

Diffusion thermique et chimique



- Diffusion thermique: la loi de Fourier et l'équation de la chaleur
- Diffusion chimique: loi de Fick et l'équation de la diffusion
- Diffusion thermo-chimique: effet Dufour et effet Soret

Thermodynamique

Hello and welcome to the thermodynamics classes. In the previous presentation, we established a formalism thermodynamics for the study of equilibrium processes in these parts of the course. We will use this dynamic formalism to study the phenomenon of thermal and chemical diffusion. The structure of our presentation is as follows. First, we will examine the phenomenon of thermal diffusion. We will present Fourier's law and deliver the heat equation. Next, we will examine the phenomenon of chemical diffusion. We will present the fixed law and deliver the diffusion equation. Finally, we will examine the phenomenon of chemical diffusion. Specifically, we will present the effects of the furnaces is solar.

Notes

Summary



0m 04s



• Rappel :

$$j_Q = T j_s$$

$$\begin{cases} j_s = L_{ss} (-\nabla T) + \sum_{B=1}^r L_{sB} (-\nabla \mu_B - q_B \nabla \varphi), \\ j_A = L_{As} (-\nabla T) + \sum_{B=1}^r L_{AB} (-\nabla \mu_B - q_B \nabla \varphi), \end{cases} \quad (10)$$

$$L_{sA} = L_{As}, \quad A = 1, \dots, r, \quad (11)$$

$$L_{AB} = L_{BA}, \quad A, B = 1, \dots, r.$$

Thermodynamique

First, we call it this phase equation that we have already met in previous lessons and which we will use in this presentation. If we have this relationship for the density the linear phenomenological relations between the two between current density and generalized vector force, as well as the reciprocity relations concerning the coefficients that appear in this phenomenological relation.

Notes

Summary



Diffusion thermique

- Considérons un solide rigide d'une seule substance A au repos: $j_A = 0$.

- Densité de courant de chaleur : $j_Q = T j_s$.

$$\begin{cases} j_s = L_{ss} (-\nabla T) + L_{sA} (-\nabla \mu_A - q_A \nabla \varphi) , \\ \overset{0}{j_A} = L_{sA} (-\nabla T) + L_{AA} (-\nabla \mu_A - q_A \nabla \varphi) , \end{cases}$$

- Les dernières relations impliquent que

$$j_Q = -\kappa \cdot \nabla T, \quad \kappa \equiv T L_{AA}^{-1} \cdot (L_{AA} \cdot L_{ss} - L_{sA}^2) . \quad (14)$$

Thermodynamique

We start with the phenomenon of thermal diffusion. Let's consider and it is the substance from which it is taken given that the medium is made up of this substance, which is at rest. Then the current density of the substance is zero. We will use the expression for the current density of heat, as it is related linear phenomenology between current density and functionality. For these phenomena, all the current manufacturers have analyzed all the forces, analyzed its vector character. Moreover, since the medium is generally anisotropic, the phenomenological coefficients that appear in this relationship. Its owner. Now, we use the fact that J_A is zero to get the second place. Logical phenomenon a linear relationship between the winner operator and the winner of the chemical potential of the substance. This relationship can be introduced to the first phenomenological relation and the results can be introduced to the expression for the heat current density. In summary, the difference in level implies that the density of heat flow is proportional to the temperature relations. The coefficients k that appear in this relationship is a function of of the phenomenological coefficients and it is given by this expression.

Notes

Summary



Diffusion thermique

- Considérons un solide rigide d'une seule substance A au repos: $j_A = 0$.

- Densité de courant de chaleur : $j_Q = T j_s$.

$$\begin{cases} j_s = L_{ss} (-\nabla T) + L_{sA} (-\nabla \mu_A - q_A \nabla \varphi) , \\ j_A = L_{sA} (-\nabla T) + L_{AA} (-\nabla \mu_A - q_A \nabla \varphi) , \end{cases}$$

- Les dernières relations impliquent que

$$j_Q = -\kappa \cdot \nabla T, \quad \kappa \equiv T L_{AA}^{-1} \cdot (L_{AA} \cdot L_{ss} - L_{sA}^2) . \quad (14)$$

- κ : tenseur de conductivité thermique.
- Les termes diagonaux constituent la *loi de Fourier*.

Thermodynamique

Since the coefficient phenomenological spark is then, the coefficient k was in iron. Also it is called in that of thermal conductivity. The diagonal terms of this set constitute the Fourier law for thermal diffusion. The term diagonal describes another phenomenon. They describe the phenomenon of appearance of the heat flow due to temperature guard, but in directions normal to the direction of the temperature gauge. In the presence of an external magnetic field, this phenomenon is called the reset effect, the double.

Notes

Summary



2m 41s

Diffusion thermique et chimique

- Soit un métal isotrope au repos contenant des électrons de conduction.
- Les électrons sont considérés comme une substance e de charge q_e .
- Loi de Fourier : $j_Q = -\kappa \nabla T$ avec $\kappa \equiv T \frac{L_{ss} L_{ee} - L_{se}^2}{L_{ee}}$.
- Application : équation de la chaleur
 - Les électrons de conduction sont immobiles dans le référentiel du métal : $v = v_e = 0 \Rightarrow j_e = 0$.
 - $j_Q = T j_s = j_u - (\mu_e + q_e \varphi) j_e^0 \Rightarrow j_Q = j_u$.

Thermodynamique

Then we consider a rigid metal isotropic at rest containing conduction electrons. Electrons are considered as a substance of electric charge. Everything is the law of crowds that is applied to. This isotropic metal is written in this form. Here, the thermal conductivity coefficients is a desired scalar quantity entropy of the metal. It is given by this relationship. It is then a function of the phenomenological coefficients of the medium. Moreover, the phenomenological coefficients are scalar. Müller spreads from the metal. Then, we will use the law for an isotropic metal to deliver the heat equation. First, we notice that the electrons of conduction are immobile in the reference frame of the metal. This means that the speed of the metal as well as the speed of the electrons are zero in the reference frame of the metal. This implies that the current density of gis electrons is equal to zero. We now consider the equation for the heat current density and we produce the expression for the entropy current density s that we delivered when we realized the local energy balance of a continuous medium. This gives us this expression for the heat current density.

Notes

Summary



3m 18s

Diffusion thermique et chimique

- Soit un métal isotrope au repos contenant des électrons de conduction.
- Les électrons sont considérés comme une substance e de charge q_e .
- Loi de Fourier : $j_Q = -\kappa \nabla T$ avec $\kappa \equiv T \frac{L_{ss} L_{ee} - L_{se}^2}{L_{ee}}$.
- Application : équation de la chaleur
 - Les électrons de conduction sont immobiles dans le référentiel du métal : $v = v_e = 0 \Rightarrow j_e = 0$.
 - $j_Q = T j_s = j_u - (\mu_e + q_e \varphi) j_e^0 \Rightarrow j_Q = j_u$.
 - L'équation de continuité d'énergie interne se réduit à: $\dot{u} = -\nabla \cdot j_u = -\nabla \cdot j_Q \Rightarrow \dot{u} = \nabla \cdot (\kappa \nabla T)$
 - A densité de masse constante : $du = c_M(T) dT \Rightarrow \dot{u} = c_M \dot{T}$. $v = 0 \Rightarrow \dot{u} = \frac{\partial u}{\partial t}$

Thermodynamique

Now we notice that given that the electron current density is zero, then the current density of electrons is equal to the internal energy current density. I got. We now consider the continuity equation for the internal energy. Since the environment is rigid, then the deformation spark is zero. This means that there is no source density for the internal energy. Then the continuity equation for energy integrity has been reduced to this expression. Now we can introduce this equation. This gives us this expression. Then we introduce the law of search in the divergence. Finally, we obtain a relation for the material derivative of the internal energy density. We note that at mass density constant, the energy density is only a function of temperature. We then have this relationship. The CN parameter that appears in this relationship is identified as the specific heat of the metal. If we divide the two sides of this equation by t 's, we arrive at a relationship between the material derivative of the internal energy density and the temperature. But since the velocity of the medium is zero, then these material derivatives are reduced to the material derivatives with respect to time.

Notes

Summary



4m 41s

Diffusion thermique et chimique

- Soit un métal isotrope au repos contenant des électrons de conduction.
- Les électrons sont considérés comme une substance e de charge q_e .
- Loi de Fourier : $\mathbf{j}_Q = -\kappa \nabla T$ avec $\kappa \equiv T \frac{L_{ss} L_{ee} - L_{se}^2}{L_{ee}}$.
- Application : équation de la chaleur
 - Les électrons de conduction sont immobiles dans le référentiel du métal : $\mathbf{v} = \mathbf{v}_e = 0 \Rightarrow \mathbf{j}_e = 0$.
 - $\mathbf{j}_Q = T \mathbf{j}_s = \mathbf{j}_u - (\mu_e + q_e \varphi) \mathbf{j}_e^0 \Rightarrow \mathbf{j}_Q = \mathbf{j}_u$.
 - L'équation de continuité d'énergie interne se réduit à : $\dot{u} = -\nabla \cdot \mathbf{j}_u = -\nabla \cdot \mathbf{j}_Q \Rightarrow \dot{u} = \nabla \cdot (\kappa \nabla T)$
 - A densité de masse constante : $du = c_M(T) dT \Rightarrow \dot{u} = c_M \dot{T}$. $\mathbf{v} = 0 \Rightarrow \dot{u} = \frac{\partial u}{\partial t} = c_M \frac{\partial T}{\partial t}$.
 - Nous arrivons alors à : $c_M \frac{\partial T}{\partial t} = \nabla \cdot (\kappa \nabla T)$.
 - Si κ est constante, la dernière relation se réduit à l'équation de la chaleur :

$$\frac{\partial T}{\partial t} = \lambda \nabla^2 T, \quad \lambda = \kappa / c_M. \quad (15)$$

Thermodynamique

This is how we get into this equation. The next step is to combine these relations for the material derivative of the internal energy density. We then come to this equation. There are some cases. For example, when the variations temperature are moderate or the conductivity coefficients thermal, it can be considered as constant. In these cases, the coefficient of thermal conductivity can go out of the divergence. We will then have the thermal conductivity coefficient multiplied by the gradient divergence of temperature, i.e. by the temperature laplacian. If K is constant, then it reduces to the heat equation. This is the wave equation that is a partial differential equation for the temperature. The lambda coefficients that appear in this relationship is defined as the ratio between the coefficients of thermal conductivity K and the specific heat of the metal.

Notes

Summary



Diffusion chimique

- Nous considérons une substance A électriquement neutre: $q_A = 0$.
- La substance est dissoute dans un fluide non-réactif et électriquement neutre.
- Nous supposons des conditions isothermes et isobares : $T = cte.$, $p = cte.$
- La deuxième relation phénoménologique résulte en la loi de Fick:

$$\mathbf{j}_A = -\mathbf{F}_A \cdot \nabla \mu_A, \quad \mathbf{F}_A \equiv \mathbf{L}_{AA}. \quad (16)$$

- \mathbf{F}_A : tenseur de diffusion chimique.
- Pour un milieu isotrope : $\mathbf{F}_A = F_A \mathbb{I}$

$$\mathbf{j}_A = -F_A \cdot \nabla \mu_A. \quad (17)$$

Thermodynamique

It is called diffusion coefficient and we continue with the phenomenon of chemical diffusion. We consider a substance to which electrically another. Since the substance is electrically another, then its electric charge is zero. The substance is dissolved in an electrically non-reactive fluid. Moreover, we assume conditions at the isobaric term level, i.e. which is constant. The second phenomenological relation results directly to the law of fixed. This is Fick's law which expresses the phenomenon of chemical diffusion. This coefficient f which appears in the physics law is equal to the phenomenological coefficient l_a . Since the medium is generally anisotropic. The coefficient f_a is a tensor. It is called chemical diffusion transfer. For Isotropic Emilia, the chemical diffusion tensor is given by this expression, that is to say that it is in phase of chemical diffusion, is expressed as the product between a scalar quantity F_1 and the identity matrix. So in the case of an isotropic medium. Fick's law can be written as follows.

Notes

Summary



7m 25s

L'équation de la diffusion

- Nous considérons une substance A isotrope, électriquement neutre et dissoute dans un fluide.
- Le fluide est isotrope, non-réactif, non-visqueux et électriquement neutre: $\mathbf{j}_A = -F_A \cdot \nabla \mu_A$.
- A température et pression constantes : $\mu_A = \mu_A(n_A) \implies \nabla \mu_A = \frac{d\mu_A}{dn_A} \nabla n_A$.
- La loi de Fick s'écrit alors sous la forme:

$$\mathbf{j}_A = -D \cdot \nabla n_A, \quad D \equiv F_A \frac{d\mu_A}{dn_A}. \quad (18)$$

- Equation de continuité pour la substance chimique A dans le référentiel du fluide:

$$\frac{\partial n_A}{\partial t} = \nabla \cdot \mathbf{j}_A. \quad (19)$$

Thermodynamique

Now we will use the law facts for an isotropic medium to derive the diffusion equation. We consider an isotropic substance a electrically, another is dissolved in a fluid. The fluid is its own non-reactive non-muscle. This is it. The law sets for this environment. We note that the coefficient f a. Here, the coefficient of chemical diffusion is a scalar. Since the medium is isotropic. Moreover, we notice that at temperature and constant pressure, the chemical potential of the substance to put at A is a function only of the density of substance A. We then have a TC function. This function allows us to obtain a relationship between. The gradient of the seismic potential of the substance a is the gradient of the density of the substance a. Now we can introduce this relationship by the law of fixed then creates the following form the coefficients two that appear in the law. The fixed is given by this expression. Now we consider the equation of continuity for the chemical substance at in the reference frame of the fluid. This is the continuity equation for the chemical substance. We notice the absence of load for the chemical substance due to the absence of chemical reaction.

Notes

Summary



8m 41s

L'équation de la diffusion

- Nous considérons une substance A isotrope, électriquement neutre et dissoute dans un fluide.
- Le fluide est isotrope, non-réactif, non-visqueux et électriquement neutre: $\mathbf{j}_A = -F_A \cdot \nabla \mu_A$.
- A température et pression constantes : $\mu_A = \mu_A(n_A) \implies \nabla \mu_A = \frac{d\mu_A}{dn_A} \nabla n_A$.
- La loi de Fick s'écrit alors sous la forme:

$$\mathbf{j}_A = -D \cdot \nabla n_A, \quad D \equiv F_A \frac{d\mu_A}{dn_A}. \quad (18)$$

- Equation de continuité pour la substance chimique A dans le référentiel du fluide:

$$\frac{\partial n_A}{\partial t} = \nabla \cdot \mathbf{j}_A. \quad (19)$$

- La combinaison de deux dernières relations donne l'équation de la diffusion :

$$\frac{\partial n_A}{\partial t} = D \nabla^2 n_A. \quad (20)$$

Thermodynamique

Moreover, on the left side of this equation, we have only the partial derivative of the density of substance A with respect to time, since the velocity of the medium is zero in the reference frame of the medium. So the combination of two final revelations. So the diffusion equation. This is the broadcasting equation. Who says partial differential equations for the density of the chemical substance at. We note that this equation has exactly the same structure with the heat equation.

Notes

Summary



Diffusion thermo-chimique: effet Dufour

- Nous considérons une substance A électriquement neutre et dissoute dans un fluide : $q_A = 0$.
- Le fluide est non-réactif, non-visqueux et électriquement neutre.
- Nous supposons l'absence de courant de matière : $j_A = 0$.
- Densité de courant de chaleur : $j_Q = T j_s$.

$$\begin{cases} j_s = L_{ss} (-\nabla T) + L_{sA} (-\nabla \mu_A - \cancel{q_A \nabla \varphi}) , \\ \cancel{j_A} = L_{sA} (-\nabla T) + L_{AA} (-\nabla \mu_A - \cancel{q_A \nabla \varphi}) , \end{cases}$$

- La combinaison des dernières relations donne :

Thermodynamique

And we continue with the phenomenon of thermo chemical diffusion. We start with the effect of the ovens. We consider the substances to which is electrically. Another is dissolved in a fluid as the substance electrically is another while its electric charge is zero. In addition, non-reactive fluids do not optically muscle another. Finally, we assume the absence of matter flow. Then the current density of the substance at J one is zero. We have this inflation for density and the phenomenological relations between the two. binary between current density and generalized force. For this problem, all generalized current densities to all generalized forces are of vector character. In addition, since the environment is in general anisotropic, the phenomenological coefficients that appear in this relation are tensors. Now we use the fact that Giat is equal to zero as well as the fact that it is all equal to zero. To obtain, from the second phenomenological relation, a linear relation between the temperature gradient and the grades from the chemical potential of the substance to this linear relationship of the products. In the first linear phenomenological relationship, and the result can then be introduces to the expression for the heat current density.

Notes

Summary



10m 49s

Diffusion thermo-chimique: effet Dufour

- Nous considérons une substance A électriquement neutre et dissoute dans un fluide : $q_A = 0$.
- Le fluide est non-réactif, non-visqueux et électriquement neutre.
- Nous supposons l'absence de courant de matière : $j_A = 0$.
- Densité de courant de chaleur : $j_Q = T j_s$.

$$\begin{cases} j_s = L_{ss} (-\nabla T) + L_{sA} (-\nabla \mu_A - \cancel{q_A} \nabla \varphi) , \\ \cancel{j_A} = L_{sA} (-\nabla T) + L_{AA} (-\nabla \mu_A - \cancel{q_A} \nabla \varphi) , \end{cases}$$

- La combinaison des dernières relations donne :

$$j_Q = -D_A \cdot \nabla \mu_A , \quad D_A \equiv T L_{sA}^{-1} \cdot (L_{sA}^2 - L_{ss} \cdot L_{AA}) , \quad (21)$$

- Cet effet thermo-chimique s'appelle *effet Dufour*.

Thermodynamique

Then the combination of the last relations of which this equation. This equation expresses the chemical ferment which is called the defect effect. The fact of creating the phenomenon of appearance of heat flow due to the chemical potential of the substances. The coefficients of one that appear in this relation is a function of phenomenological coefficients linear and it is given by this relation.

Notes

Summary



Diffusion thermo-chimique: effet Soret

- Nous considérons deux substances A et B électriquement neutres et dissoutes dans un fluide.
- Le fluide est isotrope, non-réactif, non-visqueux et électriquement neutre.

$$\begin{cases} \dot{j}_s = -L_{ss}\nabla T - L_{sA}\nabla\mu_A - L_{sB}\nabla\mu_B, \\ \dot{j}_A = -L_{As}\nabla T - L_{AA}\nabla\mu_A - L_{AB}\nabla\mu_B, \\ \dot{j}_B = -L_{Bs}\nabla T - L_{BA}\nabla\mu_A - L_{BB}\nabla\mu_B. \end{cases}$$

- Nous définissons : $\dot{j}_{A+B} \equiv \dot{j}_A + \dot{j}_B$, $\dot{j}_{A-B} \equiv \dot{j}_A - \dot{j}_B$.

$$\begin{cases} \dot{j}_{A+B} = -(L_{As} + L_{Bs})\nabla T - (L_{AA} + L_{BA})\nabla\mu_A - (L_{AB} + L_{BB})\nabla\mu_B, \\ \dot{j}_{A-B} = -(L_{As} - L_{Bs})\nabla T - (L_{AA} - L_{BA})\nabla\mu_A - (L_{AB} - L_{BB})\nabla\mu_B. \end{cases} \quad (22)$$

Thermodynamique

And we will conclude this part of the course with the presentation of the solar effect. We consider two substances A and B electrically. Another is dissolved in a fluid. The fluid is clean, non-reactive, not optically muscle another. This is the linear phenomenological relation for this environment. Now, we will define new generalized current densities. More precisely, we define said A+ B as the sum of of substance current densities A and B, and we define J a minus as the difference between the current densities of substance a and b. Using the phenomenological relations, we can obtain this expression for the new generalized current densities.

Notes

Summary



12m 44s

Diffusion thermique et chimique

• Nous définissons : $\mu_0 \equiv \frac{\mu_A + \mu_B}{2}$, $\Delta\mu \equiv \frac{\mu_A - \mu_B}{2}$.

• A l'aide de ces définitions, les relations précédentes donnent :

$$j_{A+B} = -(L_{As} + L_{Bs}) \nabla T - (L_{AA} + L_{BB} + 2L_{AB}) \nabla \mu_0 - (L_{AA} - L_{BB}) \nabla (\Delta\mu),$$

$$j_{A-B} = -(L_{As} - L_{Bs}) \nabla T - (L_{AA} - L_{BB}) \nabla \mu_0 - (L_{AA} + L_{BB} - 2L_{AB}) \nabla (\Delta\mu).$$

• A l'état d'équilibre : $j_{A+B} = 0$, $j_{A-B} = 0$.

• Les quatre dernières relations se réduisent à

$$\nabla (\Delta\mu) = -S \nabla T. \quad (23)$$

$$S \equiv \frac{1}{2} \frac{L_{AB}(L_{As} - L_{Bs}) + L_{As}L_{BB} - L_{Bs}L_{AA}}{L_{AA}L_{BB} - L_{AB}^2}.$$

• Cet effet thermo-chimique s'appelle *effet Soret* ou *thermophorèse*. Il est le réciproque de l'effet Dufour.

Thermodynamique

Moreover, we define zero as the potential means of two substances A and B, and we define delta mew as half the difference between the chemical potential of substances A and B. Using this definition. The previous relationship for the new current densities analyzed can be written in this form. But now we notice that in the equilibrium state J app Elizabeth is zero and j in minus is zero. Now we can combine these four equations. In fact, the last four relationships are reduced to this expression. The coefficients s that appear in this equation is a function of the phenomenological coefficients of the medium. Given that the medium has, the phenomenological coefficients are scalars and the coefficients are scalars. This coefficient S is given by this expression. This relationship expresses the thermo-chemical effect which is called soret effect or thermoforming. The Soret fact describes the phenomenon of the difference between the chemical potential of two substances due to temperature ice. This effect is the reciprocal of the oven effect.

Notes

Summary



Diffusion thermique et chimique



Thermodynamique

We have also reached the end of this part of thermodynamics. In the next presentation, we will examine thermoelectric effects.

Notes

Summary



15m 02s