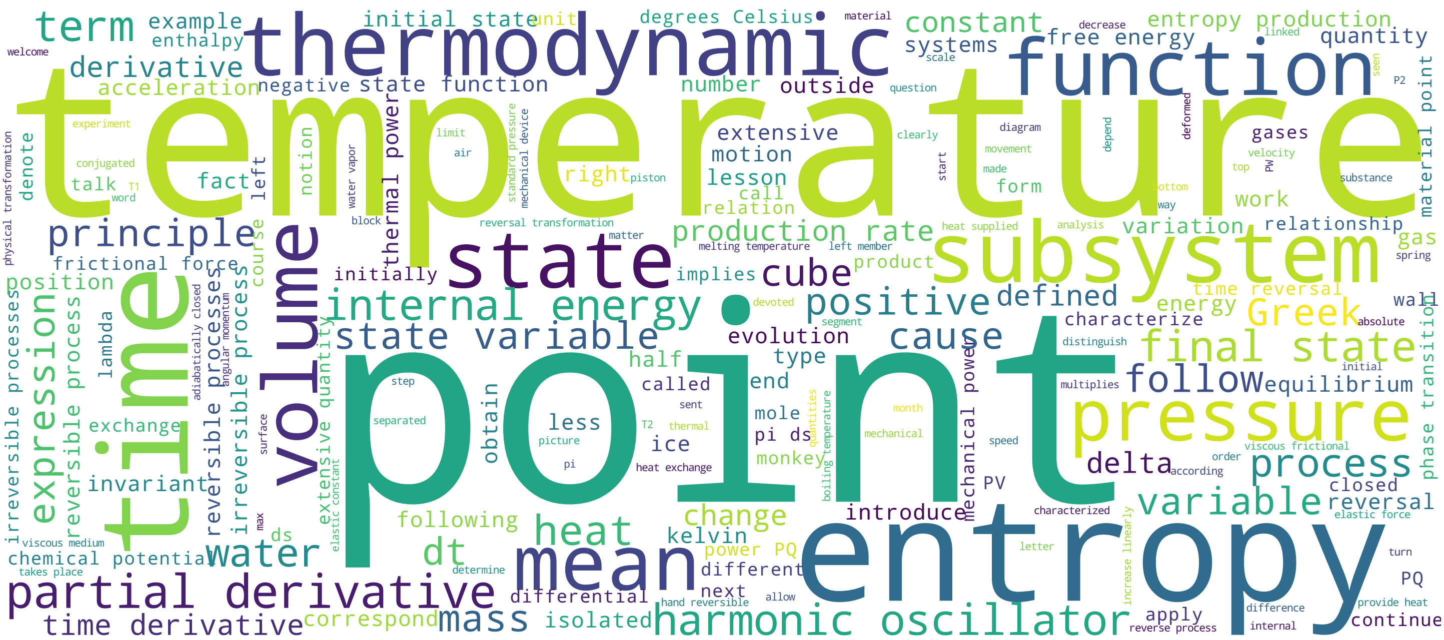
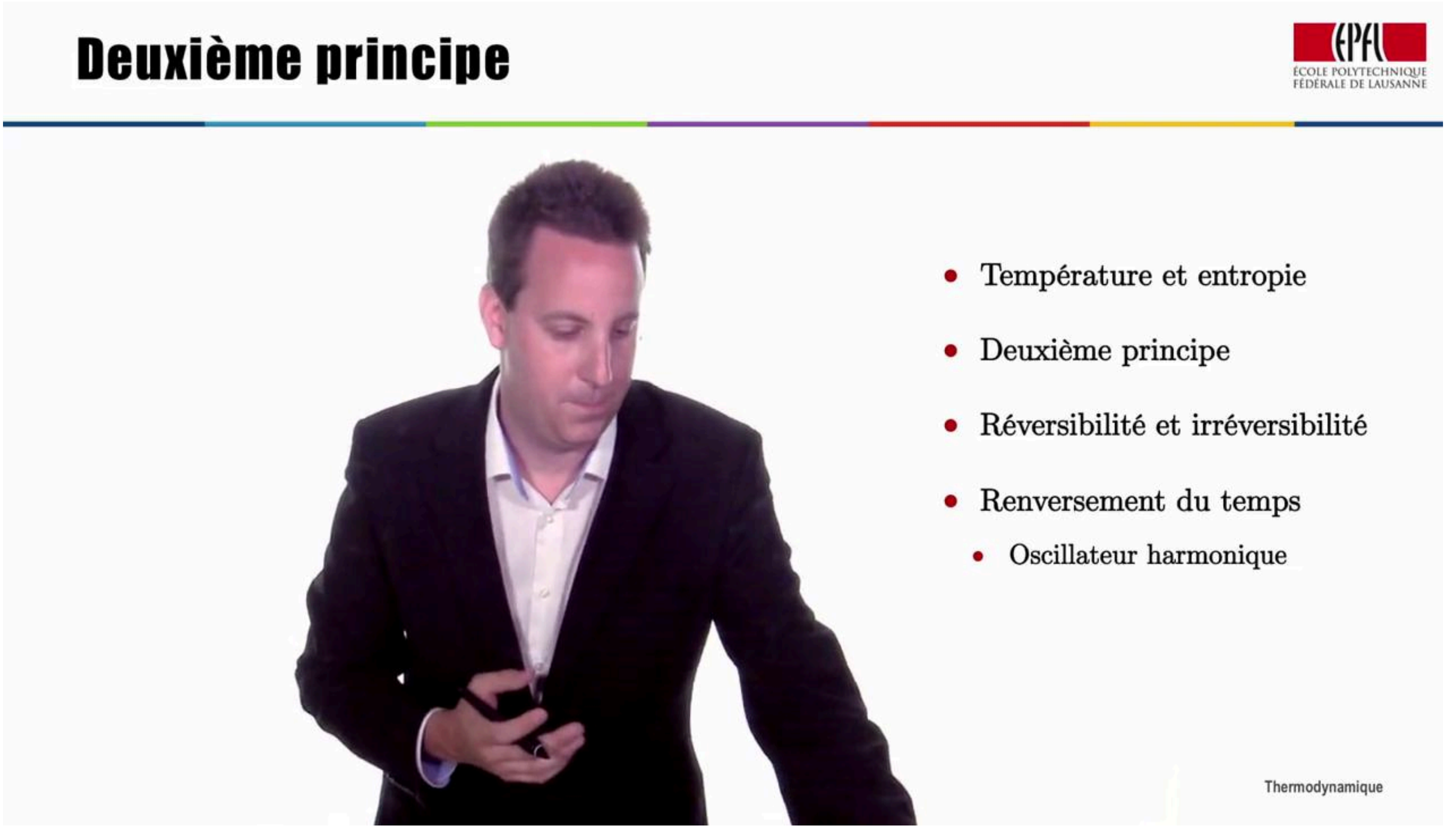
Thermodynamique

Deuxième principe

Dr. Sylvain Bréchet

Rudolf Clausisus, 1822 - 1888





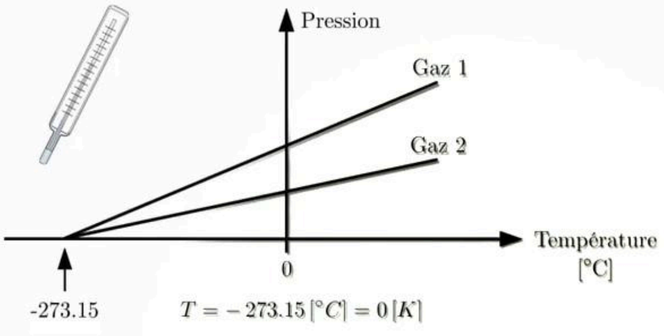
Hello and welcome to the thermodynamics wall. This lesson is devoted to the second principle. At first, we will introduce in an intuitive way two central notions in thermodynamics. It is the temperature and the entropy thanks to the entropy. We will then be able to define, to state the second principle of thermodynamics. This second principle leads us to to distinguish two different types of processes. On the one hand reversible processes and on the other hand irreversible processes. We will see that this distinction between reversibility and irreversibility is linked to a physical transformation fundamental that we call the reversal of time. We will consider a particular example which is the harmonic oscillator.

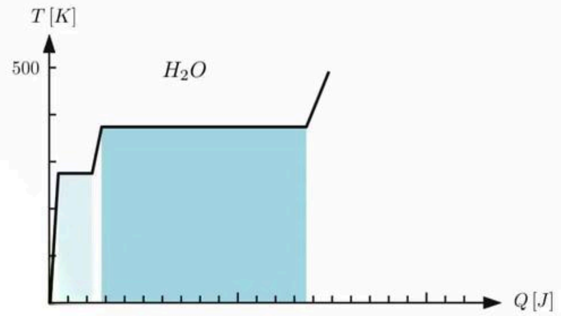
Notes

Summary

0m 05s

Température et entropie





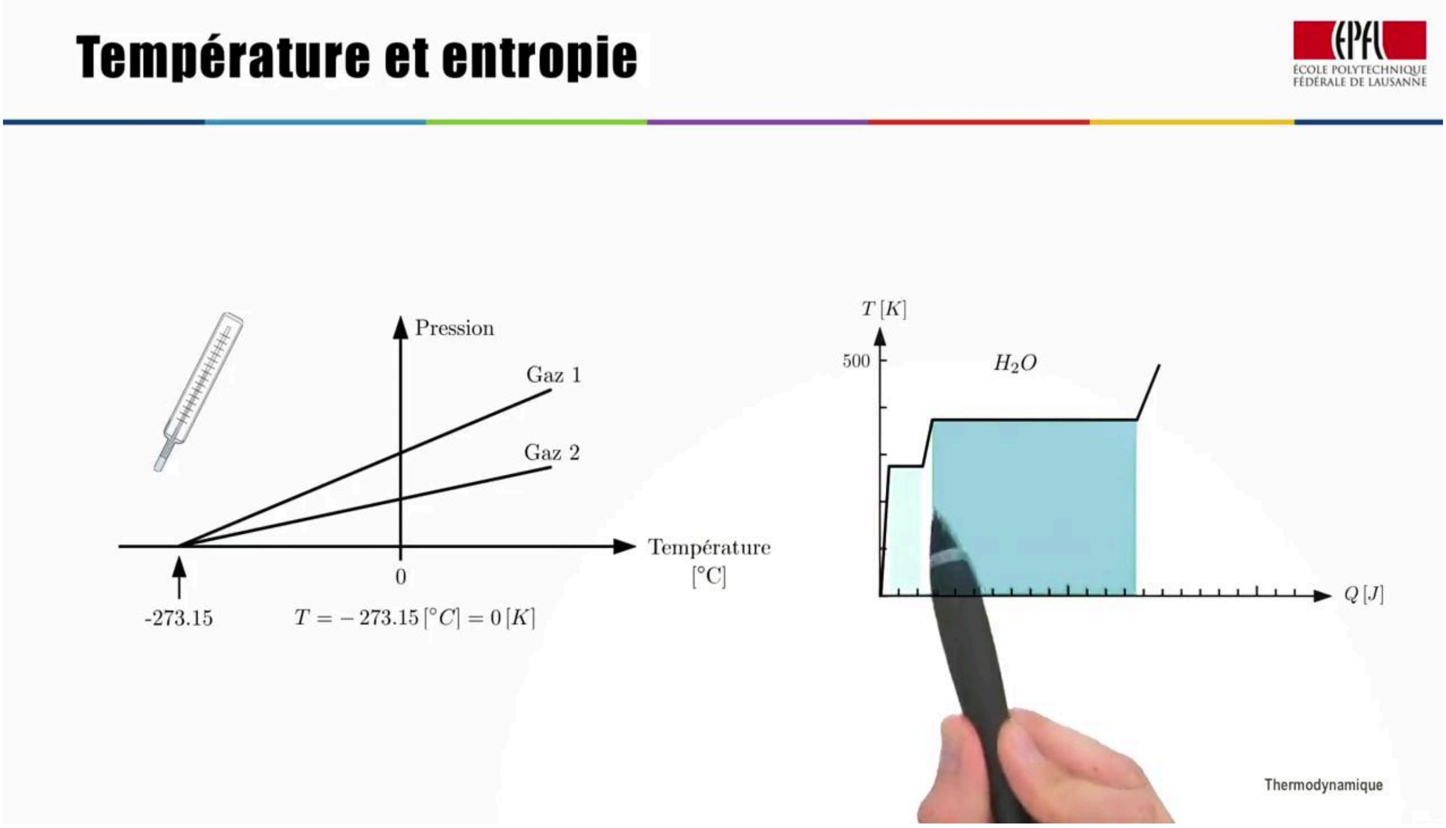
Thermodynamique

Temperature is a very intuitive physical concept. If we take for example water and we touch this water, well, we can quickly decide on the sensation we have of this water, whether it is icy, whether it is cold, whether it is lukewarm, if it is hot or if it is boiling. We can therefore order these sensations according to a scale. This scale is the temperature scale. So there are several types of units for temperature. One of the most common units, is the degrees Celsius, which are defined as follows. Zero degrees Celsius. This is the melting temperature of ice at standard pressure and 100 degrees Celsius. This is the boiling temperature of water at standard pressure. There are other units, such as Fahrenheit degrees which are more used on the other side of the Atlantic, and then the fundamental unit of the International System of Units. Thus, for the temperature, it is the kelvin. To define the kelvin, we will consider two different gases that are sufficiently diluted. Diluted gases have a property interesting, namely that their pressure depends linearly on their temperature. So, if we represent the state of these gases on a pressure-temperature diagram, we are going to have two lines for these two gases of gas and two gases.

Notes

Summary

1m 04s



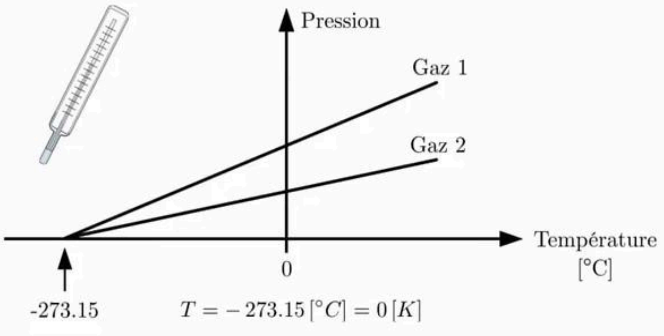
It's right-wing. They can be extrapolated to lower temperatures. And it is from the right that will end up cutting into a point whose pressure is zero and whose temperature is less than 100 sept. 3.15 degrees Celsius. This temperature is the temperature of absolute zero which corresponds to the origin of the Kelvin scale. It is therefore zero kelvin. A change of one degree Celsius corresponds to a change of one kelvin. The temperature is of course a fundamental quantity which we need to talk about thermal phenomena. The question we can ask ourselves is whether we don't need also of another magnitude, an extensive magnitude. To answer this question. We will consider that we take a cube of ice and this cube, we will heat it. Initially, it is close to absolute zero. We save it gradually, so we provide it with heat and its temperature will increase linearly with heat. This is what we see here on this temperature-heat diagram. That's the segment that's there. The temperature increases linearly until a temperature, threshold which corresponds to the melting temperature of the ice. And if we continue to provide heat to this block of ice, well, its temperature will remain constant.

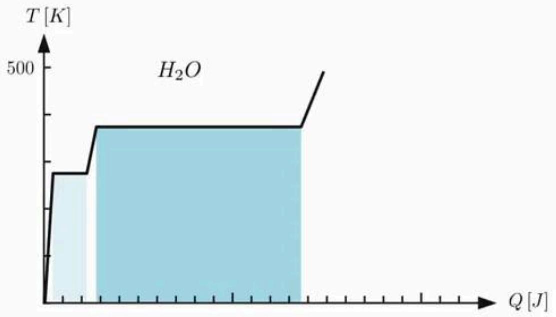
Notes

Summary

2m 44s

Température et entropie





Thermodynamique

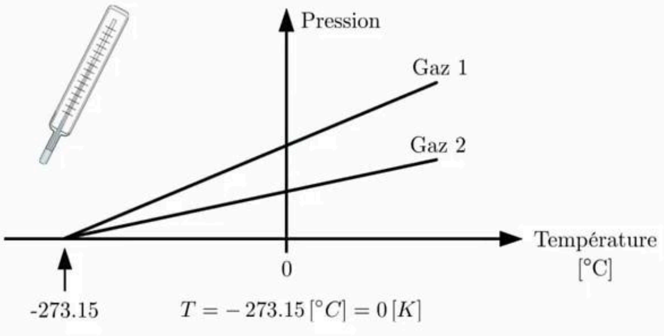
It is this melting temperature. During this process, the ice block will melt, so it will turn into water. Then if we continue to heat this block of ice. The temperature will increase linearly with the heat supplied. It is this second segment here, until we reach a second temperature, which is the boiling temperature of the water. And then, if we continue to provide heat, well, the water will gradually turn into water vapor. What will be interesting to remember on this diagram is that there are essentially two levels which correspond to a phase transition. That is to say that H2O passes from the solid state, i.e. the ice to the state liquid, i.e. water and waters pass from the liquid state, i.e. water in its gaseous state, i.e. water vapor. This phase transition takes place at constant temperature. Therefore, it will take another This is the only way to characterize this phase transition. There is something going on. The substance changes its behavior, it changes its appearance. To be able to model this. The quantity to be introduced is an extensive quantity. This extensive quantity is the quantity that is conjugated to the temperature. This is entropy. This entropy has already been encountered.

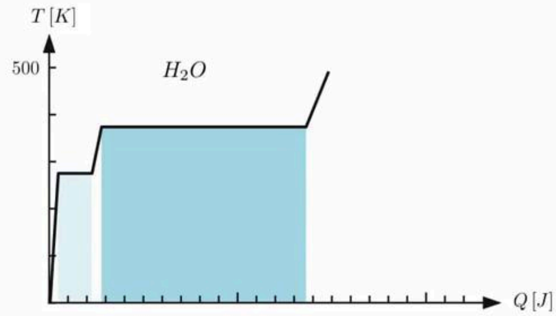
Notes

Summary

4m 14s

Température et entropie





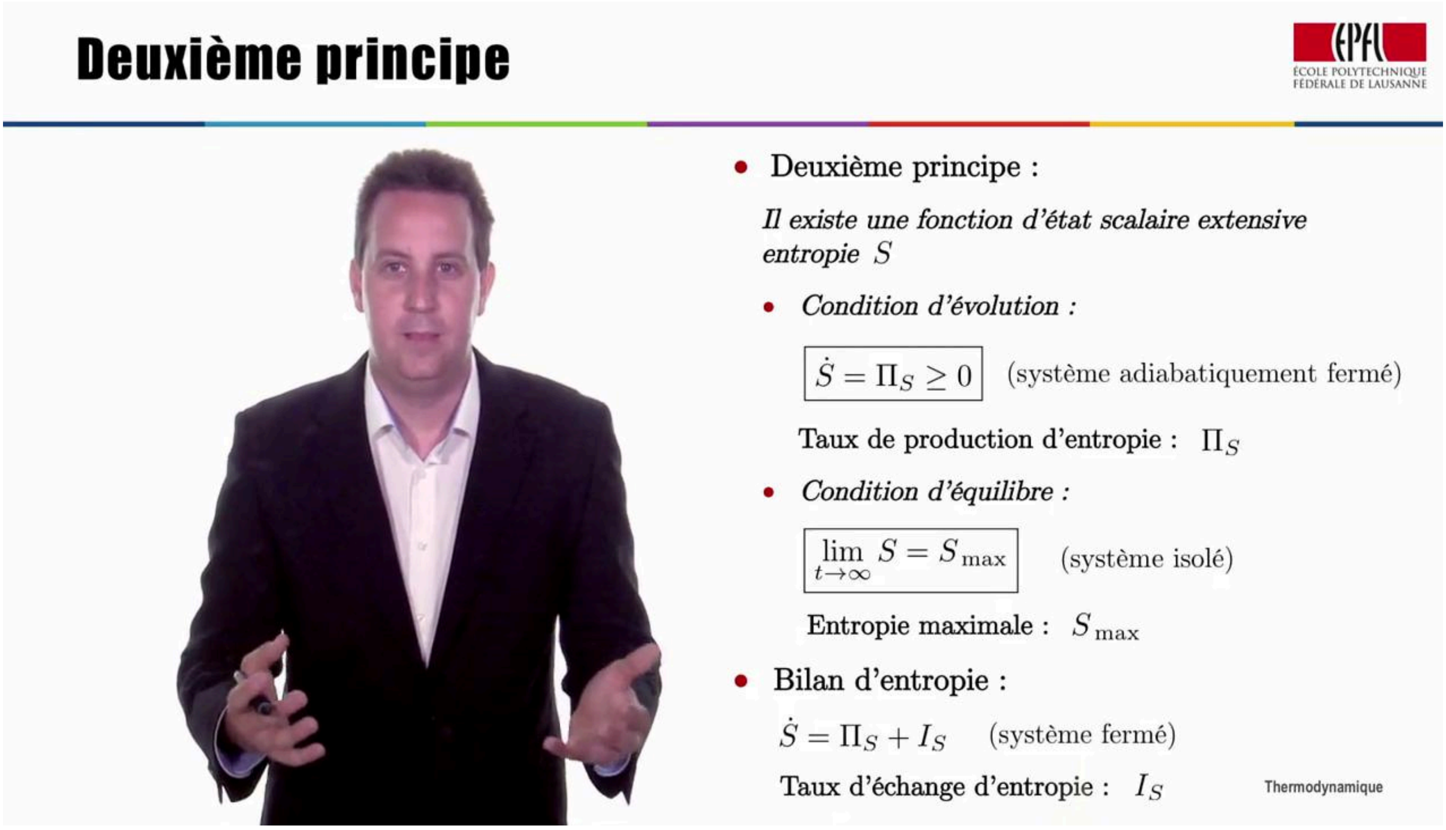
Thermodynamique

When we have dealt with thermodynamics of the harmonic oscillator, we saw that we had to introduce a new extensive quantity which was a state variable of the system. And this greatness has been identified at the end of this analysis of harmonic oscillator to entropy. The entropy is thus a quantity fundamental in thermodynamics and it turns out that entropy is at the very heart of of the second principle of thermodynamics.

Notes

Summary

5m 44s

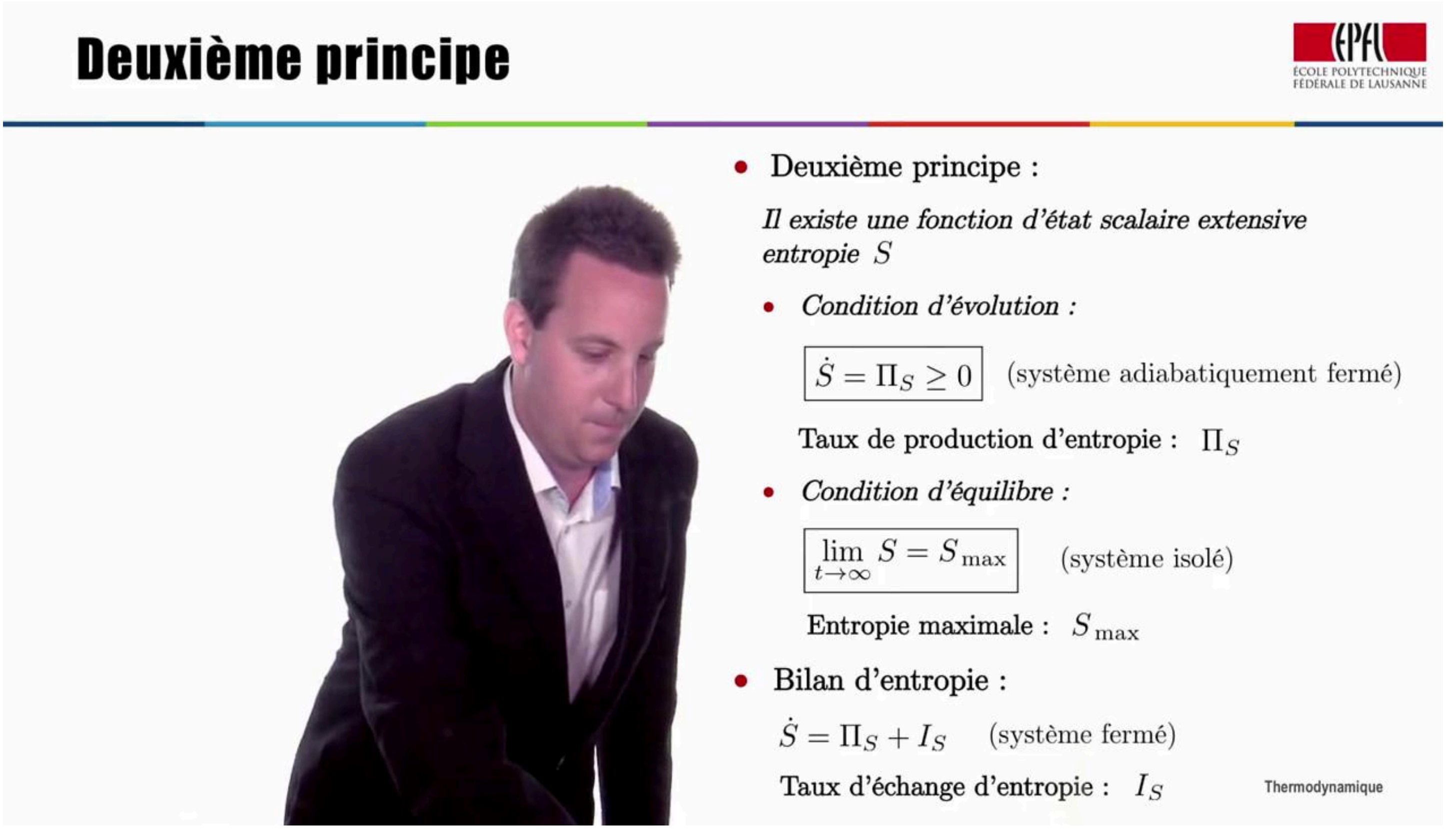


This second principle of thermodynamics is stated as follows. For any thermodynamic system, there exists a state function which is scalar and extensive, that we call entropy and that we denote by the letter S. This entropy satisfies two conditions. First of all, a condition of evolution when the system is adiabatically closed, i.e. when there is no exchange of heat between the system and the outside. In this case, the cause of the entropy variation the cause of the time derivative of entropy. It is a cause that predates the system. This is the entropy production rate. We also talk about production rate internal entropy that we will denote by pi ds. And this condition of evolution is that pi of ds can be positive, it can be zero. But never ever Pi de S will be negative. The second condition is the condition of equilibrium of the system. For an isolated system, i.e. when there is no interaction between the system and the outside. For such a system, if you wait long enough, the entropy will tend towards a maximum value which we call s max. In mathematical terms, it is the limit when the time tends to infinity of the entropy.

Notes

Summary

6m 13s



This maximum company, S-Max, must be compatible with the constraints that are imposed on the system, such as the fact that the system is made up of sub-systems that are separated by walls of different nature. It is also useful to introduce an entropy balance for a closed system, i.e. when there is heat exchange between the system and the outside. In this case, there are two causes for the variation of entropy over time. The first cause is already known, is the rate of entropy production which is internal to the system. And the second cause, it is a rate of exchange of entropy between the system and the outside. Let us denote i. From s. This entropy exchange rate can be positive. It can be zero or it can be negative.

Notes

Summary

7m 39s

Réversibilité et irréversibilité

- Processus réversible :

  $\boxed{\Pi_S = 0}$ (état initial $\leftrightarrow$ état final)

- Processus irréversible :

  $\boxed{\Pi_S > 0}$ (état initial $\rightarrow$ état final)

Thermodynamique

The second principle allows us to distinguish between two types of reversible processes on the one hand, and irreversible processes on the other hand. Reversible processes are characterized by the fact that the internal production rate of Hess entropy is zero. What does this mean? This means that we can change the initial and final states in other words. For any reversible process, there is an inverse process for which the state initial corresponds to the final state of the process and the final state corresponds to the initial state of the starting process. Let's consider an example. In the initial state, we have a monkey which is next to a mechanical device and we see that on this mechanical device, the mass is initially at the top. The process is as follows the monkey activates the crank, which makes the mass go down. And in the final state, the mass is at the bottom. This is clearly an irreversible process since we could have started by the right or the mass is at the bottom. The reversible process would have been the monkey cranking the handle in the direction This causes the mass to rise, which in the final state would be at the top. There are reversible processes.

Notes

Summary

8m 41s

Réversibilité et irréversibilité

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

- Processus réversible :

  $\boxed{\Pi_S = 0}$ (état initial $\leftrightarrow$ état final)

- Processus irréversible :

  $\boxed{\Pi_S > 0}$ (état initial $\rightarrow$ état final)

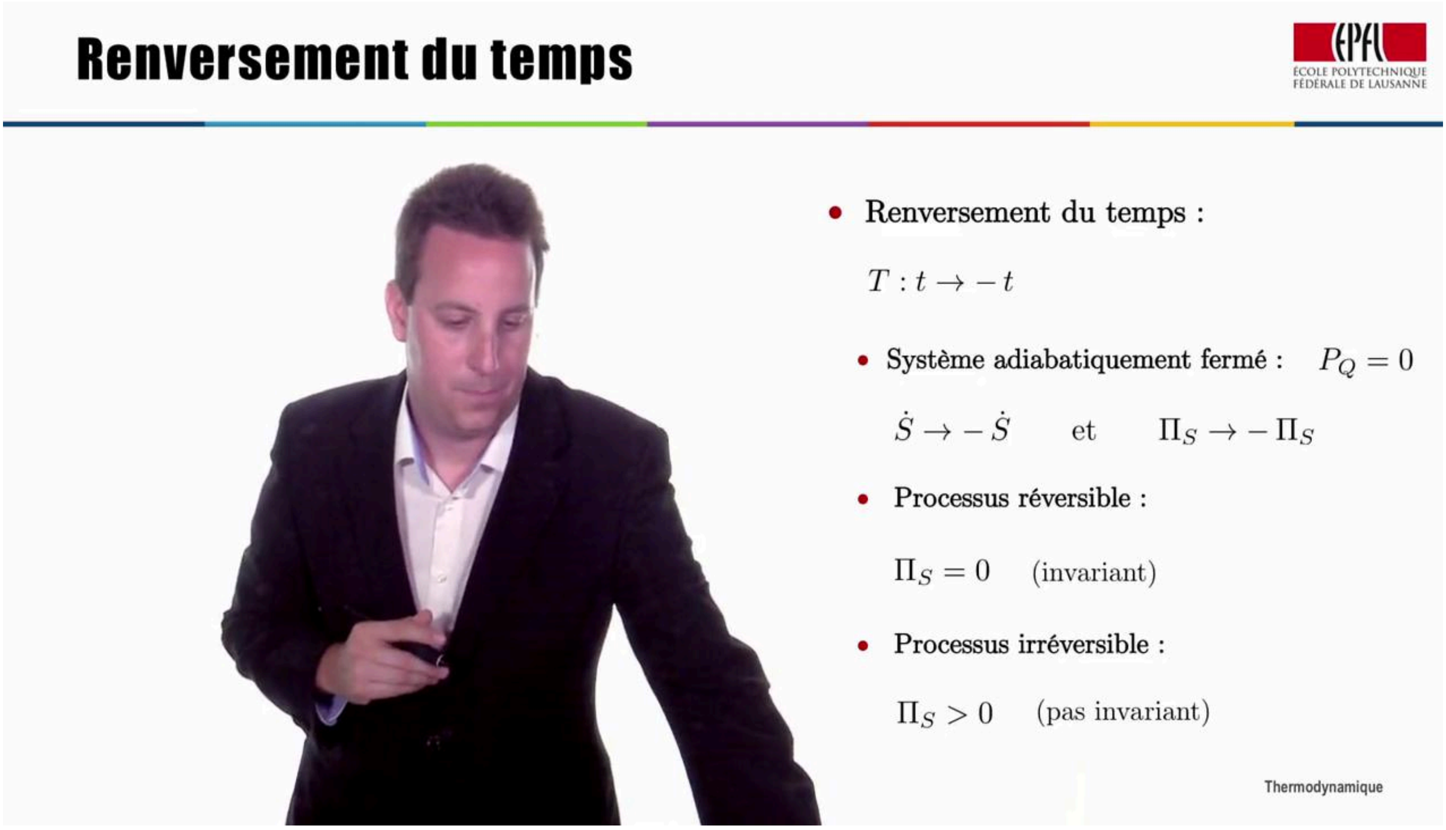
Thermodynamique

There are also irreversible processes. Irreversible processes are defined as follows. The entropy production rate is positive. What does this mean? This means that the initial and final states cannot be changed. If we have an irreversible process that will from an initial state to the final state, there will be no reverse process that would go from the final state that it would be new state to the initial state which would be the new final state. Let's take an example, another mechanical example. The monkey is next to a cube which initially is a nice geometrical cube. The process is as follows the monkey sat on the cube, he would sit on the cube and consequently he will crush the cube. And in the final state, the cube is completely crushed, it is deformed, the monkey is next to it. This process is clearly an irreversible process. Why? Well, the reverse process, if it existed, would correspond to the fact that the monkey climbs on the deformed and damaged cube. And miraculously, this cube is reformed so that it looks like the cube we had for the other process at the beginning. This is clearly science fiction. This will never happen in physics and so the process naturally takes place only from the left. To the right. It is therefore an irreversible process.

Notes

Summary

10m 16s



The physical transformation of a reversal in time allows to distinguish reversible processes from irreversible ones. This time reversal transformation is as follows. And you can see the attempt on itself. It is sent on half. We will now consider a system that is adiabatic, closed. What does it mean? This means that the thermal power PQ is zero. Therefore. If we apply the time reversal to the time derivative of entropy which is equal to ds on dt, we will have been on half. So dt over minus dt, which implies that we will send s point. On this point, and since the system is adiabatically closed, that is to say that PQ equals zero and well is this point going to be equal to the entropy production rate pi of s. So we'll send pi ds on minus pi ds. If we have a reversible process, by definition, PID is equal to zero. This means that a reversible process is invariant by reversal in time. If we have an irreversible process, by definition PDS and positive. As bidasse, of course, less picturesque. So the sign changes. The irreversible process is not invariant by reversal in time.

Notes

Summary

11m 49s

Oscillateur harmonique

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

- Position :

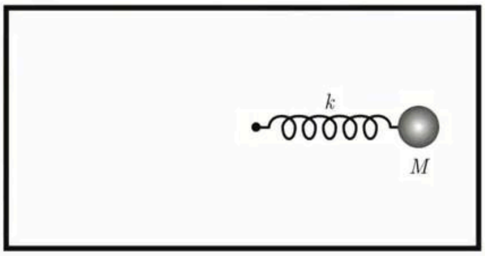
  $\boldsymbol{r} \rightarrow \boldsymbol{r}$
- Vitesse :

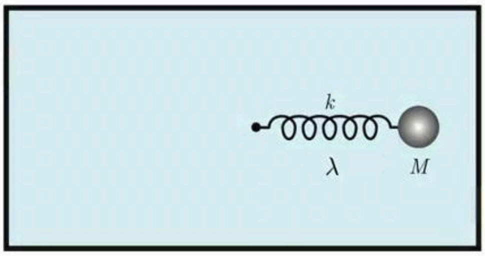
  $\boldsymbol{v} \rightarrow -\boldsymbol{v}$
- Accélération :

  $\boldsymbol{a} \rightarrow \boldsymbol{a}$
- Oscillateur harmonique (réversible) :

  $-k\,\boldsymbol{r} = M\,\boldsymbol{a} \quad \rightarrow \quad -k\,\boldsymbol{r} = M\,\boldsymbol{a}$
- Oscillateur harmonique amorti (irréversible) :

  $-k\,\boldsymbol{r} - \lambda\,\boldsymbol{v} = M\,\boldsymbol{a} \quad \rightarrow \quad -k\,\boldsymbol{r} + \lambda\,\boldsymbol{v} = M\,\boldsymbol{a}$





Thermodynamique

We will now consider an example particular application of this notion of reversal in time. This example is the harmonic oscillator. Let's first consider how the kinematic quantities are transformed by reversal in time. My position is on the R position of ensuring. The velocity is defined as the derivative of the position with respect to time dt on me dt therefore v that adheres on dt it reassures. I V. The third dimension is acceleration. The acceleration is the derivative of the velocity with respect to time dv over dt. The speed goes on itself is based on had t goes on half. Therefore, less per month is more. This means that the acceleration is sent on itself. We will consider two types of harmonic oscillator. In a first step, we will take a non cushioned that we see here on this picture, on the top picture and on this picture. This harmonic oscillator consists of of a material point M connected to a spring of elastic constant. When. The equation of motion of this harmonic oscillator is as follows. The force that acts on this material point is the elastic force. So we will have in the left member the elastic force which is of type k r.

Notes

Summary

13m 36s

Oscillateur harmonique

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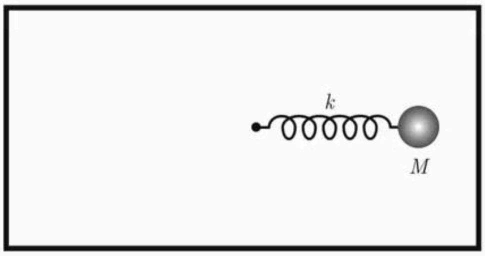

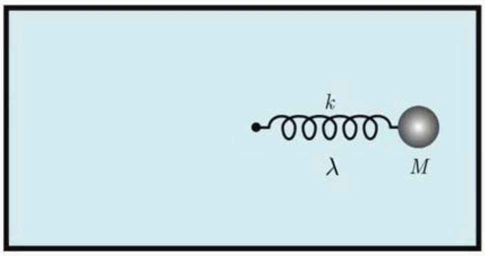

Thermodynamique

In the right hand side, we have the product of the mass for the acceleration which is invariant by reversal in time. Adjust to the parameters and the position and acceleration are also invariant by reversal in time, which means that the equation of motion. Is sent on itself. It is therefore invariant by reversal in time. So the evolution of this harmonic oscillator is a reversible evolution. Second case, we take a damped harmonic oscillator. So we have a material point of mass M which is linked to a spring of elastic constant K which is in a viscous medium. This viscous medium is a fluid which will exert a viscous frictional force. I guess we are in a laminar regime, so this viscous frictional force will be of the form minus lambda v. So we have to add this term minus month v in the left member of the equation of motion, and then we apply the time reversal transformation. The other terms are invariant. On the other hand, the term is associated with the frictional force, depends on the speed and the speed changes sign by replacement in time. So the less the tide becomes, the more. This means that the equation of the movement is different when applying the time reversal transformation.

Notes

Summary

15m 09s

Oscillateur harmonique

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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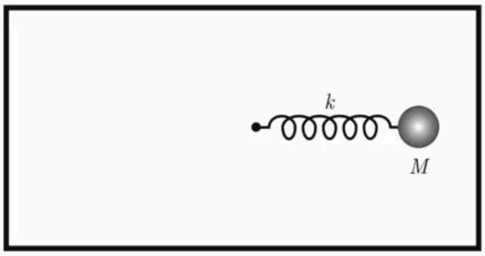

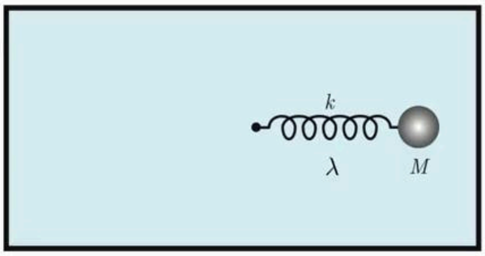

Thermodynamique

So we are dealing with a system whose evolution is irreversible and irreversible, since the amplitude of the movement of this The harmonic oscillator will decrease with time, which was not the case for the undamped harmonic oscillator.

Notes

Summary

16m 37s