UNIVERSITY OF NAIROBI

DEPARTMENT OF PHYSICS

SPH 302: THERMODYNAMICS

Tutorial 1 – 1ST Law of Thermodynamics

These Problems are Group based. Each individual to SUBMIT SOLUTIONS TO ANY THREE problems

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1. Two moles of a monatomic ideal gas at a temperature of 300K expand reversibly and isothermally to twice the original volume. Determine
   (i) the work done by the gas,
   (ii) the change in the internal energy.
   (i) the heat supplied and

2. Three moles of an ideal gas have an initial temperature of 127° C. While the temperature is kept constant, the volume is increased until the pressure drops to 40% of its original value.
   (a) Draw a P-V diagram for this process
   (b) Calculate the work done by the gas

3. A gas is contained in a cylinder fitted with a frictionless piston and is taken from state **a** to state **b** along the path **acb** as shown in Fig. 1. 80J of heat flow into the system and the system does 30J of work.

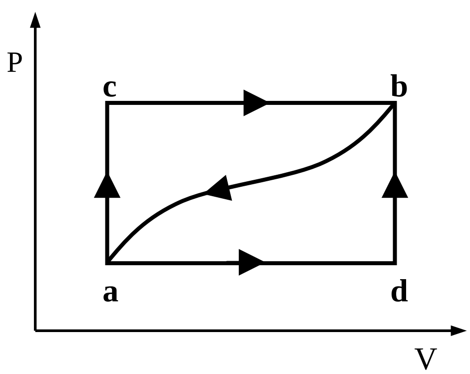


Fig. 1

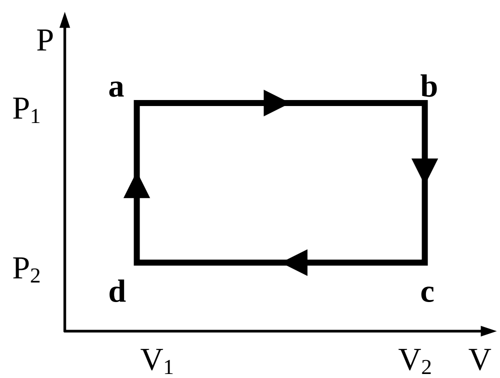


Fig. 2

   (i) How much heat flows into the system along the path **adb** if the work done by the gas system is 10J.
   (ii) When the system is returned from state **b** to **a** along the curved path, the work done on the system is 20J. Find the heat transfer.
   (iii) If $\mathbf{U_a}$ = 0 and $\mathbf{U_d}$ = 40J, find the heat absorbed in the process **ad** and **db**.

4. An ideal gas is taken through the cycle **a** → **b** → **c**→ **d** → **a** as shown in Fig. 2. If P_1 = 3 atm, P_2 = 1 atm, V_1 = 1 litre and V_2 = 2 litres, find the work done in this cycle.

5. A system is taken from state **a** to **b** along the three paths shown in the figure 3 below.
   (a) Along which path is the work done by the system greatest? The least
   (b) If $\mathbf{U_b > U_a}$, along which path is the value of the heat transfer Q the greatest? For which path is the heat absorbed or librated by the system?

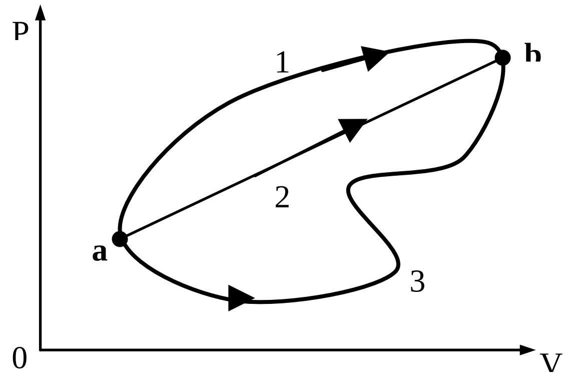
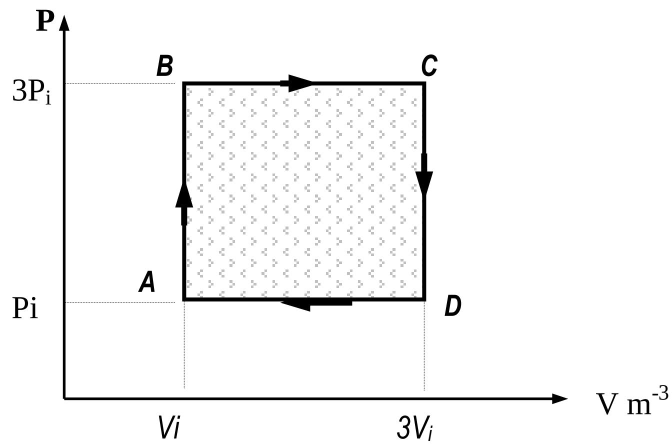
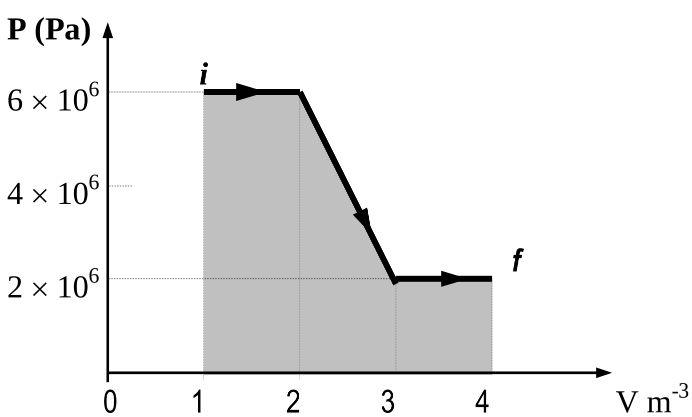


Fig.3

6. An ideal gas is taken through the cycle ABCDA as shown in Fig. 4 below. Determine
   (i) The work done on the gas per cycle
   (ii) The net heat energy added to the system per cycle
   (ii) The work done per cycle for 1.00 mol of the gas at 0 °C.



7. An ideal gas expand from state ***i*** to ***f*** as shown in Fig 5 below
   (i) Determine the work done on the gas
   (ii) the gas is now compressed from state ***f*** back to state ***i*** along the same path. Determine the work done.



8. A sample of an ideal gas is taken through the process ABCDA as shown in Fig 6 below. Process AB is adiabatic while process BC is isobaric with 100 kJ of heat entering the system. From C to D, the process is isothermal while from D to A, the process is isobaric with 150 kJ of energy leaving the system. Determine the difference in the internal energy between points A and B i.e., $\mathbf{U_B - U_A}$.

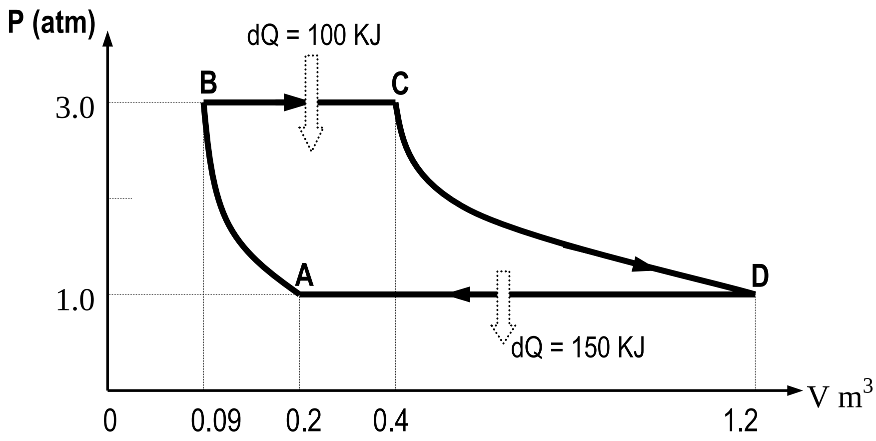


Fig. 6

10. An ideal monatomic gas (γ = 5/3) expands reversibly from a state V_1, P_1 to a volume V_2. Calculate the work done by the gas if the change takes place
   (i) Isothermally (ii) adiabatically (iii) such that PV^{γ} is a constant.

11. Fig. 7 shows an energy cycle with three reversible processes to which 16g of oxygen gas (M_r = 32) are subjected. Calculate
   (a) the heat taken from the gas during the isovolumetric cooling,
   (b) the internal energy gained by the gas during the isobaric heating (process (2)),
   (c) the work done by the gas during process (2),
   (d) the heat supplied during process (2) (two possible methods), and
   (e) the work done on the gas while it is compressed isothermally. ($C_{v,m}$ for oxygen is 21 mol^{-1} K^{-1}).

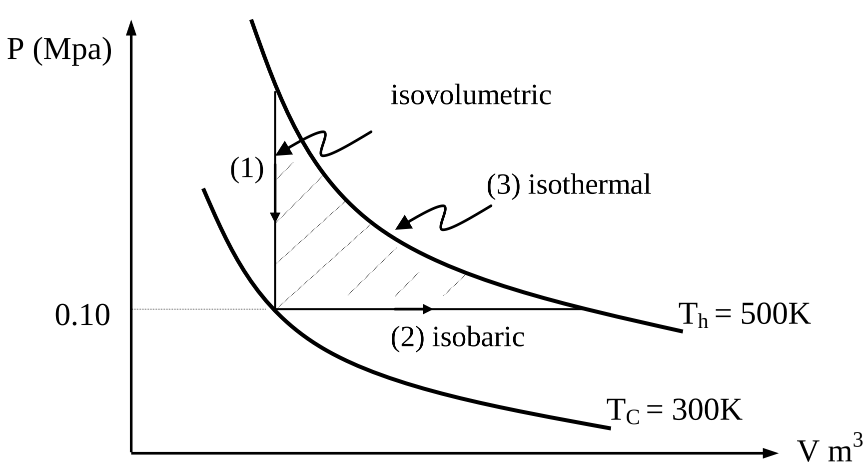


Figure 7

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Tutorial 2 – 2ND Law of Thermodynamics

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1. A reversible Carnot cycle engine operates between temperatures of 1000K and 250K. If 1.5 kJ of heat are transferred to the engine at 1000K in one cycle, find
   (i) the efficiency of the engine
   (ii) the heat transferred from the engine at 250K

2. A Carnot engine takes 2000 J of heat from a reservoir at 500K, does some work, and discards some heat to a reservoir at 350K. Determine
   (i) The work done and the heat discarded by the engine
   (ii) The thermal efficiency

3. A gasoline engine takes in 16,100 J of heat and delivers 3,700 J of work per cycle. The heat is obtained by burning gasoline with a heat of combustion of 4.6×10^4 Jg^{-1}. Determine
   (i) The thermal efficiency
   (ii) The amount of heat discarded and the mass of fuel burned in each cycle
   (iii) The power of the engine (in HP) if the engine goes through 60.0 cycles per second.

4. A Carnot engine operates between a heat source at a high temperature T_h, and a heat sink at a low temperature T_c. Which will have the greater effect on the efficiency, raising the value of T_h by ΔT, or lowering that of T_C by the same value?

5. An inventor claims to have developed an engine which takes in 11×10^7 J at 400K, rejects 5×10^7 J at 200K and delivers 16.67 kW hours of work. Would you advice investing money in this project? Explain

6. An inventor claims to have developed a heat pump that draws heat from a lake at 3.0^{o}C and delivers heat at a rate of 20 kW to a building at 35^{o}C, while using only 1.9 kW of electrical power. How would you judge the claim?.[*Resnick*]

7. A Carnot engine working as a refrigerator between 260 K and 300 K receives 2100 J of heat from the reservoir at the lower temperature. Calculate
   (i) The amount of heat ejected to the high temperature reservoir
   (ii) The work done in each cycle to operate the refrigerator
   (iii) Its efficiency

8. 0.02 moles of an ideal diatomic gas (γ = 1.4) undergoes a Carnot cycle as shown in Figure 1 with temperatures of 227 ^{o}C and 27 ^{o}C. The initial pressure, $P_a = 10.0 \times 10^5$ Pa, and during the isothermal expansion at the high temperature, the volume doubles. Determine
   (i) The pressure and volume at each of the points **a, b, c** and **d**
   (iii) ***Q, W*** and ***dU*** for each process in the cycle and for the entire cycle

(iv) The efficiency of the cycle using the results of part (ii) above and compare it with the efficiency of the Carnot engine.

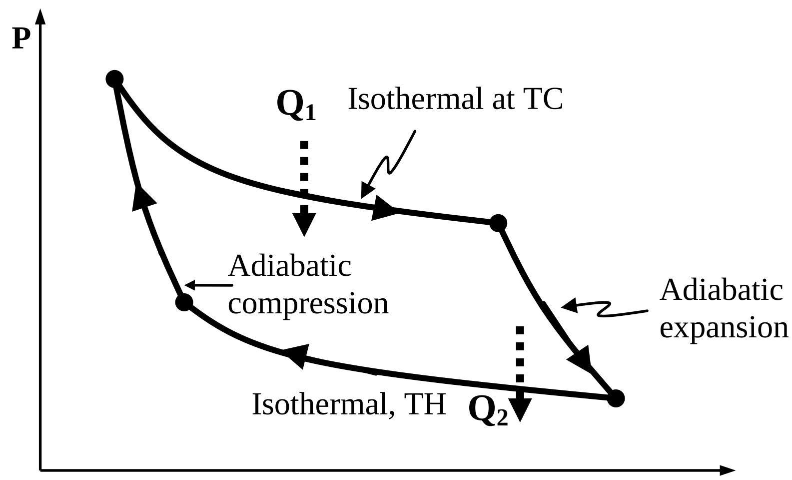

Fig 1

9. Figure 4 below shows an operation cycle for an idealized diesel engine where fuel is sprayed into the cylinder at pt B and the combustion occurs in the isobaric process B $\rightarrow$ C. Show that the efficiency of the engine can be given by

$$e = 1 - \frac{1}{\gamma}\left(\frac{T_D - T_A}{T_C - T_B}\right)$$ where symbols have their usual meaning

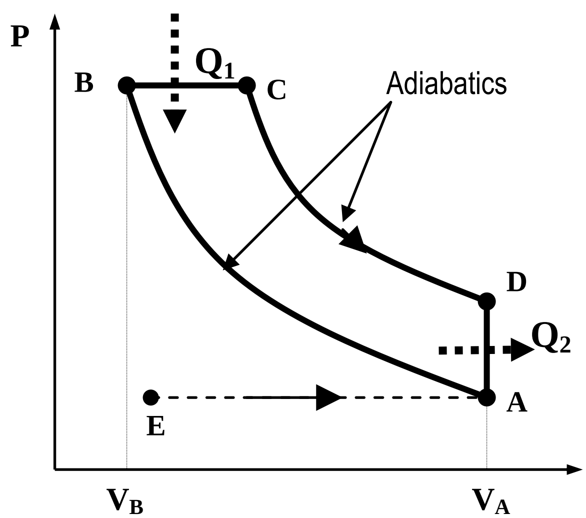

Fig. 4. P-V diagram for an ideal diesel engine

10. In a refrigerator, the cooling chamber is maintained at 290K while the outside temperature is 305K. The motor (located outside) has compression cylinders operating at 320K and the expansion coils inside the chamber operating at 280K. If the motor operates reversibly

(i) Give a schematic diagram illustrating the sequence of events
(ii) Calculate the COP of the refrigerator
(iv) How much work must be done for each transfer of 5000J of heat from the chamber?
(v) Determine the entropy change inside and outside the chamber for this amount of refrigeration?

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Tutorial Set 3 – Entropy & 2^{Nd} Law

These Problems are Group based. Each individual to SUBMIT SOLUTIONS TO ANY TWO problems

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1. 2.0 Kg liquid water at 363 K is mixed adiabatically and at constant pressure with 3.0 Kg liquid water at 283 K. Determine the total entropy change resulting from this process.

2. 1 mole of an ideal gas for which C_V = 25.12 and C_P = 33.44 J mol^{-1} K, expands adiabatically from an initial state at 340 K and 500 KPa to a final state where its volume has doubled. Find the final temperature of the gas, the work done and the entropy change of the gas for
   (ii) a reversible expansion
   (iii) a free expansion of the gas into an evacuated space (Joule's expansion).

3. The specific heat capacity of a solid at low temperature is given by

   $$C = aT + bT^2 \qquad \text{where } a \text{ and } b \text{ are constants}$$

   Determine the Entropy of the solid as a function of temperature if the entropy is zero at T = 0°C.

4. 10 Kg of water at 20 °C is converted to superheated steam at 250 °C at constant atmospheric pressure. Determine the Entropy change of water. [C_P (liquid) = 4180 J/Kg °C; C_P (vapour) = 1670 + 0.4904 T + 1.86 $\times$ 10^6 T^{-2}; Latent heat of vapourization (100°C) = 22.6 $\times$ 10^5 J/Kg].

5. One gram of water when converted to steam at atmospheric pressure occupies a volume of 1671 cm^3. The latent heat of vapourization at this temperature is 539 cal/gm.
   (i) Compare the volume of steam with the volume that would be occupied at this temperature and pressure if the water vapour were an ideal gas
   (ii) Compute the increase in the internal energy **U**, and the Entropy **S** when one gram of water is evaporated at this temperature and pressure.

6. In a refrigerator, the cooling chamber is maintained at 290 K while the outside temperature is 305 K. The motor (located outside) has compression cylinders operating at 320 K and the expansion coils inside the chamber operating at 280 K. If the motor operates reversibly
   (i) Give a schematic diagram illustrating the sequence of events
   (ii) Calculate the efficiency of the refrigerator
   (iii) How much work must be done for each transfer of 500 J of heat from the chamber?
   (iv) What entropy change occurs inside and outside the chamber for this amount of refrigeration?

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Tutorial Set 4 – Thermodynamic Potentials

These Problems are Group based. Each individual to SUBMIT SOLUTIONS TO ANY ONE problem

1. The central equation of thermodynamics is given by $TdS = dU + PdV$. If the Entropy S is a function of T and V i.e., S = S(T,V), using Maxwell's relationships, show that the above equation can be written as

$$TdS = C_P dT - T\left(\frac{dV}{dT}\right)_P dP$$

where symbols have their usual meanings.

2. One gram of water when converted to steam at atmospheric pressure occupies a volume of 1671 cm^3. The latent heat of vapourization at this temperature is 539 cal/gm.
   (iii) Compare the volume of steam with the volume that would be occupied at this temperature and pressure if the water vapour were an ideal gas
   (iv) Compute the increase in the internal energy **U**, the Entropy **S**, the Enthalpy **H**, and Gibbs function **G** when one gram of water is evaporated at this temperature and pressure.
   (v) Using your answer for **G** above, what can you say about the nature of this process

3. The Gibbs function of 1 mole of a certain gas is given by

$$G = RT\ln P + A + BP + C\frac{P^2}{2} + D\frac{P^3}{3}.$$

where A, B, C and D are constants. Find the equation of state of the gas.

4. Show that the difference between the isothermal and the adiabatic compressibility can be given by

$$K_T - K_S = T\left(\frac{V\beta^2}{C_P}\right)$$

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Tutorial 5 – Phase Changes

These Problems are Group based. Each individual to SUBMIT SOLUTIONS TO ANY ONE problem

1. Calculate under what pressure ice freezes at 272K if the change in specific volume when I kg of water freezes is 91×10^{-6} m^3. Given latent heat of ice = 3.36×10^5 JKg^{-1}.

2. Calculate the depression of melting point of ice produced by one atmosphere increase of pressure. Given that latent heat of ice = 80 cal/gm and specific volume of ice and water at 0°C are 1.091 cm^3 and 1.0 cm^3 respectively.

3. Calculate the change in the melting point o ice when it is subjected to a pressure of 100 atmospheres.

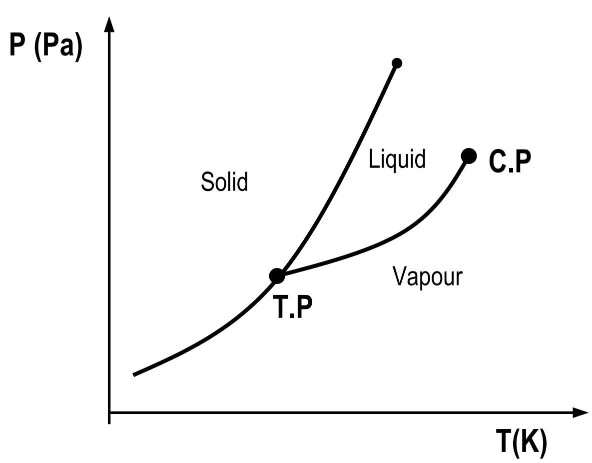
4. Calculate the change in temperature of boiling water when the pressure is increased by 27.12 mm Hg. The normal boiling point of water at atmospheric pressure is 100°C. Explain why the boiling temperature of a liquid increase with pressure?

5. Discuss the effect of increase of pressure on ice and wax under isothermal conditions.

6. Show that for a single component system, the necessary conditions for any of its two phases to be at thermodynamic equilibrium is the equivalence of their specific Gibbs functions. Hence derive the **Clausius – Clapeylon equation** for a First – Order phase change.

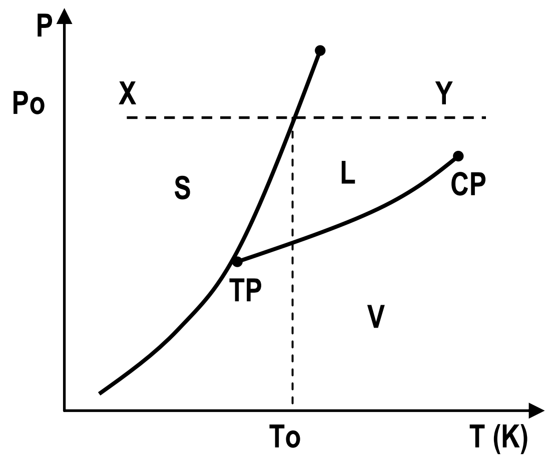
7. Establish and state the Clausius-Clapeyron's equation, $\frac{dP}{dT} = \frac{L}{T(V_2 - V_1)}$ and explain the effect of pressure on
   (a) boiling point of a liquid, and (b) melting point of a solid.

8. The Figure below shows a P-T diagram of a substance which expands on melting.



(a) Make a clearly labeled P-T diagram of a real substance which contracts on melting.
(b) Briefly explain the effect of increasing pressure on the melting point of the substance whose diagram you have.
(c) Suggest an example of such a substance.

9. The phase diagram for water is given in the figure below where TP is the triple point.



(a) Discuss with the aid of G–T diagrams the variation of Gibbs function along the section XY for both FIRST ORDER and for SECOND ORDER phase changes.
(b) Sketch the corresponding Entropy-Temperature behaviour for both FIRST ORDER and SECOND ORDER phase changes and compare the entropy of the solid phase with the entropy of the liquid phase in both the two cases

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