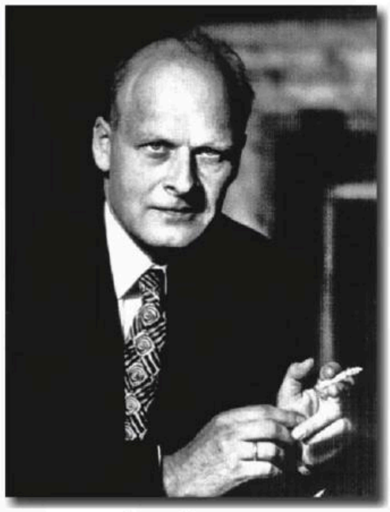
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

RESCIF
Réseau d'excellence des sciences de l'ingénieur de la Francophonie

Thermodynamique

Effets thermo-électriques



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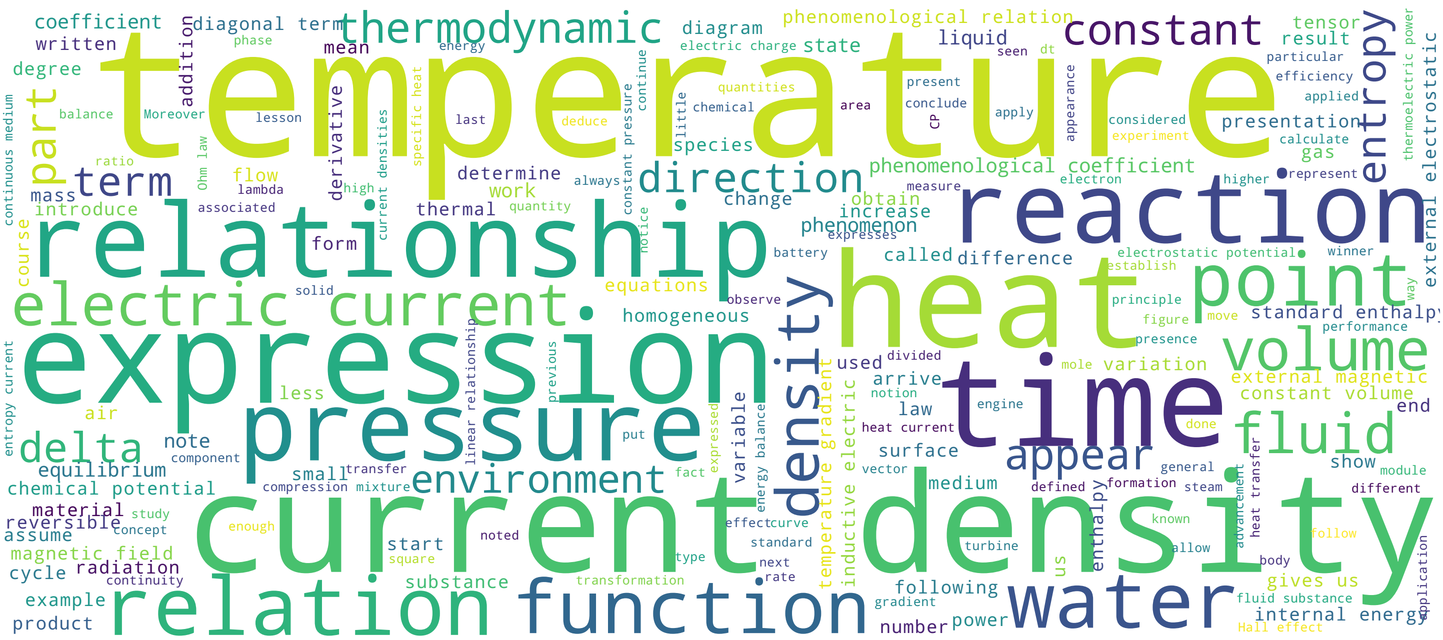
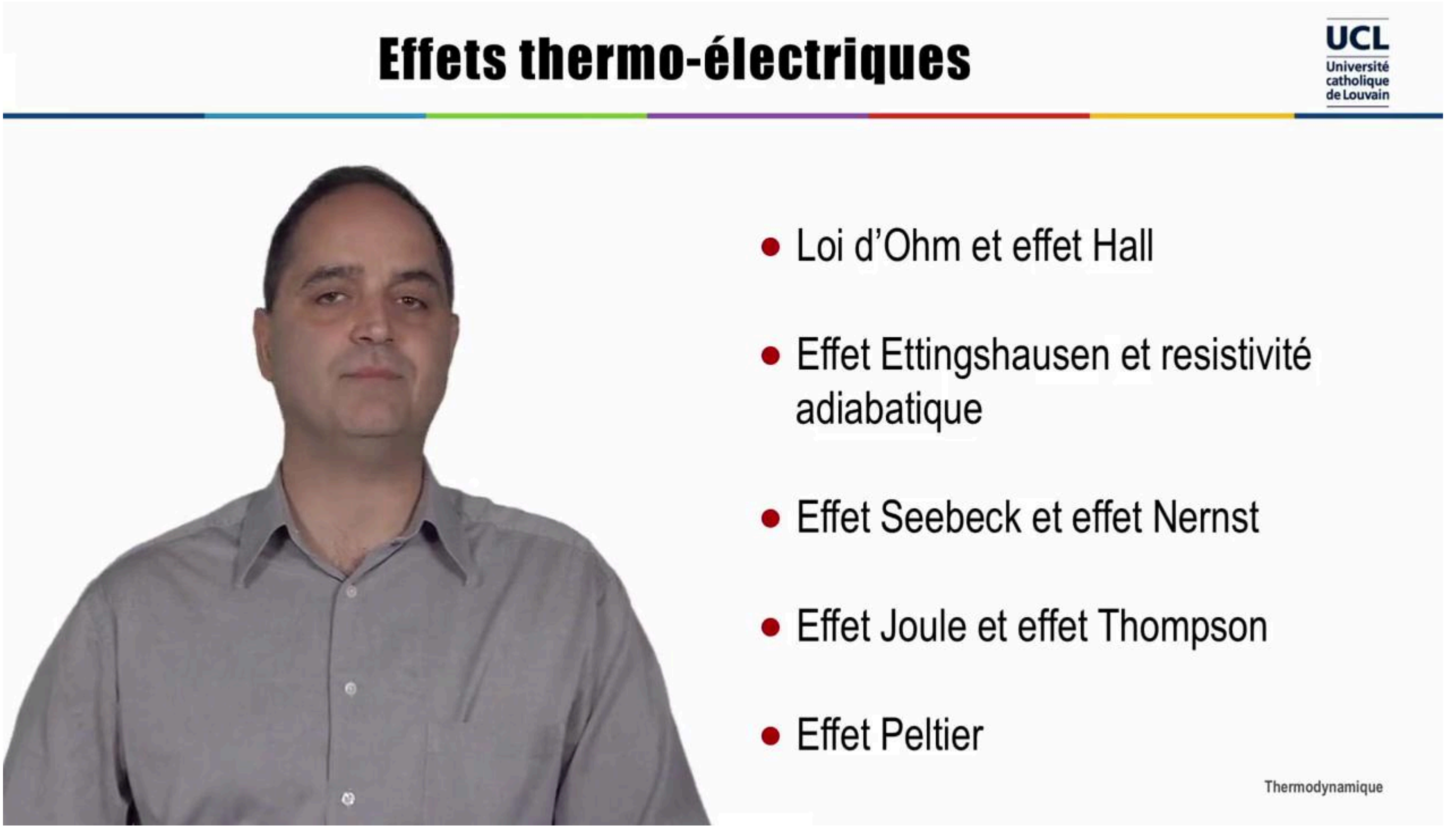


Video

EPFL



Hello and welcome to the thermodynamics classes. In this part of the course, we will examine two thermoelectric effects. The structure of our presentation is as follows. First, we will present Ohm's law and the Hall effect. Then, we will present the fact outside and we will study the notion of adiabatic resistivity. Next, we will examine the effects of Seebeck NR and Jule Thomson effects. We conclude this part of the course with the presentation of the Peltier effect.

Notes

Summary

0m 04s

Effets thermo-électriques

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Loi d'Ohm – effet Hall

- Nous considérons un fluide A homogène ($\nabla \mu_A = 0$) et non-visqueux.
- Nous supposons que la température est uniforme : $\nabla T = 0$.
- Compte tenu de $\boldsymbol{j}_q = q_A \boldsymbol{j}_A$, la deuxième relation phénoménologique donne :

$$\boldsymbol{j}_q = -\boldsymbol{\sigma} \cdot \nabla \varphi , \qquad \boldsymbol{\sigma} \equiv q_A^2 \, \mathsf{L}_{AA} . \tag{25}$$

- $\boldsymbol{\sigma}$: tenseur de conductivité électrique.

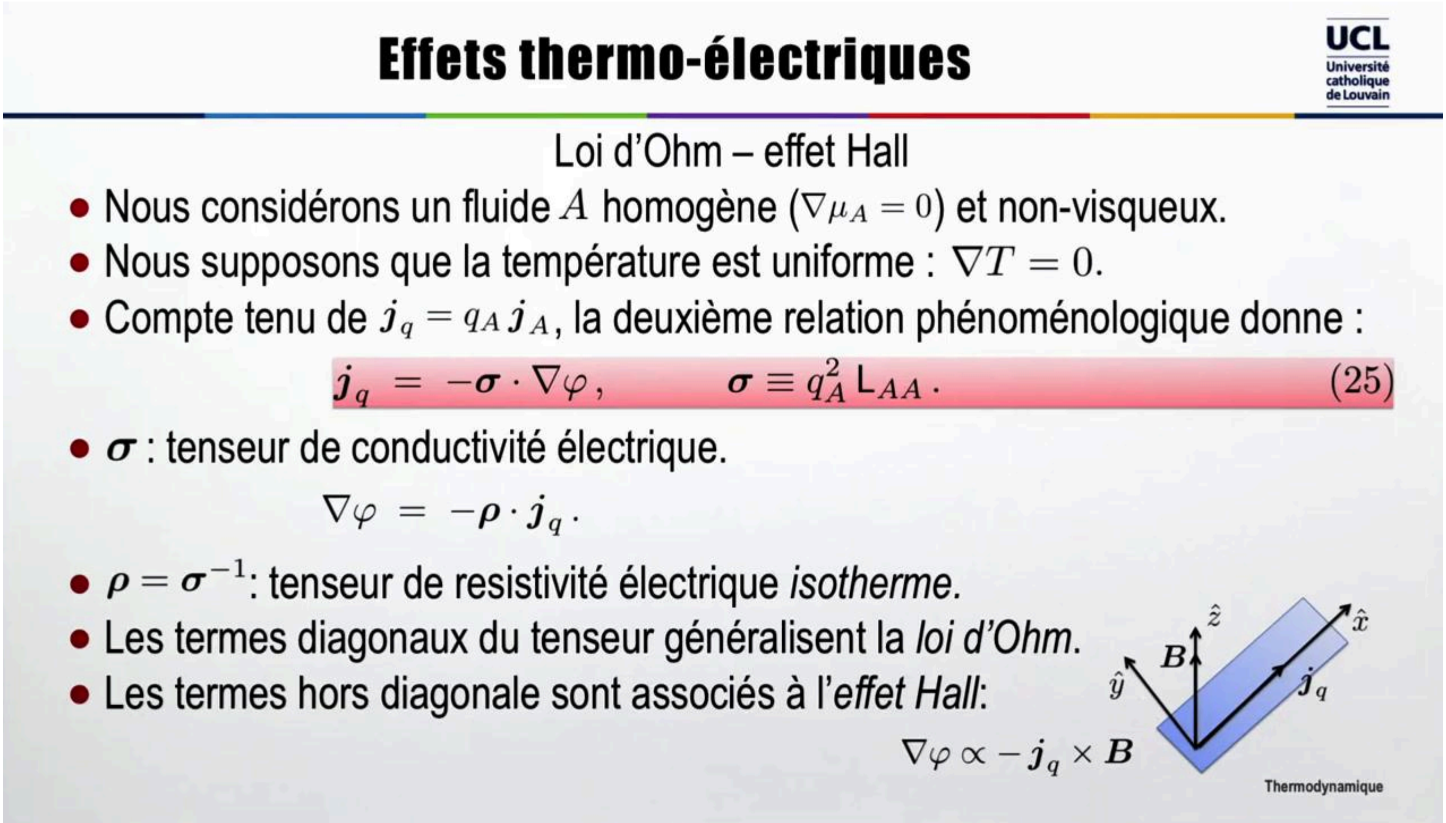
Thermodynamique

First of all, let's remember the equations that we have already told in previous lessons and which we will use in this presentation as well. First we have the relation for the heat current density as well as the phenomenological relations between the linear between current density, generalized and vector effort. In addition, we have the relationships of war reciprocity between the phenomenological coefficients that appear in this phenomenological relation. Let's start with Ohm's law and the hall effect. We consider a fluid A. Homogeneous and not since the fluid is homogeneous, then the gradient of its chemical potential is zero. Furthermore, we assume that the temperature is uniform. We then assume term-level conditions. This means that the gradient of the temperature is zero given the linear relationship between the density current, the conductive side zito and the current density of the substance. A. The second phenomenological relation gives directly. This relationship. The sigma coefficients that appear in this concept is a function of the phenomenological coefficient L A, since our environment is generally anisotropic. The phenomenological coefficients L a and the sigma coefficient are tensors.

Notes

Summary

0m 38s



Sigma is called trend with electrical conductivity. Now we can convert this relation to express the gradient in the external electrostatic potential internal graph of the inductive electric current density zittau. We then arrive at this expression. The ro coefficients that appear in this expression is the inverse of the sigma tensor. It is called tensor of electrical resistivity. It works. The diagonal term, known as the clamp, generalizes Ohm's law. Moreover, the term diagonal describes another phenomenon. They describe the phenomenon of the appearance of external orthostatic potential due to of an inductive electric current, but in directions normal to the direction of the conductive electric current in the presence of an external magnetic field. This phenomenon is known as the Hall effect, then the off-diagonal term is associated with the Hall effect. We see in this figure the representation of this effect. An inductive electric current in the X direction with an external magnetic field in the induced Z direction, ingredient of the external electrostatic potential in the I direction.

Notes

Summary

2m 04s

Effets thermo-électriques

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Effet Ettingshausen – resistivité adiabatique

- Soit un fluide A homogène ($\nabla \mu_A = 0$) et non-visqueux.
- La charge électrique du fluide est q_A.
- Nous supposons l'absence de courant de chaleur : $\boldsymbol{j}_Q = 0$.

$$\begin{cases} \cancel{\boldsymbol{j}_s}^{\,0} = \mathsf{L}_{ss}\,(-\nabla T) + \mathsf{L}_{sA}\,(-\cancel{\nabla \mu_A}^{\,0} - q_A \nabla \varphi)\,, \\ \boldsymbol{j}_A = \mathsf{L}_{sA}\,(-\nabla T) + \mathsf{L}_{AA}\,(-\cancel{\nabla \mu_A}^{\,0} - q_A \nabla \varphi)\,, \end{cases}$$

- Compte tenu de $\boldsymbol{j}_q = q_A\,\boldsymbol{j}_A$, la deuxième relation phénoménologique donne :

Thermodynamique

We continue with the ethics effect and the adiabatic resistivity. Either is fluid to homogeneous? No, since the fluid is homogeneous, then the gradient of its chemical potential is zero. The electric charge of the fluid is noted by Q at. In addition, we assume no salary flow this year, that we assume adiabatic conditions. This means that the heat current density is zero. These are the linear phenomenological relations for this environment. Here, since the environment is in general anisotropic, the phenomenological coefficients are tensions. Now, given that the current density of the air is zero, then the entropy current density is zero if. In addition, we can use the fact that the ingredients of the chemical potential of the fluid substance at is zero to obtain from the first relation a linear relationship between the temperature gradient and the temperature of the and the winner of the external orthostatic potential. This relation introduces in the second linear phenomenological relation. But given the linear relationship between the density of conductors and the current density of the fluid substance to the second relation phenomenological, we in this result.

Notes

Summary

3m 26s

Effets thermo-électriques

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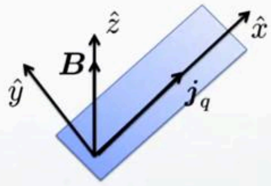
$$\nabla T = -\mathsf{E} \cdot \boldsymbol{j}_q\,, \qquad \mathsf{E} \equiv \frac{1}{q_A}\left(\mathsf{L}_{sA}^2 - \mathsf{L}_{AA} \cdot \mathsf{L}_{ss}\right)^{-1} \cdot \mathsf{L}_{sA}\,. \tag{26}$$

- Les termes hors diagonale sont associés à l'*effet Ettingshausen:*

$$\nabla T \propto -\boldsymbol{j}_q \times \boldsymbol{B}$$



- De la première relation phénoménologique, nous déduisons aussi que

$$\nabla \varphi = -\boldsymbol{\rho}_{\text{ad}} \cdot \boldsymbol{j}_q\,, \qquad \boldsymbol{\rho}_{\text{ad}} \equiv \frac{1}{q_A^2}\left(\mathsf{L}_{AA} \cdot \mathsf{L}_{ss} - \mathsf{L}_{sA}^2\right)^{-1} \cdot \mathsf{L}_{ss}\,. \tag{27}$$

- $\boldsymbol{\rho}_{\text{ad}}$: tenseur de *résistivité adiabatique*.

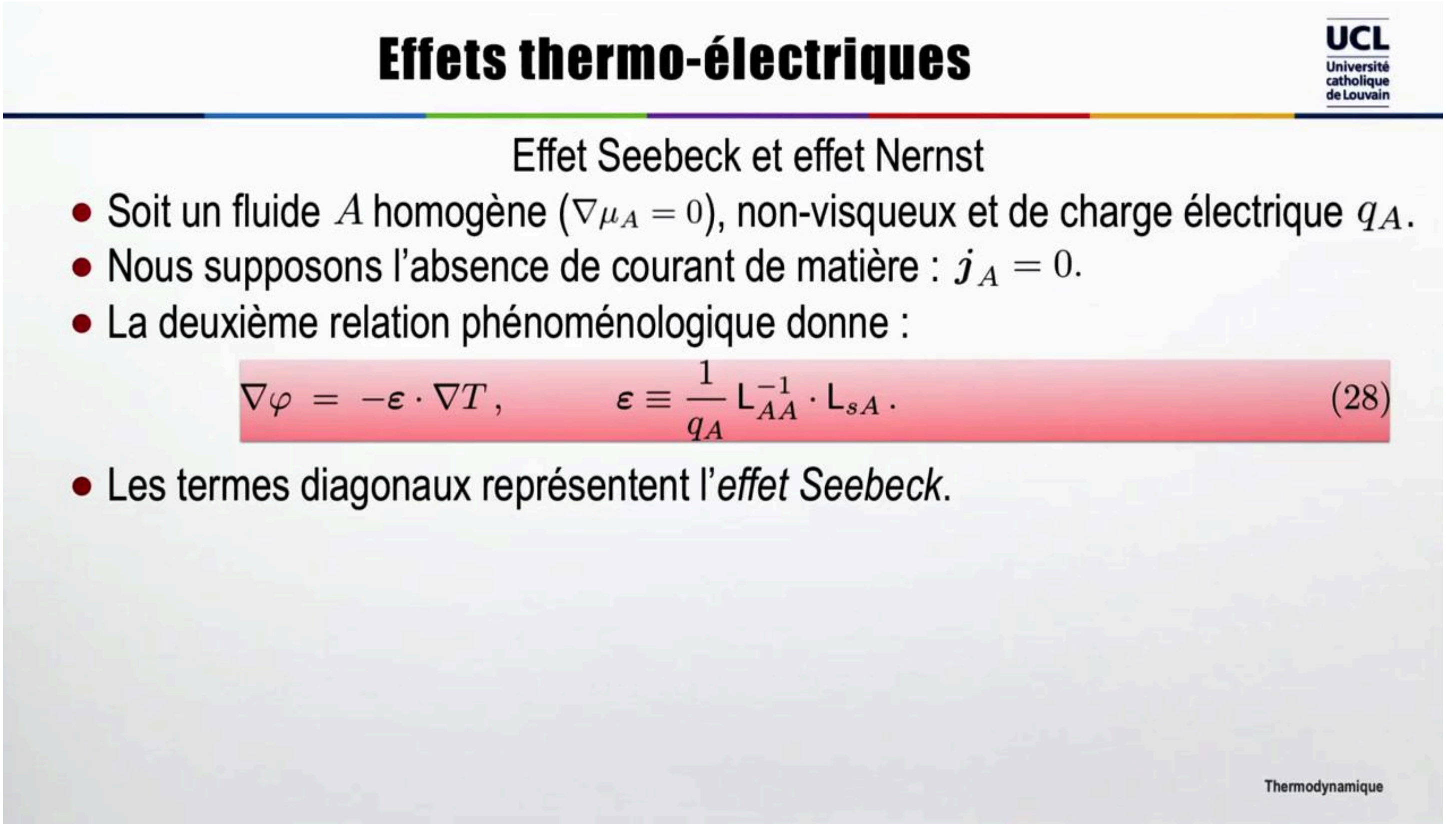
Thermodynamique

Here the coefficients that appear in this relationship is a function of of the phenomenological coefficients and it is given by this relation. Since the phenomenological coefficient is enough, then was tensor at if the diagonal term of this r. Describes the phenomenon of appearance temperature gradient due to an inductive electric current in the directions normal to the direction of the inductive electric current. In the presence of an external magnetic field. This phenomenon is known as fact is then the diagonal order term is associated with the effect is whose representation is given in this figure. An inductive electric current in the X direction with an external magnetic field in the Z direction induces a temperature gradient in the I direction. Now. We can introduce this equation in the first evaluation phenomenological evaluation during the first phenomenological evaluation. We also deduce that the winner of the external electrostatic potential is proportional to the inductive electric current density. The coefficients that appear in this relationship is a function of coefficients and it is given by this relation. Since the phenomenological coefficient of the medium are transfers, then the coefficient ro was tensor. It is called adiabatic resistivity tensor.

Notes

Summary

4m 55s



We continue with the Seebeck effects in Neste. Let be a homogeneous fluid without muscle of electric charge that is. Since the fluid is homogeneous, then the gradient of its chemical potential is zero. Moreover, we assume the absence of matter flow. This means that the current density of the fluid substance A is zero. The second phenomenological relation in directly this equation. This equation expresses the phenomenon of appearance. The external prostatic potential gradient. Because of temperature ingredients. The epsilon coefficients that appear in this relation is a function of the phenomenological coefficients of the medium and it is given by this equation. Since in general the environment is anisotropic, then the phenomenological coefficient and the epsilon coefficients are tensors. The diagonal terms of this ancestor present the Seebeck fact. It is interesting to mention that the operation of thermocouples that we use to measure temperature is based on the Seebeck effect. Moreover, the term diagonal of seven years ser epsilon describing another phenomenon. They describe the phenomenon of appearance of ice with external electrostatic potential due to of the temperature range at directions normal to the gradient direction of temperature in the presence of an external magnetic field.

Notes

Summary

6m 30s

Effets thermo-électriques

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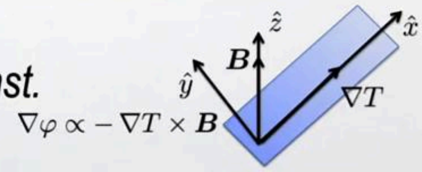
Effet Seebeck et effet Nernst

- Soit un fluide A homogène ($\nabla\mu_A = 0$), non-visqueux et de charge électrique q_A.
- Nous supposons l'absence de courant de matière : $\boldsymbol{j}_A = 0$.
- La deuxième relation phénoménologique donne :

$$\nabla\varphi = -\boldsymbol{\varepsilon}\cdot\nabla T\,, \qquad \boldsymbol{\varepsilon} \equiv \frac{1}{q_A}\,\mathsf{L}_{AA}^{-1}\cdot\mathsf{L}_{sA}\,. \tag{28}$$

- Les termes diagonaux représentent l'*effet Seebeck*.
- Les termes hors diagonale sont associés à l'*effet Nernst*.
- Pour un métal isotrope :



$$\nabla\varphi = -\varepsilon\cdot\nabla T\,, \qquad \varepsilon \equiv \frac{L_{se}}{q_A\,L_{ee}}\,. \tag{29}$$

- ε: *pouvoir thermo-électrique* des électrons.

Thermodynamique

This phenomenon is known as the next, then the off-diagonal term is associated with the next effect. We see in this figure the representation of the burst effect. A temperature gradient in the X direction with an external magnetic field in the induced Z direction. Ingredient of the external electrostatic potential in the direction. We note that for the metal isotropic, this relationship can be written in this form. Here, given his tropism of the environment, the epsilon coefficient reduces to a scalar quantity. This scalar quantity is given by this expression. It is called thermoelectric power two electrons.

Notes

Summary

8m 02s

Effets thermo-électriques

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Effet Joule et Effet Thompson

- Soit un métal isotrope contenant des électrons de conduction.
- Les électrons sont considérés comme une substance e de charge q_e.
- Les relations phénoménologiques sont ré-écrites en terme de κ, σ, ε:

$$\left.\begin{cases} \boldsymbol{j}_s = -\left(\dfrac{\kappa}{T} + \sigma\varepsilon^2\right)\nabla T - \dfrac{\sigma\varepsilon}{q_e}\nabla\left(\mu_e + q_e\varphi\right), \\ \boldsymbol{j}_e = -\dfrac{\sigma\varepsilon}{q_e}\nabla T - \dfrac{\sigma}{q_e^2}\nabla\left(\mu_e + q_e\varphi\right). \end{cases}\right\} \Longrightarrow \quad \boldsymbol{j}_s = -\frac{\kappa}{T}\nabla T + \varepsilon\, q_e\, \boldsymbol{j}_e\,. \tag{30}$$

$$\left.\begin{array}{l} \boldsymbol{j}_Q = T\,\boldsymbol{j}_s \\ \boldsymbol{j}_q = q_e\,\boldsymbol{j}_e \end{array}\right\} \overset{(30)}{\Longrightarrow} \quad \boldsymbol{j}_Q = -\frac{\kappa}{T}\nabla T + T\,\varepsilon\,\boldsymbol{j}_q\,. \tag{31}$$

Thermodynamique

We now move on to the effects. Jules S. Thomson. Let be an isotropic metal containing conduction electrons. The conduction electrons are considered as an electrical discharge substance. We note that the relationships can be written in terms of the conductivity coefficient K, the electrical conductivity coefficient sigma, of the thermoelectric power of epsilon electrons. And these are the phenomenological relations written in terms of these three coefficients. Now we can combine these two relations to obtain this expression for the entropy current density. Now we can use this relation for the current density of heat as well as this relation for the electric current density. We can introduce these two relations in this equation, which gives us this expression for the heat current density.

Notes

Summary

8m 56s

Effets thermo-électriques

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- En régime stationnaire, l'équation de continuité de charge électrique se réduit à :

$$\nabla \cdot \boldsymbol{j}_q = 0 . \tag{32}$$

$$\left.\begin{aligned} \boldsymbol{j}_s &= \frac{1}{T}\left(\boldsymbol{j}_u - \sum_{A=1}^{r} (\mu_A + q_A \varphi)\, \boldsymbol{j}_e\right) \\ \boldsymbol{j}_Q &= T\, \boldsymbol{j}_s \\ \boldsymbol{j}_q &= q_e\, \boldsymbol{j}_e \end{aligned}\right\} \overset{\nabla \cdot}{\Longrightarrow} \quad \nabla \cdot \boldsymbol{j}_u = \nabla \cdot \boldsymbol{j}_Q + \frac{1}{q_e} \boldsymbol{j}_q \cdot \boldsymbol{\nabla}(\mu_e + q_e \varphi) . \tag{33}$$

- La combinaison des trois derniers résultats donne l'équation suivante :

$$\nabla \cdot \boldsymbol{j}_u = -\kappa \nabla^2 T + T\, \boldsymbol{j}_q \cdot \nabla \varepsilon - \frac{\boldsymbol{j}_q^2}{\sigma} . \tag{34}$$

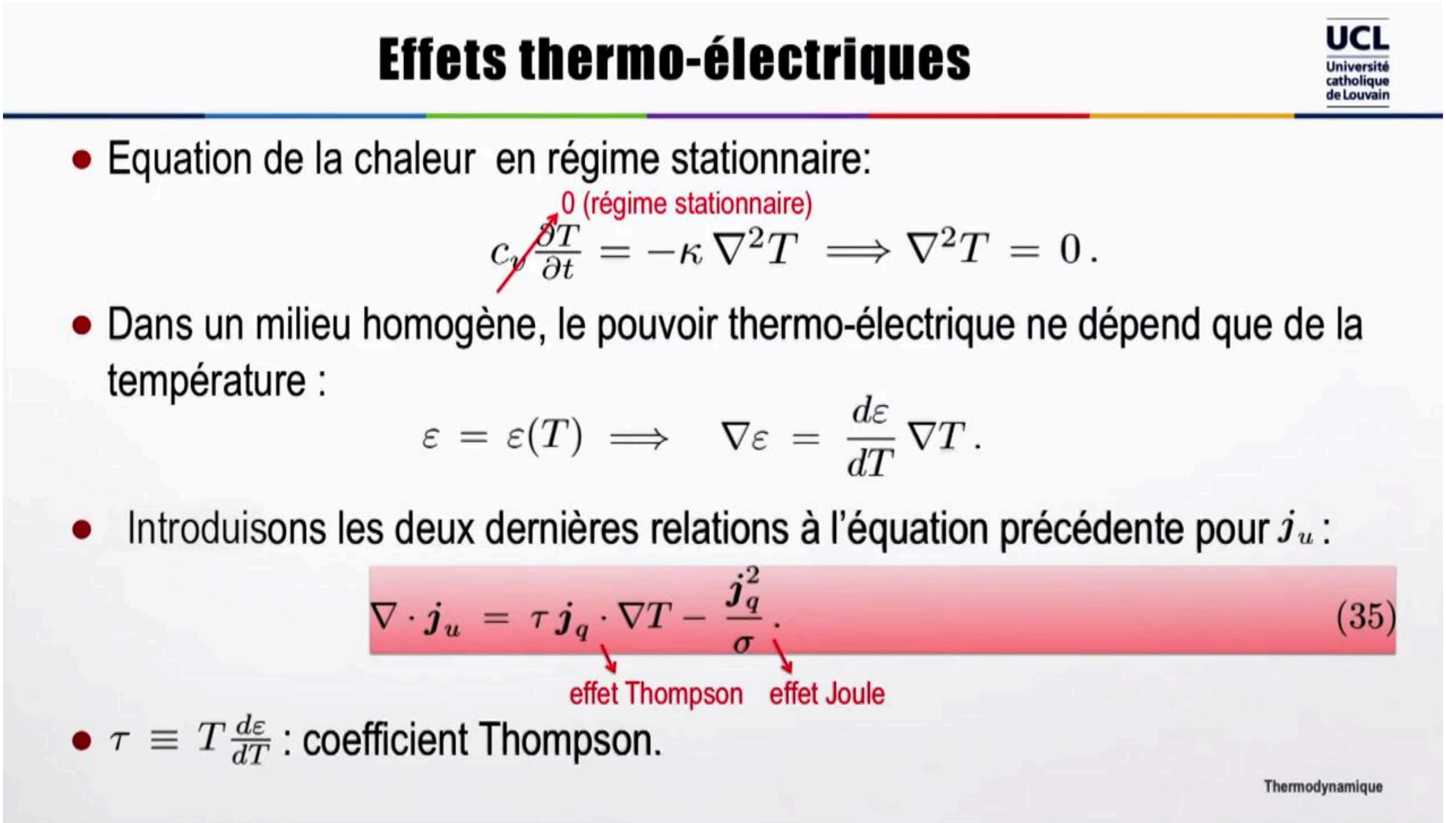
Thermodynamique

Now we notice that a stationary regime, the electric charge continuity equation reduced to this equation. Then we establish the expression for the entropy current density and we derived when we have realized the local energy balance of a continuous medium. We also introduce this expression for the Calexico current density, and this expression for the conductive electric current density. We can introduce this relationship. In this equation and then we can take the divergence of the result. Then we arrive at this equation for the divergence of the internal energy density. Now we can combine this equation. This equation as well as the equation that we have previously for the heat current density. The combination of the last three results in the following equation. We note that in this area, On the right side of this equation, we have the temperature laplacian. But we observe that the laplacian of temperature also appears in the heat equation.

Notes

Summary

9m 59s



We now consider the heat equation of heat equation. We note that it summarizes stationary terms on the left-hand side of this equation, and no longer. As a stationary summary, the partial derivative of temperature with respect to time is zero. This implies that, in steady state, the temperature laplacian is also zero by the way. In a homogeneous environment, the thermoelectric power of electrons depends only on the temperature. We then have an equation of this type. This equation allows us to express the winner of the thermoelectric power of the electrons in terms of the temperature frame. Now, we translate the last relationship, i.e. this relationship and this relationship to the previous equation for the internal energy current density. We then arrive at this equation. The first term on the right side of this equation expresses the Thomson fact. The Thomson fact describes the density power, the mix generated by a current density and the temperature drop. The tau coefficients that appear in this term is given by this relationship. They are called Thomson's coefficient. Finally, the second term on the The right-hand side of this equation expresses the Joule effect.

Notes

Summary

11m 17s

Effets thermo-électriques

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Effet Peltier

- Soit une jonction entre deux métaux isotropes A et B parcourus par un courant électrique, $\boldsymbol{j}_q$.
- La jonction est à température uniforme : $\nabla T = 0$.
- La relation : $\boldsymbol{j}_Q = -\frac{\kappa}{T}\nabla T + T\,\varepsilon\,\boldsymbol{j}_q$, donne :

$$\begin{aligned}\boldsymbol{j}_Q^A &= T\,\varepsilon_A\,\boldsymbol{j}_q^A\,,\\ \boldsymbol{j}_Q^B &= T\,\varepsilon_B\,\boldsymbol{j}_q^B\,.\end{aligned}$$

- A travers la jonction : $\boldsymbol{j}_q = \boldsymbol{j}_q^A = \boldsymbol{j}_q^B$.

$$\boldsymbol{j}_Q^B - \boldsymbol{j}_Q^A = \pi_{AB}\,\boldsymbol{j}_q\,, \qquad \pi_{AB} \equiv T\,(\varepsilon_B - \varepsilon_A)\,, \tag{36}$$

- π_{AB} : coefficient Peltier.

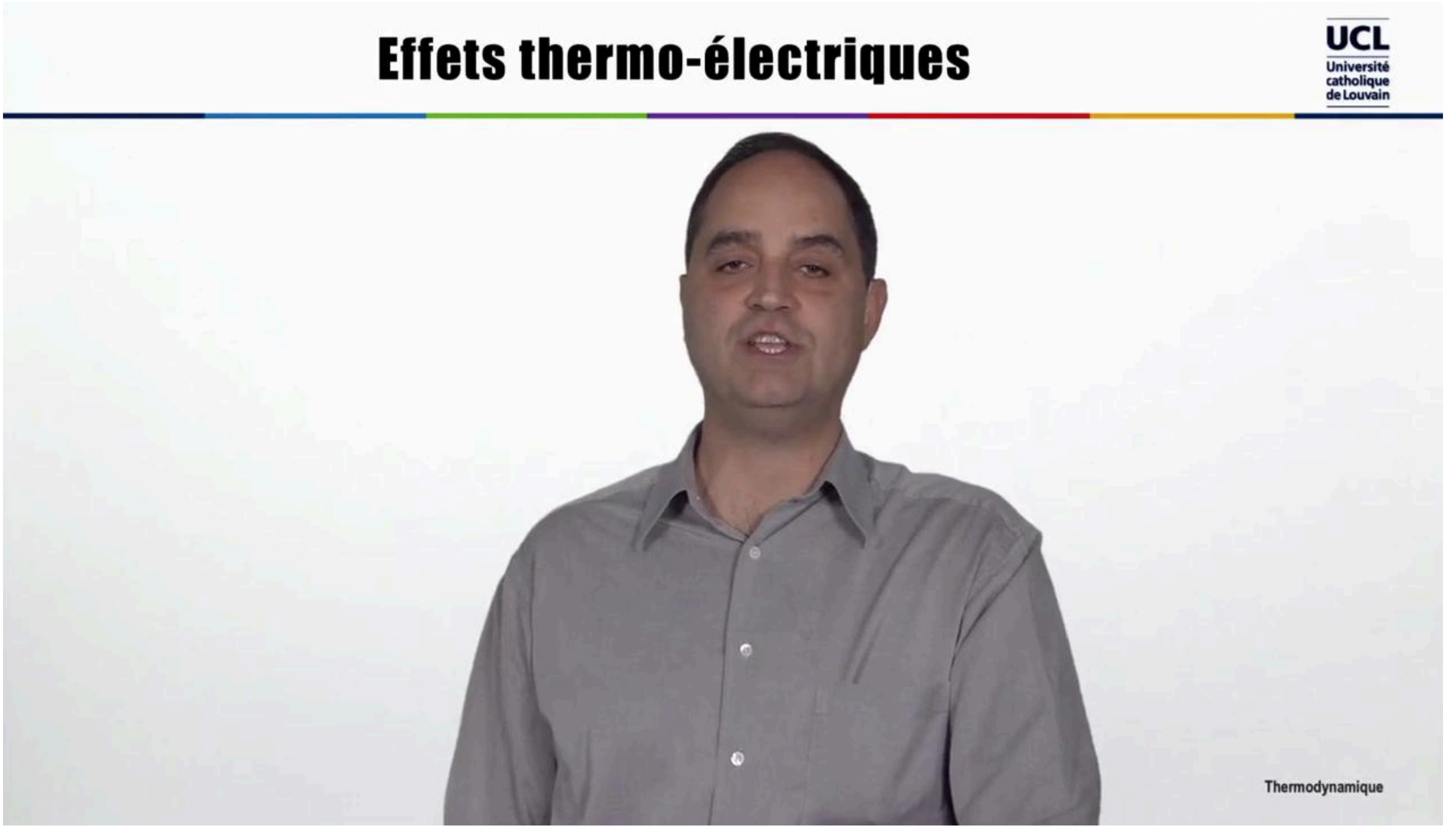
Thermodynamique

The Joule fact describes the density of thermal power generated by an electric current density at constant temperature and we will conclude this part of the course with the presentation of the Peltier effect, i.e. junctions between two metals isotropic A and B through which an electric current flows. If everything. The junction is maintained at temperature uniform, then we climbed is equal to zero. In addition, the relationship or density of a small ground current that we derived earlier gives us this expression for the current density of wages in the DOM being finally through the junction, the conductive electric current densities for the DM are equal. Now we can be with the help of this equation, we arrive at this result. This result expresses the Peltier effect. The Peltier fact is moreover the balance thermal junctions between two different materials A and B by an electric current whose density is equal to zero. The coefficients that appear in this relationship is given by this equation. His name is Peltier coefficient.

Notes

Summary

12m 48s



We have now reached the end of this part of the thermodynamics course.

Notes

Summary

14m 03s