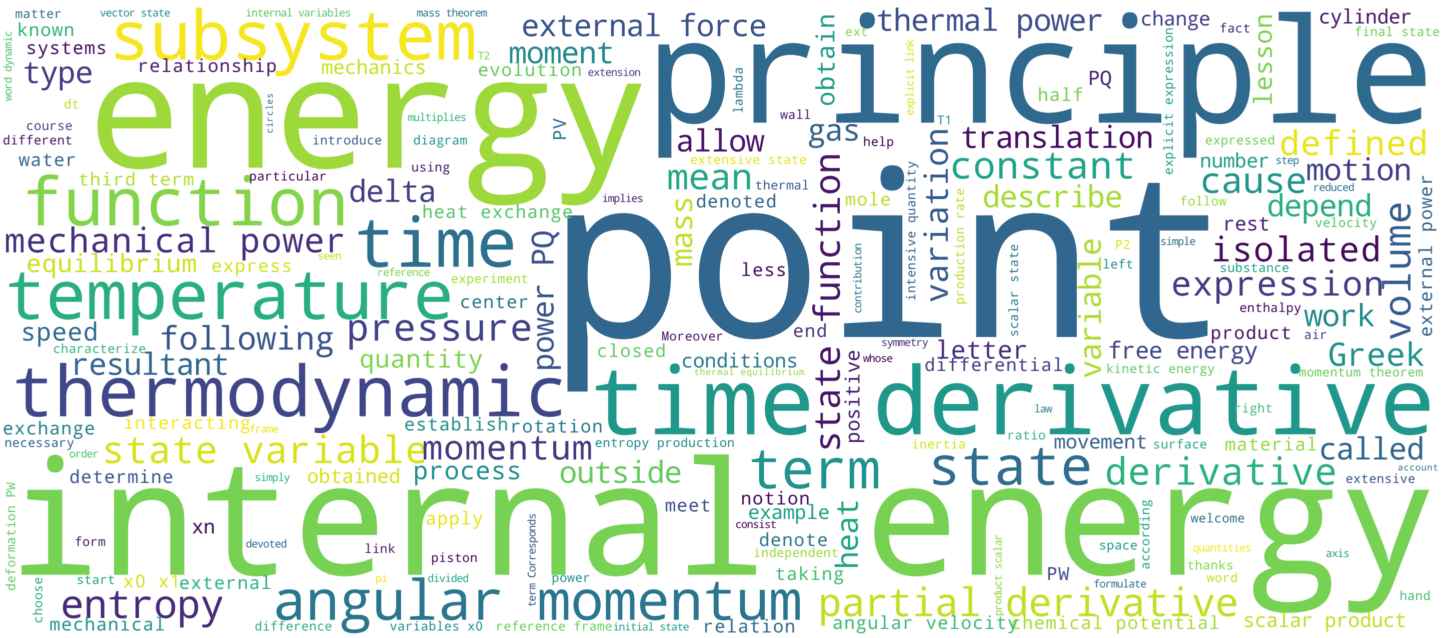
Thermodynamique

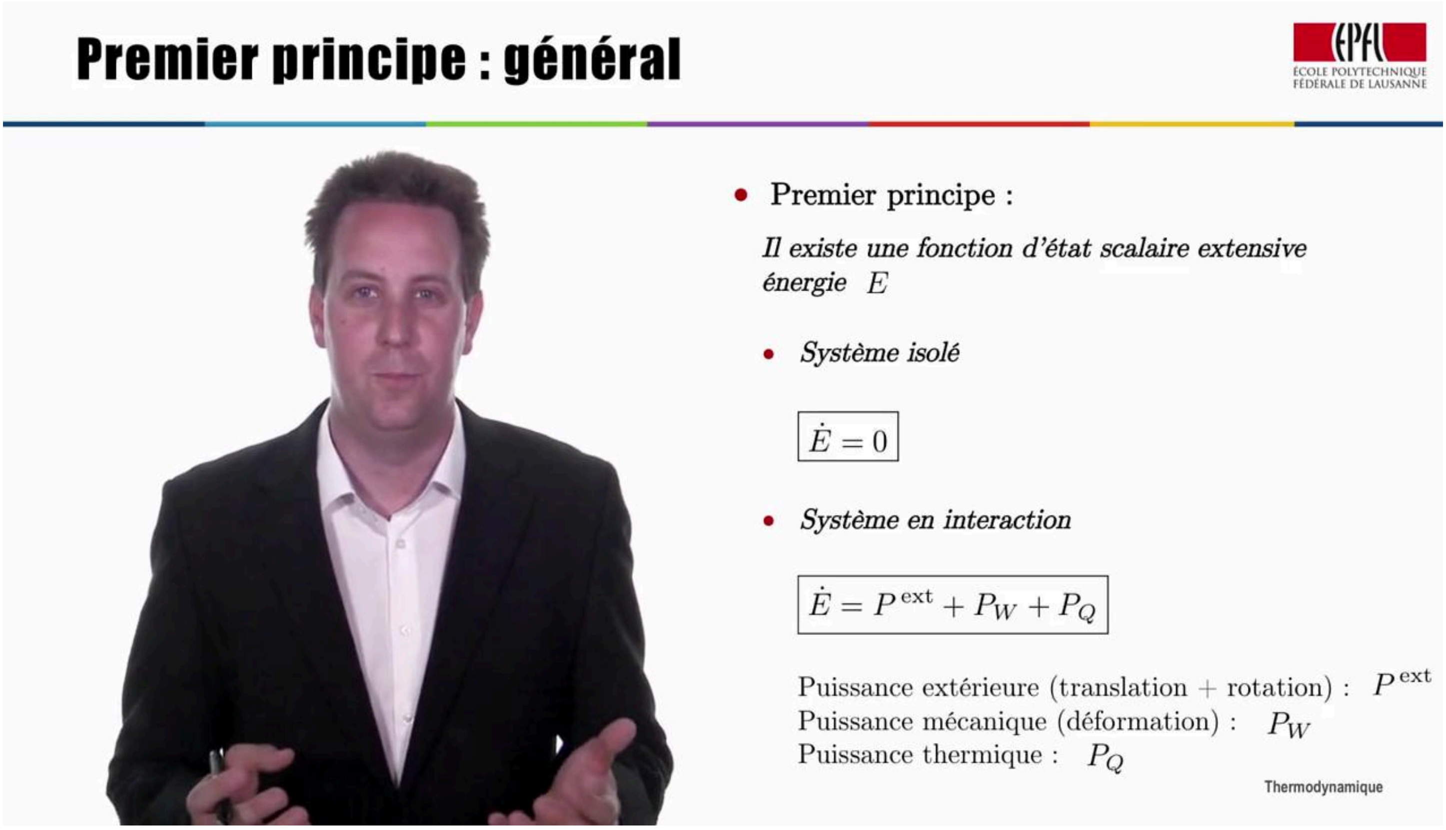
Premier principe

Dr. Sylvain Bréchet

James Prescott Joule, 1818 - 1889



Video

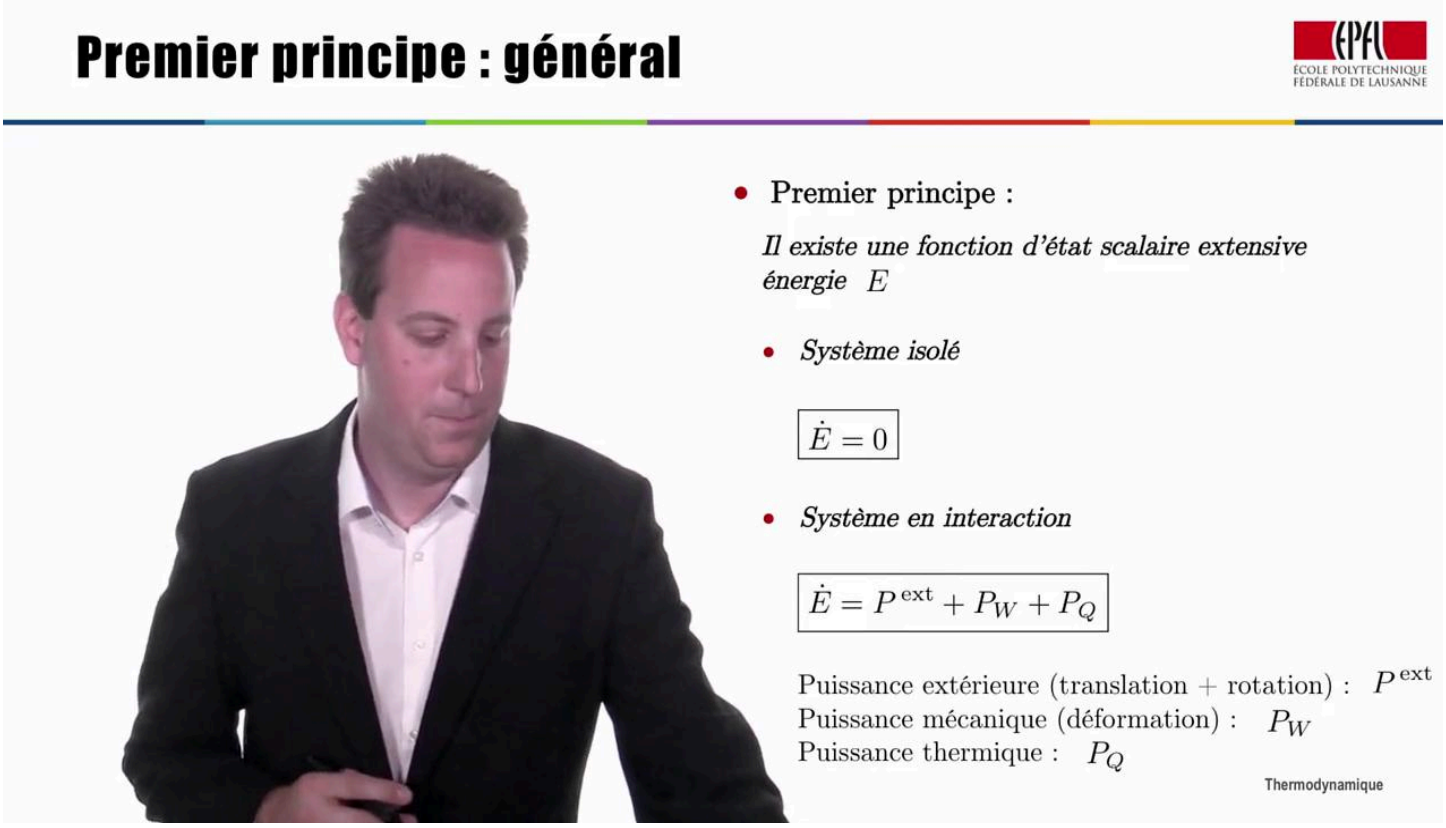


Hello and welcome to make fun of thermodynamics. This lesson is devoted to the first principle. Thermodynamics is based on two fundamental principles which are the first and second principles. It is with the help of these two principles that laws can be derived. First, in this lesson, we will formulate the first principle. In general, we will try to consider two extensions of this first principle in translation first, then in rotation. Next, and it is with the help of this first principle, in a second time, that we can establish an explicit link between thermodynamics and mechanics. In order to establish this link, we will introduce the quantities which are energy, kinetic energy, and in translation first, then in rotation, and the internal energy. And it is thanks to this notion of internal energy that we will be able to to formulate the first principle in the reference frame where the system is at rest. Let's start with the general formulation of the first principle of thermodynamics. This first principle states that for any thermodynamic system, there is a scalar state function and extensive that we call energy and that we denote by the letter. It meets the following two conditions.

Notes

Summary

0m 05s



First, if the system is isolated, the time derivative of the energy is zero, which means that the energy is a constant. Second, if the system is interacting with externally, the cause of the variation of the energy because of the time derivative of the energy is a power. So, there are three types of power that cause the variation of the first one. The first type of power is the external power and external which causes the modification of states of translational motion or the state of rotational motion. The second type of power is mechanical power, the mechanical power that causes the deformation of the system. This mechanical power is denoted by a p. W. And then the third type of power, is the thermal power denoted by 1PQ and describes the heat exchange between the system and the outside.

Notes

Summary

1m 43s

Premier principe : rotation

- Premier principe (rotation) :

  Il existe une fonction d'état vectorielle extensive moment cinétique $\boldsymbol{L}$

  - *Système isolé*

    $$\boxed{\dot{\boldsymbol{L}} = \boldsymbol{0}}$$

  - *Système en interaction (thm. du moment cinétique)*

    $$\boxed{\dot{\boldsymbol{L}} = \boldsymbol{M}^{\,\text{ext}}}$$

  Résultante des moments de forces extérieures : $\boldsymbol{M}^{\,\text{ext}}$

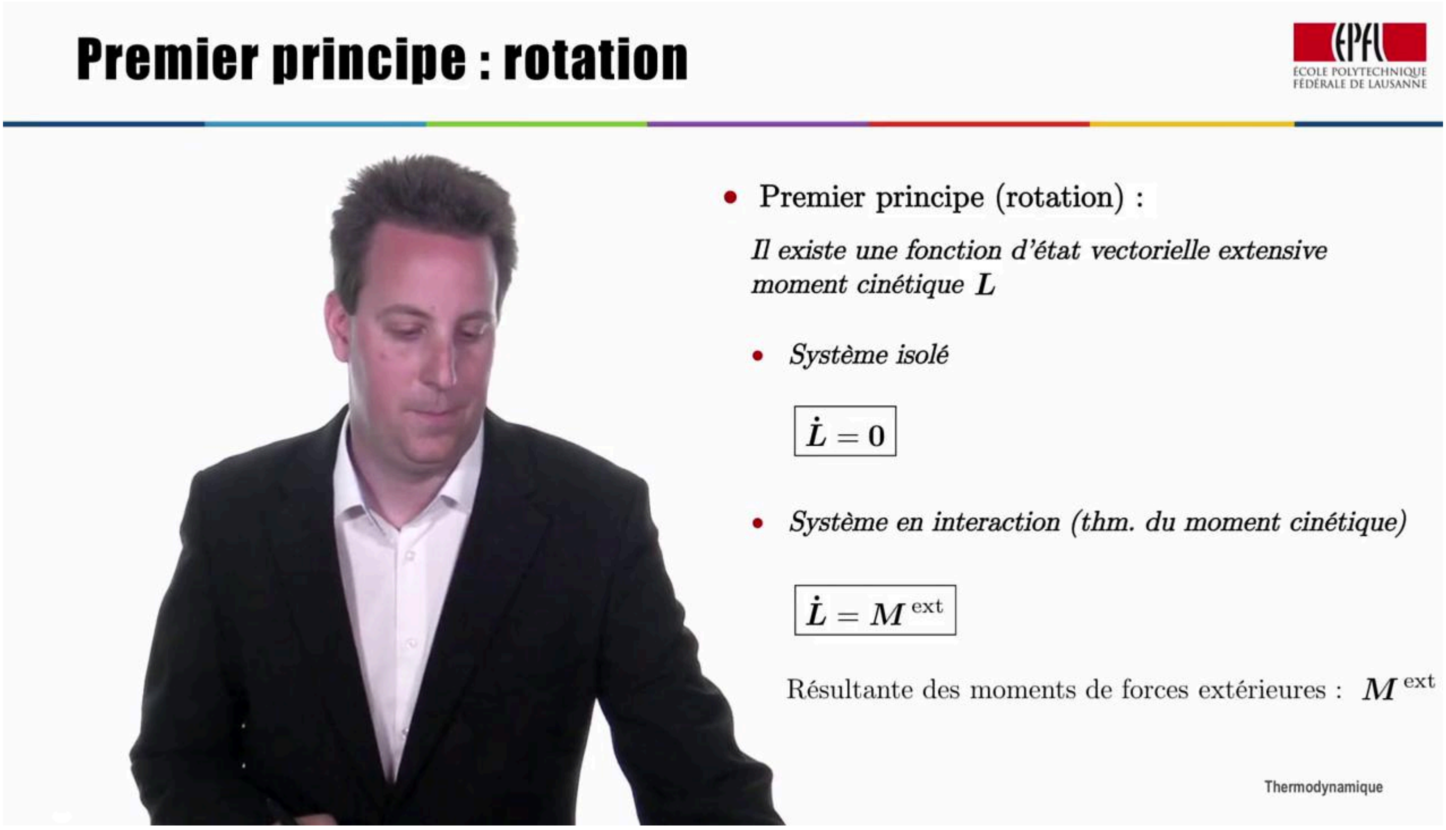
Thermodynamique

We can now extend this first principle to translation. This extension states that for any thermodynamic system, there is an extensive vector state function which is called the quantity of movement and that we will denote by the letter P. It meets the following two conditions. If the system is isolated, the time derivative of the momentum is zero. This means that the momentum is a constant. In other words, the system is in uniform rectilinear motion. If the system is interacting. Second. The cause that causes the variation of the system's momentum. It is the resultant of the external forces f. Ext. So the time derivative of the quantity of motion is equal to the resultant of the external forces. This is called the center of mass theorem. In mechanics. The second extension of the first principle has to do with rotation. It states that for any thermodynamic system, there is a vector state function This is called the angular momentum and is denoted by the letter L. It meets the following two conditions. First, if the system is isolated, the time derivative of angular momentum is zero, which means that the angular momentum is a constant. Therefore, in this case, the system is in uniform circular motion.

Notes

Summary

3m 01s

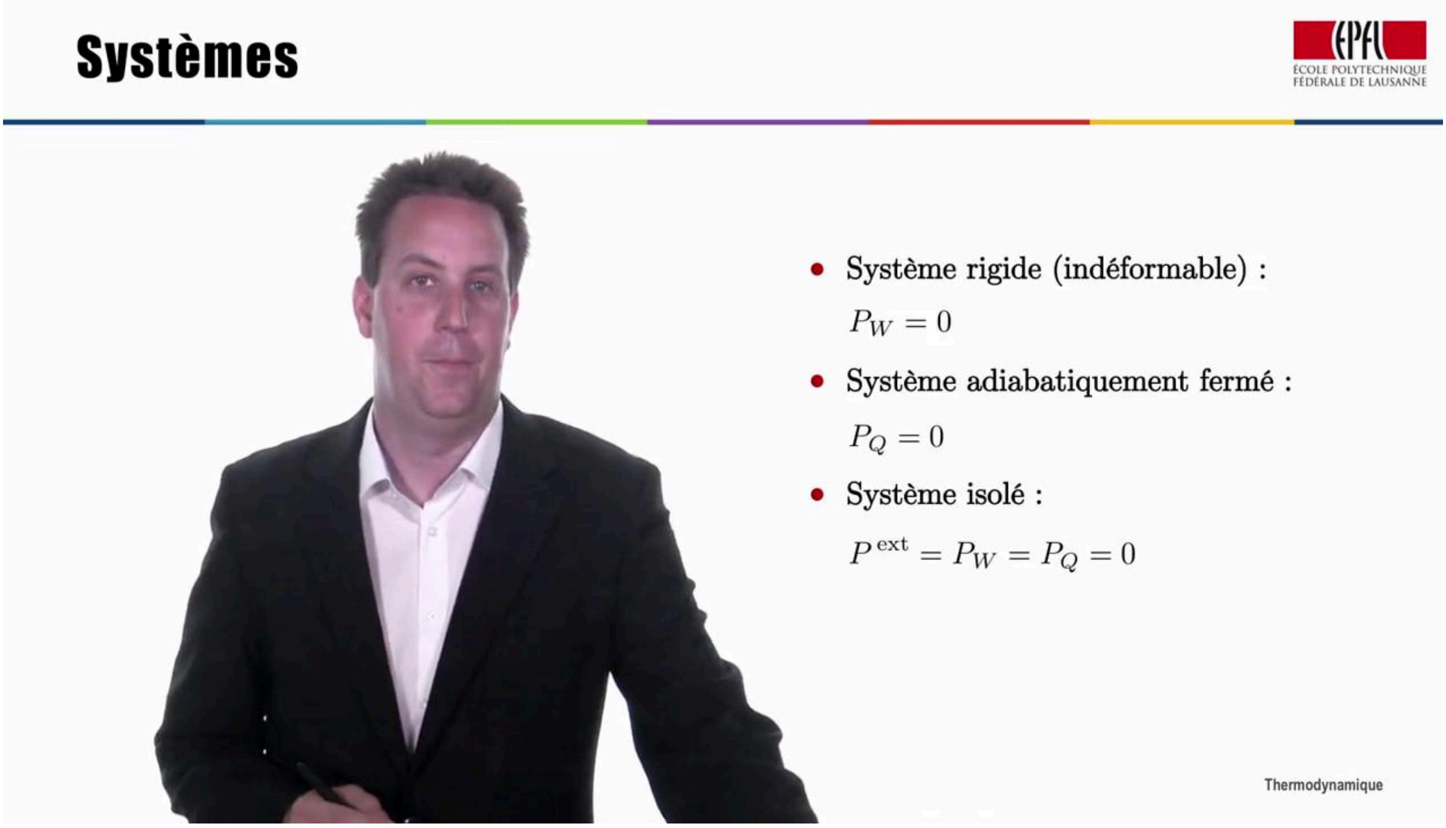


Second, if the system is interacting with the outside world. The cause of the variation of the angular momentum. It is the resultant of the moments of external forces. Therefore, the time derivative of angular momentum is. The point is equal to the resultant of the moments of external forces. This is well known in mechanics since it is the angular momentum theorem.

Notes

Summary

4m 46s



With the help of these powers that we have just defined, we can categorize the different types of thermodynamic systems. If the system is rigid, i.e. non-deformable, the mechanical power of deformation PW will be zero. If the system is adiabatically closed, i.e. there is no heat exchange between the system and the outside. In this case, the thermal power PQ will be zero. If the system is isolated, i.e. there is no interaction between the system and outside, all powers are zero, which means that the external power, the mechanical power and the thermal power PQ are zero.

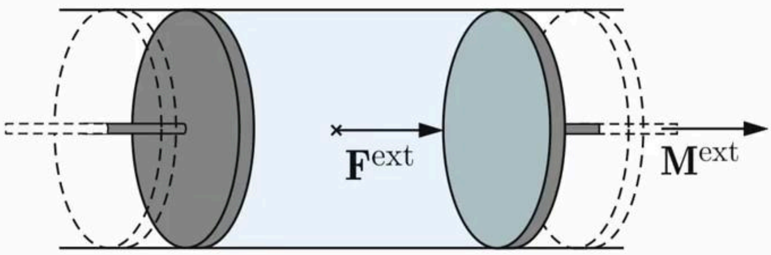
Notes

Summary

5m 18s

Thermodynamique et mécanique

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



- Variables d'état extensives :

  $\{\boldsymbol{P}, \boldsymbol{L}, X_0, X_1, .., X_n\}$

- Quantité de mouvement + théorème du centre de masse :

  $\boldsymbol{P} = M\,\boldsymbol{v} \qquad \Rightarrow \qquad \boldsymbol{F}^{\,\text{ext}} = \dot{\boldsymbol{P}} = M\,\dot{\boldsymbol{v}}$

- Moment cinétique + théorème du moment cinétique :

  $\boldsymbol{L} = I\,\boldsymbol{\omega} \qquad \Rightarrow \qquad \boldsymbol{M}^{\,\text{ext}} = \dot{\boldsymbol{L}} = I\,\dot{\boldsymbol{\omega}}$

Thermodynamique

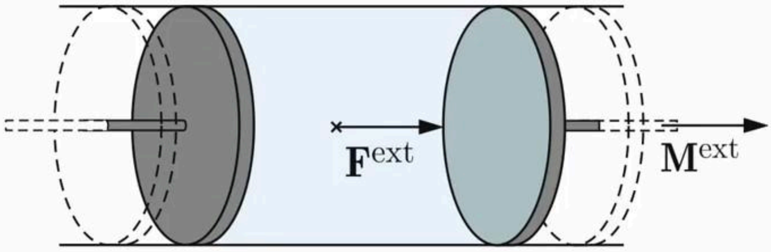
Thanks to this first principle, we are now able to establish an explicit link between thermodynamics and mechanics. For this, we will consider a system. Which is general enough to allow this link. This system is as follows. It is a homogeneous gas which is in a cylinder which is closed by two pistons that are free to slide in the cylinder. This cylinder can be a movement of translation in space and it can also be a movement of rotation around its central axis of symmetry. To be able to describe the state of this system, you will have to specify the corresponding extensive state variables to describe the translational state of motion of the system. It will be necessary to choose as state variables the momentum P to describe the state of motion of this system around its axis of symmetry, it will be necessary to choose as state variables the angular momentum L and in all generality, it is still necessary to add internal extensive state variables which allow to describe the internal thermodynamics of the gas. These variables are the variables x0 x1 up to xn. The momentum of the system. P is equal to the product of the mass. Times the speed V.

Notes

Summary

6m 14s

Thermodynamique et mécanique



- Variables d'état extensives :

  $\{\boldsymbol{P}, \boldsymbol{L}, X_0, X_1, .., X_n\}$

- Quantité de mouvement + théorème du centre de masse :

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- Moment cinétique + théorème du moment cinétique :

  $\boldsymbol{L} = I\,\boldsymbol{\omega} \qquad \Rightarrow \qquad \boldsymbol{M}^{\text{ext}} = \dot{\boldsymbol{L}} = I\,\dot{\boldsymbol{\omega}}$

Thermodynamique

Here, we can apply the center of mass theorem which states that the resultant of the external forces f ext is equal to to the time derivative of the momentum of the points. Since the gas is enclosed in the cylinder, the mass is constant, which means that p is equal to m v point. The angular momentum of the system is defined as the product of the moment of inertia with respect to the axis of symmetry. Times the omega angular velocity. We can apply the angular momentum theorem which states. That the resultant of the external force moments m ext is equal to. The time derivative of angular momentum is the point. As the moment of inertia is constant, it also points i omega point.

Notes

Summary

7m 51s

Energie, énergie cinétique et énergie interne

- Energie fonction d'état :
  $E\left(\boldsymbol{P},\boldsymbol{L},X_0,X_1,..,X_n\right)$
- Grandeurs intensives conjuguées :
  - Vitesse
    $$\boldsymbol{v}=\frac{\partial E\left(\boldsymbol{P},\boldsymbol{L},X_0,X_1,..,X_n\right)}{\partial \boldsymbol{P}}=\frac{\boldsymbol{P}}{M}$$
  - Vitesse angulaire
    $$\boldsymbol{\omega}=\frac{\partial E\left(\boldsymbol{P},\boldsymbol{L},X_0,X_1,..,X_n\right)}{\partial \boldsymbol{L}}=\frac{\boldsymbol{L}}{I}$$
- Energie :
  $$E\left(\boldsymbol{P},\boldsymbol{L},X_0,X_1,..,X_n\right)=\frac{1}{2}\boldsymbol{v}\cdot\boldsymbol{P}+\frac{1}{2}\boldsymbol{\omega}\cdot\boldsymbol{L}+U(X_0,X_1,..,X_n)$$

Thermodynamique

the Energy of this system is a state function. It is therefore a function of the different state variables of the system and is a function of p, l and the set of x, i.e. x0, x1 up to xn. Can now define the intensive quantities, conjugate respectively to the momentum P and the angular momentum L. The size combined with the quantity of movement p, it is the speed V which, in a thermodynamic perspective, is defined as the derivative of the energy with respect to the momentum p. Moreover, it is known that the speed is obtained by taking the ratio of the momentum p to the mass M. The angular speed is defined as the intensive quantity conjugated to the angular momentum l. In a thermodynamic approach, it is defined as the partial derivative of with respect to l. Moreover, it is known that it is equal to the ratio of the angular momentum l divided by the moment of inertia. Given its two relations for velocity and angular velocity. We are now able to express this energy explicitly as a function of the variables p, l and the set of X. This energy consists of three terms. The first term. Corresponds to the kinetic energy of translation. It is expressed as half of the product scalar of the velocity for the momentum.

Notes

Summary

8m 52s

Dérivée temporelle de l'énergie

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

- Dérivée temporelle de l'énergie :

$$\dot{E}\left(\boldsymbol{P}, \boldsymbol{L}, X_0, X_1, .., X_n\right) = \boldsymbol{v} \cdot \dot{\boldsymbol{P}} + \boldsymbol{\omega} \cdot \dot{\boldsymbol{L}} + \dot{U}(X_0, X_1, .., X_n)$$

- Théorèmes du centre de masse et du moment cinétique :

$$\dot{E} = \boldsymbol{F}^{\,\text{ext}} \cdot \boldsymbol{v} + \boldsymbol{M}^{\,\text{ext}} \cdot \boldsymbol{\omega} + \dot{U}$$

- Puissance extérieure (translation + rotation) :

$$P^{\,\text{ext}} = \boldsymbol{F}^{\,\text{ext}} \cdot \boldsymbol{v} + \boldsymbol{M}^{\,\text{ext}} \cdot \boldsymbol{\omega} \quad \Rightarrow \quad \dot{E} = P^{\,\text{ext}} + \dot{U}$$

- Premier principe :

$$\dot{E} = P^{\,\text{ext}} + P_W + P_Q$$

- Premier principe (référentiel au repos) :

$$\dot{U} = P_W + P_Q$$

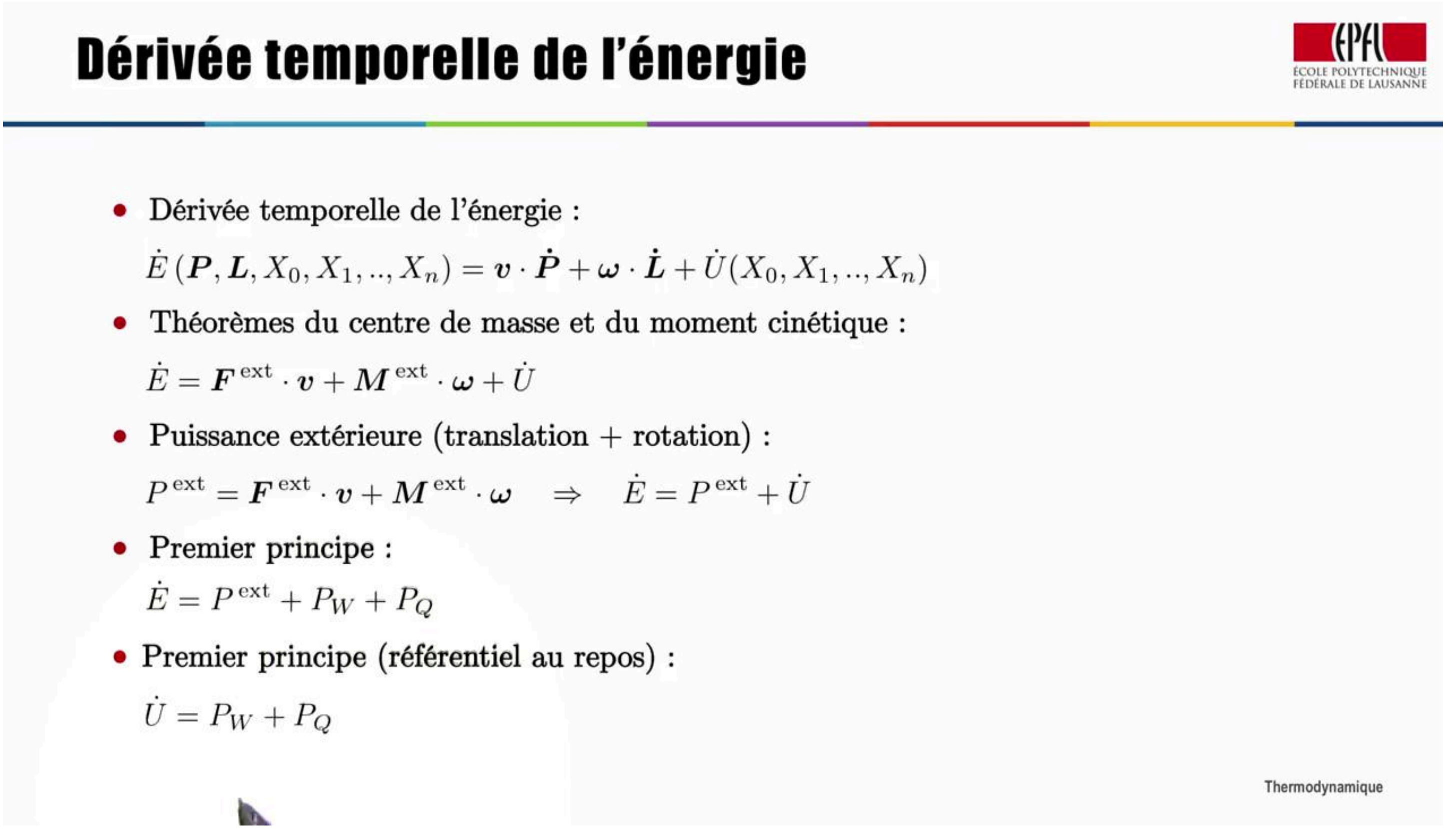
Thermodynamique

The second term corresponds to the kinetic energy of rotation. It is expressed as a half of the scalar product between the angular velocity and angular momentum, and there remains a third term. This third term is independent of the state of motion. It is independent of the PL variables. It depends only on the internal variables x0, x1 up to XN. This type of energy is therefore the internal energy of the system. In the particular case. Or P and they are zero, i.e. there is no state of motion. In this case and in this case only, the energy of the system is reduced to the internal energy. the internal energy U is therefore interpreted as as the energy of the system in the reference frame where the system is at rest. We want to determine the thermodynamics of this system. In the word thermodynamics, there is the word dynamic. The word dynamic means that we are interested in a temporal evolution. So we make derivatives that depend on time. The first step will be to. Determine the time derivative of the energy. Energy is a state function that depends on the state variables of the system. The time derivative of the energy will consist of three terms.

Notes

Summary

10m 35s



The first term is obtained by taking the partial derivative of the energy with respect to the momentum. Then we take the scalar product with the derivative of the momentum with respect to time. The second term is obtained by taking the partial derivative of the energy with respect to the angular momentum. Then we take the scalar product with the time derivative of the angular momentum. And then the third term, is simply the time derivative of the internal energy. Which depends on internal variables. X0 x1 up to xn. Now, we try to express the time derivative of P, the time derivative of l in terms of the causes that give them birth, that is to say, the resultant of the external forces on the one hand, and the resultant of the moments of external forces on the other. On the other hand, we do this using the center of mass and angular momentum theorems. If we now look at this derivative with respect to time of the energy. Well, by mechanics, we recognize the first two terms. The first two terms correspond to the external power. Which allows to modify the state of motion of translation and rotation of the system. It is the power as we define it in solid mechanics, undeformable and external.

Notes

Summary

12m 11s

Dérivée temporelle de l'énergie

- Dérivée temporelle de l'énergie :

$$\dot{E}\left(\boldsymbol{P},\boldsymbol{L},X_0,X_1,..,X_n\right)=\boldsymbol{v}\cdot\dot{\boldsymbol{P}}+\boldsymbol{\omega}\cdot\dot{\boldsymbol{L}}+\dot{U}(X_0,X_1,..,X_n)$$

- Théorèmes du centre de masse et du moment cinétique :

$$\dot{E}=\boldsymbol{F}^{\,\text{ext}}\cdot\boldsymbol{v}+\boldsymbol{M}^{\,\text{ext}}\cdot\boldsymbol{\omega}+\dot{U}$$

- Puissance extérieure (translation + rotation) :

$$P^{\,\text{ext}}=\boldsymbol{F}^{\,\text{ext}}\cdot\boldsymbol{v}+\boldsymbol{M}^{\,\text{ext}}\cdot\boldsymbol{\omega}\quad\Rightarrow\quad\dot{E}=P^{\,\text{ext}}+\dot{U}$$

- Premier principe :

$$\dot{E}=P^{\,\text{ext}}+P_W+P_Q$$

- Premier principe (référentiel au repos) :

$$\dot{U}=P_W+P_Q$$

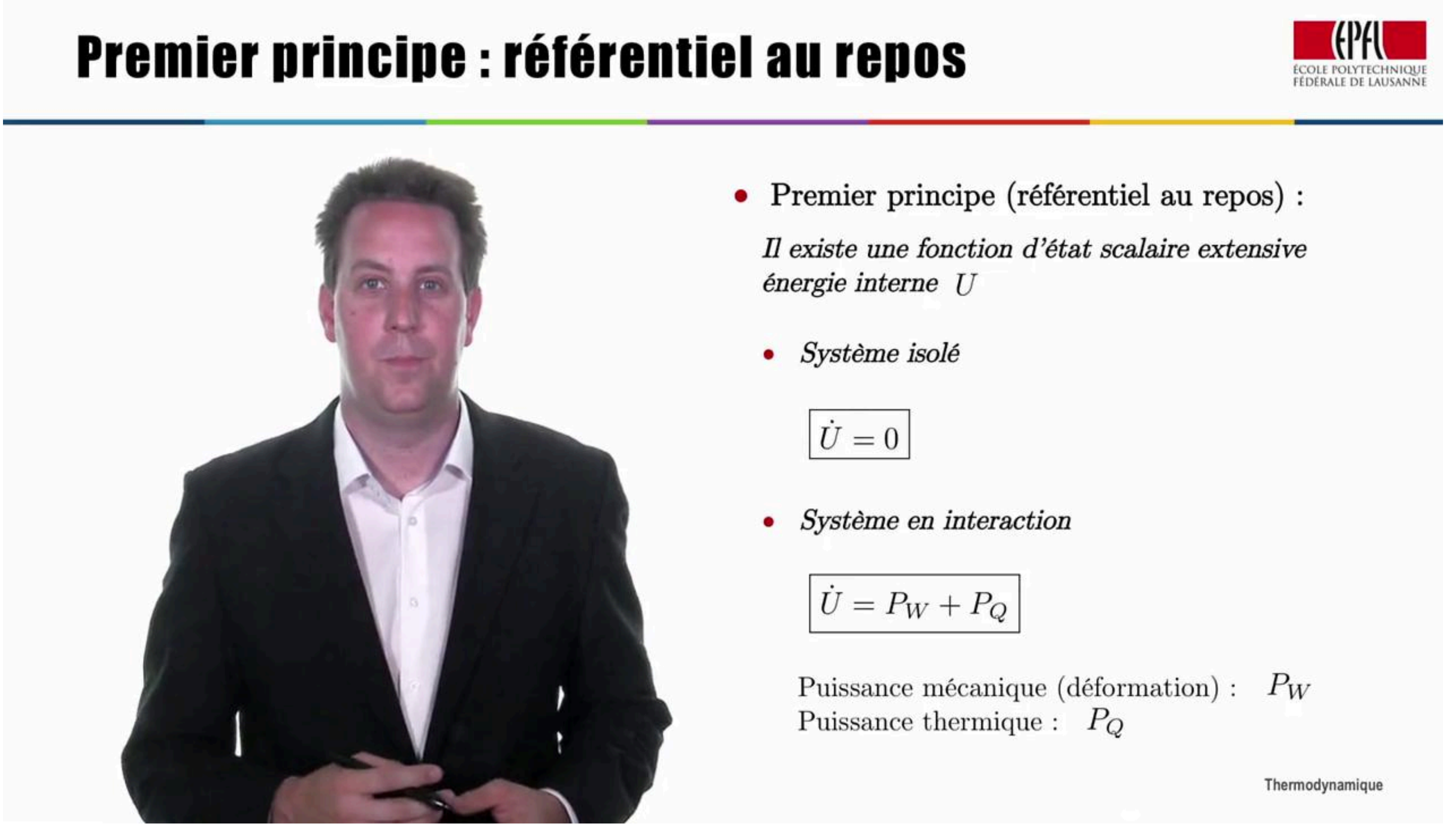
Thermodynamique

And consisting of two terms. The first term is the scalar product of the external effect with the speed and the second term is the product scalar of m outside with the angular velocity. Therefore, we can express the derivative with respect to to the time of the energy, as the sum of the external power e.g. and the derivative with respect to time of the internal energy of the point. Now we can compare. This expression of the derivative with respect to at the time of the energy, with the expression of the derivative with respect to time of the energy obtained by the first principle which states that this derivative of energy with respect to time is equal to the exterior. Plus pw, plus pq. By comparing these two equations. We obtain what is called the first principle in the reference frame. At the end, the system is at rest. That is, we have an explicit expression for the time derivative of the internal energy of the point which is equal to the sum of two contributions the mechanical power of deformation PW and the thermal power PQ.

Notes

Summary

13m 38s



We can now reformulate the first principle in the following way formal in the frame of reference where the system is at rest. In this frame of reference. The first principle states that there is an extensive scalar state function, called internal energy, denoted by the letter u satisfies the following two conditions. Firstly, if the system is isolated, the time derivative of the internal energy of the point is zero, which means that the internal energy u is a constant. Second, if the system is interacting with the outside, the cause of the variation of the internal energy. The point is precisely due to two powers the mechanical power of deformation PWR and the thermal power PQ.

Notes

Summary

14m 53s