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INSA | INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON

Formation initiale aux métiers d'ingénieurs
Filière : SCAN

1ère année
10 mai 2019

THERMODYNAMICS – Exam 2 - 2h

All documents are forbidden and calculators are allowed.
Answers must be justified. The results will be given with appropriate significant digits.
The three exercises are independent.

Exercise 1: Otto Cycle Thermal Machine (14 pts)

This exercise studies the cycle of the four-stroke engine which was invented by Beau de Rochas in 1862 and implemented in practice by the German engineer Otto in 1875. The operation of the motor is cyclic. The system consists of the air-fuel mixture contained in a cylinder (see figure 1).

It breaks down into 4 successive "strokes" or steps described as follows:

- **1- Intake.** The inlet valve opens; the piston descends and pulls the fuel-air gas mixture from the carburettor.
- **2- Compression.** The intake and exhaust valves are closed; the piston, going up, compresses the mixture.
- **3- Combustion.** The valves are still closed: the compressed air-fuel mixture is ignited by a spark plug. The pressure increases sharply, the piston is pushed down.
- **4- Exhaust.** The piston rises, the exhaust valve opens. The burned gases are expelled. At the end of the fourth lap, the piston and the valves returned to their original position.

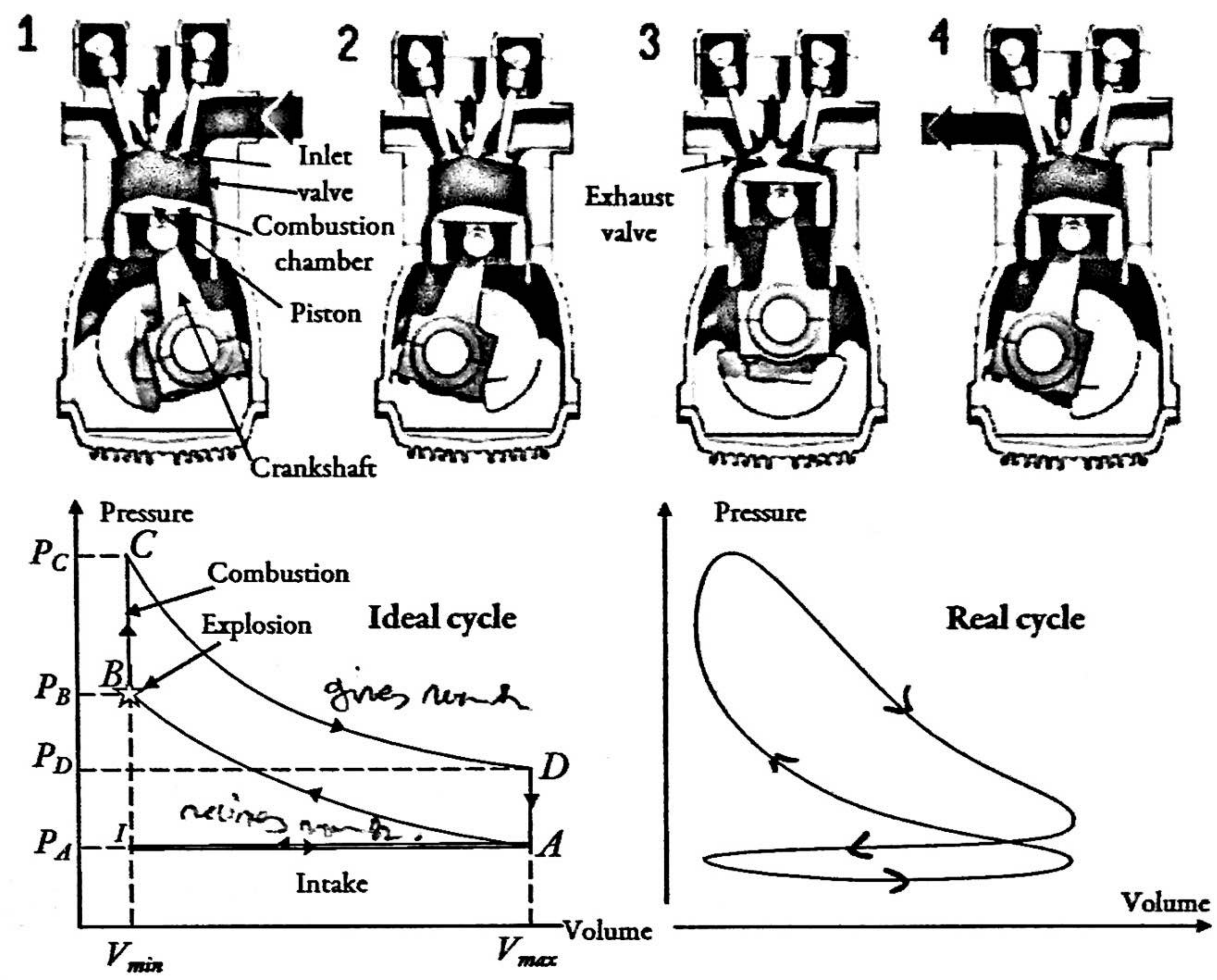

Figure 1: Operation of of 4-stroke engine

The operation of the engine is shown schematically in a (P, V) Clapeyron diagram (see figure 1) where P is the pressure of the gaseous air-fuel mixture (considered an ideal gas) contained in the volume V of the cylinder chamber. The successive processes of the cycle are described as follows:

- **I to A:** inlet of gas-air mixture into the combustion chamber;
- **A to B: reversible adiabatic compression;**
- **B to C: abrupt isochoric combustion;**
- **C to D: reversible adiabatic expansion;**
- **D to A: abrupt isochoric cooling;**
- **A to I:** the rise of the piston evacuates the burned gas to the outside.

The following values are given: $V_A = 800$ mL, $V_B = 90.0$ mL, $P_A = 1.00$ bar, $T_A = 340$ K, $T_C = 2430$ K.
During the **ABCDA cycle, the total number of moles is considered constant** (the amount of air being much greater than that of fuel or products of combustion).

Study of the cycle

1) Indicate on the diagram (on the "sheet to attach to your copy") the location of the studied system.
2) Justify the adiabatic nature of the compression from A to B and the expansion from C to D.
3) Determine the number of moles of total gas n, as well as P, V and T for each of the states A, B, C and D. Summarize the values in a table.
4) Express literally as a function of R, n, γ, T_A, T_B, T_C and T_D (as necessary) the works and heats exchanged during the four processes constituting the ABCDA cycle. Calculate all values and present them in a table. Conclude on the nature of the cycle.
5) Calculate the entropy variations of the system during the four processes constituting the ABCDA cycle. Comment.

Performance study

6) Express the Coefficient of Performance (CoP) of the cycle as a function of the work and the heat quantities involved. The work involved in the calculation of the CoP is the total work W_T coming out of the machine. Show that CoP is expressed according to: $1 + (T_A - T_D)/(T_C - T_B)$. Give its numerical value.
7) Calculate, in horsepower (a horsepower (hp) is equivalent to 736 W), the power of this engine at 4500 rpm (revolution per minute). One cycle equals two crankshaft revolutions (see Figure 1).
8) Compare the ideal and real cycles in terms of performance.

Influence of combustion (BC stage of the ABCDA cycle)

The reaction that takes place within the chamber is a combustion reaction between the fuel (in the problem, the octane C_8H_{18} will be chosen) and the dioxygen of air. These are injected **in stoichiometric proportions.**

9) Write the balanced equation of combustion with formation of gaseous water.
10) Knowing that the composition of air (in molar percentages) is 20% O_2 and 80% N_2, show that, at the moment of injection, the molar fraction of octane (x_{octane}) is equal to 0.0157. Deduce the mass of octane injected for the combustion.
11) The amount of heat released by the combustion of octane in the confinement conditions of the chamber is 447×10^2 kJ.kg^{-1}. Compare the corresponding value of Q'_{BC} with that obtained in question 5. How can you explain this difference?

Exercice 2 : adiabatic system (2 pts)

100 moles of ideal gas initially in the initial state of 30°C under 1.5 bar are submitted to an abrupt expansion against the surrounding constant pressure $P_{ext} = 1$ bar.

Applying the first law to an ideal gas show that final temperature is $T = 274$ K.

Exercise 3: refrigerating machine (4 pts)

One kilogram of pure ammonia (NH_3) used as a refrigerant reversibly flows through the ABCDEFA cycle described in the following operating diagram of a refrigerating machine:

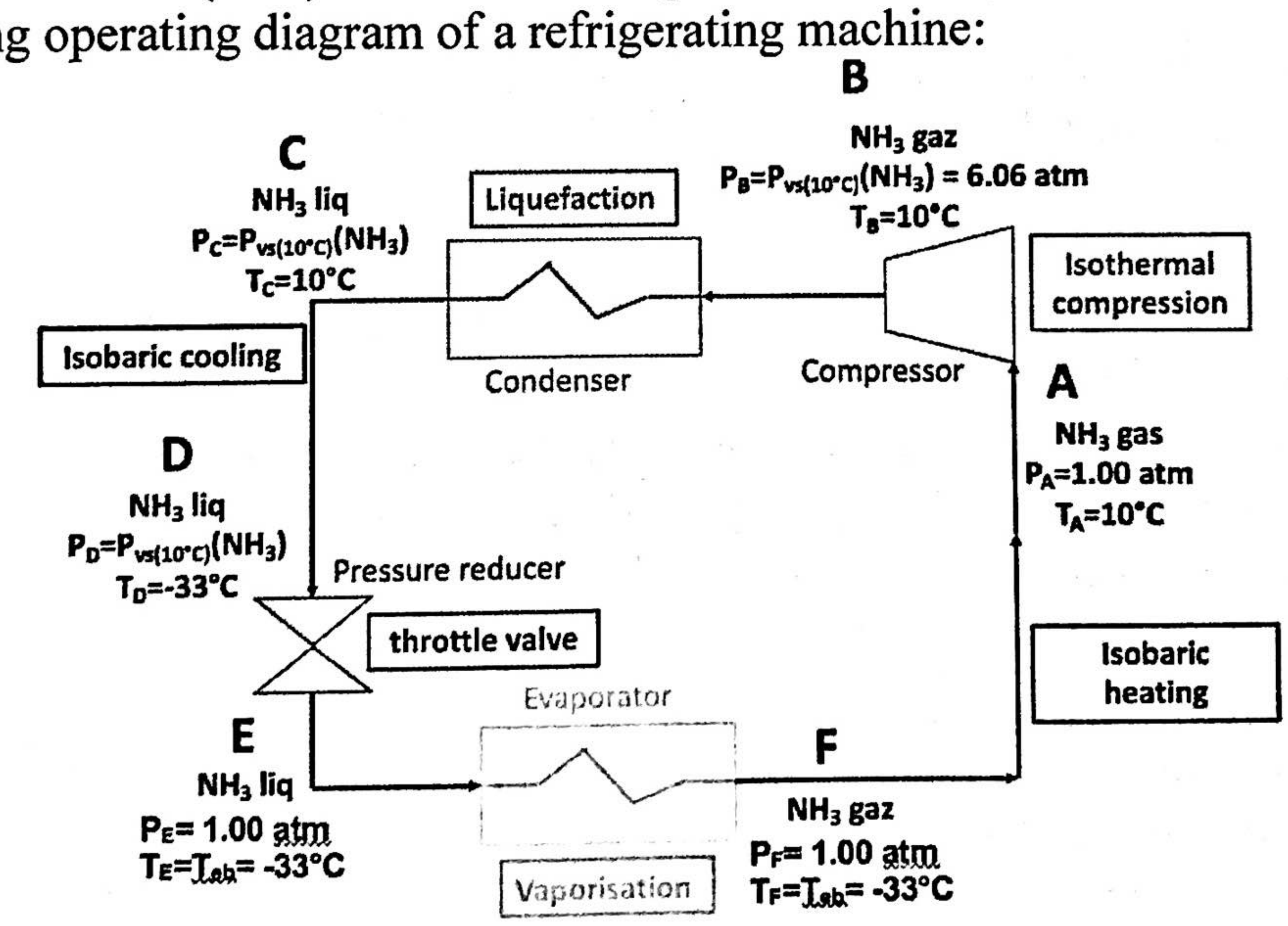

Figure 2: Operation of a refrigerating machine traversed by the ammonia refrigerant

In the (P, T) and (P, V) diagrams provided on the "sheet to attach to your copy", represent the cycle ABCDEFA of diagram 2 traversed by the refrigerant NH_3, specifying the physical states of NH_3. In the gaseous state, NH_3 will be considered an ideal gas.

Data

All gases will be assimilated to ideal diatomic gases, with: $\overline{C_p} = 29.1$ J/mol/K, $\overline{C_v} = 20.8$ J/mol/K and $R =$ 8.31 J/mol/K.

Element or compound	H	C	N	O	air
Molar Mass (g.mol^{-1})	1	12	14	16	29

Saturated vapor pressures of NH_3: $P_{vs\,(10°C)} = 6.06$ atm ; $P_{vs\,(-33°C)} = 1.00$ atm

Specific volume of liquid NH_3: 1.61 L· kg^{-1} (considered as constant).

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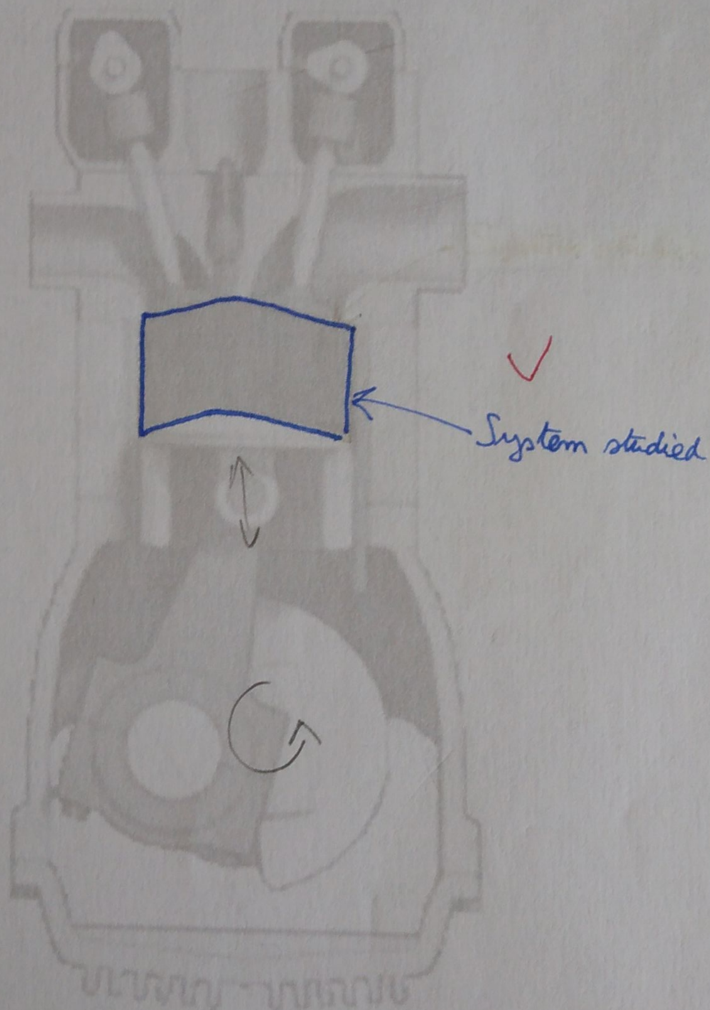
NAME : CAREL

FIRST NAME : Tind-haé

GROUP : 63

Exercise 1: Otto Cycle Thermal Machine



1) Indicate on this diagram of operation of a four-stoke engine where the studied system is located.

NAME:

FIRST NAME:

GROUP:

Sheet to attach with your copy

Exercise 3: refrigerating machine ABCDEFA cycle in diagrams (P, T) and (P, V)