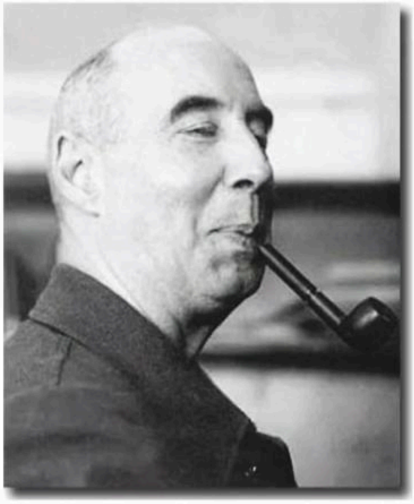
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

RESCIF
Réseau d'excellence des sciences de l'ingénieur de la Francophonie

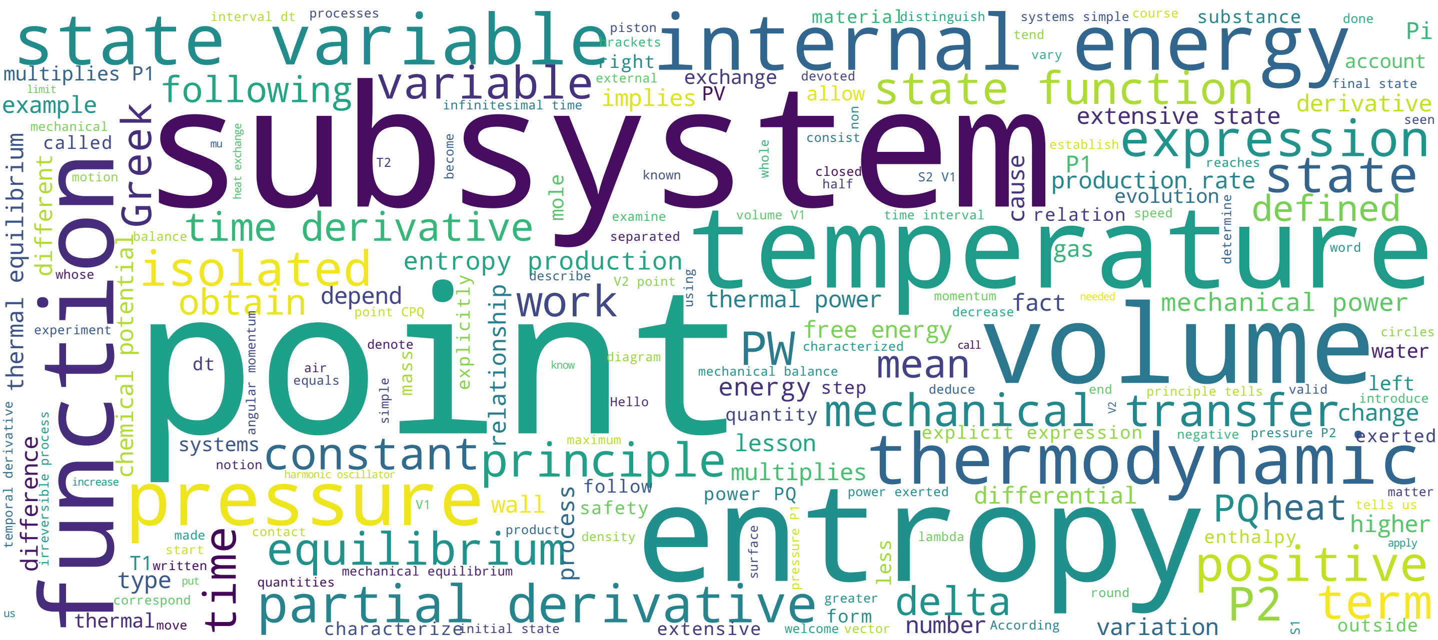
Thermodynamique

Equilibre mécanique et transfert mécanique

Dr. Sylvain Bréchet



Ernst Carl Gerlach Stückelberg, 1905 - 1984



EPFL

Video

Hello and welcome to make fun of thermodynamics. This lesson is devoted to mechanical equilibrium and mechanical transfers. To do this, we will consider an isolated system that is made up of two sub-systems simple systems that are separated by a so-called moving and impermeable wall. In a first step, we will establish the equilibrium condition and in a second step, we will examine the mechanical transfer.

Notes

Summary

0m 05s

Paroi diatherme mobile et imperméable

- **Système isolé :** $P_Q = P_W = 0$
- **Sous-systèmes simples (1) et (2)**
- **Variables d'état extensives :**
  - **Entropies** S_1 et S_2
  - **Volumes** V_1 et V_2
- **Equilibre thermique :**

$$T\left(S_1, V_1\right) = T\left(S_2, V_2\right)$$

- **Premier principe (sous-systèmes 1 et 2) :**

$$\dot{U}_1(S_1, V_1) = T\left(S_1, V_1\right)\dot{S}_1 - p_1\left(S_1, V_1\right)\dot{V}_1 = P_Q^{(21)} + P_W^{(21)}$$

$$\dot{U}_2(S_2, V_2) = T\left(S_2, V_2\right)\dot{S}_2 - p_2\left(S_2, V_2\right)\dot{V}_2 = P_Q^{(12)} + P_W^{(12)}$$

- **Energie interne (fonction d'état extensive) :**

$$U\left(S_1, S_2, V_1, V_2\right) = U_1\left(S_1, V_1\right) + U_2\left(S_2, V_2\right)$$

- **Premier principe (système isolé) :**

$$\dot{U}\left(S_1, S_2, V_1, V_2\right) = \dot{U}_1\left(S_1, V_1\right) + \dot{U}_2\left(S_2, V_2\right)$$

$$= P_Q^{(21)} + P_W^{(21)} + P_Q^{(12)} + P_W^{(12)} = 0$$

- **Identités :**

$$\dot{U}_1\left(S_1, V_1\right) = -\,\dot{U}_2\left(S_2, V_2\right)$$

$$P_Q^{(12)} + P_W^{(12)} = -\,P_Q^{(21)} - P_W^{(21)}$$

Thermodynamique

We therefore consider an isolated system. Which consists of two simple sub-systems simple sub-system one here simple, two there, which are separated by a wall said to term mobile and impermeable since the system is insulated. The thermal power PQ is the power mechanical PW that are exerted by the outside on the system. They suck? To characterize the thermodynamics of this system, two types of extensive state variables are needed. First of all, entropy. Then the volume. For each simple subsystem, we need an entropy variable and a volume variable. The four state variables are therefore an S2, V1 and V2. It is assumed that this system has already reached the state of thermal equilibrium. When a system reaches a thermal equilibrium, this means that both subsystems have the same temperature. Temperature is a state function, it is therefore a function of the state variables of each subsystem. Therefore, the thermal equilibrium is written as follows. The temperature T of the first subsystem, which is a function of S1 and becomes, is equal to the temperature T of the second sub-system, which is a function of S2 and V2. Internal energy, temperature and pressure are state functions.

Notes

Summary

0m 32s

Paroi diatherme mobile et imperméable

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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$$\dot{U}_1(S_1, V_1) = T(S_1, V_1)\,\dot{S}_1 - p_1(S_1, V_1)\,\dot{V}_1 = P_Q^{(21)} + P_W^{(21)}$$

$$\dot{U}_2(S_2, V_2) = T(S_2, V_2)\,\dot{S}_2 - p_2(S_2, V_2)\,\dot{V}_2 = P_Q^{(12)} + P_W^{(12)}$$

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$$U(S_1, S_2, V_1, V_2) = U_1(S_1, V_1) + U_2(S_2, V_2)$$

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$$= P_Q^{(21)} + P_W^{(21)} + P_Q^{(12)} + P_W^{(12)} = 0$$

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$$P_Q^{(12)} + P_W^{(12)} = -P_Q^{(21)} - P_W^{(21)}$$

Thermodynamique

They are therefore functions of the state variables of each subsystem. The one point CT is one point minus t1 v one point. The first principle tells us that the cause of the time variation of one. It is. The thermal and mechanical powers that are exerted by the second sub system on the first subsystem, namely PQ two one and PW two one. In a similar way two points. CT. Is it 2.01 p2? V. Two points. And the cause of the variation of the internal energy of the second subsystem. According to the first principle, it is the thermal power and the mechanical power exerted by the first subsystem on the second subsystem, i. e. PQ one two and PW one two. the Internal Energy, it is a state function, so the internal energy. For the whole system, it is a function of the set of the state variables of the system, i.e. it is a function of S1, S2, V1 and V2, an extensive state function. Thus the internal energy u of the system. And the sum of the internal energy of this system. One of the internal energy two. Of the subsystem. Two. We can now take the time derivative of this relation. Eight points is one point plus two points. According to the first principle. There was a point. CPQ of one, pw of one and u two point.

Notes

Summary

2m 13s

Paroi diatherme mobile et imperméable

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$$U(S_1, S_2, V_1, V_2) = U_1(S_1, V_1) + U_2(S_2, V_2)$$

- **Premier principe (système isolé) :**

$$\dot{U}(S_1, S_2, V_1, V_2) = \dot{U}_1(S_1, V_1) + \dot{U}_2(S_2, V_2)$$
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- **Identités :**

$$\dot{U}_1(S_1, V_1) = -\dot{U}_2(S_2, V_2)$$
$$P_Q^{(12)} + P_W^{(12)} = -P_Q^{(21)} - P_W^{(21)}$$

Thermodynamique

CPQ one two plus PW one two. Therefore, if the system is isolated, the first principle tells us that the point is zero. So we get two identities. First of all, there was a point that equals less points. And then PQ one more pw one two that is equal to me. PQ two one minus pw two one.

Notes

Summary

4m 13s

Dérivée partielle de l'entropie

- Dérivées temporelles de l'entropie :

$$\dot{S}_1 = \frac{1}{T\left(S_1, V_1\right)}\left(\dot{U}_1\left(S_1, V_1\right) + p_1\left(S_1, V_1\right)\dot{V}_1\right)$$
$$\dot{S}_2 = \frac{1}{T\left(S_2, V_2\right)}\left(\dot{U}_2\left(S_2, V_2\right) + p_2\left(S_2, V_2\right)\dot{V}_2\right)$$

- Système isolé :

$$\dot{U}_2\left(S_2, V_2\right) = -\,\dot{U}_1\left(S_1, V_1\right) \quad \text{et} \quad \dot{V}_2 = -\,\dot{V}_1$$

- Dérivée temporelle de l'entropie :

$$\dot{S} = \frac{1}{T\left(S_1, V_1\right)}\Big(p_1\left(S_1, V_1\right) - p_2\left(S_2, V_2\right)\Big)\dot{V}_1$$

- Identités : $dS = \dot{S}\,dt$ et $dV_1 = \dot{V}_1\,dt$

- Dérivée partielle de l'entropie :

$$\frac{\partial S}{\partial V_1} = \frac{1}{T(S_1, V_1)}\Big(p_1(S_1, V_1) - p_2(S_2, V_2)\Big)$$

Thermodynamique

We must now take into account explicitly of extensibility, entropy and volume. Entropy is a state variable extensive, so the entropy S of the system is the sum of the entropy S one of the first and the entropy S two of the second subsystem. Volume is also an extensive state variable. Therefore, the volume V of the system is the sum of the volume V1 of the first subsystem and the volume V2 of the second subsystem. We can now take temporal derivatives of these state variables. First of all this point one point plus is two points. Then 20 points. Which is equal had one point higher two points. Finally, we explicitly take into account the fact that that the system is isolated if the system is isolated. According to the second principle is this point is equal to Pi of s which is positive or zero. And if the system is isolated, the volume of the system is constant, so v points is zero, which implies that v one point is equal to -22 points. Therefore, if the volume of a subsystem increases, the volume of the other subsystem will decrease and vice versa using of the expression we established earlier for eu one point and u of points. We can now derive expressions for s a point and s of points.

Notes

Summary

4m 43s

Equilibre mécanique

- **Dérivée partielle de l'entropie :**

$$\frac{\partial S}{\partial V_1} = \frac{1}{T(S_1, V_1)} \Big(p_1(S_1, V_1) - p_2(S_2, V_2) \Big)$$

- **Deuxième principe (condition d'équilibre) :**

$$\frac{\partial S}{\partial V_1} = 0 \qquad \text{(maximum d'entropie)}$$

- **Equilibre mécanique :**

$$\boxed{p_1\left(S_1, V_1\right) = p_2\left(S_2, V_2\right)}$$

Le premier et le deuxième principes requièrent que les pressions des sous-systèmes aient la même valeur à l'équilibre mécanique.

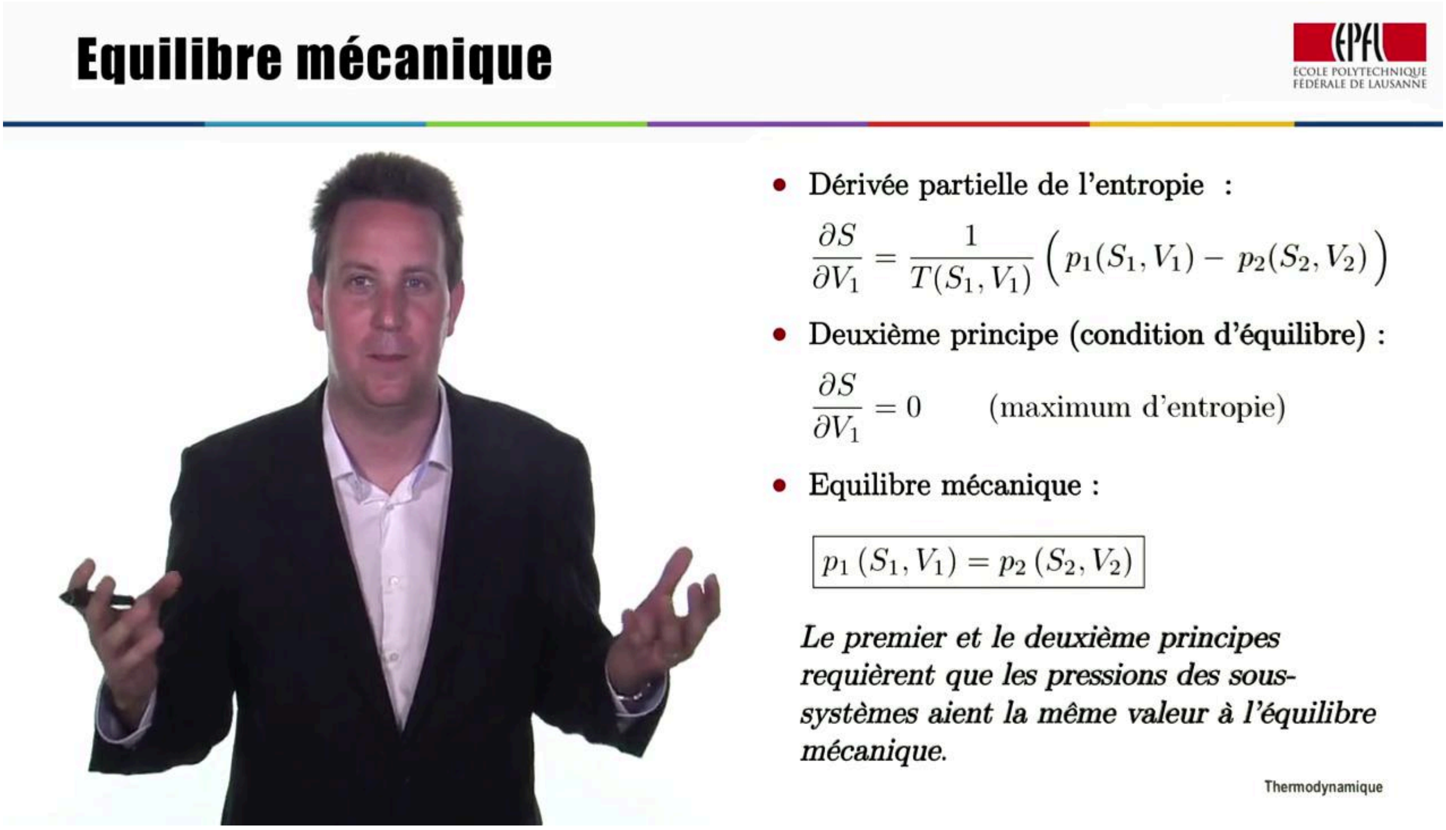
Thermodynamique

S 1.71 on the temperature that multiplies U a point plus p1. V a point and S 2.71 on T which multiplies u two points plus p2 v two points. We will now explicitly take into account the fact that the system is isolated, i.e. u of points is equal to minus and one point. And that V2 points is equal to minus v1 one point. This allows us to deduce the explicit expression. The time derivative of entropy of the system is the point which is the sum of one point and s two points. This is written as a surtout which multiplies P1 minus p2 the however v a point. We now want to put this equation back into shape to make differentials appear explicitly. So we have multiplied by the infinitesimal time interval dt and we obtain in the left member DS and in the right member The last term is the differential of the volume of the first subsystem, i.e. rubber. We can now take the derivative partial entropy with respect to the volume of the first subsystem s on circles comes equal to a safety that multiplies the difference in pressures, i.e. P1 and P2. The second principle of thermodynamics, and more precisely the condition of the second principle, states that entropy is maximum at equilibrium, therefore at equilibrium, the partial derivative of the entropy with respect to the volume of the first sub system, i.e.

Notes

Summary

6m 14s



round s on round V1 and null. Given the expression which is on the first line, i.e. circles on circles V1. A safety that multiplies P1 and minus P2. Given this expression of the maximum of entropy, we obtain the equilibrium condition mechanics, namely that the terms in brackets in the first expression must cancel each other out, which implies. Mechanical balance. The pressure of the first subsystem P1 must be equal to the pressure of the second subsystem P2. Therefore, the first and second principles requires that the pressures of the subsystems and the same value at equilibrium before the system reaches the state of mechanical equilibrium.

Notes

Summary

8m 05s

Transfert mécanique

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

- **Dérivée temporelle de l'entropie** $(p_1 \neq p_2)$:

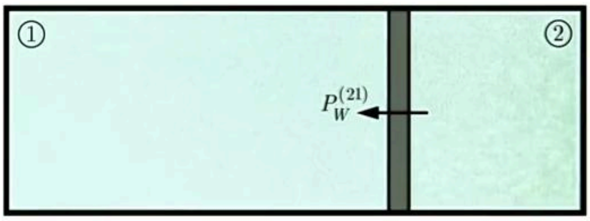
$$\dot{S} = \frac{1}{T(S_1, V_1)} \Big(p_1(S_1, V_1) - p_2(S_2, V_2) \Big) \dot{V}_1$$

- **Système isolé (procesus irréversible) :**

$$\dot{S} = \Pi_S > 0$$

- **Taux de production d'entropie :**

$$\Pi_S = \frac{1}{T(S_1, V_1)} \Big(p_1(S_1, V_1) - p_2(S_2, V_2) \Big) \dot{V}_1 > 0$$



- **Transfert mécanique :**
  - Travail effectué : $p_+ \Rightarrow p_-$
  - Processus irréversible : $\Pi_S > 0$
  - Nul à l'équilibre mécanique : $p_1 = p_2$

- $p_1 > p_2 \quad \Rightarrow \quad \dot{V}_1 > 0 \quad \Rightarrow \quad P_W^{(12)} = -p_1(S_1, V_1)\,\dot{V}_2 = p_1(S_1, V_1)\,\dot{V}_1 > 0$
- $p_2 > p_1 \quad \Rightarrow \quad \dot{V}_1 < 0 \quad \Rightarrow \quad P_W^{(21)} = -p_2(S_2, V_2)\,\dot{V}_1 > 0$

Thermodynamique

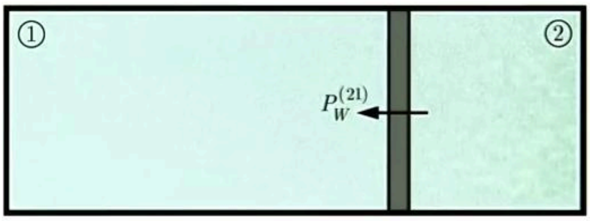
There is a mechanical transfer between the two subsystems. The mechanical balance is characterized by by the equality of the pressures of the two subsystems. Therefore, during the mechanical transfer, the pressure P1 of the first subsystem is different from the pressure P2 of the second subsystem. To examine these mechanical transfers, we will base ourselves on the expression of the temporal derivative of the entropy. Is this the point? It is a security that multiplies p1 month, P2 times, v a point. P1 is different from P2. Moreover, since there is a mechanical transfer. The volume v1 of the first subsystem will vary. Therefore it is non-zero, which implies that. Is this point and not zero? Moreover, we have a system that is isolated. For an isolated system. This point is equal to the entropy production rate Pi of S. Since this point is non-zero and is equal to Pi of S. It must therefore be positive, which means that we are dealing with an irreversible process. The explicit expression of the rate of entropy production is therefore the following. Then of s, it is on the temperature that multiplies P1 and P2. That is, a 20-point drop, is positive. We must now distinguish two cases.

Notes

Summary

9m 02s

Transfert mécanique



- **Dérivée temporelle de l'entropie** $(p_1 \neq p_2)$:

$$\dot{S} = \frac{1}{T(S_1, V_1)} \Big(p_1(S_1, V_1) - p_2(S_2, V_2) \Big) \dot{V}_1$$

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Thermodynamique

In the first case, we consider that the pressure B1 of the first is higher than the pressure P2 of the second subsystem. This implies that the difference. Of the two terms in parentheses here is positive. Therefore, for pi of s to be positive, 20 one points must also be positive. The power The mechanical force exerted by the first subsystem ensures the second subsystem. PW two is defined as less. P1 v2 point. It is also known that V of point is equal to V a point, so p w a two cp1 v a point that is positive. Therefore, if the pressure of the first subsystem is higher than the pressure P2 of the second subsystem, there is a work which is carried out by the first sub-system on the second under system, i.e. the wall will move to the right. Second scenario. P2 is greater than P1. In this case, the difference of the two terms that appear in the expression of the entropy production rate is negative. For copy of S is positive definite, then 21 points must also be negative. Mechanical power exerted by the subsystem of its subsystem one PW two is defined as P2. V. One point. It is therefore positive. Therefore, if the P2 pressure of the sub system two is higher than the pressure P1 of subsystem one.

Notes

Summary

10m 36s

Transfert mécanique

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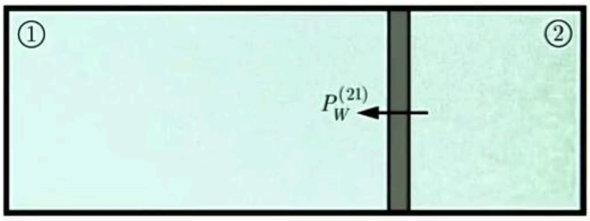

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- $p_2 > p_1 \Rightarrow \dot{V}_1 < 0 \Rightarrow P_W^{(21)} = -p_2(S_2, V_2)\dot{V}_1 > 0$

Thermodynamique

Subsystem two will perform work on subsystem one. This work. Will correspond to a shift of the wall to the left. Therefore. During a mechanical transfer. The work is done by the sub system with the highest pressure. Rated B+ on the sub-system with the lowest pressure, noted P months, this mechanical transfer is a process irreversible, i.e. pi of s is positive. And this mechanical transfer goes on gradually. Bring the system to a state of mechanical equilibrium P1 is equal to P2, i.e. the mechanical transfer is zero.

Notes

Summary

12m 25s