFF	ON	ON
OFF	ON	OFF	ON
OFF	ON	ON	ON
ON	OFF	OFF	OFF
ON	OFF	ON	OFF
ON	ON	OFF	OFF
ON	ON	ON	OFF

(c) Draw a more simplified logic circuit of the following: **(10)**



Contd P/2

3. (a) Mention different types of actuators used in mechatronics systems. Discuss the use-cases of different types of actuators with their relative merits and demerits. **(12)**

   (b) Define 'sensor', transducer' and 'actuator'. List some typical sensors used for temperature, force/pressure, position, acceleration and light intensity measurements. Classify them as 'active' or 'passive'. **(13)**

   (c) Illustrate the working principle of a 'linear' motor. **(10)**

4. (a) What is Robotics? How would you differentiate between 'Mechatronics' and 'Robotics'? **(10)**

   (b) What is 3D printing technology? What is G-code in 3D printing? What are the alternatives of G-code? **(12)**

   (c) Define 'Machine Learning? Differentiate in with 'Artificial Intelligence'. **(13)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) Make comparison between **(10)**

   (i) active and passive electrical component

   (ii) inductor and capacitor

   (b) Briefly explain the working principle of the followings: **(10)**

   (i) diode, (ii) zener diode,

   (c) Briefly explain the function of transistor as **(15)**

   (i) current controlled current source

   (ii) switch

6. (a) Compare BJT and MOSFET as electronic switch **(10)**

   (b) Mention some of the characteristics of a OPamp **(10)**

   (c) Draw a circuit diagram of a PID controller using op-amps. **(10)**

   (d) What are the types of filters? **(5)**

7. (a) Make brief comparison between Neumann and Harvard architecture of microprocessors. **(15)**

   (b) Make brief comparison between micro-processor and microcontroller. **(10)**

   (c) Write a short note on IoT **(10)**

Contd P/3

8. (a) Mention some of the key characteristics of PLC. Compare PLC with PC. **(10)**

   (b) Give examples of Discrete and Data I/O of PLCs. **(10)**

   (c) Draw a LD program of the following activities of a batch process. Fill a container with liquid, stir the liquid for 5 minutes, and drain the container. The sequences of operations are as follows. **(15)**

   (i) open the fill value and fills the liquid until it is full.

   (ii) liquid in container is stirred for 5 minutes.

   (iii) Drain value is open & kept open until the draining is completed.

L-4/T-II/ME **Date : 03/05/2023**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4T-II B. Sc. Engineering Examinations 2020-2021

Sub : **IPE 481** (Industrial Management)

Full Marks : 280 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

1. (a) Outback Outfitters sells recreational equipment. One of the company's products, a small camp stove, sells for \$ 50 per unit. Variable expenses are \$32 per stove, and fixed expenses associated with the stove total \$ 108,000 per month. Do the following: **($26\frac{2}{3}$)**

(i) Compute the break-even point in number of stoves and in total sales dollars.

(ii) If the variable expenses per stove increase as a percentage of the selling price, will it result in a higher or a lower break-even point? Why? (Assume that the fixed expenses remain unchanged.)

(iii) At present, the company is selling 8,000 stoves per month. The sales manager is convinced that a 10% reduction in the selling price would result in a 25% increase in monthly sales of stoves. Prepare two contribution format income statements, one under present operating conditions, and one as operations would appear after the proposed changes. Show both total and per unit data on your statements.

(iv) Refer to the data in (iii) above. How many stoves would have to be sold at the new selling price to yield a minimum net operating income of \$35,000 per month?

(b) Mr. Joe, president of a New York-based financial service, believes there is a relationship between the number of client contacts and the dollar amount of sales. To document this assertion, he gathered the following sample information. **(20)**

Number of contracts, X	Sales in \$1000, Y
16	26
11	17
20	28
15	30
44	78
23	30
46	87
50	85
56	120
48	111

In the data table, the X column indicates the number of client contacts last month, and the Y column shows the value of sales (\$ thousands) last month for each client sampled.

(i) Determine the regression equation

(ii) Determine the estimated sales if 54 contacts are made.

Contd P/2

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2. Creekstone Corporation manufactures and sells a seasonal product that has peak sales in the third quarter. The following information concerns operations for Year 2-the coming year, and for the first two quarters of Year 3: **(46⅔)**

	Year 2 Quarter				Year 3 Quarter	
	1	2	3	4	1	2
Budgeted unit sales (US$)	35,000	65,000	90,000	45,000	80,000	65,000

The company's single product sells for $8 per unit. Budgeted sales in units for the next six quarters are as follows (all sales are on credit). Sales are collected in the following pattern: 75% in the quarter the sales are made, and the remaining 25% in the following quarter. On January 1, Year 2, the company's balance sheet showed $65,000 in accounts receivable, all of which will be collected in the first quarter of the year. Bad debts are negligible and can be ignored. The company desires an ending finished goods inventory at the end of each quarter equal to 30% of the budgeted unit sales for the next quarter. On December 31, Year 1, the company had 12,000 units on hand. Five pounds of raw materials are required to complete one unit of product. The company requires ending raw materials inventory at the end of each quarter equal to 10% of the following quarter's production needs. On December 31, Year 1, the company had 23,000 pounds of raw materials on hand. The raw material costs $0.80 per pound. Raw material purchases are paid for in the following pattern: 60% paid in the quarter the purchases are made, and the remaining 40% is paid in the following quarter. On January 1, Year 2, the company's balance sheet showed $81,500 in accounts payable for raw material purchases, all of which will be paid for in the first quarter of the year.

Prepare the following budgets and schedules for the year, showing both quarterly and total figures:

(i) A sales budget and a schedule of expected cash collections.

(ii) A production budget.

(iii) A direct materials budget and a schedule of expected cash payments for purchases of materials.

3. Sierra Corporation produces and sells a single product, a bluetooth soundbox. Selected cost and operating data relating to the product for two years are given below. All money amounts are in unit of US dollars ($): **(46⅔)**

	US $
Selling price per unit	68
Manufacturing costs:	
Variable per unit produced:	
Direct materials	13
Direct labor	8
Variable overhead	4
Fixed per year	125,000
Selling and administrative costs:	
Variable per unit sold	5
Fixed per year	65,000

Contd P/3

IPE 481

Contd...Q.No. 3

	Year 1 (Units)	Year 2 (Units)
Units in beginning inventory	0	2,000
Units produced during the year	10,000	6,000
Units sold during the year	8,000	8,000
Units in ending inventory	2,000	0

Do following:

(i) Assume the company uses absorption costing. Compute the unit product cost in each year. Then prepare an income statement for each year.

(ii) Assume the company uses variable costing. Compute the unit product cost in each year. Then prepare an income statement for each year.

(iv) Reconcile the variable costing and absorption costing net operating incomes.

4. (a) ABC Pharmaceuticals is considering purchasing a new manufacturing machine that costs \$100,000. The machine is expected to have a useful life of 8 years, during which it will generate an annual cash inflow of \$25,000. However, the machine will require annual maintenance costs of \$5,000 per year. At the end of the 8-year useful life, the machine can be sold for \$10,000. Assuming a required rate of return of 12%, what is the present worth of the investment in the machine? Should the company purchase the machine? **($16\frac{2}{3}$)**

(b) Ford Automobiles is considering investing in a new manufacturing facility that will cost \$10 million. The facility is expected to have a useful life of 20 years and generate annual revenue of \$4 million with an annual operating cost of \$1.5 million. The facility will also require a major renovation at the end of the tenth year, which will cost \$5 million. At the end of the 20-year useful life, the facility can be sold for \$1 million. Assuming a required rate of return of 12%, what is the annual worth of the investment in the facility? Should the company invest in the facility? **(15)**

(c) A company is considering investing a new project that requires an initial investment of \$1,000,000. The project is expected to generated cash inflows of \$200,000 per year for 15 years. The project also has a salvage value of \$50,000 at the end of the 15th year. If the company's required rate of return is 10%, what is the discounted payback period for the project? Should the company invest in the project based on this analysis? **(15)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) Briefly explain the relative advantages and disadvantages of different performance appraisal methods. What are the four different outcomes that may result from any selection decision? Explain. **($20\frac{2}{3}$)**

Contd P/4

IPE 481

Contd...Q.No. 5

(b) How can breaking up a single link impact the effectiveness of the entire motivation process? Explain based on the Expectancy theory. **(16)**

(c) Mention different roles of managers according to Henry Mintzberg. **(10)**

6. (a) Explain different elements of bureaucracy model of Max Weber. **(20 $\frac{2}{3}$)**

   (b) Answer the following questions in the light of Reinforcement theory: **(16)**

   (i) How can engineering students be motivated to secure good grades?

   (ii) How can public transport drivers be motivated to drive safely?

   (c) Define organization. Briefly explain the six key elements for organizational design. **(10)**

7. (a) "The corporate world is filled with stories of leaders who failed to achieve greatness because they failed to understand the context, they were working in." Explain with the help of Fiedler contingency model of leadership. **(26 $\frac{2}{3}$)**

   (b) Compare groups and teams. List the important characteristics of effective teams. "Some conflict is absolutely necessary for a group to perform effectively."- Do you agree? Justify your answer. **(20)**

8. (a) Explain the factors which influence consumer behavior. **(20 $\frac{2}{3}$)**

   (b) Mention different patterns of target market selection with appropriate examples. **(16)**

   (c) Why demographic environment is crucial in marketing analysis? **(10)**
