THERMODYNAMICS ANSWER SHEET

Team Name: KEY Team #: ______________

Members: 1. ______________________________

2. ______________________________

1. B 2. D 3. E 4. B (2 points each)

5. D 6. B 7. E 8. A

9. (a) The energy needed to melt 2 kg of ice at 0°C is $Q_1 = L_f m$, where L_f = latent heat of fusion.

$Q_1 = 334 \text{ kJ/kg} \cdot 2 \text{ kg} = \underline{668 \text{ kJ}}$

The energy needed to bring the water to 0°C is $Q_2 = C_p m \Delta T$ where C_p is specific heat @constant pressure.

$Q_2 = 4.186 \text{ kJ/kgK} \cdot 4 \text{ kg} \cdot 25 \text{ K} = \underline{419 \text{ kJ}}$

Since $Q_1 > Q_2$, the ice will not be totally melted and the mixture will remain at $\boxed{0°C}$. (1 pt. for each formula, 1 pt for each energy value, 1 pt for final answer → 5 pts total)

(b)

Yes (see part A)

(1 point)

(c) $\Delta S = m c_v \ln\left(\frac{T_f}{T_i}\right) = 2 \text{ kg} \cdot 4.168 \frac{\text{kJ}}{\text{kg}} \cdot \ln\left(\frac{273.15 \text{ K}}{298.15 \text{ K}}\right)$

$\boxed{\Delta S = -0.73 \text{ kJ/K}}$ (−730 J/K)

(1 pt for formula, 1 pt for using absolute temperatures [e.g. K instead of °C], 1 pt for correct answer → 3 points total)

10. (a) Since we may assume that hydrogen behaves as an ideal gas, use the ideal gas law.

$P_{init} V_{init} = m_{init} R T_{init}$

$100 \text{ kPa} \cdot 3 \text{ m}^3 = m_{init} \cdot 4.124 \frac{\text{kJ}}{\text{kgK}} \cdot 300 \text{ K}$

$\boxed{m_{init} = 0.24 \text{ kg}}$

(1 point for formula, 1 point for answer → 2 points total)

(b) Write an energy balance:

$E_{tank,init} + E_{in} = E_{tank,final} + E_{loss}$

$m_{init} C_v T_{init} + m_{in} C_v T_{in} = m_{final} C_v T_{final} + E_{loss}$

Writing a mass balance, $m_{final} = m_{init} + m_{in} = 1.24 \text{ kg}$

So $0.24 \text{ kg} \cdot 10.3 \frac{\text{kJ}}{\text{kgK}} \cdot 300 \text{ K} + 1.0 \text{ kg} \cdot 10.3 \frac{\text{kJ}}{\text{kgK}} \cdot 400 \text{ K} = 1.24 \text{ kg} \cdot 10.3 \frac{\text{kJ}}{\text{kgK}} \cdot T_{final} + 300 \text{ kJ}$

$\boxed{T_{final} = 357 \text{ K}}$ (1 pt for energy conservation, 1 pt for accounting for heat loss, 1 pt for answer → 3 pts total)

(c) Apply the ideal gas law again.

$P_{final} V_{final} = m_{final} R T_{final}$

$P_{final} \cdot 3\,m^3 = 1.24\,kg \cdot 4.124\,\frac{kJ}{kgK} \cdot 357\,K$

$\boxed{P_{final} = 609\,kPa}$

(1 point for formula, 1 point for answer)

(d) $U_{init} = m_{init} C_v T_{init} = 0.24\,kg \cdot 10.3\,\frac{kJ}{kgK} \cdot 300\,K = 741.6\,kJ$

$U_{final} = m_{final} C_v T_{final} = 1.24\,kg \cdot 10.3\,\frac{kJ}{kgK} \cdot 357\,K = 4559.6\,kJ$

$\Delta U_{final} = U_{final} - U_{init} = \boxed{3818\,kJ}$

(1 point for formula, 1 pt for taking difference, 1 pt for answer → 3 pts total)

11. For conduction, $q = kA\frac{\Delta T}{t}$

$$5\,W = 200\,\frac{W}{mK} \cdot (0.005\,m)^2 \cdot \frac{\Delta T}{0.001\,m}$$

$\boxed{\Delta T = 1K = 1°C}$

(1 pt for formula, 1 pt for answer → 2 pt total)

12. In the Carnot cycle, the amount of work produced depends on the difference between the high and low temperatures (so the colder it is outside, the more work would be produced, and the faster it would go)

(2 pts for correct explanation)

13. The Carnot Cycle is reversible, so the efficiency of any <u>real</u> engine must be lower than the Carnot efficiency.

Efficiency of Carnot cycle: $\eta_{th} = \frac{W_{net,out}}{Q_{in}}$

Applying 2nd law of thermodynamics, $W_{net,out} = Q_{in} - Q_{out}$ so $\eta_{th} = 1 - \frac{Q_{out}}{Q_{in}}$ or $1 - \frac{Q_L}{Q_H}$

Since Q is proportional to T ($Q = mcT$), $\eta_{th,carnot} = 1 - \frac{T_L}{T_H}$

So for these temperatures, $\eta_{th,carnot} = 1 - \frac{300K}{1000K} = \underline{70\%}$

So an 80% efficiency is $\boxed{\text{not possible}}$

(1 pt for Carnot efficiency, 1 pt for realizing efficiency cannot exceed Carnot, 1 pt for answer → 3 pt total)

14. Energy radiated spherically from bulb to surface of sphere 2m away:

$$E = \frac{60\ W}{4\pi r^2} = \frac{60\ W}{4\pi (2m)^2} \approx 1.1937\ \frac{W}{m^2}$$

$$1.1937\ W/m^2 \cdot 0.0603\ m^2 = \boxed{0.072\ W = 72\ mW}$$

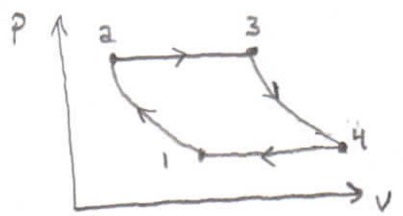
(2 pts for correct setup, 1 pt for correct answer → 3 pts total)

15.

	Pressure [kPa]	Temperature [K]	Enthalpy [kJ/kg]
State 1	100	300	302
State 2	1000	579	582
State 3	1000	1975	1985
State 4	100	1023	1028

+0.2 pt per answer

Drawing a P-V diagram:



From 1→2 we have isentropic compression. Isentropic processes obey the relationship

$$\frac{P_1}{P_2} = \left[\frac{V_2}{V_1}\right]^{k} = \left[\frac{T_1}{T_2}\right]^{\frac{k}{k-1}}$$

So here, $$\frac{100\ kPa}{1000\ kPa} = \left[\frac{300\ K}{T_2}\right]^{1.4/0.4} \rightarrow \boxed{T_2 = 579\ K}$$

(+2 for process)

Since air is assumed to be an ideal gas, $pv = RT$.

Enthalpy $h = u + pv$. Here internal energy $u = C_v T$ so we have $h = C_v T + RT$.

(+2 for process) Or $h = c_p T$ if we just use C_p directly!

For state 1, $h_1 = 0.718\ \frac{kJ}{kgK} \cdot 300\ K + 0.287\ \frac{kJ}{kgK} \cdot 300\ K = 301.5\ \frac{kJ}{kg}$

or $h_1 = 1.005\ \frac{kJ}{kgK} \cdot 300\ K = 301.5\ \frac{kJ}{kg}$

For state 2, $h_2 = C_p T = 1.005\ \frac{kJ}{kgK} \cdot 579\ K = 581.9\ \frac{kJ}{kg}$

From 3→4 we have isentropic expansion. We know $P_3 = 1000\ kPa$, $P_4 = 100\ kPa$, $T_4 = 750°C$.

+1 for converting to K

$$\frac{P_3}{P_4} = \left[\frac{T_3}{T_4}\right]^{\frac{k}{k-1}} \rightarrow \frac{1000\ kPa}{100\ kPa} = \left[\frac{T_3}{1023\ K}\right]^{\frac{1.4}{0.4}} \rightarrow \boxed{T_3 = 1975\ K}$$

OVER →

Now $h_3 = C_p T_3 = 1.005 \frac{kJ}{kgK} \cdot 1975\,K = \boxed{1985 \frac{kJ}{kg}}$

$h_4 = C_p T_4 = 1.005 \frac{kJ}{kgK} \cdot 1023\,K = \boxed{1028 \frac{kJ}{kg}}$