Formulas and data (on the other side).

You may rip off this page from the test and you do not need to hand it in.

Vapour equation: P = Po exp(L/RTo - L/RT) where Po and To are reference values.

Efficiencies and Costs of Operation:

$$e = \frac{W}{Q_{in}}, \text{ where } W = Q_{in} - Q_{out},\ Q_{in} = Q_h,\ Q_{out} = Q_c$$

$$e_{max} = e_{Carnot} = 1 - \frac{T_C}{T_H}$$

$$\text{COP} = \frac{Q_{in}}{W}, \text{ where } W + Q_{in} = Q_{out},\ Q_{in} = Q_c,\ Q_{out} = Q_h$$

$$\text{COP}_{max} = \frac{T_c}{T_h - T_c}$$

Enthalpy $H = U + PV$

Helmholtz free energy $F = U - ST$

Gibbs free energy $G = U + PV - ST = H - ST$

$$\begin{aligned} dU &= T\ dS - P\ dV + \mu dN, &&\text{U=U(S,V,N)} \\ dH &= T\ dS + V\ dP + \mu dN, &&\text{H=H(S,P,N)} \\ dF &= -S\ dT - P\ dV + \mu dN, &&\text{F=F(T,V,N)} \\ dG &= -S\ dT + V\ dP + \mu dN, &&\text{G=G(T,P,N)} \end{aligned}$$

$$G = N\mu$$

Clausius-Clapeyron:

$$\frac{\partial P}{\partial T} = \frac{\Delta S}{\Delta V} = \frac{L}{T\Delta V}$$

T (°C)	P (bar)	H_{water} (kJ)	H_{steam} (kJ)	S_{water} (kJ/K)	S_{steam} (kJ/K)
0	0.006	0	2501	0	9.156
10	0.012	42	2520	0.151	8.901
20	0.023	84	2538	0.297	8.667
30	0.042	126	2556	0.437	8.453
50	0.123	209	2592	0.704	8.076
100	1.013	419	2676	1.307	7.355

Table 4.1. Properties of saturated water/steam. Pressures are given in bars, where 1 bar = 10^5 Pa ≈ 1 atm. All values are for 1 kg of fluid, and are measured relative to liquid water at the triple point (0.01°C and 0.006 bar). Excerpted from Keenan et al. (1978).

		Temperature (°C)				
P (bar)		200	300	400	500	600
1.0	H (kJ)	2875	3074	3278	3488	3705
	S (kJ/K)	7.834	8.216	8.544	8.834	9.098
3.0	H (kJ)	2866	3069	3275	3486	3703
	S (kJ/K)	7.312	7.702	8.033	8.325	8.589
10	H (kJ)	2828	3051	3264	3479	3698
	S (kJ/K)	6.694	7.123	7.465	7.762	8.029
30	H (kJ)		2994	3231	3457	3682
	S (kJ/K)		6.539	6.921	7.234	7.509
100	H (kJ)			3097	3374	3625
	S (kJ/K)			6.212	6.597	6.903
300	H (kJ)			2151	3081	3444
	S (kJ/K)			4.473	5.791	6.233

Table 4.2. Properties of superheated steam. All values are for 1 kg of fluid, and are measured relative to liquid water at the triple point. Excerpted from Keenan et al. (1978).

Physical Constants

$$k = 1.381 \times 10^{-23}\ \mathrm{J/K}$$
$$= 8.617 \times 10^{-5}\ \mathrm{eV/K}$$
$$N_A = 6.022 \times 10^{23}$$
$$R = 8.315\ \mathrm{J/mol{\cdot}K}$$
$$h = 6.626 \times 10^{-34}\ \mathrm{J{\cdot}s}$$
$$= 4.136 \times 10^{-15}\ \mathrm{eV{\cdot}s}$$
$$c = 2.998 \times 10^{8}\ \mathrm{m/s}$$
$$G = 6.673 \times 10^{-11}\ \mathrm{N{\cdot}m^2/kg^2}$$
$$e = 1.602 \times 10^{-19}\ \mathrm{C}$$
$$m_e = 9.109 \times 10^{-31}\ \mathrm{kg}$$
$$m_p = 1.673 \times 10^{-27}\ \mathrm{kg}$$

Unit Conversions

$$1\ \mathrm{atm} = 1.013\ \mathrm{bar} = 1.013 \times 10^5\ \mathrm{N/m^2}$$
$$= 14.7\ \mathrm{lb/in^2} = 760\ \mathrm{mm\,Hg}$$
$$(T \text{ in } {}^\circ\mathrm{C}) = (T \text{ in K}) - 273.15$$
$$(T \text{ in } {}^\circ\mathrm{F}) = \tfrac{9}{5}(T \text{ in } {}^\circ\mathrm{C}) + 32$$
$$1\ {}^\circ\mathrm{R} = \tfrac{5}{9}\ \mathrm{K}$$
$$1\ \mathrm{cal} = 4.186\ \mathrm{J}$$
$$1\ \mathrm{Btu} = 1054\ \mathrm{J}$$
$$1\ \mathrm{eV} = 1.602 \times 10^{-19}\ \mathrm{J}$$
$$1\ \mathrm{u} = 1.661 \times 10^{-27}\ \mathrm{kg}$$