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**TD Thermodynamic**

**L3**

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**Lesson n°1: Thermodynamics’ basics**

**Exercise 1- Compression of a perfect gas.**

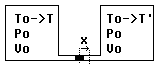
A system composed of *n* moles of a given perfect gas, evolves between an initial and a final equilibrium state at constant Temperature. The final pressure increases by 20% (compared to the initial value). What is the increase of volume in percentage?

**Exercise 2- Perfect gas differential thermometer**

This thermometer, intended to measure small perturbances in temperature, consists of two identical perfect gas reservoirs connected by a junction tube of small section *s*. The tube is horizontal and has a mercury indexer in the middle isolating the gases from each other. In an initial state both gases occupy the same volume *V0* under the same conditions, pressure *P0* and temperature *T0*.

The left gas is brought to the temperature T and the right gas to a slightly lower temperature then *T*, *T’*.

The mercury moves a short length *x* (x\*S <<V0).



The purpose of this exercise is to express the difference in temperature (T-T’) as a function of *V0*, *s*, *x* and *T*.

1. After a certain period, the mercury is immobile. Why?
2. How does this translate from a thermodynamic point of view?
3. Express the volume V and V’ of, respectively, the left and right tank as a function of *V0*, *s* and *x*.
4. Express *T’* as a function of *T*, *V0*, *s* and *x*.
5. Deduce the following equation:

**Exercise 3- Expansion of an argon bottle.**

On a steel bottle of height *H=1.6m*, the manufacturer put the following information:

- Argon: *10m3*.

- *200 bars* at the temperature of *20°C*.

The bottle is equipped with a regulator, which delivers argon at atmospheric pressure (1 bar) while maintaining the temperature.

Consider that the argon inside the bottle behaves like a perfect gas.

1. How is Argon used in the industry?
2. Do you consider the approximation of argon to a perfect gas legitimate?
3. Determine the internal volume of the bottle.
4. What is the volume of argon that can be used at atmospheric pressure (constant temperature).
5. How many mols of argon are inside the bottle?

**Exercise 4- Overpressure in an alcohol thermometer.**

An alcohol thermometer is at a temperature in which its reservoir is completely filled. The liquid’s state equation is of the type:



The following thermoelastic coefficients are known:

 and 

Assume that these coefficients are constant.

1. Consider a change of temperature of . What is the overpressure caused by this disturbance?
2. What effect can the overpressure cause on the thermometer?
3. Give a concrete example of your childhood where this situation could occur and propose a solution and/or precaution.

**Exercise 5- Dilatation of a showcase.**

Consider a glass crystal of a showcase is a rectangle of 3x4m and is in contact with the outside environment, which temperature varies from -10°C in winter to +30°C in summer.

The length L of the glass obeys a state function of the type: .

The linear expansion coefficient of the glass for a L length is defined as:



1. Express the variation of length L as a function of the coefficient *λ,* the initial length L0 and the temperature variation ΔT.
2. For the following increments on length Δ(L1 – L0) and Δ(L2 – L0), where *L1 =3m* and *L2 =4m*. Calculate the implications on the temperature.
3. Deduce the change of the glass’ area between the winter and summer and calculate the value.
4. How can the manufacturer take this into account?

**Lesson n°2: 1st principle of Thermodynamics**

**Exercise 1- Study of two bricks.**

**Part A**

Two bricks of thermal capacities, respectively, C1 and C2 and initial temperatures of, respectively, T1 and T2. The two bricks are brought into contact with each other and are thermally isolated from the outside environment:

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1. Calculate of the final equilibrium temperature Tf of the two bricks.

**Part B**

Keeping the same initial system, to brick 1 a resistance R0 traversed by a current I is added.

1. Deduce the expression for the new final temperature Tf’ achieved by the two bricks after equilibrium is achieved.

**Exercise 2- Work of pressure forces of a perfect gas**

*N* moles of gas undergo a reversible isothermal compression from state 1 defined by (P0, T0) to state 2 defined by (2P0, T0).

Express the work energy received by the gas, considering a perfect gas.

**Exercise 3- Measurement of the heat capacity of silver.**

To measure the thermal capacity of silver a calorimeter containing a mass *me = 200g* of water at the temperature *Te = 18.9°C* is used.

1. In a preliminary phase, the heat capacity C0 of the calorimeter was determined by dipping an ohmic conductor of resistance *R0 = 100 Ώ* traversed by a current of intensity *I = 0.8 A*. After *t = 100s* a temperature rise of *ΔT = 7K* was observed. Calculate C0.
2. On the same calorimeter, containing a mass of water *me = 200g* at the temperature of *Te = 18.9°C*, a silver block of mass *mAg =82g* at *TAg = 90°C* is introduced. Once thermal equilibrium is reached, the temperature is *Tf = 20.3°C*. Determine the specific heat capacity CAg of silver.

Heat capacity of water: *Ce = 4,187 kJ.K-1.kg-1*.

**Exercise 4- Heating of a school.**

The school’s heating is studied during a winter day. *Text* is the temperature of the air outside of the school, which is assumed to be constant. It is also assumed that all the school, at every moment, is at the same temperature *T(t)*. *C* is the thermal capacity of the school and the thermal power *Pth* lost by the school is of the type: .

Data:

- *Text = 263 K*;

*- C = 7,6.107 J.K-1*;

*- k=6.103W.K-1.*

**Part A**

The school heating is stopped at the instant *t0 = 0s*, where the temperature is *T1 = 293K*.

1. By making a thermal balance between the instants t0 + dt, establish the differential equation verified by *T(t).*
2. Resolve the equation to obtain *T(t).*
3. Determine the temperature *T(t)* of the school after *t1 = 3 hours* of stopping the heating.

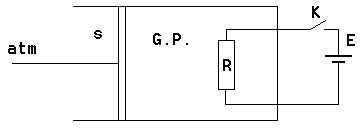
**Part B**

Assume now that the temperature at the instant 0 is *T2*= 275K and the school heating is turned on. The radiations have a thermal power *Pch* = 210 kW, which is constant over time.

1. Establish the differential equation verified by *T(t).*
2. Resolve the equation to obtain *T(t).*
3. Calculate the moment *T2* for which the temperature of the school is *Tf = 293K*.

**Exercise 5- Isochoric and isothermal transformation of a perfect gas.**

The following device is studied:

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An adiabatic cylinder closed by an adiabatic piston, of section *S*, contains *n* moles of a perfect gas, initially at the temperature *T0* and at the atmospheric pressure *P0*. It’s molar heat capacity at constant volume *Cvm* is known. The cylinder also contains a resistor *r* fed by an ideal source of voltage *E*.

**Part A**

The operator maintains the piston in its initial position and lowers the switch K. The resistance *r* varies in function of the temperature according to the following law:



1. Express the law of variation of the temperature T in function of the time t.
2. Deduce the law of variation of the pressure P of the gas as a function of time t.

**Part B**

The operator now slowly moves the piston performing an isothermal transformation from the state: perfect gas and switch K closed.

3) Express the law of variation of volume V (t) as a function of time t.

4) Deduce the speed of the piston.

**Lesson n°3: 2nd principle of Thermodynamics**

**Exercise 1- Entropy creation in two bricks.**

**Part A**

Consider two bricks of, respectively, heat capacity C1 and C2, initially at the temperatures *T1* and *T2*. They are brought into contact with each other and thermally isolated from the outside:

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The final temperature corresponds to: .

1) Calculate the entropy variation of the brick Σ1.

2) Calculate the entropy variation of the brick Σ2.

3) Calculate the entropy variation of the set of two bricks Σ1 and Σ2.

4) Deduce the entropy created during the evolution of the system.

**Part B**

Assume that the two bricks have the same thermal capacity: *C*.

1. Show that the transformation is necessarily irreversible if . What is the cause of this irreversibility?

**Part C**

With the same initial system, in brick 1 a resistance *R0*is inserted. The resistance is traversed by a current *I* for a time *t*.

The final temperature was calculated and corresponds to: 

6) Calculate the entropy created during the evolution of the system.

7) Show that, if the bricks are identical and initially at the same temperature, the transformation is irreversible. What is the cause of this irreversibility?

**Exercise 2- Entropy of a perfect gas.**

**Part A**

1) Determine the variation of the entropy of the perfect gas according to the pressure P and temperature T during a transformation of a state 1 to a state 2.

2) Determine the variation of the entropy of the perfect gas according to the pressure P and volume V during a transformation of a state 1 to a state 2.

**Part B.**

3) Deduce the variation of entropy of one mole of a perfect gas when it undergoes a reversible adiabatic transformation,

4) Determine the entropy variation of one mole of a perfect gas when it undergoes an isothermal transformation of *P0 = 1 bar, V0 = 22.4L* to *P1 = 5 bar*.

R = 8.315 J.K-1.mol-1

**Exercise 3- Reversibility criteria; monothermal transformation and entropic balance sheet.**

A solid of thermal capacity *C*, initially at the temperature *T0*, is considered to be in thermal contact with an invariable heat source of temperature *TS*.

Express between the initial state and the final state:

1) The solid’s variation of entropy .

2) The source’s variation of entropy .

3) The entropy generated during the transformation .

4) Check that his sign is positive if  with .

**Exercise 4- Joule effect and creation of entropy.**

An ohmic conductor of electrical resistance *R* is considered independent of the temperature. This resistance is placed in the ambient air at the temperature *T0* (constant). It is crossed by an electric current of intensity *I* and dissipates by Joule effect a constant electric power . In a steady state, the state functions relating to the ohmic conductor are independent of time (internal energy and entropy).

1) Apply the first principle of thermodynamics to the ohmic conductor. Deduce the heat exchanged by the driver  with the external environment as a function of the duration *dt* of the exchange, *R* and *I*.

2) What is the entropy received  by the ohmic conductor between *t* and *t + dt*.

3) Deduce the expression for the entropy production  per unit of time in the ohmic conductor.

**Lesson#4: Thermal Machines**

**Exercise 1- Study of a conventional heat pump.**

To maintain the temperature of a building at *T1 = 20°C*, while the temperature outside is *T2 = 5°C*, an energy of *W = 2.108J* per hour must be provided. We ask . A heat Pump is used.

1) Indicate under which conditions the heat pump must operate so that the power consumed is minimal.

2) Give the schematic diagram indicating the sign of heat and work received by the fluid circulating in the heat pump.

3) Define and calculate the theoretical maximum efficiency *e* of the pump under these conditions.

4) Show that it depends only on the temperatures *T1* and *T2*.

5) Calculate the minimum power consumed by the heat pump.

6) If the actual efficiency is 4, what is the power consumed?

7) The outside temperature is constant at *T2* = 5°C, for which inside temperature *T1* is the efficiency maximum? Interpret. Under what circumstances is the pump especially useful?

**Exercise 2- Entropic diagram; Graphic method.**

Consider a gas that can be assumed as perfect. The gas undergoes the following reversible cycle:

• AB: isothermal expansion at *T2*,

• BC: adiabatic from *T2* to *T1* > *T2*,

• CD: isothermal compression at *T1*,

• DA: adiabatic *T1* to *T2*.

1) Represent the cycle in Clapeyron coordinates (P, V).

2) Represent the cycle in the entropy diagram (T, S).

3) Determine using the Clapeyron diagram whether it is a heat engine cycle or a heat pump type cycle.

4) Find the previous result using the entropy diagram.

5) Compare the cycle areas of the two representations.

6) Define the effectiveness *e* of the system in study

7) Calculate it by graphical method. Does it depend on the nature of the fluid?

**Exercise 3- Cycle of a diesel engine.**

Consider *n* moles of a perfect gas that undergoes the following reversible transformations:

• State (1) → state (2): Adiabatic compression

• State (2) → state (3): Constant pressure dilatation

• State (3) → state (4): Adiabatic relaxation

• State (4) → status (1): Constant volume cooling.

**Information:**

* Each state is initially defined by the pressure *Pi*, the temperature *Ti* and the volume *Vi* (*i* varies from 1 to 4).
* 
*  and 

1) Summarize the cycle on a Clapeyron chart.

2) Give the expressions of pressure, volume and temperature for the states (3) and (4), as a function of *P1*, *V1*, *T1*, *a* and *b*.

Calculate these values ​​numerically for one mole of gas.

3) Calculate the work and heat exchanged for all the transformations undergone. Specify the meaning of exchanges.

4) Show that the efficiency η of an engine operating according to this cycle, can be put in the following form:



1. Digitally calculate η. Comment on the resulting value.

Data:

* *a = 9* and *b = 3*;
* *P1 = 1 bar*; *T1 = 300K*;
* *R = 8.315 J. K-1 mol-1*;
* Cym = 20.8 J. K-1 mol-1.