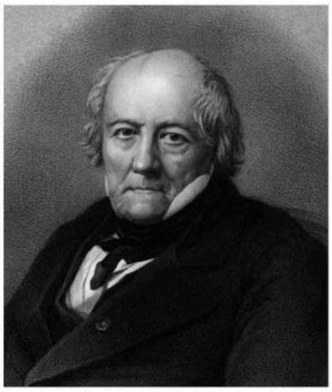
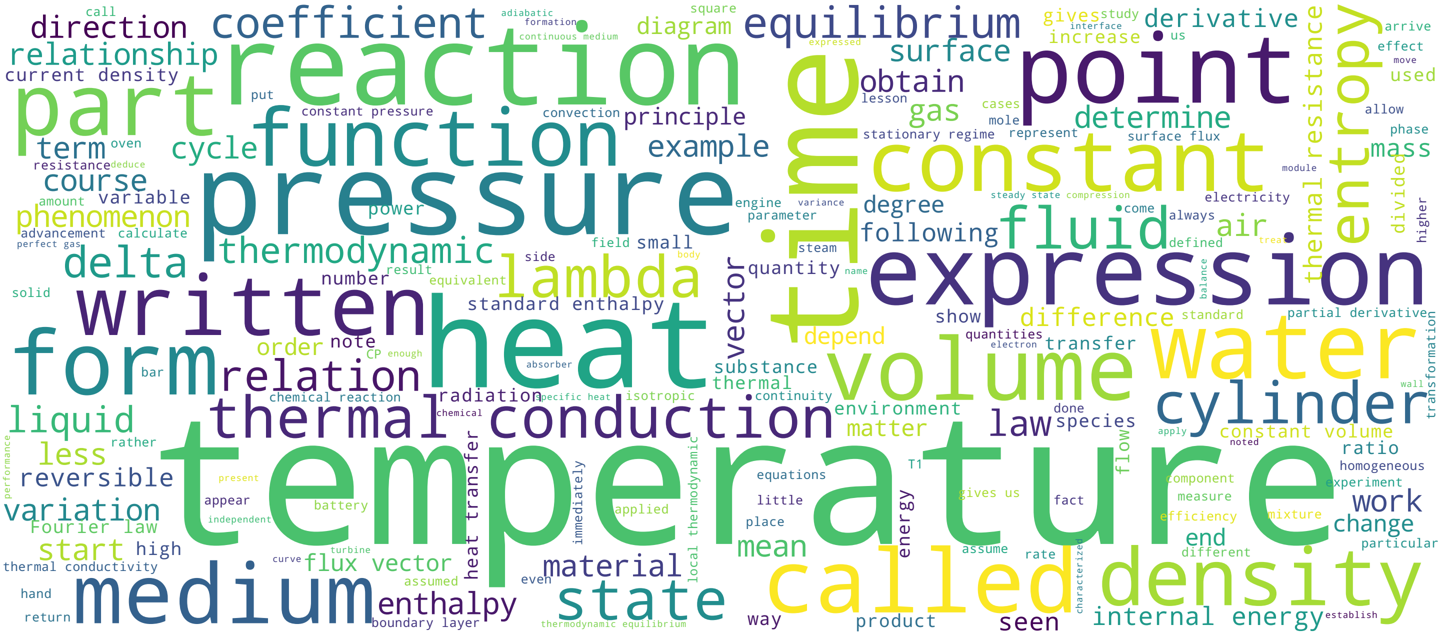
## Thermodynamique

# Transfert conductif en régime stationnaire

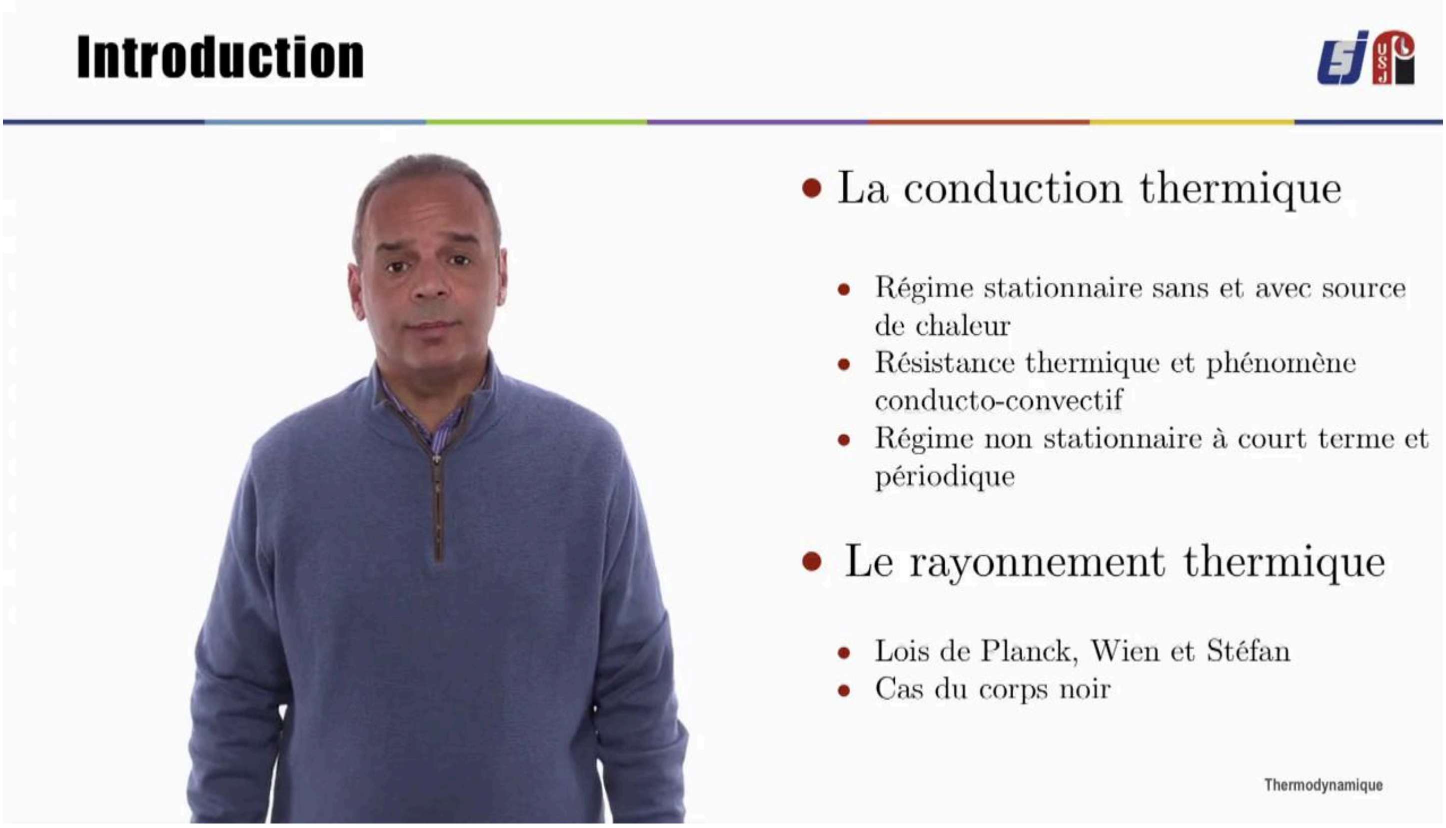
Prof. Marwan Brouche



Jean-Baptiste Biot, 1774-1862




Video

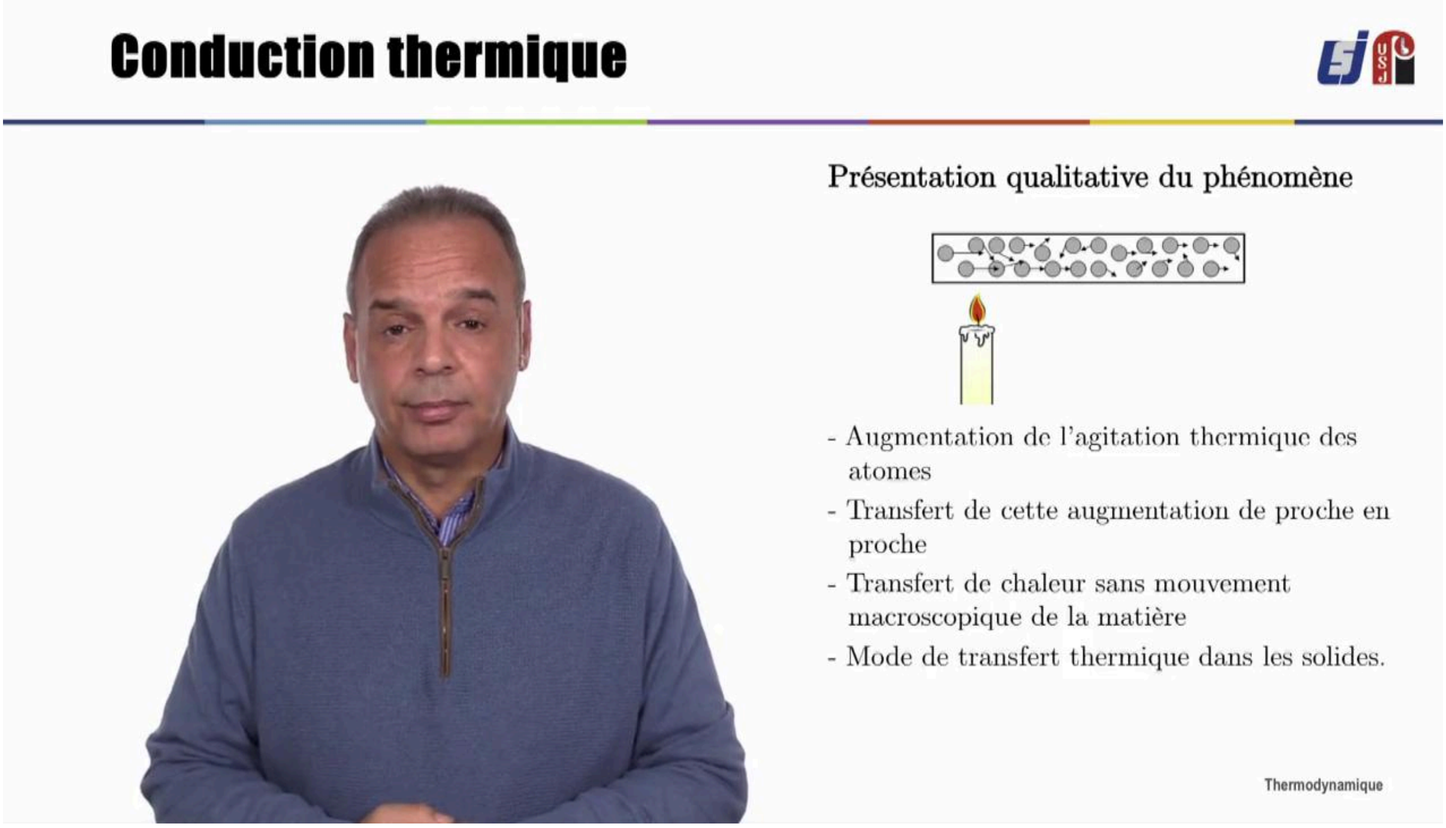



Hello, my name is Marouane Blush. I am a professor of physics at the Higher School of Engineering in Beirut. It is an institution that is part of Saint Joseph University in Lebanon. Today, we are going to do together a course of thermodynamics and a well of thermodynamics, namely heat transfer. Our heat transfer course is divided into three parts. The first part, we will talk about the thermal conduction in stationary regime. In the second part, we will deal with thermal conduction in steady state and finally, we will treat the thermal radiation.

Notes

Summary

0m 04s



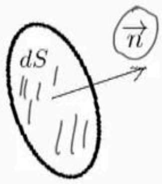

In this first part of our course. We will treat the conduction in stationary regime. What does steady state mean? This means that when the temperature does not depend on time and that the temperature will depend only on the spatial variable, we will start by giving a qualitative explanation to these thermal conduction phenomena for that. Let's take the example of a metal bar which is heated at one end by a candle. We will realize this after a while. At some point the temperature will rise along the bar. To understand what is going on, it is necessary to go to the microscopic level of the matter. At the microscopic level of the matter, there are particles that are in perpetual motion. This is called thermal agitation. When we heat locally there, we increase the thermal agitation and this thermal agitation will be transfer from one to the other along the wall. As you can see, it is a heat transfer, but without macroscopic movement of the matter. So it is this phenomenon that we call thermal conduction. This thermal conduction, it, is predominant especially in solid media. There is another phenomenon of transfer which is predominant in the environments fluids, it is convection, convection. Unlike thermal conduction, it is a mode of transfer with macroscopic movement of the matter.

Notes

Summary

0m 41s

# Flux de chaleur surfacique




Le flux d'énergie thermique, traversant $dS$ dans le sens de $\vec{n}$ et par unité de temps, s'écrit :

$$\delta\Phi_{(W)} = \phi_{(W/m^2)}\, dS_{(m^2)}$$

$\phi$ : flux surfacique, $\phi = \vec{j} \cdot \vec{n}$

$\vec{j}$ : vecteur de flux surfacique (ou vecteur de densité surfacique)

$$\delta\Phi = \vec{j} \cdot \vec{n}\, dS$$

$$\Phi = \iint_S \phi\, dS = \iint_S \vec{j} \cdot \vec{n}\, dS$$

$$T_1 < T_2 < T_3$$

Sens de $\overrightarrow{j^{cd}}$

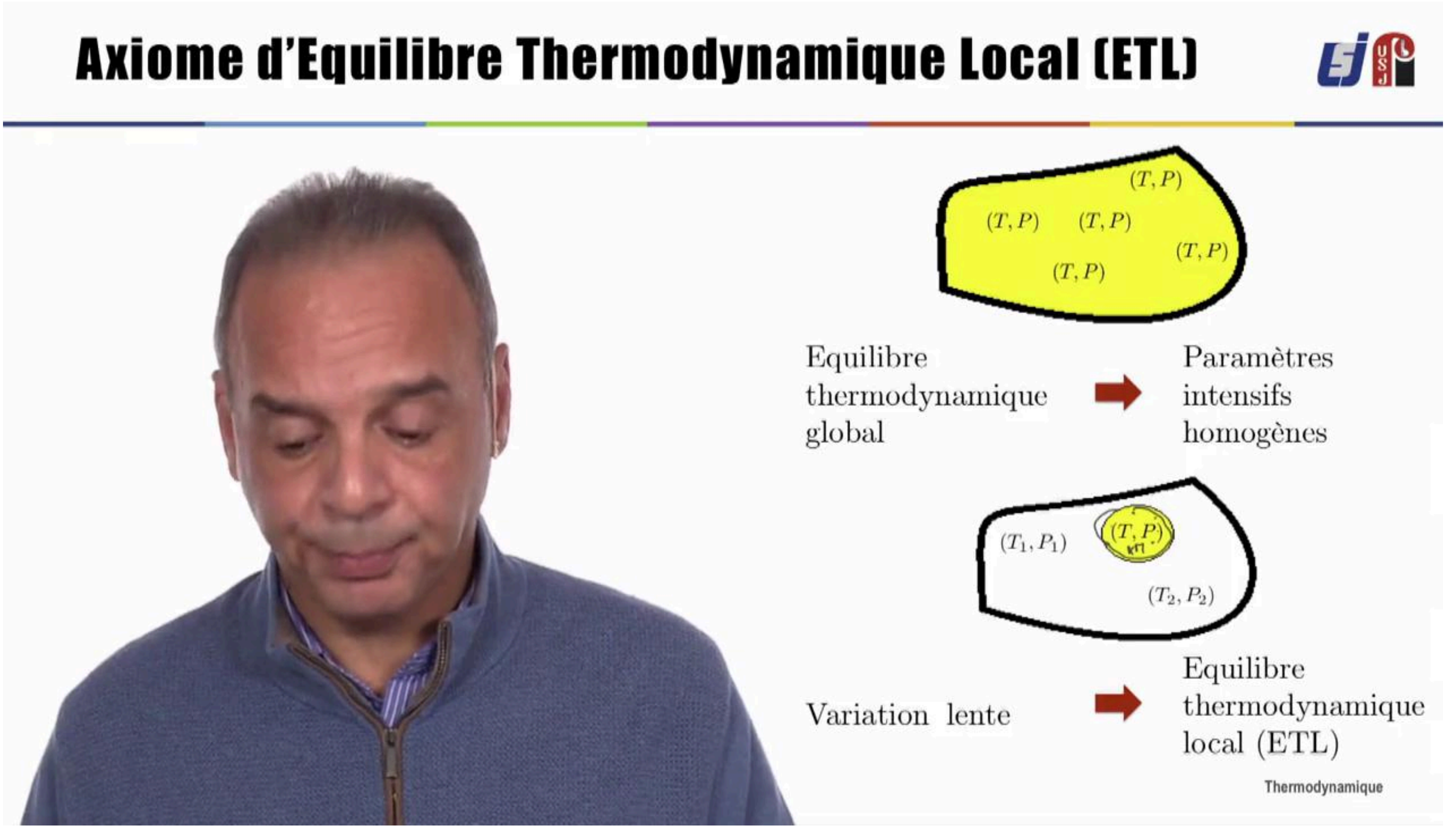
Thermodynamique

We have just given an explanation qualitative to the phenomenon of thermal conduction. Now we will try to quantify this phenomenon. To do this, consider an elementary surface of S1 and take a vector N, a unit vector which is perpendicular to DF. The thermal energy flow through DS in the direction of N and per unit time is written as phi by ds, phi being the surface flux. The surface flux can also be written as in the form of a scalar product of a vector j by the unit vector n. This vector j is called the surface flux vector. Also, we can. It can be called a surface density vector. If we return to the expression of the thermal density that passes through C in the direction of N, we write it as J by n by EDF. Now this is a reasoning on an elementary surface DS. If we now want to consider a macroscopic surface S, it is enough to integrate this quantity there on the whole surface studied. As you can see. It is a surface flow vector. So the vector character will impose a direction of energy transfer. And in the case of conduction, this direction of transfers will be done always from the highest to the lowest temperature.

Notes

Summary

2m 01s



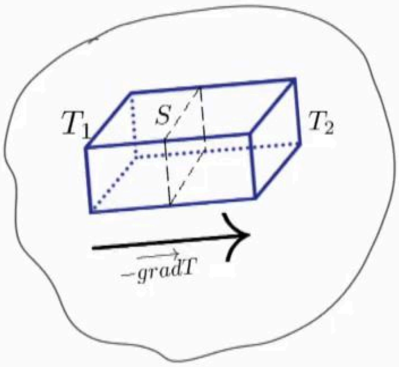

When a system is in equilibrium thermodynamic and global, all its physical parameters are homogeneous. It means. These parameters are the same everywhere in this system. However, when there is a phenomenon of conduction, the system, necessarily, it is out of equilibrium. But we will assume that the temperature variations are very slow. Why? This way, I can consider a point M belonging to the system and surrounded. 6.1 by an elementary surface and makes think that this surface is in equilibrium. This way, I can define in each point of this surface a temperature and a pressure. And we speak in these cases of local thermodynamic equilibrium, also called l.

Notes

Summary

3m 44s

# Loi de Fourier et analogie avec la loi d'Ohm




- Milieu homogène et isotrope
- E.T.L $_{///}$
- Loi de Joseph Fourier donne l'expression de vecteur flux surfacique pour le phénomène de conduction thermique

$$\overrightarrow{j^{cd}} = -\lambda\, \overrightarrow{grad}\, T$$

- $\lambda(W.m^{-1}.K^{-1})$ : conductivité thermique du milieu
- Le signe (-) implique que le transfert se fait du point le plus chaud au point le plus froid

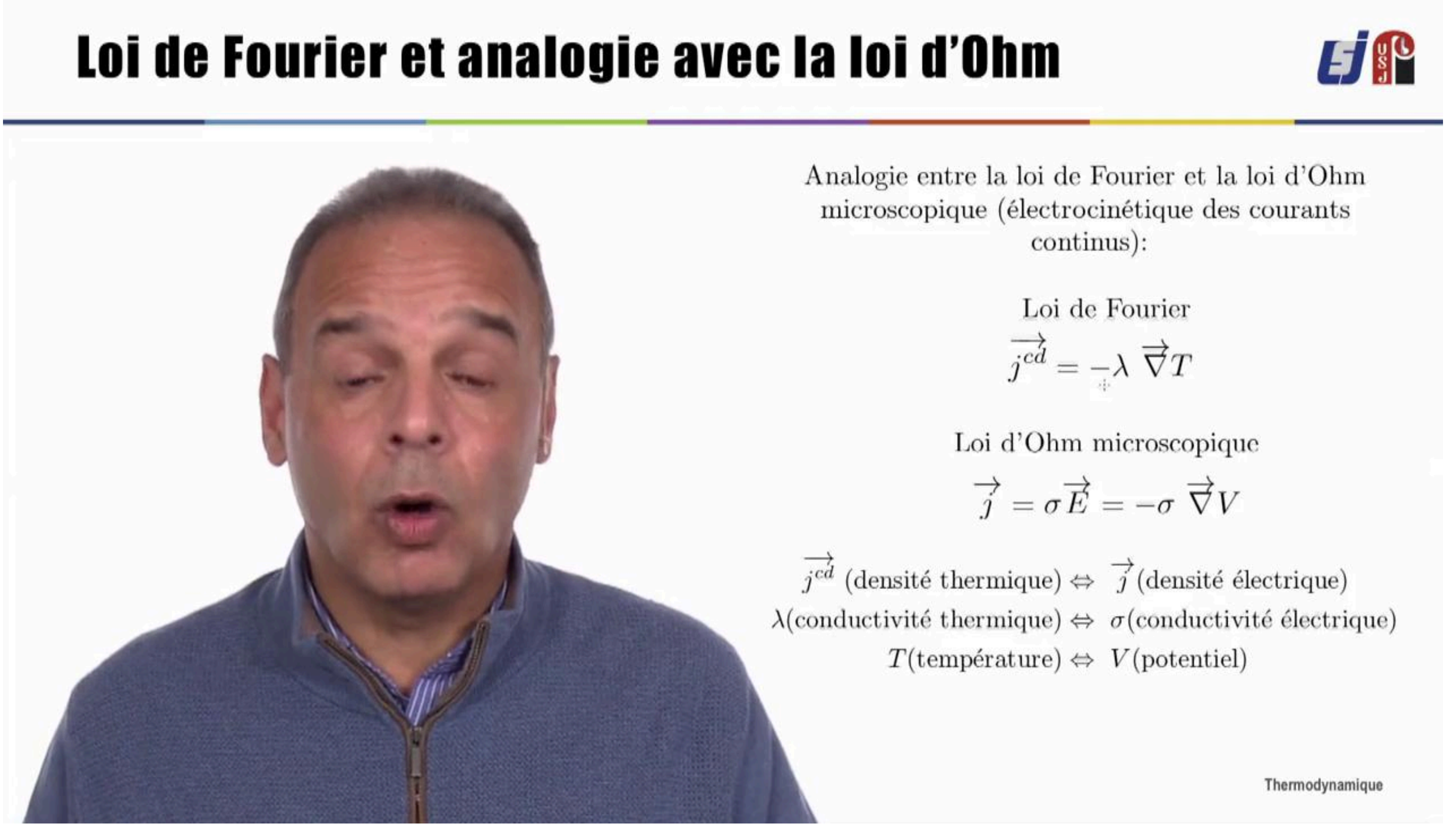
Thermodynamique

We will now state the law of Fourier which will give the expression of the flux vector. In the case of the phenomenon of thermal conduction. To do this, let's consider an environment assumed to be homogeneous and isotropic, and it is assumed that the action of the hotel, i.e. the local thermodynamic equilibrium, is valid. Fourier's law states that the conductive flux vector is written in this case there in the form of lambda by gradient of t. Lambda is called the thermal conductivity of the medium. Its unit is the watt per meter ampere kelvin one and the sign at least in this law implies that the transfer is made always from the hottest point to the coldest point.

Notes

Summary

4m 35s

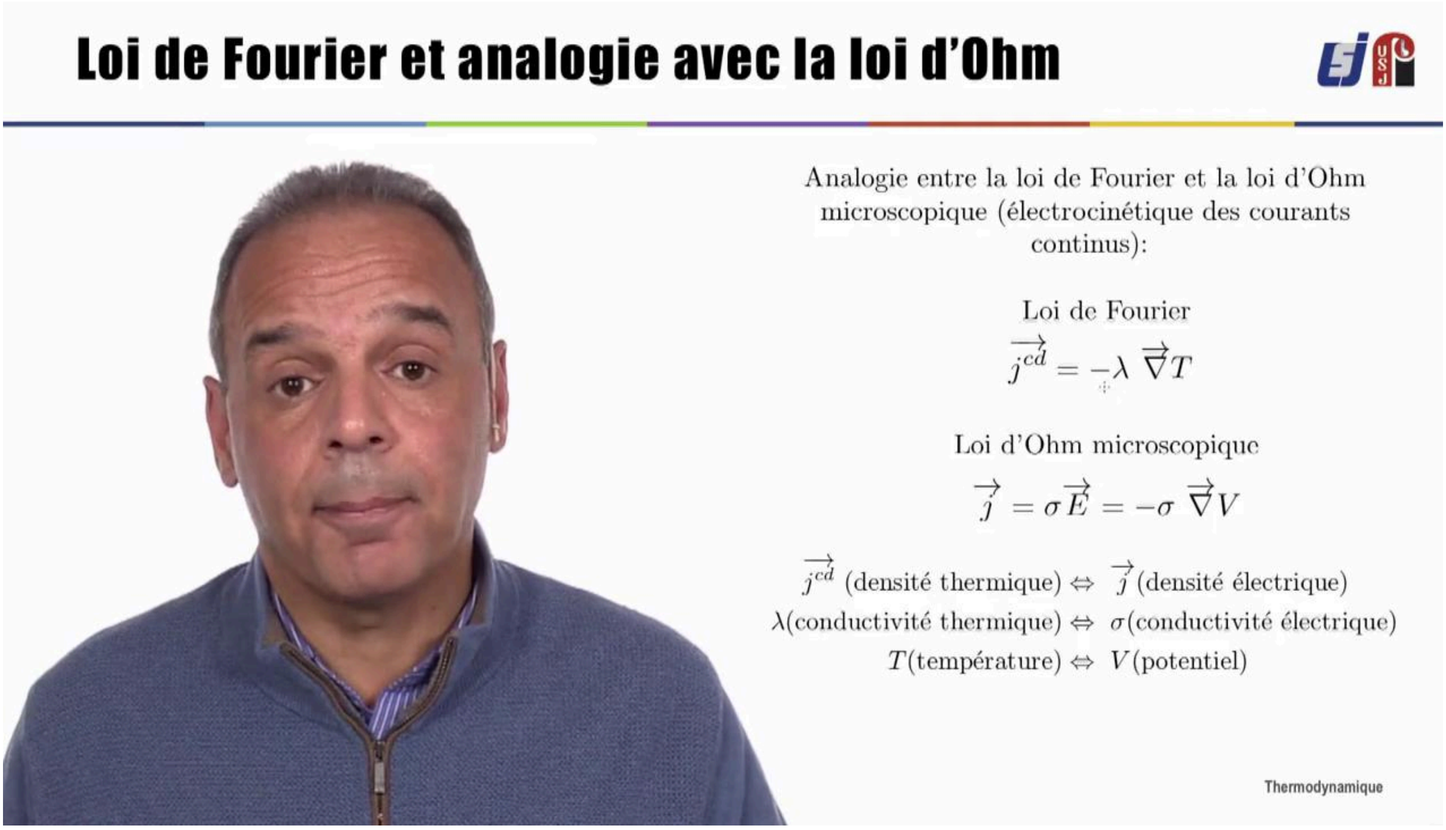



The lambda thermal behaviour depends of course on the nature of the environment considered, but it can also depend sometimes on the temperature. We have put here some orders of magnitude for this thermal conductivity. We start with the solid media and if we look at the values, we see immediately that they are Copper and silver are the best thermal conductors. I must point out here that these environments, copper and silver, are also very good electrical conductors. That is to say that the two phenomena, thermal and electrical phenomena, are usually free when moving to the second table. In fluid media, we can see immediately that the value of lambda will decrease enormously. Why? Because generally, in these fluid media, it is the thermal convection which predominates and masks the thermal conduction. We have just seen that the Fourier law in the expression of the flux vector in the form of less than T. Now, in electricity, there is also a law called the microscopic Ohm's law, which relates the electrical density or potential gradient. By the formula J is equal to a gradient segment of 20. It is immediately clear that there is a perfect analogy between Fourier's law and the microscopic Ohm's law.

Notes

Summary

5m 24s

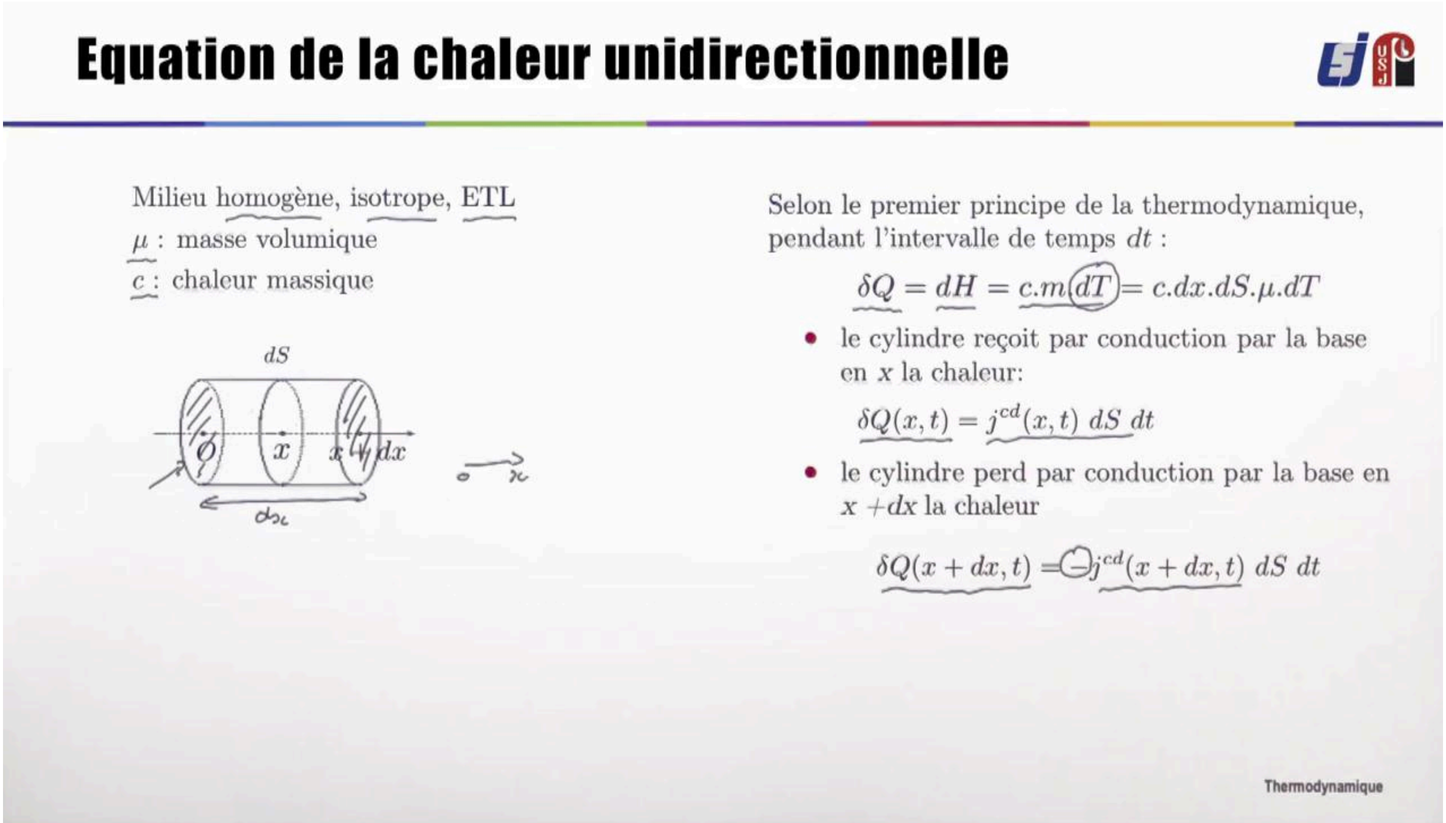



We can even make an equivalence between the different parameters of the two domains, i.e. the thermal density. In the field of constructive transfers, its equivalent in electricity, it will be g the electric density. The thermal conductivity lambda will find its equivalent in electricity sigma which is the electrical conductivity and finally the temperature equivalent. This is the potential in the field of electricity.

Notes

Summary

6m 46s

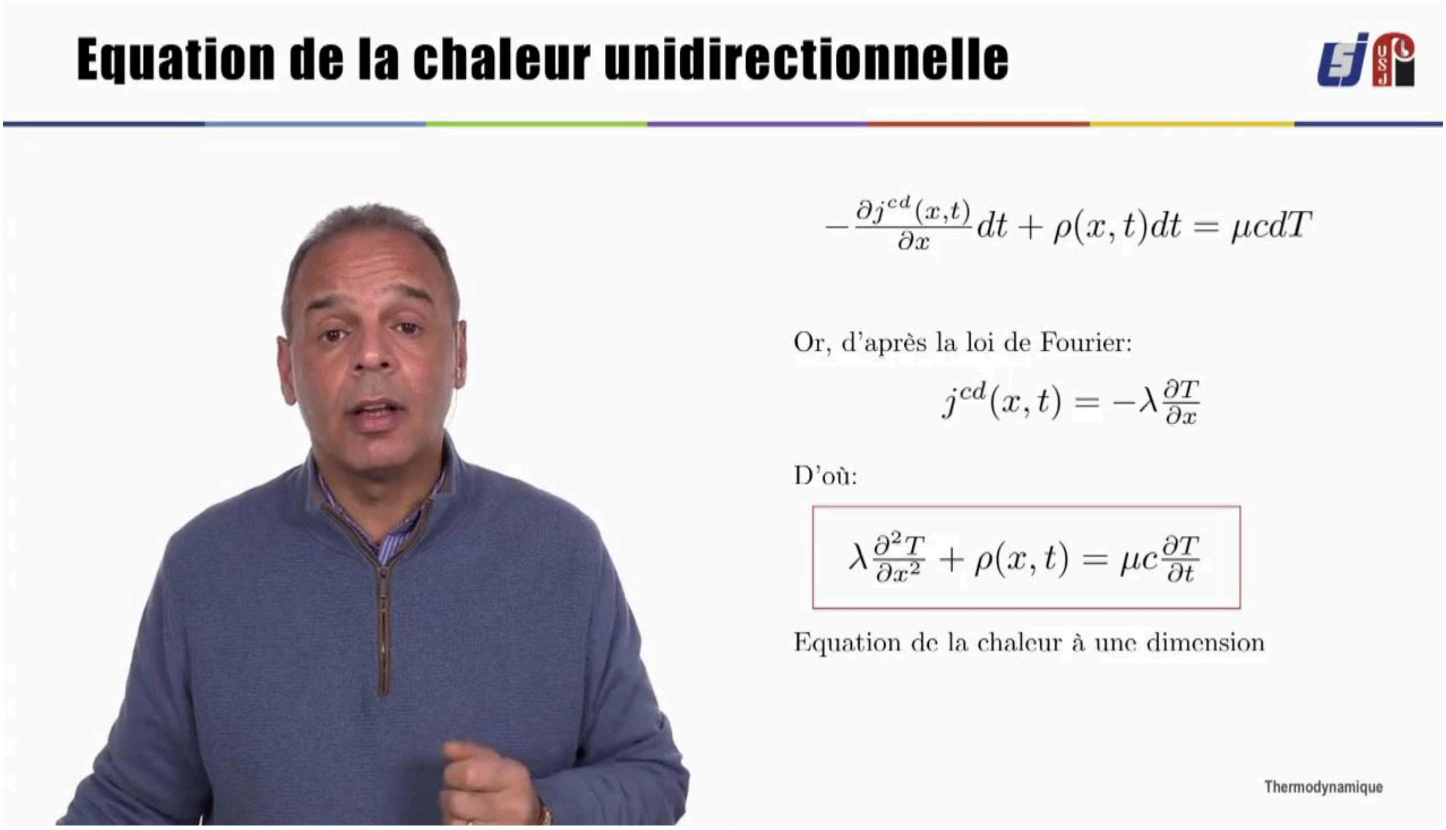



We will now establish the heat diffusion equation in a medium that is assumed to be homogeneous and isotropic and in which the local thermodynamic equilibrium is assumed to be valid. This medium is characterized by its density and by its mass heat. It is an insulator by thought, a cylinder. Of length BX and normal section DS. We will assume that the conduction is unidirectional, i.e. it will be done only along the X axis. Applying the first principle of thermodynamics on this cylinder during the time interval dt. Heat exchange between the cylinder and the outside environment will be equal to the variation of the enthalpy of this cylinder, which is written as c by the mass of the cylinder by the variation of the temperature of the cylinder of the big ones. Let's now make the thermal balance of this cylinder with the external environment. Through the DS section in X, there is a quantity of heat that will return by conviction, which is written as j cd by dt spaces and by the section of s in x plus dx. There is an amount of heat. Who will come out. During the tin time which is written as I gave in X+ it was tin BS and the sinn here means that the heat is lost by the cylinder.

Notes

Summary

7m 17s

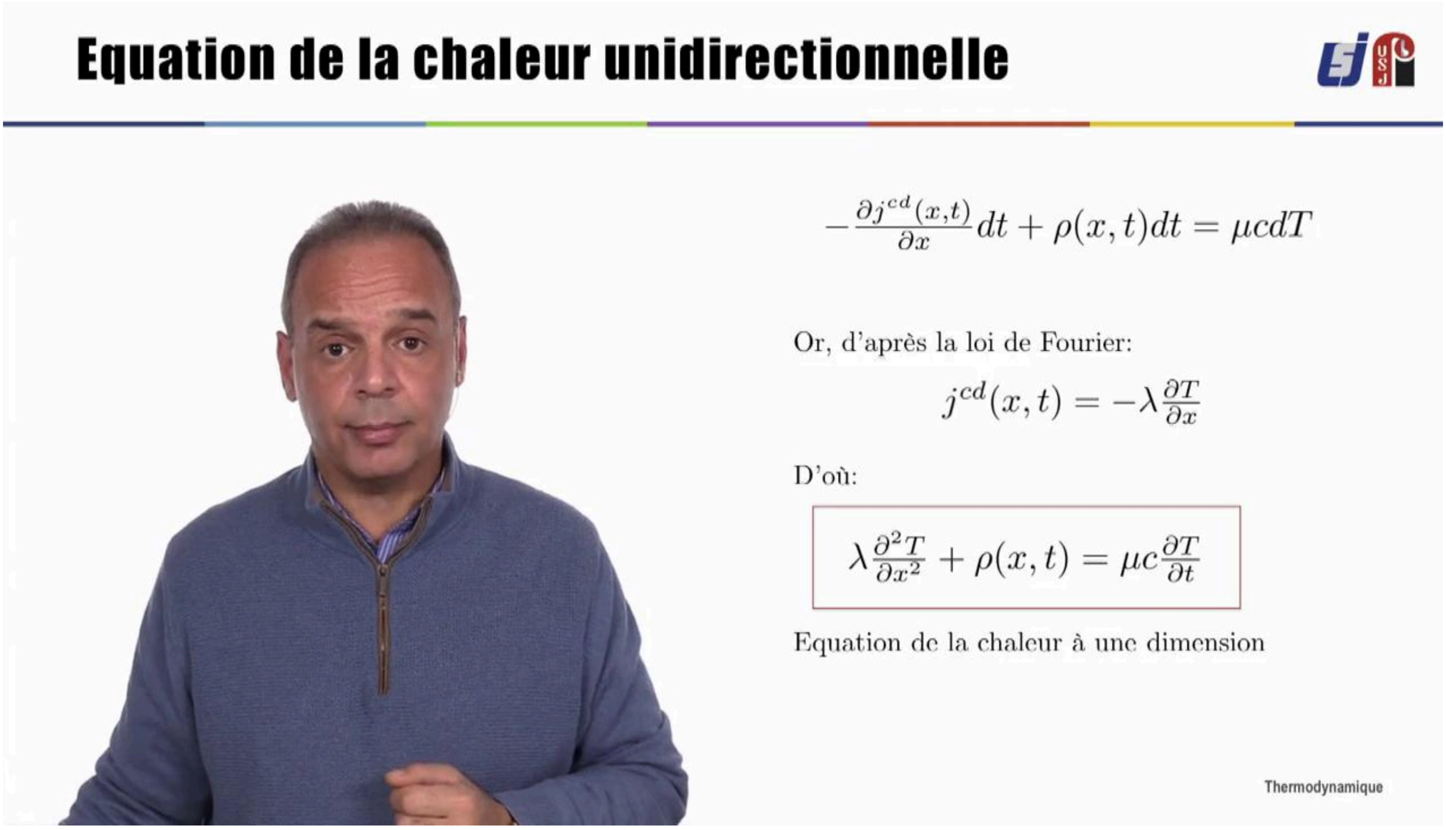



It can have an internal energy source, a chemical reaction, a nuclear reaction which releases inside these cylinders there a volumetric power of energy characterized by was thus. the Energy released by. This internal source of energy will be written in the form of, represented by the elementary volume of the cylinder, i.e. dx by s by the elementary tin time. Let's go back to the equation that translates the first principle of thermodynamics replacing these thermal exchanges and that we have just mentioned. In this equation, we will come across the following equation. The difference between the flux vector at x and dx shows here the partial derivative of the surface vector with respect to the spatial variable x. Now replacing this surface flow vector by the expression which is given by the Fourier law. We arrive at a final equation which is written in the form of lambda by the second derivative of the temperature with respect to x square. The more it is the power density given by the internal source of energy equal to the product of the density, by the mass heat, by the partial derivative of the temperature with respect to time. This equation is called the heat equation.

Notes

Summary

9m 08s

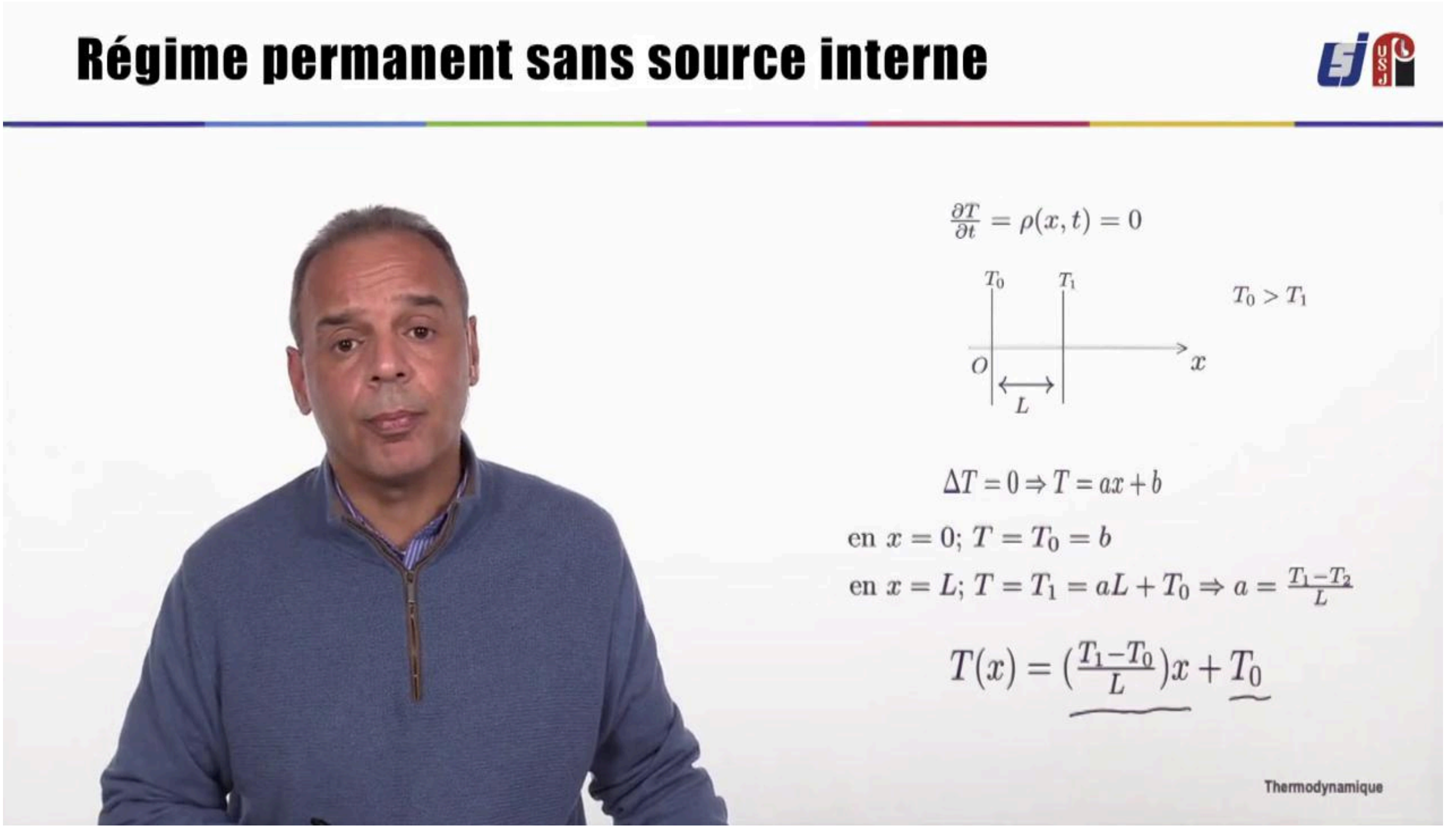



In the case of unidirectional conduction, immediately, we can see that there is a difference between the derivation with respect to time and the derivation with respect to to the spatial value, because in one case we are at the first order and in a second case we are at the second order, which gives the diffusivity of the thermal conduction.

Notes

Summary

10m 32s

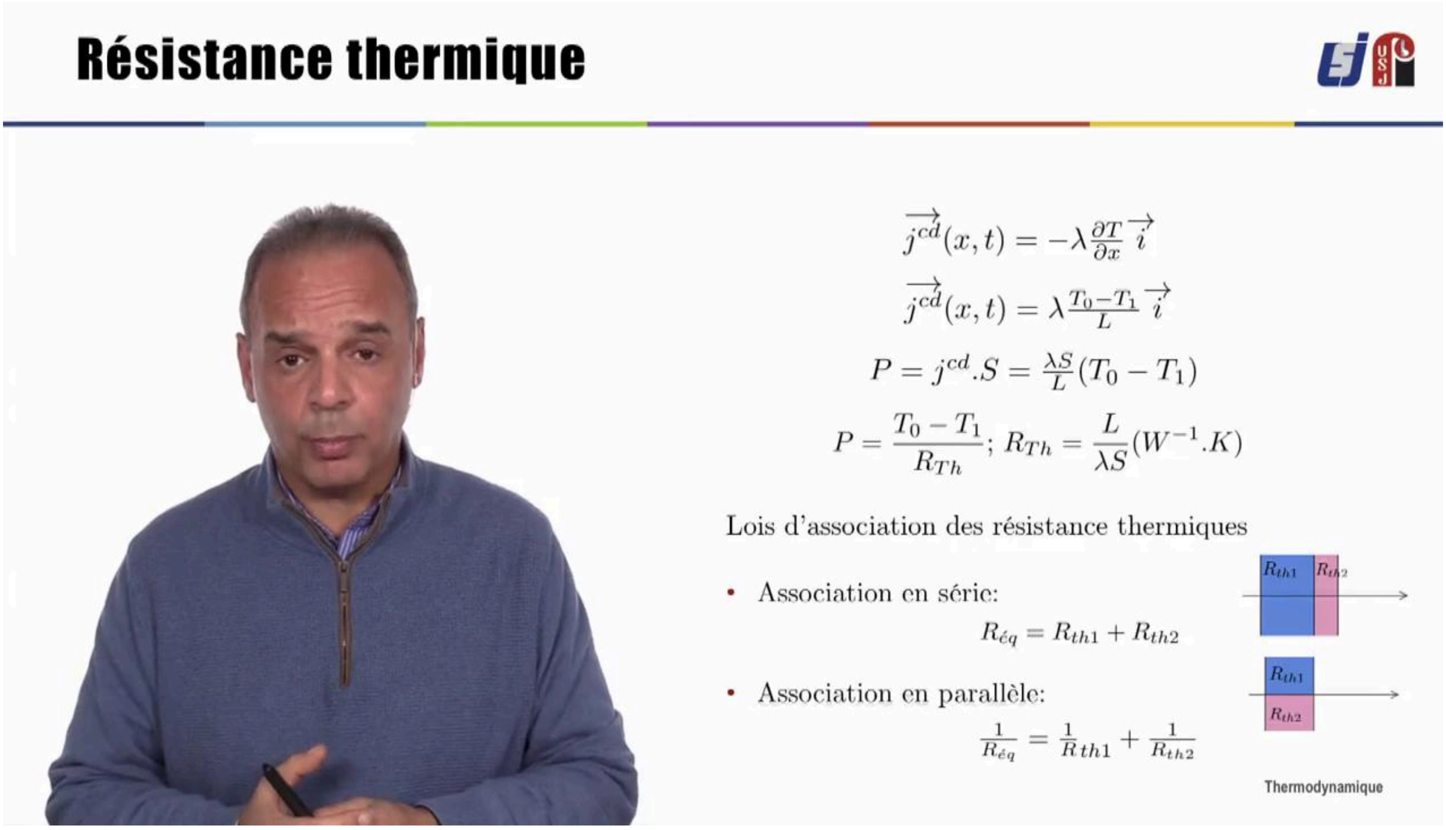



We will now take a case especially in the case where there is no internal source of energy. We are always in the case where the temperature is independent of time. What does that mean? The regime is a stationary regime. To treat this case, we will consider a wall of thickness. L such x is equal to zero, we impose the temperature T0 and we try equal to L. The temperature is equal to T1 and it is assumed that the temperature T0 is higher than the temperature T1. The heat equation established previously will be written in our case as the laplacian of T equal to zero. A double integration with respect to the variable X gives us a function linear of the temperature with two constants A and B. To determine these two constants, we must take the boundary conditions, i.e. x equal to zero. The temperature is zero. X is equal to L, the temperature is equal to T1. In these cases, we will finally write the temperature as a function of X in the form of t1 t0 on l X plus t0.

Notes

Summary

10m 54s



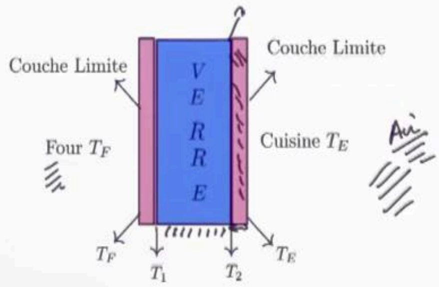

From Fourier's law, we can determine the surface flux vector. Since it is less the partial derivative of T with respect to X. The thermal power can even be determined. Just multiply the flow vector surface by the surface s through which the thermal energy passes. We obtain an equation which gives the value of pin as a function of the temperature difference t0 t1. So P is equal to lambda is L by t0 t1. One can always write this power there in the form of the difference of temperature on a parameter that we will call the thermal resistance of the medium. By identification, the thermal resistance of the medium will be written as l over lambda s. As in electricity, the physical center of this resistance will be the following the more the medium will have a resistance the less good a thermal conductor it will be and the laws of association of the thermal resistances and the are the same that the laws of association for electrical resistance. What does that mean? If I take for example an association in series, I place two media in series characterized by the thermal resistance un th un and a second resistance rt h2. The equivalent resistance will be the sum of two resistances. It is now, we place two middles in parallel. One on the equivalent resistance is going to be equal to a tu hth one plus a RT Th2.

Notes

Summary

12m 04s

# Couche limite et influence conducto-convectif




Formation d'une couche de fluide d'épaisseur $d$ à l'interface entre l'air et le verre.

- $h = \frac{\lambda_F}{d}$ Coefficient de transfert conducto-convectif
- $R_{CL} = \frac{d}{\lambda_F . S} = \frac{1}{h.S}$
- $R_{CL}$ dépend de l'écoulement du fluide
- $j^{cc} = h \; \Delta T$ loi de Newton

| Mode de transfert | Fluide | $h(W.m^{-2}.K^{-1})$ |
|---|---|---|
| Convection naturelle | *Gaz*<br>*Eau* | 5 à 30<br>100 à 1000 |
| Convection force | *Gaz*<br>*Eau* | 100 à 300<br>300 à 1200 |

Thermodynamique

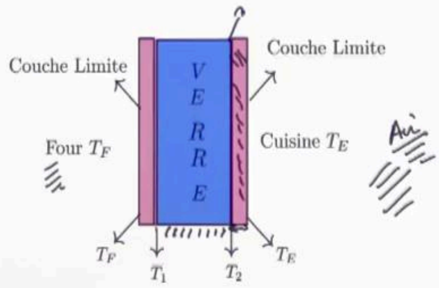
We will now study the influence of of convection on the phenomenon of thermal conduction. To do this, let's take the practical example of a oven that is placed inside a kitchen. The oven, or rather the oven door, will be characterized here. A medium of a certain thickness towards the air in the kitchen is on this side. The inside of the oven is on this side. It turns out that, at the interface between the solid and the fluid, there will be a boundary layer that will form. It's a layer of fluid that airs in here. The particles are immobile, that is to say that the transfer will be done in the form of a convective transfer. The width of this boundary layer will depend on two things: the viscosity of the fluid and the movement of the fluid around it. Green. From there, we can determine or rather define. A coefficient h which is the ratio of the thermal quantity of the fluid on the thickness of the layer, which is called transfer evolution convective conductor and deduce a thermal resistance of this boundary layer which is the ratio of D to lambda f not s. Of course, this thermal resistance which is thermal birth of the layer limit will depend on the fluid flow, i.e.

Notes

Summary

13m 37s

# Couche limite et influence conducto-convectif

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| Mode de transfert | Fluide | $h(W.m^{-2}.K^{-1})$ |
|---|---|---|
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| | *Eau* | 100 à 1000 |
| Convection force | *Gaz* | 100 à 300 |
| | *Eau* | 300 à 1200 |

Thermodynamique

convection and the nature of the fluids. The conductive flux vector that crosses the boundary layer, we will call it j cc because it is the convective conductor and will be equal in our case here at hPa delta T called under the name of Newton's law. In the following table, we gave some order of magnitude for H and we see immediately that when you change from natural convection to forced convection. The value of H will be much more high in the case of forced convection.

Notes

Summary

15m 10s

# Conclusion


We have just seen in this first part. The phenomenon of contradiction in a very particular regime is the stationary regime, i.e. when the temperature is independent of time. An equation has been established which is called the heat equation. From this equation, we can determine the distribution spatial temperature in the student environment, and we have also defined what is called a thermal resistance which will give us information on the degree of thermal conductivity of the medium. And finally, we have seen the influence of convection on the conduction phenomena, a phenomenon called conduction-convection. I now invite you to watch the video in which we will expose application on thermal conduction in a composite wall.

Notes

Summary

15m 48s