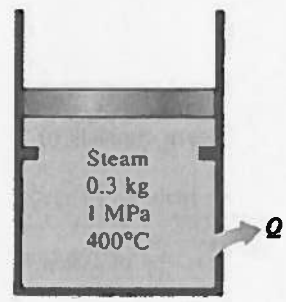
CONCORDIA UNIVERSITY
FACULTY OF ENGINEERING AND COMPUTER SCIENCE
DEPARTMENT OF MECHANICAL ENGINEERING

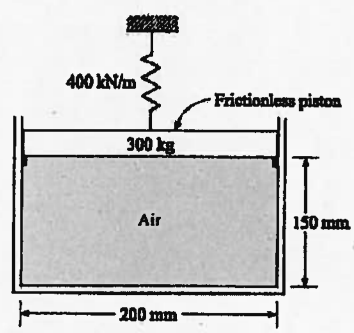
PROBLEM I [12 pts]
A piston-cylinder device with a set of stops initially contains 0.3 kg of steam at 1.0 MPa and 400°C. The location of the stops corresponds to 60 percent of the initial volume. Now the steam is cooled. Determine the compression work if the final state is:

a) 1.0 MPa and 250°C,
b) 500 kPa
c) Also determine the temperature at the final state in part (b).



W (a)	22.16 kJ
W (b)	36.79 kJ
T_2	151.8 °C

PROBLEM II [12 pts]
Six grams of air is contained in the cylinder shown in the figure below. The air is heated until the piston raises 50 mm. The spring just touches the piston initially. Calculate:
a) the temperature when the piston leaves the stops,
b) the work done .



T_1	530 K
W	0.304 kJ

PROBLEM III [6 pts]

- Explain physically why C_p is higher than C_v for an ideal gas?
- Demonstrate that for an ideal gas: $C_p - C_v = R$.
- What does the area under a Cp *.vs* T graph represents?

CONSTANTS FOR ALL PROBLEMS: P_{atm}= 100 kPa For air: R=0.2870 kJ/ kg K

TABLE A–5

Saturated water—Pressure table

Press., P kPa	Sat. temp., T_{sat} °C	Specific volume, m³/kg: Sat. liquid, v_f	Sat. vapor, v_g	Internal energy, kJ/kg: Sat. liquid, u_f	Evap., u_{fg}	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	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7	0.4762	7.9176	8.3938
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738	8.2501
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9	0.6492	7.4996	8.1488
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3	0.7549	7.2522	8.0071
20	60.06	0.001017	7.6481	251.40	2204.6	2456.0	251.42	2357.5	2608.9	0.8320	7.0752	7.9073
25	64.96	0.001020	6.2034	271.93	2190.4	2462.4	271.96	2345.5	2617.5	0.8932	6.9370	7.8302
30	69.09	0.001022	5.2287	289.24	2178.5	2467.7	289.27	2335.3	2624.6	0.9441	6.8234	7.7675
40	75.86	0.001026	3.9933	317.58	2158.8	2476.3	317.62	2318.4	2636.1	1.0261	6.6430	7.6691
50	81.32	0.001030	3.2403	340.49	2142.7	2483.2	340.54	2304.7	2645.2	1.0912	6.5019	7.5931
75	91.76	0.001037	2.2172	384.36	2111.8	2496.1	384.44	2278.0	2662.4	1.2132	6.2426	7.4558
100	99.61	0.001043	1.6941	417.40	2088.2	2505.6	417.51	2257.5	2675.0	1.3028	6.0562	7.3589
101.325	99.97	0.001043	1.6734	418.95	2087.0	2506.0	419.06	2256.5	2675.6	1.3069	6.0476	7.3545
125	105.97	0.001048	1.3750	444.23	2068.8	2513.0	444.36	2240.6	2684.9	1.3741	5.9100	7.2841
150	111.35	0.001053	1.1594	466.97	2052.3	2519.2	467.13	2226.0	2693.1	1.4337	5.7894	7.2231
175	116.04	0.001057	1.0037	486.82	2037.7	2524.5	487.01	2213.1	2700.2	1.4850	5.6865	7.1716
200	120.21	0.001061	0.88578	504.50	2024.6	2529.1	504.71	2201.6	2706.3	1.5302	5.5968	7.1270
225	123.97	0.001064	0.79329	520.47	2012.7	2533.2	520.71	2191.0	2711.7	1.5706	5.5171	7.0877
250	127.41	0.001067	0.71873	535.08	2001.8	2536.8	535.35	2181.2	2716.5	1.6072	5.4453	7.0525
275	130.58	0.001070	0.65732	548.57	1991.6	2540.1	548.86	2172.0	2720.9	1.6408	5.3800	7.0207
300	133.52	0.001073	0.60582	561.11	1982.1	2543.2	561.43	2163.5	2724.9	1.6717	5.3200	6.9917
325	136.27	0.001076	0.56199	572.84	1973.1	2545.9	573.19	2155.4	2728.6	1.7005	5.2645	6.9650
350	138.86	0.001079	0.52422	583.89	1964.6	2548.5	584.26	2147.7	2732.0	1.7274	5.2128	6.9402
375	141.30	0.001081	0.49133	594.32	1956.6	2550.9	594.73	2140.4	2735.1	1.7526	5.1645	6.9171
400	143.61	0.001084	0.46242	604.22	1948.9	2553.1	604.66	2133.4	2738.1	1.7765	5.1191	6.8955
450	147.90	0.001088	0.41392	622.65	1934.5	2557.1	623.14	2120.3	2743.4	1.8205	5.0356	6.8561
500	151.83	0.001093	0.37483	639.54	1921.2	2560.7	640.09	2108.0	2748.1	1.8604	4.9603	6.8207
550	155.46	0.001097	0.34261	655.16	1908.8	2563.9	655.77	2096.6	2752.4	1.8970	4.8916	6.7886
600	158.83	0.001101	0.31560	669.72	1897.1	2566.8	670.38	2085.8	2756.2	1.9308	4.8285	6.7593
650	161.98	0.001104	0.29260	683.37	1886.1	2569.4	684.08	2075.5	2759.6	1.9623	4.7699	6.7322

TABLE

Saturat

Press., P kPa
800
850
900
950
1000
1100
1200
1300
1400
1500
1750
2000
2250
2500
3000
3500
4000
5000
6000
7000
8000
9000
10,000
11,000
12,000
13,000
14,000
15,000
16,000
17,000
18,000
19,000
20,000
21,000
22,000

TABLE A–6

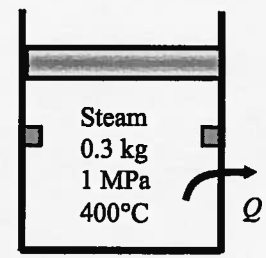
Superheated water (*Continued*)

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	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	P = 1.00 MPa (179.88°C)				P = 1.20 MPa (187.96°C)				P = 1.40 MPa (195.04°C)			
Sat.	0.19437	2582.8	2777.1	6.5850	0.16326	2587.8	2783.8	6.5217	0.14078	2591.8	2788.9	6.4675
200	0.20602	2622.3	2828.3	6.6956	0.16934	2612.9	2816.1	6.5909	0.14303	2602.7	2803.0	6.4975
250	0.23275	2710.4	2943.1	6.9265	0.19241	2704.7	2935.6	6.8313	0.16356	2698.9	2927.9	6.7488
300	0.25799	2793.7	3051.6	7.1246	0.21386	2789.7	3046.3	7.0335	0.18233	2785.7	3040.9	6.9553
350	0.28250	2875.7	3158.2	7.3029	0.23455	2872.7	3154.2	7.2139	0.20029	2869.7	3150.1	7.1379
400	0.30661	2957.9	3264.5	7.4670	0.25482	2955.5	3261.3	7.3793	0.21782	2953.1	3258.1	7.3046
500	0.35411	3125.0	3479.1	7.7642	0.29464	3123.4	3477.0	7.6779	0.25216	3121.8	3474.8	7.6047
600	0.40111	3297.5	3698.6	8.0311	0.33395	3296.3	3697.0	7.9456	0.28597	3295.1	3695.5	7.8730
700	0.44783	3476.3	3924.1	8.2755	0.37297	3475.3	3922.9	8.1904	0.31951	3474.4	3921.7	8.1183
800	0.49438	3661.7	4156.1	8.5024	0.41184	3661.0	4155.2	8.4176	0.35288	3660.3	4154.3	8.3458
900	0.54083	3853.9	4394.8	8.7150	0.45059	3853.3	4394.0	8.6303	0.38614	3852.7	4393.3	8.5587
1000	0.58721	4052.7	4640.0	8.9155	0.48928	4052.2	4639.4	8.8310	0.41933	4051.7	4638.8	8.7595
1100	0.63354	4257.9	4891.4	9.1057	0.52792	4257.5	4891.0	9.0212	0.45247	4257.0	4890.5	8.9497

4-9 A piston-cylinder device with a set of stops contains steam at a specified state. Now, the steam is cooled. The compression work for two cases and the final temperature are to be determined.

Analysis (a) The specific volumes for the initial and final states are (Table A-6)

2 $\left.\begin{array}{l} P_1 = 1\,\text{MPa} \\ T_1 = 400°\text{C} \end{array}\right\} v_1 = 0.30661\,\text{m}^3/\text{kg}$ $\quad \left.\begin{array}{l} P_2 = 1\,\text{MPa} \\ T_2 = 250°\text{C} \end{array}\right\} v_2 = 0.23275\,\text{m}^3/\text{kg}$ 2



Noting that pressure is constant during the process, the boundary work is determined from

2 $W_b = mP(v_1 - v_2) = (0.3\,\text{kg})(1000\,\text{kPa})(0.30661 - 0.23275)\text{m}^3/\text{kg} = \mathbf{22.16\,kJ}$

(b) The volume of the cylinder at the final state is 60% of initial volume. Then, the boundary work becomes

$$W_b = mP(v_1 - 0.60v_1) = (0.3\,\text{kg})(1000\,\text{kPa})(0.30661 - 0.60 \times 0.30661)\text{m}^3/\text{kg} = \mathbf{36.79\,kJ}$$ 4

The temperature at the final state is

$$\left.\begin{array}{l} P_2 = 0.5\,\text{MPa} \\ v_2 = (0.60 \times 0.30661)\,\text{m}^3/\text{kg} \end{array}\right\} T_2 = \mathbf{151.8°C} \quad \text{(Table A-5)}$$ 2

3.3 Air is compressed in a cylinder such that the volume changes from 100 to 10 in^3. The initial pressure is 50 psia and the temperature is held constant at 100 °F. Calculate the work.

The work is given by $W = \int P\,dV$. For the isothermal process the equation of state allows us to write

$$PV = mRT = \text{const.}$$

since the mass m, the gas constant R, and the temperature T are all constant. Letting the constant be $P_1 V_1$, the above becomes $P = P_1 V_1 / V$, so that

$$W = P_1 V_1 \int_{V_1}^{V_2} \frac{dV}{V} = P_1 V_1 \ln\frac{V_2}{V_1} = (50)(144)\left(\frac{100}{1728}\right)\ln\frac{10}{100} = -959 \text{ ft-lbf}$$

3.4 Six grams of air is contained in the cylinder shown in Fig. 3-13. The air is heated until the piston raises 50 mm. The spring just touches the piston initially. Calculate (*a*) the temperature when the piston leaves the stops and (*b*) the work done by the air on the piston.

(*a*) The pressure in the air when the piston just raises from the stops is found by balancing the forces on the piston:

$$PA = P_{\text{atm}}A + W \qquad \frac{P\pi(0.2)^2}{4} = (100\,000)\frac{\pi(0.2)^2}{4} + (300)(9.81) \qquad 4$$

$$\therefore P = 193\,700 \text{ Pa} \quad \text{or } 193.7 \text{ kPa}$$

The temperature is found from the ideal-gas law:

$$T = \frac{PV}{mR} = \frac{(193.7)(0.15)(\pi)(0.2)^2/4}{(0.006)(0.287)} = 530 \text{ K} \qquad 2$$

(*b*) The work done by the air is considered to be composed of two parts: the work to raise the piston and the work to compress the spring. The work required to raise the piston a distance of 0.05 m is

$$W = (F)(d) = (P)(A)(d) = (193.7)\frac{\pi(0.2)^2}{4}(0.05) = 0.304 \text{ kJ} \qquad 3$$

The work required to compress the spring is $W = \frac{1}{2}Kx^2 = \frac{1}{2}(400)(0.05^2) = 0.5$ kJ. The total work 2 required by the air to raise the piston is

$$W = 0.304 + 0.5 = 0.804 \text{ kJ} \qquad 4$$

3.5 Two kilograms of air experiences the three-process cycle shown in Fig. 3-14. Calculate the net work.

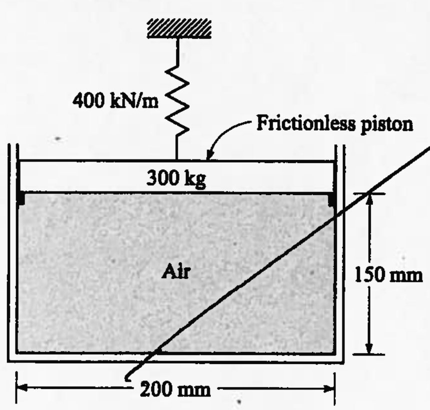


Fig. 3-13

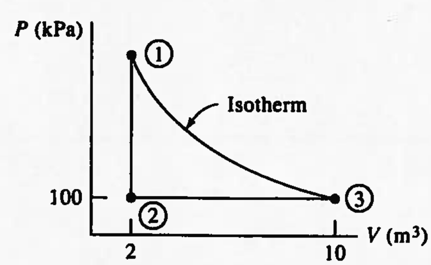


Fig. 3-14

Pr III

1). writing simply becouse $C_p - C_v = R$

is wrong since the question was:

explain physically.

for the same heat addition, the increase in T^{o} will be higher at $v = c^t$ than at $P = c^t$.

2 since, any specific heat is defined as the ratio of heat over a variation in T^{o}, $\left(\frac{Q}{\Delta T}\right)$

then $C_p > C_v$

possible other explanation: because at $P = c^t$, a part of the heat is also used to lift the piston and then to generate work.

2) see next page 2

3) The heat provided 2

oR

the variation in enthalpy.

and

$$h_2 - h_1 = \int_{T_1}^{T_2} c_p \cdot dT$$

Example

Determine the enthalpy change, Δh, of nitrogen, in kJ/kg, as it is heated from 600 to 1000K, using (a) the empirical data for h from the nitrogen table (Table A-18), (b) the empirical specific heat equation as a function of temperature (Table A-2c), (c) the C_P value at the average temperature (Table A-2b), and (d) the C_P value at room temperature (Table A-2a). Also determine the percentage error in each case.

Note

For non-ideal gases: internal energy and enthalpy changes are found using the empirical gas tables. Also changes in internal energy can be found using C_V for constant volume processes. Changes in enthalpy can be found using C_P, providing that the process is constant pressure.

For ideal gases: internal energy and enthalpy changes may be found using empirical gas tables. Also changes in internal energy may be found using C_V for any process since internal energy is a function of temperature alone. Also changes in enthalpy may be found using C_P for any process since enthalpy is a function of temperature alone.

II.9.3. Relationship between C_V and C_P:

We have: $h = u + P v$

For an ideal gas $Pv = RT$ so that

$$h = u + R \cdot T$$

Differentiating $dh = du + R \cdot dT$

Divide by dT $dh/dT = du/dT + R$

Recall definition of C_V and C_P for an ideal gas

$$\mathbf{C_P = C_V + R}$$

We can also define specific Heat Ratio, k as

$$k \equiv \frac{C_P}{C_V}$$