

Thermodynamics

Test June 13th 2022

<input type="text"/>	0	<input type="text"/>	0	<input type="text"/>	0	<input type="text"/>	0	<input type="text"/>	0	<input type="text"/>	0	<input type="text"/>	0
<input type="text"/>	1	<input type="text"/>	1	<input type="text"/>	1	<input type="text"/>	1	<input type="text"/>	1	<input type="text"/>	1	<input type="text"/>	1
<input type="text"/>	2	<input type="text"/>	2	<input type="text"/>	2	<input type="text"/>	2	<input type="text"/>	2	<input type="text"/>	2	<input type="text"/>	2
<input type="text"/>	3	<input type="text"/>	3	<input type="text"/>	3	<input type="text"/>	3	<input type="text"/>	3	<input type="text"/>	3	<input type="text"/>	3
<input type="text"/>	4	<input type="text"/>	4	<input type="text"/>	4	<input type="text"/>	4	<input type="text"/>	4	<input type="text"/>	4	<input type="text"/>	4
<input type="text"/>	5	<input type="text"/>	5	<input type="text"/>	5	<input type="text"/>	5	<input type="text"/>	5	<input type="text"/>	5	<input type="text"/>	5
<input type="text"/>	6	<input type="text"/>	6	<input type="text"/>	6	<input type="text"/>	6	<input type="text"/>	6	<input type="text"/>	6	<input type="text"/>	6
<input type="text"/>	7	<input type="text"/>	7	<input type="text"/>	7	<input type="text"/>	7	<input type="text"/>	7	<input type="text"/>	7	<input type="text"/>	7
<input type="text"/>	8	<input type="text"/>	8	<input type="text"/>	8	<input type="text"/>	8	<input type="text"/>	8	<input type="text"/>	8	<input type="text"/>	8
<input type="text"/>	9	<input type="text"/>	9	<input type="text"/>	9	<input type="text"/>	9	<input type="text"/>	9	<input type="text"/>	9	<input type="text"/>	9

← Please enter your student number, and write your name above.

NAME, First Name :

.....

Duration : 3 h - All documents and all calculators authorised - No computer or tablet, no wifi no 4/5G

Ammonia : thermodynamic data

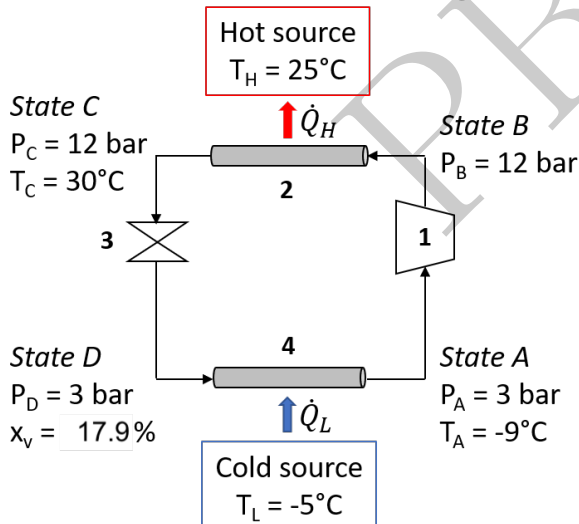
$$\bar{C}_v(\text{NH}_3) = 28.00 \text{ J/(molK)}$$

$$\bar{C}_p(\text{NH}_3) = 36.31 \text{ J/(molK)}$$

$$\Delta_{\text{vap}} H_{303}(\text{NH}_3) = 1146 \text{ kJ/kg}$$

$$\Delta_{\text{vap}} H_{264}(\text{NH}_3) = 1294 \text{ kJ/kg}$$

1 Ammonia as refrigerant fluid (8 points)



The use of ammonia as refrigerant fluid started in France in 1850's and then it spread worldwide being used to create ice, keep food cold, and in air conditioners. Nowadays, due to its lower cost and environmental impact, ammonia is largely used as replacement of CFC's and Freon as refrigerant fluid for cold storage of food and for large scale cooling requirements such as large office buildings, hospitals, ice rinks.

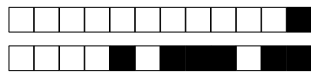
Let's now study the ammonia-based refrigerator used in ice rinks to avoid ice melting. This cycle is schematised in the picture and is made of :

- 1) an adiabatic compressor (shaft work W_s);
- 2, 4) two isobaric heat exchangers;
- 3) an adiabatic expansion valve ($W_{CD} = 0$).

The fluid starts in state A as a saturated vapour¹ at 3 bar (mass flow rate $\dot{m}(\text{NH}_3) = 161 \text{ kg/h}$) and, after the compression and the successive heat exchange with external air (hot source) arrives to the state C as a saturated liquid². After the expansion, the fluid is in state D at the liquid/vapour equilibrium ($x_v = n_{\text{gas}}/n_{\text{tot}} = 17.9\%$) and it goes back to state A by exchanging heat with the ice rink (cold source).

1. A vapour that is about to condensate (vapour and liquid are at equilibrium).

2. A liquid that is about to vaporise (vapour and liquid are at equilibrium).



Question 1 Give the literal expression of temperature T_B^{irrev} as function of $\dot{m}(\text{NH}_3)$, $M(\text{NH}_3)$, T_A , $\bar{C}_p(\text{NH}_3)$ and irreversible shaft power \dot{W}_s^{irrev} considering an irreversible compression.

☐ Vide ☐ 0 ☐ 1 ☐ 2 ☐ 3

.....

.....

.....

.....

Question 2 Give the literal expression of temperature T_B^{rev} as function of P_B , P_A , T_A , $\bar{C}_v(\text{NH}_3)$ and $\bar{C}_p(\text{NH}_3)$ considering an reversible compression

☐ Vide ☐ 0 ☐ 1 ☐ 2 ☐ 3

.....

.....

.....

.....

Question 3 What is the numerical value of T_B^{rev} (in °C) ?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9

Question 4 Considering from now on that the compression is irreversible and that $T_B^{\text{irrev}} = T_B = 172.26^\circ\text{C}$, give the power \dot{W}_{AB} transferred during the compression as a function of data given in the text.

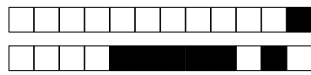
☐ Vide ☐ 0 ☐ 1 ☐ 2 ☐ 3

.....

.....

.....

.....



Question 5 What is the numerical value of \dot{W}_{AB} (kW) ?

<input type="text"/>	+		<input type="text"/> 0	<input type="text"/> 1	<input type="text"/> 2	<input type="text"/> 3	<input type="text"/> 4	<input type="text"/> 5	<input type="text"/> 6	<input type="text"/> 7	<input type="text"/> 8	<input type="text"/> 9
			<input type="text"/> 0	<input type="text"/> 1	<input type="text"/> 2	<input type="text"/> 3	<input type="text"/> 4	<input type="text"/> 5	<input type="text"/> 6	<input type="text"/> 7	<input type="text"/> 8	<input type="text"/> 9
			.									
<input type="text"/>	-		<input type="text"/> 0	<input type="text"/> 1	<input type="text"/> 2	<input type="text"/> 3	<input type="text"/> 4	<input type="text"/> 5	<input type="text"/> 6	<input type="text"/> 7	<input type="text"/> 8	<input type="text"/> 9

Question 6 Gives the expression of the rate of entropy created \dot{S}_{cre} during the compression.

Vide 0 1 2 3 4

.....
.....
.....
.....
.....
.....

Question 7 What is the numerical value of \dot{S}_{cre} (in J/(K s)) ?

<input type="text"/> 0	<input type="text"/> 1	<input type="text"/> 2	<input type="text"/> 3	<input type="text"/> 4	<input type="text"/> 5	<input type="text"/> 6	<input type="text"/> 7	<input type="text"/> 8	<input type="text"/> 9
<input type="text"/> 0	<input type="text"/> 1	<input type="text"/> 2	<input type="text"/> 3	<input type="text"/> 4	<input type="text"/> 5	<input type="text"/> 6	<input type="text"/> 7	<input type="text"/> 8	<input type="text"/> 9
.									
<input type="text"/> 0	<input type="text"/> 1	<input type="text"/> 2	<input type="text"/> 3	<input type="text"/> 4	<input type="text"/> 5	<input type="text"/> 6	<input type="text"/> 7	<input type="text"/> 8	<input type="text"/> 9

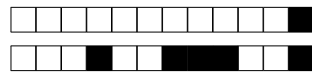
Question 8 Gives the expression of the rate of heat exchanged \dot{Q}_H with the hot source between states B and C as a function of data given in the text.

Vide 0 1 2 3

.....
.....
.....
.....

Question 9 What is the numerical value of \dot{Q}_H (in kW) ?

<input type="text"/>	+		<input type="text"/> 0	<input type="text"/> 1	<input type="text"/> 2	<input type="text"/> 3	<input type="text"/> 4	<input type="text"/> 5	<input type="text"/> 6	<input type="text"/> 7	<input type="text"/> 8	<input type="text"/> 9
			<input type="text"/> 0	<input type="text"/> 1	<input type="text"/> 2	<input type="text"/> 3	<input type="text"/> 4	<input type="text"/> 5	<input type="text"/> 6	<input type="text"/> 7	<input type="text"/> 8	<input type="text"/> 9
			.									
<input type="text"/>	-		<input type="text"/> 0	<input type="text"/> 1	<input type="text"/> 2	<input type="text"/> 3	<input type="text"/> 4	<input type="text"/> 5	<input type="text"/> 6	<input type="text"/> 7	<input type="text"/> 8	<input type="text"/> 9



Question 10 Gives the expression of the rate of heat exchanged \dot{Q}_L with the cold source between states D and A as a function of data given in the text.

☐ Vide ☐ 0 ☐ 1 ☐ 2 ☐ 3

.....

.....

.....

.....

Question 11 What is the numerical value of \dot{Q}_L (in kW) ?

☐+

<input type="checkbox"/> 0	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8	<input type="checkbox"/> 9	
<input type="checkbox"/> 0	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8	<input type="checkbox"/> 9	
.										
<input type="checkbox"/> -	<input type="checkbox"/> 0	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8	<input type="checkbox"/> 9

Question 12 What is the numerical value of $\dot{Q}_L + \dot{Q}_H + \dot{W}_{AB}$ (in kW) ?

☐+

<input type="checkbox"/> 0	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8	<input type="checkbox"/> 9	
<input type="checkbox"/> 0	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8	<input type="checkbox"/> 9	
.										
<input type="checkbox"/> -	<input type="checkbox"/> 0	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8	<input type="checkbox"/> 9

Question 13 What is the numerical value of the real COP COP^{real} ?

☐+

<input type="checkbox"/> 0	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8	<input type="checkbox"/> 9	
<input type="checkbox"/> 0	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8	<input type="checkbox"/> 9	
.										
<input type="checkbox"/> -	<input type="checkbox"/> 0	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> 6	<input type="checkbox"/> 7	<input type="checkbox"/> 8	<input type="checkbox"/> 9

Question 14 Demonstrate the expression of the ideal COP COP^{ideal} of the thermal machine as a function of data given in the text.

☐ Vide ☐ 0 ☐ 1 ☐ 2

.....

.....

.....

.....

.....

.....



Question 15 What is the numerical value of the ideal COP COP^{ideal} ?

	<input type="text"/>	0	<input type="text"/>	1	<input type="text"/>	2	<input type="text"/>	3	<input type="text"/>	4	<input type="text"/>	5	<input type="text"/>	6	<input type="text"/>	7	<input type="text"/>	8	<input type="text"/>	9	
	.																				
<input type="text"/>	+	<input type="text"/>	0	<input type="text"/>	1	<input type="text"/>	2	<input type="text"/>	3	<input type="text"/>	4	<input type="text"/>	5	<input type="text"/>	6	<input type="text"/>	7	<input type="text"/>	8	<input type="text"/>	9
<input type="text"/>	-	<input type="text"/>	0	<input type="text"/>	1	<input type="text"/>	2	<input type="text"/>	3	<input type="text"/>	4	<input type="text"/>	5	<input type="text"/>	6	<input type="text"/>	7	<input type="text"/>	8	<input type="text"/>	9

Question 16 Cite some sources of irreversibility.

Vide 0 1 2

.....
.....
.....

2 Ammonia as fuel (5 points)

Among the different applications of ammonia, one concerns its possible use as carbon-free fuel as replacement of current fossile fuels. Indeed, several studies are currently carried on to produce ammonia from carbon-free sources and then, burn it as a fuel. This exercice concerns the combustion of gaseous ammonia at 298 K and 1 bar giving gaseous nitrogen and gaseous water.

Question 17 Write the combustion reaction of **one** mole of ammonia.

Vide 0 1 2

.....
.....

Question 18 Give the expression of the standard reaction enthalpy $\Delta_r H$ of the combustion of **one** mole of ammonia.

Vide 0 1 2

.....
.....

Question 19 What is the numerical value of $\Delta_r H$ (in kJ/mol) ?

	<input type="text"/>	0	<input type="text"/>	1	<input type="text"/>	2	<input type="text"/>	3	<input type="text"/>	4	<input type="text"/>	5	<input type="text"/>	6	<input type="text"/>	7	<input type="text"/>	8	<input type="text"/>	9	
	.																				
<input type="text"/>	+	<input type="text"/>	0	<input type="text"/>	1	<input type="text"/>	2	<input type="text"/>	3	<input type="text"/>	4	<input type="text"/>	5	<input type="text"/>	6	<input type="text"/>	7	<input type="text"/>	8	<input type="text"/>	9
<input type="text"/>	-	<input type="text"/>	0	<input type="text"/>	1	<input type="text"/>	2	<input type="text"/>	3	<input type="text"/>	4	<input type="text"/>	5	<input type="text"/>	6	<input type="text"/>	7	<input type="text"/>	8	<input type="text"/>	9

Question 20 What is the numerical value of the standard reaction energy $\Delta_r U$ of **one** mole of ammonia.(in kJ/mol) ?

	<input type="text"/>	0	<input type="text"/>	1	<input type="text"/>	2	<input type="text"/>	3	<input type="text"/>	4	<input type="text"/>	5	<input type="text"/>	6	<input type="text"/>	7	<input type="text"/>	8	<input type="text"/>	9	
	.																				
<input type="text"/>	+	<input type="text"/>	0	<input type="text"/>	1	<input type="text"/>	2	<input type="text"/>	3	<input type="text"/>	4	<input type="text"/>	5	<input type="text"/>	6	<input type="text"/>	7	<input type="text"/>	8	<input type="text"/>	9
<input type="text"/>	-	<input type="text"/>	0	<input type="text"/>	1	<input type="text"/>	2	<input type="text"/>	3	<input type="text"/>	4	<input type="text"/>	5	<input type="text"/>	6	<input type="text"/>	7	<input type="text"/>	8	<input type="text"/>	9



Question 21 Give the expression of the created entropy S_{cre} of this reaction as a function of temperature T .

☐ Vide ☐ 0 ☐ 1 ☐ 2

.....

.....

.....

.....

Question 22 What is the numerical value of S_{cre} at 298 K (in kJ/mol/K) ?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
.
☐ + ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
☐ - ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9

Question 23 At 298 K, the combustion reaction of ammonia is :

☐ Impossible ☐ Irreversible ☐ Reversible

Question 24 Give the RICE chart of the combustion reaction of ammonia for 1 mol of ammonia in air with molar ratio of air equals to r ($n_{\text{air}}/n_{\text{NH}_3} = r$).

☐ Vide ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4

.....

.....

.....

.....

Question 25 What is the minimal value of r for the combustion to be complete ?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
.
☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9

Question 26 If $r = 4$, what is the value of ξ_M at the end of the reaction ?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
.
☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9



Question 27 Prove that the flame temperature T_f obtained by the combustion of an initial mixture of ammonia in air with molar ratio of air equals to r ($n_{\text{air}}/n_{\text{NH}_3} = r$, such that no reactant remains) and by considering that a fraction η of the heat released by the combustion is lost to the surroundings and that the heat capacities are independent of the temperature is :

$$T_f = T_0 - \frac{(1 - \eta)\Delta_r H_{298}}{\eta [C_p(\text{NH}_3) + \frac{3}{4}C_p(\text{O}_2) + 3C_p(\text{N}_2)] + (1 - \eta) [\frac{7}{2}C_p(\text{N}_2) + \frac{3}{2}C_p(\text{H}_2\text{O})]}$$

☐ Vide ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4

.....

.....

.....

.....

.....

.....

.....

.....

.....

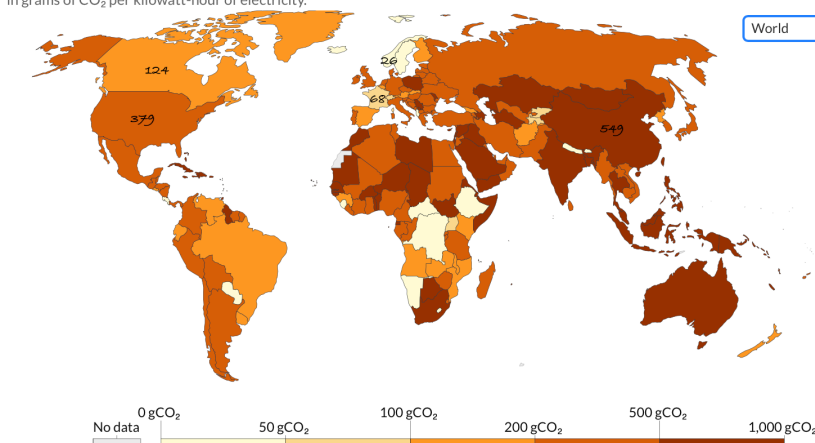
.....

3 Carbon assessment of an electric car (7pts)

Carbon intensity of electricity, 2021

Carbon intensity measures the amount of greenhouse gases emitted per unit of electricity produced. Here it is measured in grams of CO₂ per kilowatt-hour of electricity.

Our World
in Data



Source: Ember Climate (from various sources including the European Environment Agency and EIA)

OurWorldInData.org/energy • CC BY

► 2000

○ 2021

An average car needs 180 W.h/km of mechanical energy to move and transport passengers.

Cars can be powered by :

- a gasoline engine (efficiency $\eta^{\text{gas}} = 0.35$). Gasoline is considered as C_8H_{18} . Its combustion releases carbon dioxide and water. The heat of formation of gasoline is $\Delta_f H_{\text{C}_8\text{H}_{18}} = -250 \text{ kJ/mol}$ and its density is $\rho = 700 \text{ kg/m}^3$.
- an electric engine (efficiency $\eta^{\text{elec}} = 0.85$) powered by a set of batteries (efficiency $\eta^{\text{bat}} = 0.8$).

Extraction and production of gasoline emits 720 g of CO₂ per liter. The production of a battery for an electric car emits 6000 kg of CO₂. The life span of cars is $L = 150\,000 \text{ km}$. The Carbon intensity of electricity (mass of CO₂ per kWh of electricity produced) is given in the map.

Question 28 Estimate the net gain in CO₂ per km of an electric vehicle compared to a gasoline one.

☐ Vide ☐ Faux ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

☐ Vide ☐ Faux ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

[illegible]