

MAE 3310

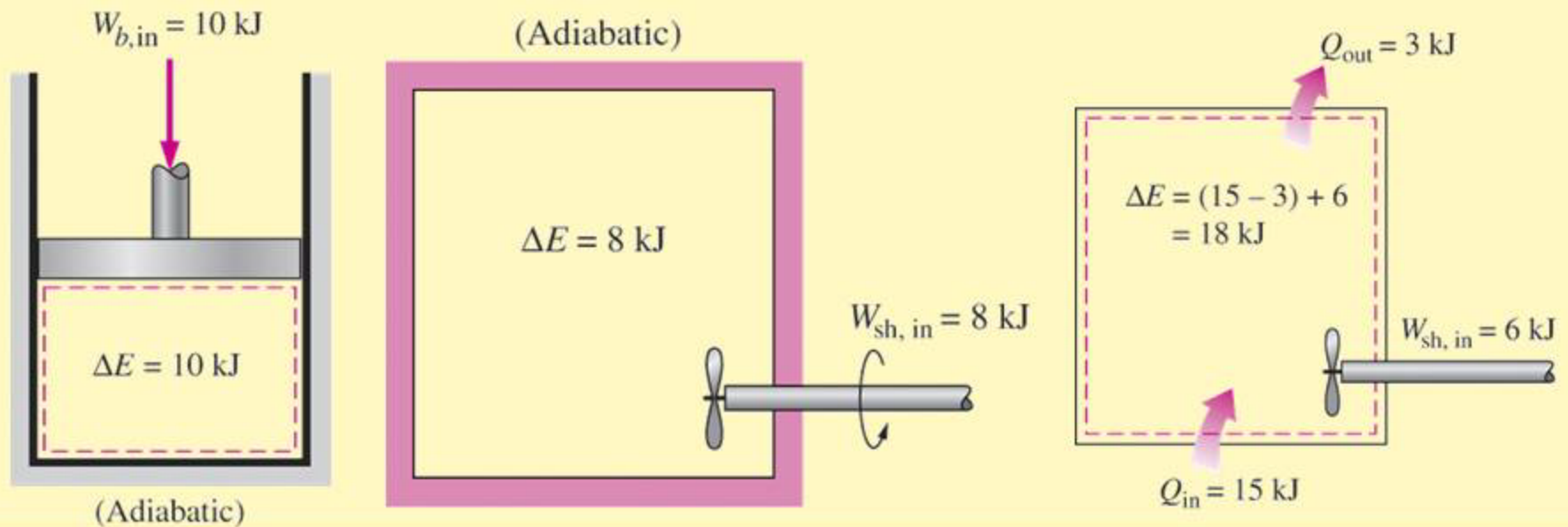
FIRST LAW OF THERMODYNAMICS
&
PROPERTIES OF PURE SUBSTANCES

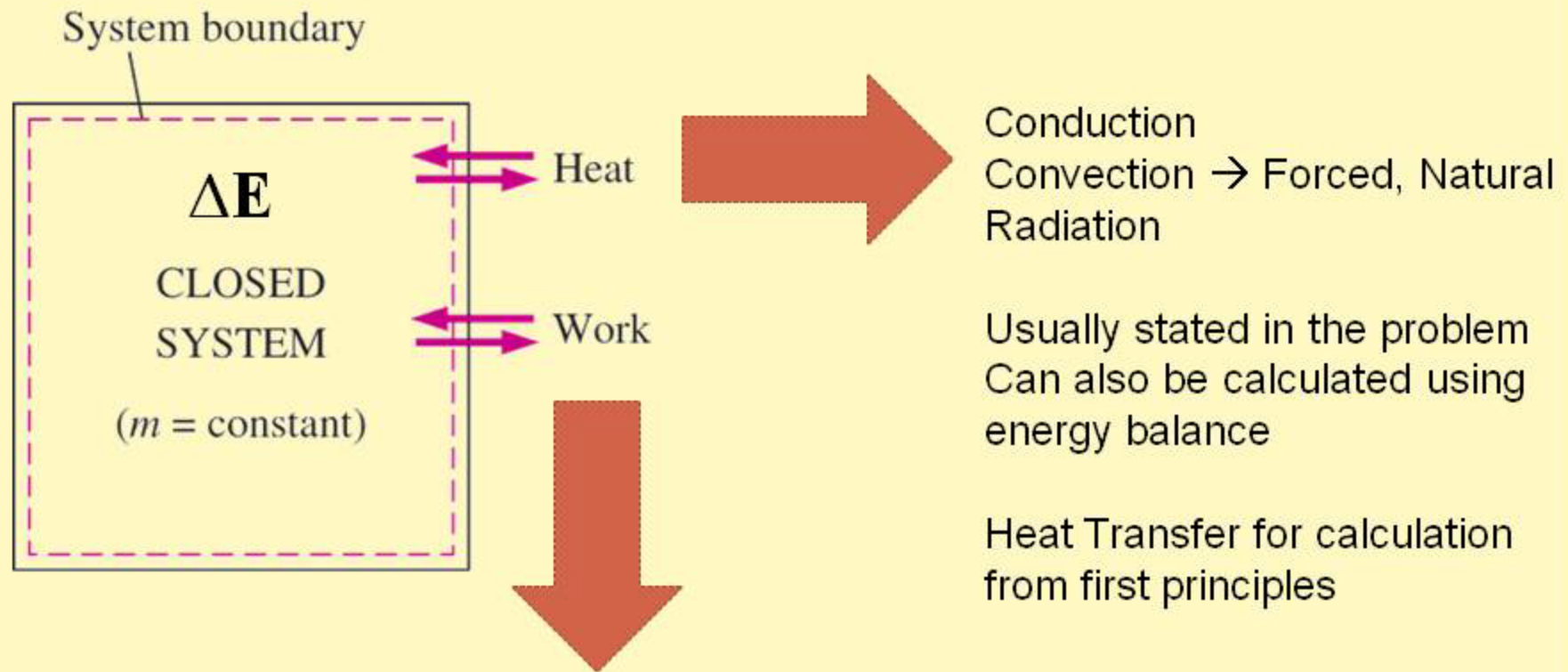
THE FIRST LAW OF THERMODYNAMICS

Principle of Energy Conservation

The energy accumulation or depletion in a control mass or control volume is given by

$$\underbrace{\left(\text{Total Energy Entering the System} \right)}_{\mathbf{E_{in}}} - \underbrace{\left(\text{Total Energy Leaving the System} \right)}_{\mathbf{E_{out}}} = \underbrace{\left(\text{Change in total energy of the System} \right)}_{\mathbf{\Delta E_{system}}}$$



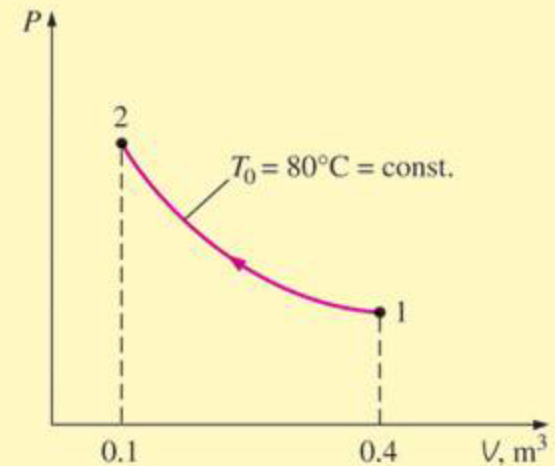
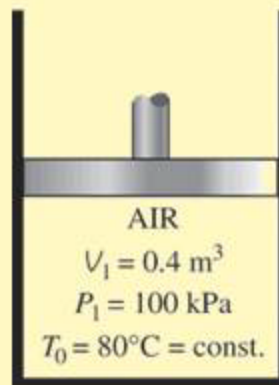
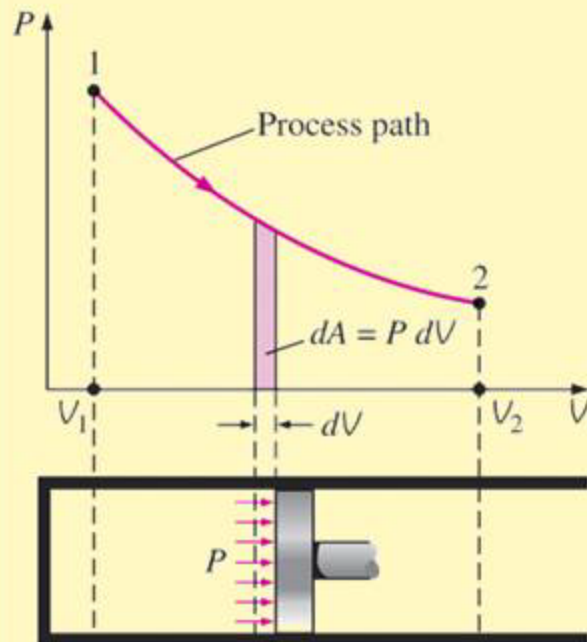


Computed using System and Process definition
Reversible or quasi equilibrium assumption

Expansion / Compression
Electrical
Stretching
Flow work
.....
.....

Force Balance
Internal force due to
system pressure
balancing external
forces

Expansion / Compression

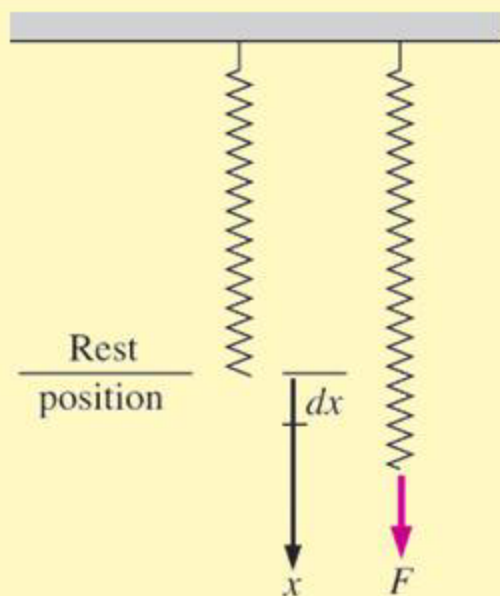


Equation of State (Equilibrium property relationships)
 Ideal Gas

$$P V = m R T$$

$$P \bar{V} = R_u T$$

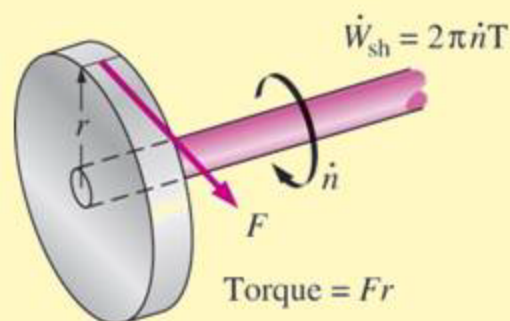
\bar{V} is the molar specific volume, m^3/mole



$$F_{spring} = kx \quad (\text{kN}) \quad k \text{ is the spring constant (kN/m)}$$

$$\delta W_{spring} = \int_{x_1}^{x_2} kx \, dx \quad (\text{kJ})$$

$$W_{spring} = \frac{1}{2} k (x_2^2 - x_1^2) \quad (\text{kJ})$$



$$\dot{W}_{shaft} = 2\pi \dot{n} T$$

$$\dot{n} = 4000 \text{ rpm}$$

$$T = 200 \text{ N.m}$$

$$= 2\pi \left(4000 \frac{1}{\text{min}} \right) (200 \text{ N.m}) \left(\frac{1 \text{ min}}{60 \text{ s}} \right) \left(\frac{1 \text{ kJ}}{1000 \text{ N.m}} \right)$$

$$= 83.8 \text{ (kW)}$$

Flow Work

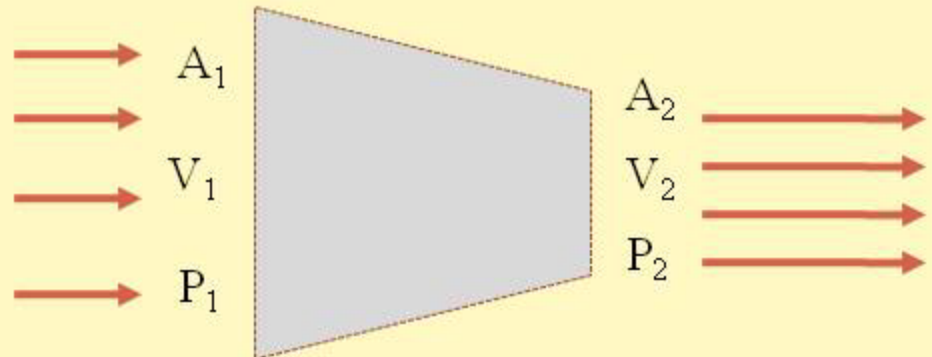
Bernoulli's principle

Pressure in a flowing fluid adjusts itself with the speed or velocity of the fluid
Fluids will expend pressure energy for kinetic energy

Bernoulli's equation is a conservation of energy principle

$$\underbrace{\frac{P_1}{\rho} + \frac{1}{2} V_1^2 + g z_1}_{e_{1,\text{mech}}} = \underbrace{\frac{P_2}{\rho} + \frac{1}{2} V_2^2 + g z_2}_{e_{2,\text{mech}}}$$

The term $\left(\frac{P_1 - P_2}{\rho}\right)$ represents the flow work that is required to move the fluid



THE FIRST LAW OF THERMODYNAMICS

Principle of Energy Conservation for a flow system

The energy accumulation or depletion in a control mass or control volume is given by

$$\underbrace{\left(\begin{array}{c} \text{Total Energy Entering} \\ \text{the System} \end{array} \right)}_{\mathbf{E}_{\text{in}}} - \underbrace{\left(\begin{array}{c} \text{Total Energy Leaving} \\ \text{the System} \end{array} \right)}_{\mathbf{E}_{\text{out}}} = \underbrace{\left(\begin{array}{c} \text{Change in total energy} \\ \text{of the System} \end{array} \right)}_{\Delta \mathbf{E}_{\text{system}}}$$

$$Q_{\text{in}} + W_{\text{in}} + E_{\text{mass,in}}$$

$$Q_{\text{out}} + W_{\text{out}} + E_{\text{mass,out}}$$

$$\Delta E = (\Delta U + \Delta KE + \Delta PE)$$

$$E_{\text{mass,in}} = \dot{m}_{\text{in}} e_{\text{mech,in}}$$

$$E_{\text{mass,out}} = \dot{m}_{\text{in}} e_{\text{mech,out}}$$

Efficiency (η) \rightarrow Performance

$$\text{Performance} = \left(\frac{\text{Desired Output}}{\text{Required Input}} \right) = \left(\frac{\text{Benefits}}{\text{Costs}} \right)$$

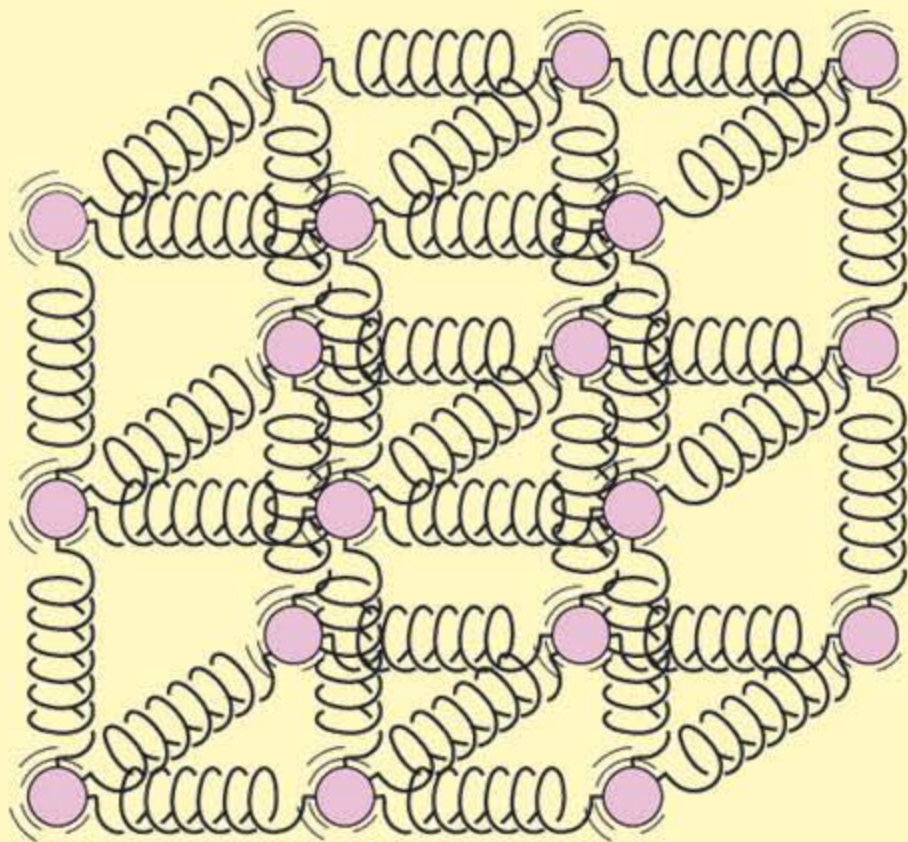
$$\eta_{\text{combustion}} = \left(\frac{Q}{HV} \right) \left(\frac{\text{Amount of Heat released during combustion}}{\text{Heating value of fuel burned}} \right)$$

$$\eta_{\text{thermal}} = \left(\frac{\dot{W}_{\text{shaft}}}{\dot{Q}} \right)$$

$$\eta_{\text{overall}} = \eta_{\text{combustion}} \eta_{\text{thermal}} \eta_{\text{generator}}$$

$$\eta_{\text{generator}} = \left(\frac{P_{\text{electric}}}{\dot{W}_{\text{shaft}}} \right)$$

$$= \left(\frac{P_{\text{electric}}}{\dot{m}_{\text{fuel}} HV} \right)$$

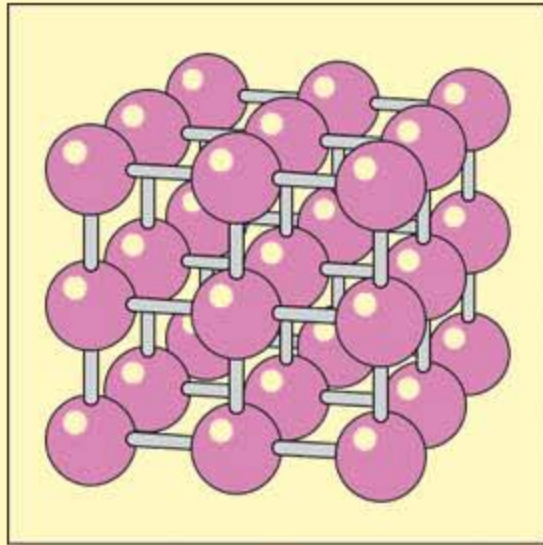


Molecules kept in position by spring like intermolecular forces

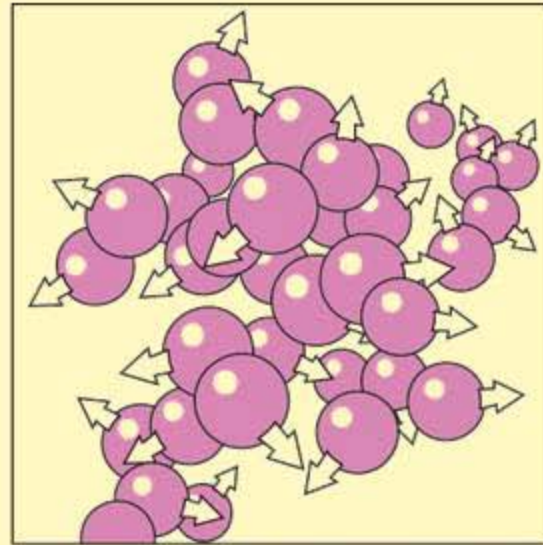
Solids

Liquids

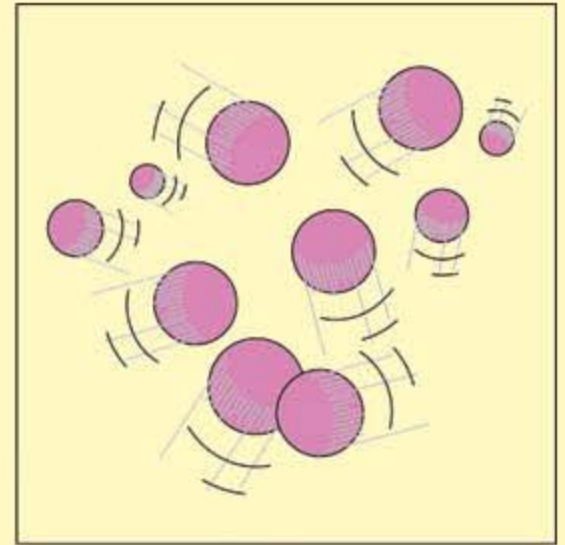
Gases



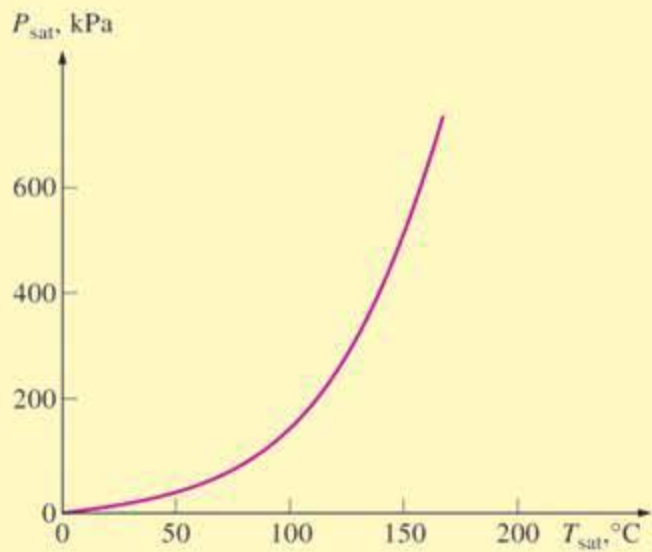
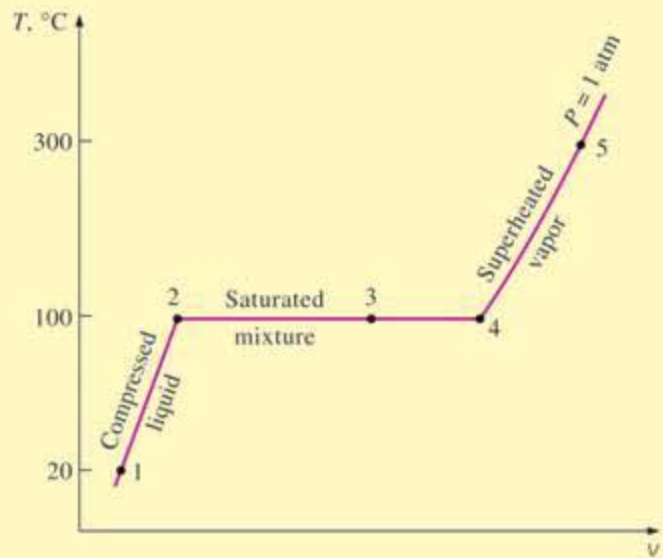
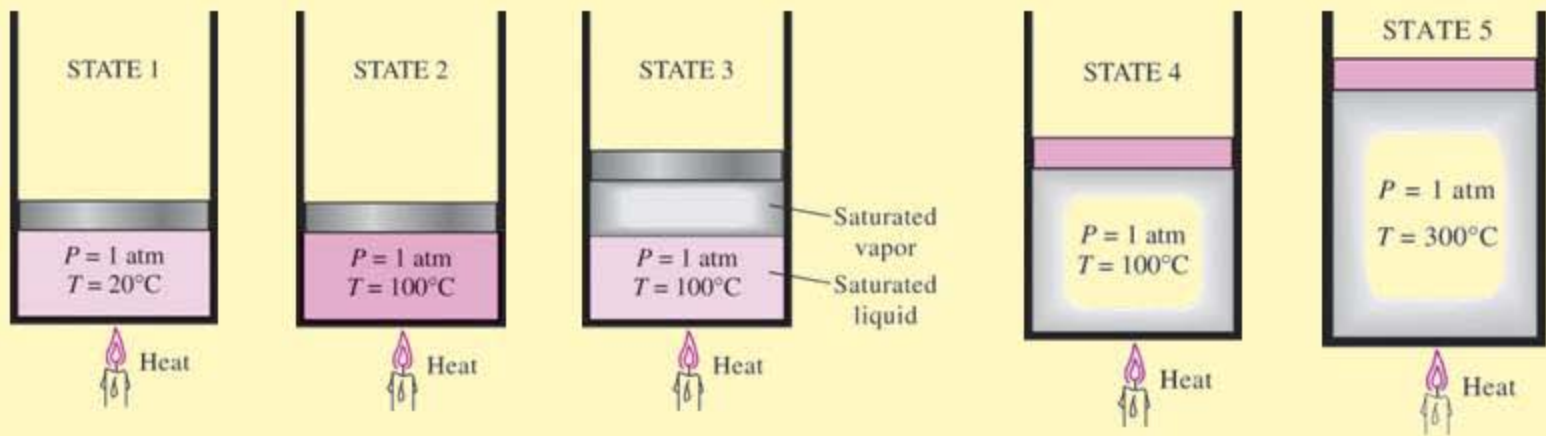
(a)

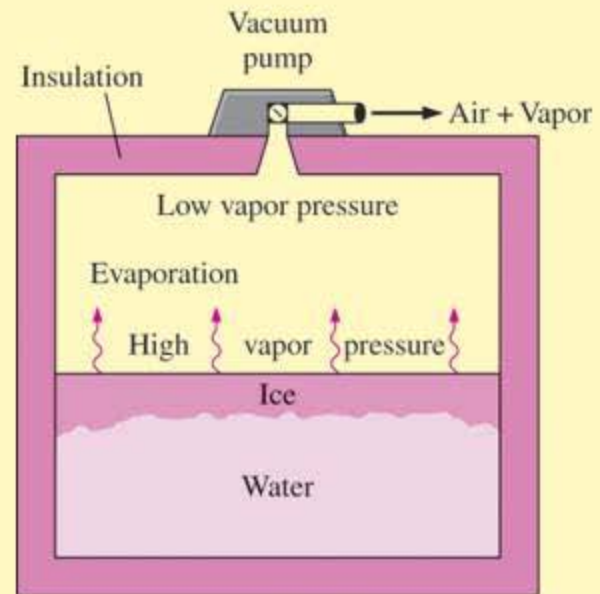
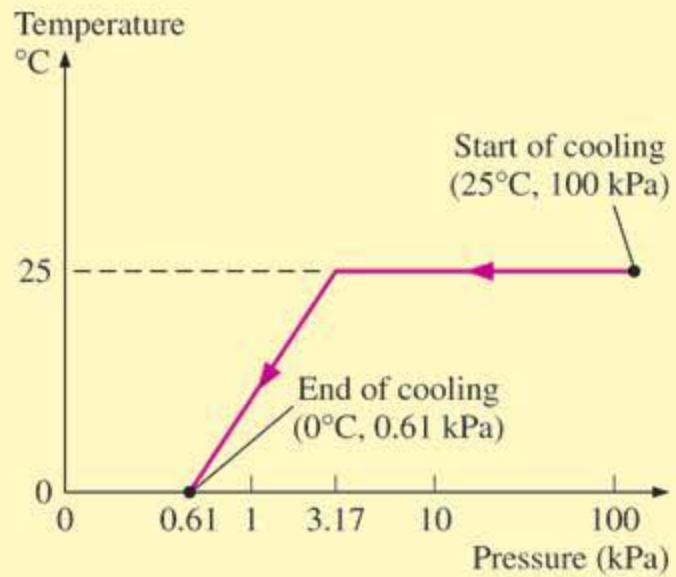


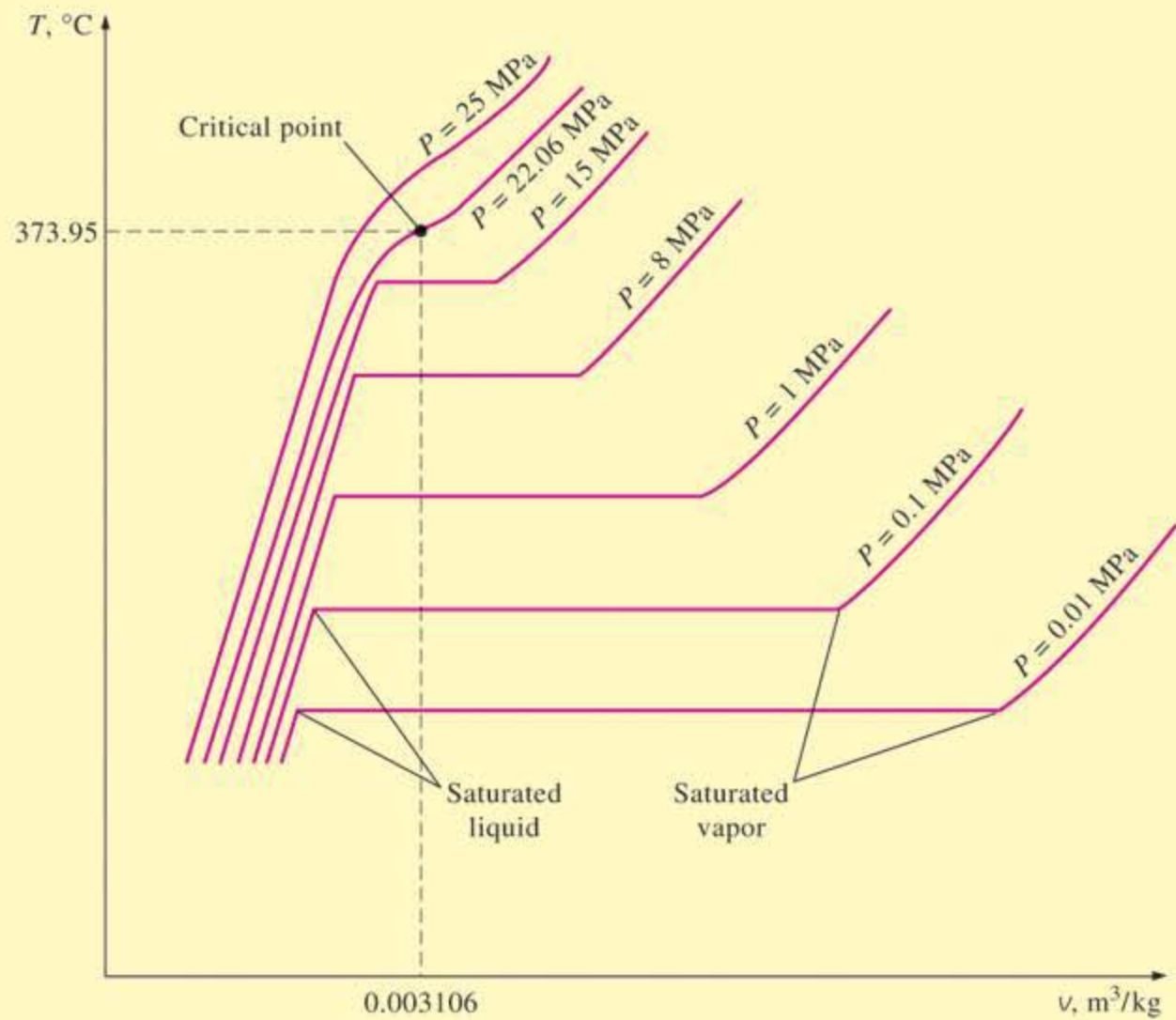
(b)

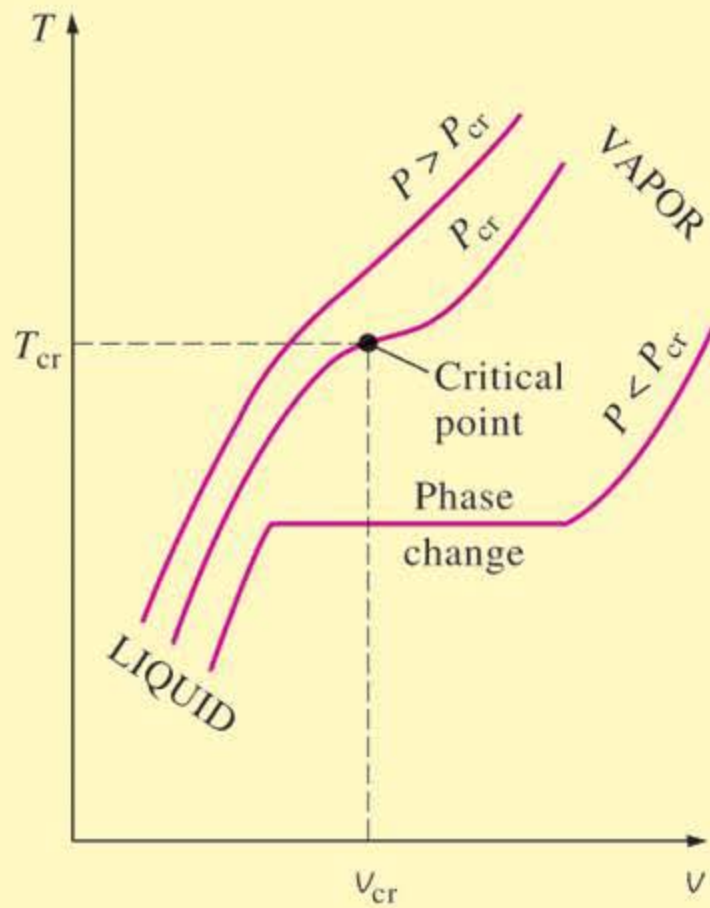


(c)









Saturated water—Temperature table

Temp., °C	Sat. pressure, P_{sat} , kPa	Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
		Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
10	0.0117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
20	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
30	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
40	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
50	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
60	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
70	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
80	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
90	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556
95	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
100	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
110	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898
120	19.947	0.001017	7.6670	251.16	2204.7	2455.9	251.18	2357.7	2608.8	0.8313	7.0769	7.9082
130	25.043	0.001020	6.1935	272.09	2190.3	2462.4	272.12	2345.4	2617.5	0.8937	6.9360	7.8296
140	31.202	0.001023	5.0396	293.04	2175.8	2468.9	293.07	2333.0	2626.1	0.9551	6.7989	7.7540
150	38.597	0.001026	4.1291	313.99	2161.3	2475.3	314.03	2320.6	2634.6	1.0158	6.6655	7.6812
160	47.416	0.001029	3.4053	334.97	2146.6	2481.6	335.02	2308.0	2643.0	1.0756	6.5355	7.6111
170	57.868	0.001032	2.8261	355.96	2131.9	2487.8	356.02	2295.3	2651.4	1.1346	6.4089	7.5435
180	70.183	0.001036	2.3593	376.97	2117.0	2494.0	377.04	2282.5	2659.6	1.1929	6.2853	7.4782
190	84.609	0.001040	1.9808	398.00	2102.0	2500.1	398.09	2269.6	2667.6	1.2504	6.1647	7.4151
200	101.42	0.001043	1.6720	419.06	2087.0	2506.0	419.17	2256.4	2675.6	1.3072	6.0470	7.3542

290	7441.8	0.001366	0.025554	1279.7	1296.9	2576.5	1289.8	1476.9	2766.7	3.1608	2.6225	5.7834
295	7999.0	0.001384	0.023528	1306.0	1264.5	2570.5	1317.1	1441.6	2758.7	3.2076	2.5374	5.7450
300	8587.9	0.001404	0.021659	1332.7	1230.9	2563.6	1344.8	1404.8	2749.6	3.2548	2.4511	5.7059
305	9209.4	0.001425	0.019932	1360.0	1195.9	2555.8	1373.1	1366.3	2739.4	3.3024	2.3633	5.6657
310	9865.0	0.001447	0.018333	1387.7	1159.3	2547.1	1402.0	1325.9	2727.9	3.3506	2.2737	5.6243
315	10,556	0.001472	0.016849	1416.1	1121.1	2537.2	1431.6	1283.4	2715.0	3.3994	2.1821	5.5816
320	11,284	0.001499	0.015470	1445.1	1080.9	2526.0	1462.0	1238.5	2700.6	3.4491	2.0881	5.5372
325	12,051	0.001528	0.014183	1475.0	1038.5	2513.4	1493.4	1191.0	2684.3	3.4998	1.9911	5.4908
330	12,858	0.001560	0.012979	1505.7	993.5	2499.2	1525.8	1140.3	2666.0	3.5516	1.8906	5.4422
335	13,707	0.001597	0.011848	1537.5	945.5	2483.0	1559.4	1086.0	2645.4	3.6050	1.7857	5.3907
340	14,601	0.001638	0.010783	1570.7	893.8	2464.5	1594.6	1027.4	2622.0	3.6602	1.6756	5.3358
345	15,541	0.001685	0.009772	1605.5	837.7	2443.2	1631.7	963.4	2595.1	3.7179	1.5585	5.2765
350	16,529	0.001741	0.008806	1642.4	775.9	2418.3	1671.2	892.7	2563.9	3.7788	1.4326	5.2114
355	17,570	0.001808	0.007872	1682.2	706.4	2388.6	1714.0	812.9	2526.9	3.8442	1.2942	5.1384
360	18,666	0.001895	0.006950	1726.2	625.7	2351.9	1761.5	720.1	2481.6	3.9165	1.1373	5.0537
365	19,822	0.002015	0.006009	1777.2	526.4	2303.6	1817.2	605.5	2422.7	4.0004	0.9489	4.9493
370	21,044	0.002217	0.004953	1844.5	385.6	2230.1	1891.2	443.1	2334.3	4.1119	0.6890	4.8009
373.95	22,064	0.003106	0.003106	2015.7	0	2015.7	2084.3	0	2084.3	4.4070	0	4.4070

Source: Tables A-4 through A-8 are generated using the Engineering Equation Solver (EES) software developed by S. A. Klein and F. L. Alvarado. The routine used in calculations is the highly accurate Steam_IAPWS, which incorporates the 1995 Formulation for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use, issued by The International Association for the Properties of Water and Steam (IAPWS). This formulation replaces the 1984 formulation of Haar, Gallagher, and Kell (NBS/NRC Steam Tables, Hemisphere Publishing Co., 1984), which is also available in EES as the routine STEAM. The new formulation is based on the correlations of Saul and Wagner (J. Phys. Chem. Ref. Data, 16, 893, 1987) with modifications to adjust to the International Temperature Scale of 1990. The modifications are described by Wagner and Pruss (J. Phys. Chem. Ref. Data, 22, 783, 1993). The properties of ice are based on Hyland and Wexler, "Formulations for the Thermodynamic Properties of the Saturated Phases of H₂O from 173.15 K to 473.15 K," *ASHRAE Trans.*, Part 2A, Paper 2793, 1983.

