UNIVESITY OF SWAZILAND
FACULTY OF SCIENCE AND ENGINEERING
DEPARTMENT OF PHYSICS

Main Examination 2017/2018
COURSE NAME: Thermodynamics/Thermofluids
COURSE CODE: PHY242/EEE202
TIME ALLOWED: 3 hours

ANSWER ANY FIVE (5) QUESTIONS. ALL QUESTIONS CARRY EQUAL MARKS

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The exam paper has seven(7) printed pages, including an appendix.

Question 1

(a). An engine, with an ideal gas as the working substance, operates in the reversible cycle, $1 \to 2 \to 3 \to 1$, shown in figure 1. Assume that P_1, V_1 and P_3 as well as heat capacity C_v and C_p are known.

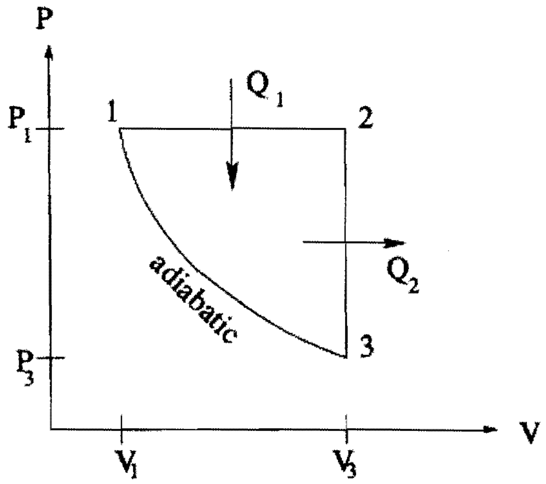

Figure 1:

(i) Derive the expressions for the work, heat flow and the internal energy change for each leg of the cycle.

[10 marks]

(ii) Calculate the entropy change for each leg of the cycle. What is the net change of the entropy? Why?

[4 marks]

(iii) Define the efficiency of an engine.

[2 marks]

(iv) Show that in our case the efficiency is given by

$$e = 1 - \frac{1}{\gamma}\left(\frac{1 - \dfrac{P_3}{P_1}}{1 - \dfrac{V_1}{V_3}}\right)$$

where $\gamma = \dfrac{C_p}{C_v}$.

[4 marks]

Question 2

(a). Define a **universe** in thermodynamics.

[1 marks]

(b). What is the difference between **heat** and **temperature** in thermodynamics?

[2 marks]

(c). What is the **specific heat capacity** of a substance?

[2 marks]

(d). Define the following terms;

(i) Isochoric (Isometric) process.

[2 marks]

(ii) Adiabatic process.

[2 marks]

(iii) Closed system.

[2 marks]

(e). A 1.0 mol sample of an ideal gas is kept at 0.0 °C during an expansion from 3.0 ℓ to 10.0 ℓ.

(i) How much work is done during the gas expansion?

[2 marks]

(ii) How much energy transfer by heat occurs with the surroundings in this process?

[3 marks]

(iii) If the gas is returned to the original volume by means of an isobaric process, how much work is done by the gas?

[2 marks]

(f). What is the difference between **intensive** and **extensive** properties of a thermodynamic system?

[2 marks]

Question 3

(a). One mole of ideal gas with constant heat capacity C_v is placed inside a cylinder. The cylinder is thermally insulated from the environment and inside the cylinder there is a piston which can move without friction along the vertical axis. Pressure, P_1 is applied to the piston. At some point, P_1 is abruptly changed to P_2 (e.g. by adding or removing a weight from the piston). As a result, the gas volume changes adiabatically.

(i) Show that

$$V_2 = \frac{RT_2}{P_2}$$

[2 marks]

(ii) Show that after equilibrium has been reached, the temperature T_2 can be expressed as

$$T_2 = \frac{C_v P_1 + P_2 V_2}{C_p}$$

[3 marks]

(b). A perfect gas at a pressure of 58 bar and a temperature of 450 K has a density of 50 kg/m^3. The ratio of specific heats γ is 1.48 .

(i) Calculate the values of molar mass $\tilde{m}$, C_p and C_v.

[5 marks]

(ii) Calculate change in specific entropy of the gas if the pressure is raised 100 bar and the temperature is lowered to 400 K.

[5 marks]

(c) Calculate the increase in internal energy of a gas in a closed system during a process in which -100 J of heat transfer and 400 J of work transfer take place.

[5 marks]

Question 4

(a). Show that while the slope of the fusion curve in a P-T diagram for substances that contract on freezing is positive, the slope of the fusion curve of the substances that expand on freezing is negative.

[5 marks]

(b). Determine the rate of heat rejection from a reversible heat engine operating between a hot reservoir at 900 K and a cold reservoir at 400 K if the engine produces a power output of 400 kW.

[5 marks]

(c). The latent heat of fusion of water at $0°$ C and 1 atm is $l_{12} = 3.34 \times 10^5$ J/kg. The volumes per gram in the solid and liquid phase are $v_1 = 1.09$ cm^3/g, $v_2 = 1.00$ cm^3/g respectively. Calculate the slope of the fusion curve (in atm/K) at 0 ° C. [5 marks]

(d). A reversible heat engine is operating between a hot reservoir at 900 K and a cold reservoir at 500 K.

(i) Calculate the efficiency of this engine.

[2 marks]

(ii) The temperature of one of the heat reservoirs can be changed by 100 K up or down. What is the highest efficiency that can be achieved by making this temperature change?

[3 marks]

Question 5

(a). Consider n moles of an ideal gas with constant specific isochoric heat capacity C_v.

(i) Derive an expression for the internal energy of the gas.

[4 marks]

(ii) Show that the isobaric heat capacity $C_p = C_v + R$, where R is the universal gas constant.

[5 marks]

(b) A 10 cm diameter copper ball is to be heated from 100 °C to an average temperature of 150 °C in 30 minutes. Taking the average density and specific heat of copper in this temperature range to be $\rho = 8950\ kg/m^3$ and $C_p = 0.395\ kJ/(kg \cdot K)$, respectively, determine the total amount of heat transfer to the copper ball and the average rate of heat transfer to the ball.

[5 marks]

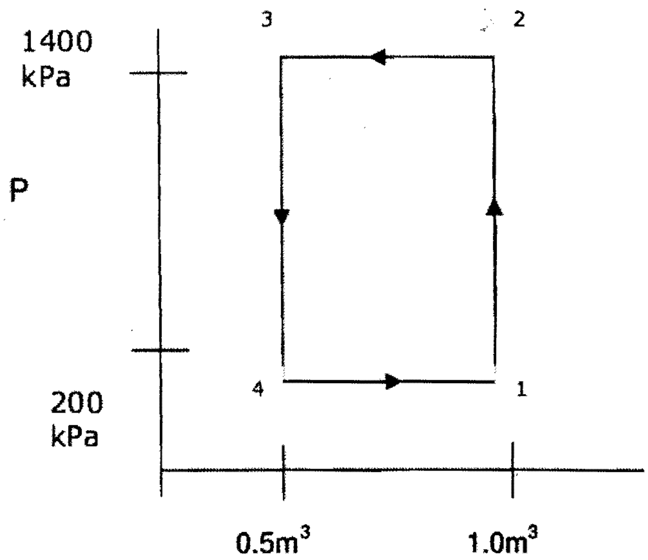

Figure 2:

(c) Calculate the work input to the closed system undergoing the cycle shown in Figure 2 .

[6 marks]

Question 6

(a). A sample of ideal gas is expanded to twice its original volume of 1.0 m^3 in a quasi-static process for which $P = \eta V^4$, with $\eta = 5.0\ atm/m^{12}$, as shown in Figure 3. How much work is done on the expanding gas?

[6 marks]

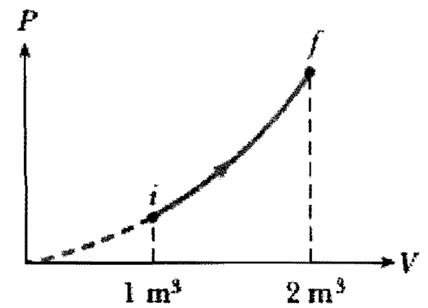

Figure 3:

(b). 100 grams of ice at −15 °C are placed in a container. How much heat in joules must be added to do the following?

(i) Raise the temperature of the ice to 0 °C.

[6 marks]

(ii) Melt the ice.

[2 marks]

(iii) Heat water from 0 °C to 100 °C.

[2 marks]

(iv) Change water to steam.

[2 marks]

(c). An ice cube having a mass of 50 grams and an initial temperature of −10 °C is placed in 400 grams of 40 °C water. What is the final temperature of the mixture if the effects of the container can be neglected?

[6 marks]

Appendix

Some usefull information

- $W = \int_{v_i}^{v_f} PdV$
- $\frac{dP}{dT}|_{1\to 2} = \frac{l_{12}}{T(v_2 - v_1)}$
- $dU(S, V) = TdS - PdV$
- $F = U - TS$
- $G = U - TS + PV$
- $H = U + PV$
- $PV = nRT$
- $PV^{\gamma} =$ const.
- $R = 8.31 J/\text{mol}^{-1}\text{K}^{-1}$. universal gas constant
- $k_B = 1.38 \times 10^{-23}\text{JK}^{-1}$. Boltzmann constant
- 1 atm $= 1.013 \times 10^5$ Pa
- Specific heat capacity of water= 4186 $\text{Jkg}^{-1}\text{K}^{-1}$
- Linear expansion coefficient for steel, $\alpha = 11 \times 10^{-6}$ $(°\text{C})^{-1}$,
- specific latent heat of vaporization of water = 2260000J/kg
- specific latent heat of fusion of water = 334000J/kg
- specific heat capacity of ice = 2060 $\text{Jkg}^{-1}\text{K}^{-1}$