Thermodynamique

Systèmes simples

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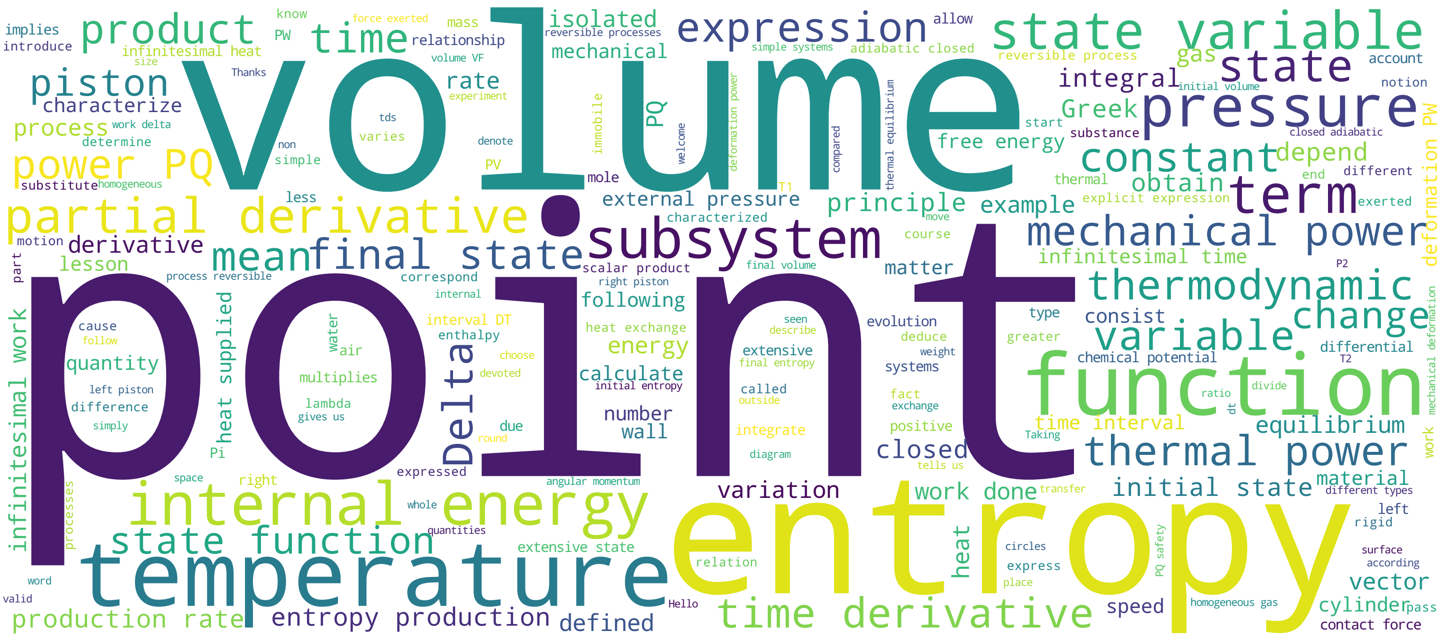
Rudolf Clausisus, 1822 - 1888



Video

Systèmes simples

- Système rigide fermé
- Système mécanique adiabatiquement fermé
- Système fermé
- Travail et chaleur

Thermodynamique

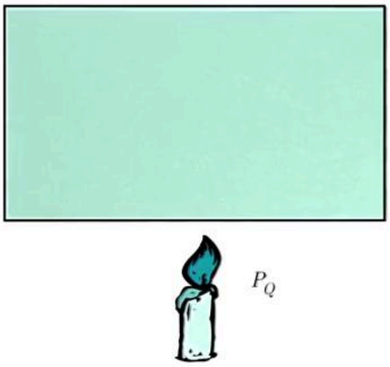
Hello and welcome to this thermodynamic moment. This lesson is devoted to simple systems. We will consider different types of simple systems. First, a system that is rigid and closed. Second, a closed adiabatic mechanical system and thirdly, a system that is closed. And for these different systems, we will express the work and heat according to the corresponding state variables.

Notes

Summary

0m 05s

Système rigide fermé



- Système rigide : $P_W = 0$
- Variable d'état extensive :
  - Entropie S

- **Premier principe :**

  $\dot{U}(S) = T(S)\,\dot{S} = P_Q$

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

  $\Pi_S = 0$ (processus réversible)

- **Chaleur infinitésimale fournie :**

  $\delta Q = P_Q\,dt = T(S)\,dS$ (processus réversible)

- **Chaleur fournie** $(i \rightarrow f)$:

  $$Q_{if} = \int_i^f \delta Q = \int_{S_i}^{S_f} T(S)\,dS \quad \text{(processus réversible)}$$

Thermodynamique

So let's start with the rigid and closed system. This system consists of a gas that is homogeneous and is in an enclosure whose walls are immobile and says in the long run, i.e. they let pass the heat that we symbolize here by this candle. So the thermal power PQ is not zero. The system is rigid, which means that the mechanical power of deformation PW is zero, so its volume is constant. The amount of material that is in this system is also constant since the system is closed. So the only quantity that varies is actually the entropy. So we will choose as extensive state variable the entropy s of this system. the internal energy U and the temperature T are state functions. They will therefore be a function of of the entropy S which is the state variable of the system. We can calculate the derivative time of the internal energy of the point which is equal to the partial derivative of the internal energy U compared to the entropy S, which is by definition the temperature T which depends on other parts. Let be the time derivative of the entropy S. This space. By the first principle. We know that if PW is zero, then the point reduces to a peak. Looking at this last identity, namely that TS point is equal to PQ.

Notes

Summary

0m 38s

Système mécanique adiabatiquement fermé

- **Système adiabatiquement fermé :**

  $P_Q = 0$

- **Processus réversibles :**

  $\Pi_S = 0 \qquad \Rightarrow \qquad \dot{S} = 0$

- **Variable d'état extensive :**
  - **Volume** V
- **Premier principe :**

  $\dot{U}(V) = -p(V)\,\dot{V} = P_W$

- **Travail infinitésimal effectué :**

  $\delta W = P_W\,dt = -p(V)\,dV \qquad$ (processus réversible)

- **Travail effectué** $(i \to f)$:

  $$W_{if} = \int_i^f \delta W = -\int_{V_i}^{V_f} p(V)\,dV \qquad \text{(processus réversible)}$$

Thermodynamique

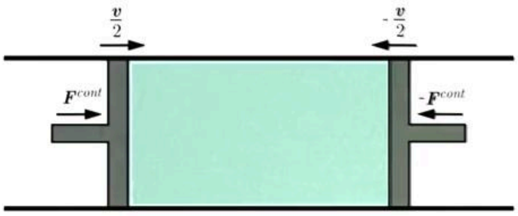
We deduce that this point is equal to PQ Safety. This means that there is only an entropy exchange rate in this equation, but that there is no entropy production rate. Therefore, the entropy production rate Pi of S is zero, which means that the processes that take place on this rigid closed system, which are heat exchange processes, are reversible processes. We can now calculate the infinitesimal heat that is supplied to the system. It is delta which by definition is equal to the product of the thermal power. PQ requires an infinitesimal time interval. DT. Considering the first principle, we see that PQ equals thirteen points, which means that PQ DT will be equal to T ds. By integrating this infinitesimal heat supplied to the system, we obtain the heat supplied to the system for a process that goes from the initial state i to the final state f. It is q y f which is the IIF integral of Delta q. We substitute the explicit form of Delta ku as a function of of the entropy S, that is to say tds that we will integrate initial to final state. the state is characterized by the variable of state, so we integrate from the initial entropy s i to the final entropy scf.

Notes

Summary

2m 22s

Système mécanique adiabatiquement fermé



- **Système adiabatiquement fermé :**

$$P_Q = 0$$

- **Processus réversibles :**

$$\Pi_S = 0 \qquad \Rightarrow \qquad \dot{S} = 0$$

- **Variable d'état extensive :**
  - **Volume** V
- **Premier principe :**

$$\dot{U}(V) = -\,p(V)\,\dot{V} = P_W$$

- **Travail infinitésimal effectué :**

$$\delta W = P_W\,dt = -\,p(V)\,dV \qquad \text{(processus réversible)}$$

- **Travail effectué** $(i \rightarrow f)$ **:**

$$W_{if} = \int_i^f \delta W = -\int_{V_i}^{V_f} p(V)\,dV \qquad \text{(processus réversible)}$$

Thermodynamique

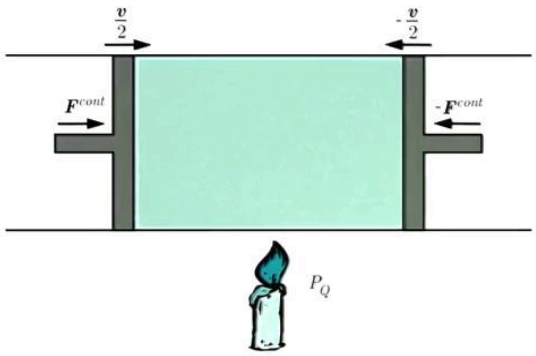
The second system that we will characterize, it is the mechanical system which is adiabatic, closed. The system consists of a homogeneous gas in a cylinder. And it is closed by two pistons. The pistons are free to slide symmetrically. This implies that the center of mass of the system is immobile, so we do not take into account its state of motion. It is assumed that the walls of the cylinder are adiabatic walls and that the pistons are also adiabatic, which means that the system is adiabatic closed. Therefore, the thermal power PQ is null and we will consider only reversible processes on this system. By definition, if we have processes reversible, the rate of entropy production of Hess is zero since the thermal power PQ is zero. And the entropy balance equation. We only get the time derivative of the entropy at this point is zero, which means that s is constant. The system is closed, therefore the quantity of matter in this system is constant. The only size that varies, is the volume of the system since we can move the pistons. Therefore, the extensive state variable that we will use to characterize this system, it is the volume V. Internal energy and pressure PS are functions of the state, so they are functions of the volume V.

Notes

Summary

3m 57s

Système fermé



- **Variables d'état extensives :**
  - Entropie S
  - Volume V

- **Premier principe :**

$$\dot{U}(S,V) = T(S,V)\,\dot{S} - p\,(S,V)\,\dot{V} = P_W + P_Q$$

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

$$\Pi_S = \frac{1}{T(S,V)}\left(P_W + p\,(S,V)\,\dot{V}\right) \geq 0$$

- **Puissance mécanique (déformation) :**

$$P_W = \boldsymbol{F}^{\,\text{cont}} \cdot \frac{\boldsymbol{v}}{2} + \left(-\boldsymbol{F}^{\,\text{cont}}\right) \cdot \left(-\frac{\boldsymbol{v}}{2}\right) = \boldsymbol{F}^{\,\text{cont}} \cdot \boldsymbol{v}$$

- **Force de contact et taux de variation de volume :**

$$\boldsymbol{F}^{\,\text{cont}} = p^{\,\text{ext}}\,\boldsymbol{A} \qquad \dot{V} = -\,\boldsymbol{A} \cdot \boldsymbol{v}$$

- **Puissance mécanique :**

$$P_W = -\,p^{\,\text{ext}}\,\dot{V}$$

Thermodynamique

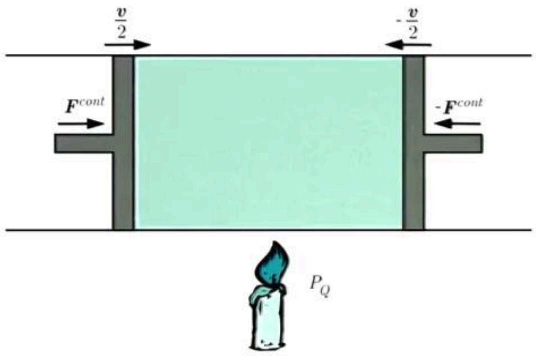
We can now calculate the time derivative of the internal energy Q. This time derivative gives us the following result. This is the partial derivative of the internal energy U with respect to the volume v, which by definition is equal to the pressure p which depends on the volume V. Times the derivative of the volume V with respect to time cv. Item. The first principle tells us that if the thermal power PQ is zero, then it will be equal to the mechanical power of deformation. PW. So now we can. Obtain an explicit expression for the infinitesimal work that is done. On this system. When we have a reversible process, then the infinitesimal work is Delta W which is defined as p w dt. PW is equal to minus p v point. So pw dt is me. PW. BV. Using this expression of the infinitesimal work done on the system, we can find the work done from the initial state to the final state. F. Simply to calculate the work done. WF We integrate the infinitesimal work delta w from the initial state i to the final state. F. The variable is volume. So we'll integrate. From initial volume to final volume VF. POS, we add a six month. The third type of system that we will consider, it is a simple, closed system.

Notes

Summary

5m 46s

Système fermé



- **Variables d'état extensives :**
  - Entropie S
  - Volume V

- **Premier principe :**

$$\dot{U}(S,V) = T(S,V)\,\dot{S} - p\,(S,V)\,\dot{V} = P_W + P_Q$$

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

$$\Pi_S = \frac{1}{T(S,V)}\Big(P_W + p\,(S,V)\,\dot{V}\Big) \geq 0$$

- **Puissance mécanique (déformation) :**

$$P_W = \boldsymbol{F}^{\,\mathrm{cont}} \cdot \frac{\boldsymbol{v}}{2} + \left(-\boldsymbol{F}^{\,\mathrm{cont}}\right) \cdot \left(-\frac{\boldsymbol{v}}{2}\right) = \boldsymbol{F}^{\,\mathrm{cont}} \cdot \boldsymbol{v}$$

- **Force de contact et taux de variation de volume :**

$$\boldsymbol{F}^{\,\mathrm{cont}} = p^{\,\mathrm{ext}}\,\boldsymbol{A} \qquad \dot{V} = -\,\boldsymbol{A} \cdot \boldsymbol{v}$$

- **Puissance mécanique :**

$$P_W = -\,p^{\,\mathrm{ext}}\,\dot{V}$$

Thermodynamique

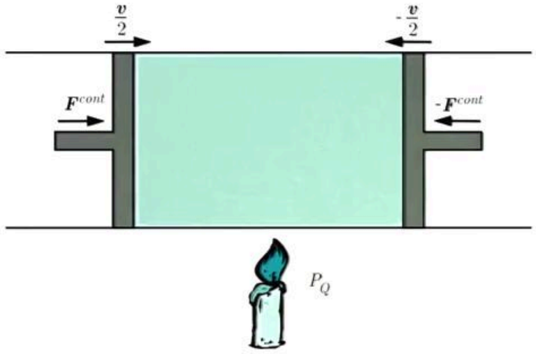
The system consists of a homogeneous gas which is located in a cylinder that is closed by two pistons. It is similar to the previous system, except that the walls of the cylinder and the pistons are term walls, so it lets heat through, so there is heat exchange. So PQ is non-zero. The system is closed so there is no exchange of matter. To report on of the variation of the volume and the variation of entropy, we will choose as extensive state variables the entropy S and the volume V. Internal energy, temperature T and pressure P are state functions. They are therefore functions of the variables of state of this system which are between parts and the volume p. We can now determine the time derivative of the internal energy. Which consists of two terms. The first term is the partial derivative of Hull with respect to s which corresponds to the temperature. The second term, is the partial derivative of the internal energy U compared to the volume V, which corresponds to minus the pressure. Faith. 20 point. The first principle also states that the time derivative of the internal energy is equal to the sum. The mechanical power of deformation PW and the thermal power PQ.

Notes

Summary

7m 38s

Système fermé



- **Variables d'état extensives :**
  - Entropie S
  - Volume V

- **Premier principe :**

$$\dot{U}(S,V) = T(S,V)\,\dot{S} - p\,(S,V)\,\dot{V} = P_W + P_Q$$

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

$$\Pi_S = \frac{1}{T(S,V)}\left(P_W + p\,(S,V)\,\dot{V}\right) \geq 0$$

- **Puissance mécanique (déformation) :**

$$P_W = \boldsymbol{F}^{\,\text{cont}} \cdot \frac{\boldsymbol{v}}{2} + \left(-\boldsymbol{F}^{\,\text{cont}}\right) \cdot \left(-\frac{\boldsymbol{v}}{2}\right) = \boldsymbol{F}^{\,\text{cont}} \cdot \boldsymbol{v}$$

- **Force de contact et taux de variation de volume :**

$$\boldsymbol{F}^{\,\text{cont}} = p^{\,\text{ext}}\,\boldsymbol{A} \qquad \dot{V} = -\,\boldsymbol{A} \cdot \boldsymbol{v}$$

- **Puissance mécanique :**

$$P_W = -\,p^{\,\text{ext}}\,\dot{V}$$

Thermodynamique

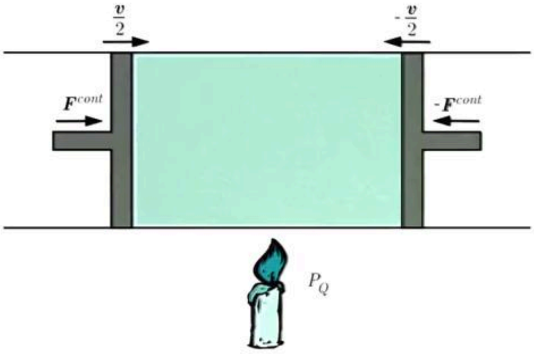
We can now obtain an expression explicit for the entropy production rate which is defined for a system adiabatic closed, ie when PQ is zero. So we take the last previous identity. And then we pass the second term from the middle member into the right member and divide it by the temperature. For a closed adiabatic system is this point is equal to Pi of s. Therefore, pi of s is equal to one on the temperature which multiplies the mechanical power of deformation pw plus the product of the pressure p times the rate of volume change v point. All this is greater than or equal to zero. We must now characterize the mechanical power of deformation. Which is due to the contact forces that are exerted by the pistons on the gas. So there are two terms. The left term is due to the contact force exerted by the left piston. And the term on the right is due to the contact force exerted by the right piston. These terms add up and so in the end, the mechanical power will be equal to the scalar product of the contact force. Times the speed. This speed v is interpreted. Like the relative speed between the pistons, i.e. the speed of the left piston in the reference frame of the right piston.

Notes

Summary

9m 17s

Système fermé



- **Variables d'état extensives :**
  - Entropie S
  - Volume V

- **Premier principe :**

$$\dot{U}(S,V) = T(S,V)\,\dot{S} - p\,(S,V)\,\dot{V} = P_W + P_Q$$

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$$\Pi_S = \frac{1}{T(S,V)}\left(P_W + p\,(S,V)\,\dot{V}\right) \geq 0$$

- **Puissance mécanique (déformation) :**

$$P_W = \boldsymbol{F}^{\,\text{cont}} \cdot \frac{\boldsymbol{v}}{2} + \left(-\boldsymbol{F}^{\,\text{cont}}\right) \cdot \left(-\frac{\boldsymbol{v}}{2}\right) = \boldsymbol{F}^{\,\text{cont}} \cdot \boldsymbol{v}$$

- **Force de contact et taux de variation de volume :**

$$\boldsymbol{F}^{\,\text{cont}} = p^{\,\text{ext}}\,\boldsymbol{A} \qquad \dot{V} = -\,\boldsymbol{A} \cdot \boldsymbol{v}$$

- **Puissance mécanique :**

$$P_W = -\,p^{\,\text{ext}}\,\dot{V}$$

Thermodynamique

We can now introduce a vector R. This vector r is the vector a. This vector a is defined positive. From the left to the right. Its standard corresponds to the air. From a piston. We can express the strength of contacts discounting based on these discount vectors. This is the product. From the external pressure, e.g. One time. And then the volume variation. The rate of change of volume v point. Is equal. A me the scalar product of the vector a with the velocity vector v. Taking into account these two expressions, we can now reformulate the mechanical power of deformation in terms. From the external pressure. This mechanical power is then expressed as follows. PW is equal to me. The external pressure for example. The rate of change of volume V point. We can now take this expression of the mechanical power and substitute it in the expression of the entropy production rate. We highlight v point which is the rate of change of volume.

Notes

Summary

10m 58s

Système fermé : processus réversible

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

$$\Pi_S = \frac{1}{T(S,V)}\left(p\,(S,V) - p^{\,\text{ext}}\right)\dot{V} \geq 0$$

- **Processus réversible :**

$$\Pi_S = 0 \qquad \Rightarrow \qquad p\,(S,V) = p^{\,\text{ext}}$$

- **Puissance mécanique (déformation) :**

$$P_W = -\,p\,(S,V)\,\dot{V} \qquad \text{(processus réversible)}$$

- **Puissance thermique :**

$$P_Q = T(S,V)\,\dot{S} \qquad \text{(processus réversible)}$$

Thermodynamique

The entropy production rate then takes the following form. Pi ds is equal to one on the temperature, which is a function of the entropy S and the volume V which multiplies the difference between the pressure of the system which is a state function that depends of S and V, minus the external pressure which is not a state function. And the whole is multiplied by the rate of change of volume V weight. The entropy production rate is greater than or equal to zero. We will now consider a process reversible, i.e. by definition, pi2 is zero if pi is zero. The terms in brackets cancel each other out, which implies that the pressure which is a state function that depends on the entropy S and volume V, will be equal to the external pressure e.g.. We can then re-express the power mechanics of the information in terms of the state variables of the system. Thanks to this identity, the mechanical deformation power W is then expressed as minus. The product of the pressure which is a function of of the entropy S of the volume V sees the rate of change of volume V point. It is also possible for a reversible process. Expressing the power thermal PQ as a function of the system state variables for a process reversible is this weight is equal to the ratio of PQ safety.

Notes

Summary

12m 25s

Système fermé : processus réversible

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

$$\Pi_S = \frac{1}{T(S,V)} \Big(p\,(S,V) - p^{\,\text{ext}} \Big)\, \dot{V} \geq 0$$

- **Processus réversible :**

$$\Pi_S = 0 \qquad \Rightarrow \qquad p\,(S,V) = p^{\,\text{ext}}$$

- **Puissance mécanique (déformation) :**

$$P_W = -\,p\,(S,V)\,\dot{V} \qquad \text{(processus réversible)}$$

- **Puissance thermique :**

$$P_Q = T(S,V)\,\dot{S} \qquad \text{(processus réversible)}$$

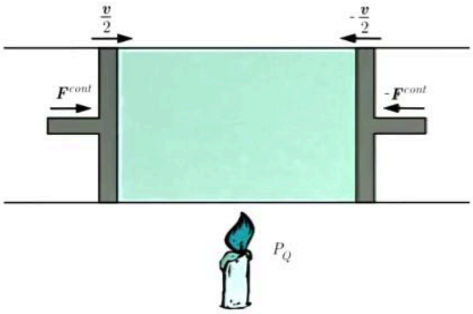
Thermodynamique

Therefore, the thermal power PQ is equal to the product of the temperature which depends on of the state variables entropy S and volume V. Is the time derivative of entropy this point?

Notes

Summary

13m 58s



- **Travail infinitésimal effectué :**

$$\delta W = P_W \, dt = -\,p\,(S,V)\,dV \qquad \text{(processus réversible)}$$

- **Chaleur infinitésimale fournie :**

$$\delta Q = P_Q \, dt = T\,(S,V)\,dS \qquad \text{(processus réversible)}$$

- **Travail effectué** $(i \to f)$ **:**

$$W_{if} = \int_i^f \delta W = -\int_{V_i}^{V_f} p\,(S,V)\,dV \qquad \text{(processus réversible)}$$

- **Chaleur fournie** $(i \to f)$ **:**

$$Q_{if} = \int_i^f \delta Q = \int_{S_i}^{S_f} T(S,V)\,dS \qquad \text{(processus réversible)}$$

Thermodynamique

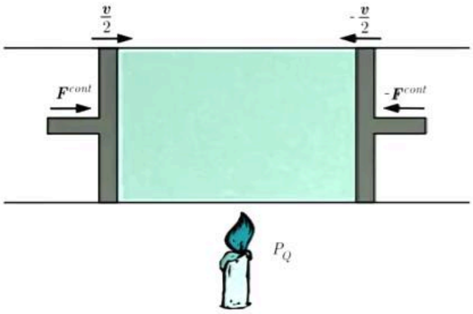
Using these definitions, of the mechanical power of deformation PWM and the thermal power PQ, we can now establish explicit expressions for the work done on the system and the heat provided to the system in terms of the system state variables. The infinitesimal work that is done. Delta W is equal to the product of the mechanical deformation power PWM for an infinitesimal time interval DT, which is equal to minus p. The pressure which is a function of the entropy and the cold volume dv. The infinitesimal heat that is provided to the delta system q It is the product of the thermal power PQ. For an infinitesimal time interval DT, which is equal to the product of the temperature which is a function of the entropy of the volume V times ds. We can now integrate these two expressions to obtain and respectively the work done of an initial state and a final state f and the heat supplied to the system from an initial state i a final state f the work done. W f. It is the integral from the initial state to the final state. F Of infinitesimal work. Delta W. The state variable that is varied is the volume. We will have the integral on the volume. The integral of the product, the pressure which depends on the entropy of the volume v.

Notes

Summary

14m 15s

Système fermé : travail et chaleur



- **Travail infinitésimal effectué :**

$$\delta W = P_W\, dt = -\, p\,(S,V)\, dV \qquad \text{(processus réversible)}$$

- **Chaleur infinitésimale fournie :**

$$\delta Q = P_Q\, dt = T\,(S,V)\, dS \qquad \text{(processus réversible)}$$

- **Travail effectué** $(i \to f)$ **:**

$$W_{if} = \int_i^f \delta W = -\int_{V_i}^{V_f} p\,(S,V)\, dV \qquad \text{(processus réversible)}$$

- **Chaleur fournie** $(i \to f)$ **:**

$$Q_{if} = \int_i^f \delta Q = \int_{S_i}^{S_f} T(S,V)\, dS \qquad \text{(processus réversible)}$$

Thermodynamique

Times dv. This is a volume integration, so it is an integral that will be done from the initial volume 28 to the final volume. VF. The heat supplied during the process from the initial state to the final state. F cooks. It is the integral from the initial state to the final state. F of Delta. Q. It is thus an integral on entropy. It is the integral of the initial entropy and this at the input to the final entropy s f of the product of the temperature which is a function of the entropy and the volume. Faith ds.

Notes

Summary

15m 49s