

# COMPOSANTS SEMI-CONDUCTEURS

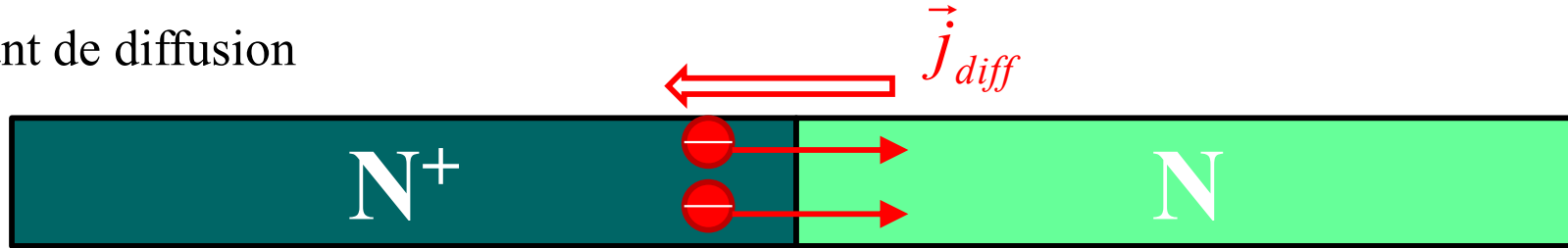
## III) Solutions S3

P.A. Besse

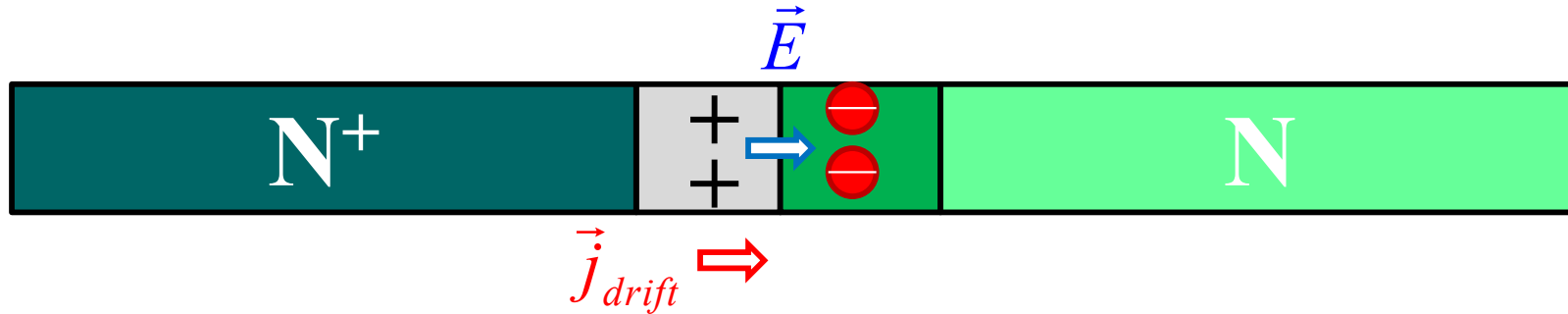
EPFL

# Exercice 3.1: Equilibre: courant de diffusion - courant de drift

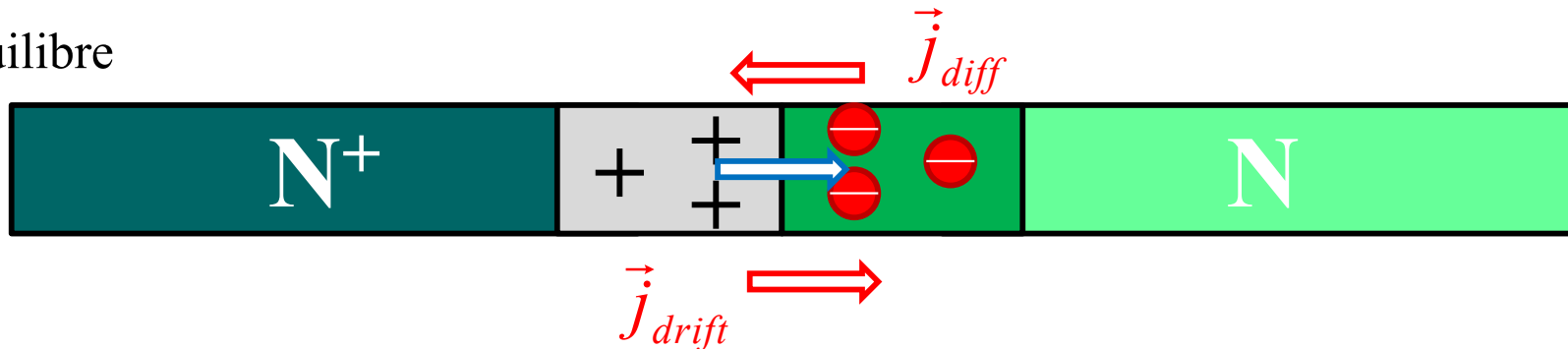
a) Courant de diffusion



b) Zones de déplétion et d'accumulation → champ électrique



c) Equilibre



« 3 inconnues, 3 équations »

Solutions pour une structure à l'équilibre:

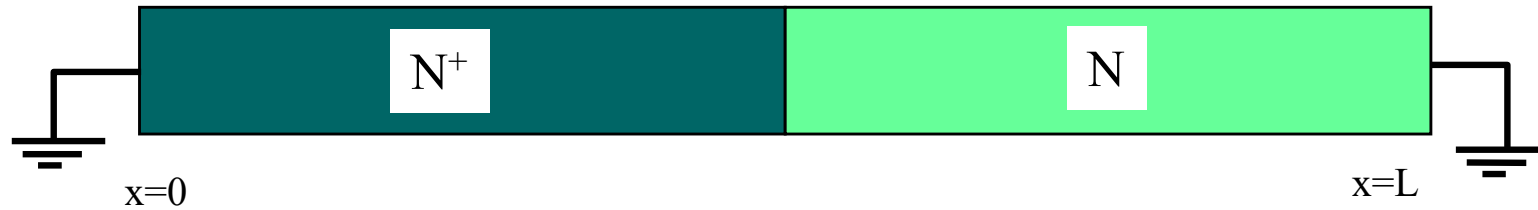
3 inconnues:      champ électrique E, (ou potentiel électrique  $\phi$ )  
                          concentration d'électrons libres n  
                          concentration de trous p

3 équations:

① 
$$\text{div}(\vec{E}) = \frac{1}{\epsilon_0 \epsilon} q (p + N_d^+ - n - N_a^-)$$

② 
$$\vec{j}_{tot} = \vec{j}_{drift,n} + \vec{j}_{drift,p} + \vec{j}_{dif,n} + \vec{j}_{dif,p} = 0$$

③ 
$$n \cdot p = n_i^2$$



$$p = n_i^2 / n$$

Mais p est ici négligeable ! → pas nécessaire de résoudre

$$\text{div}(\vec{E}) = \frac{1}{\epsilon_0 \epsilon} q (N_d^+ - n) \quad \rightarrow \quad \frac{\partial E}{\partial x} = \frac{q}{\epsilon_0 \epsilon} (N_d - n)$$

Inconnues:

$$qn\mu_n E + kT\mu_n \text{grad}(n) = 0 \quad \rightarrow \quad \frac{1}{n} \frac{\partial n}{\partial x} = \frac{\partial \ln(n)}{\partial x} = -\frac{q}{kT} E$$

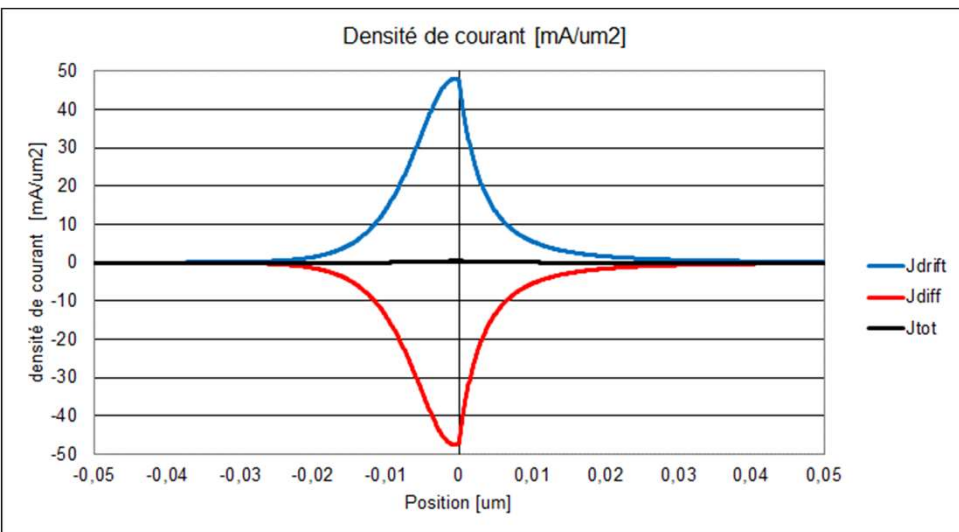
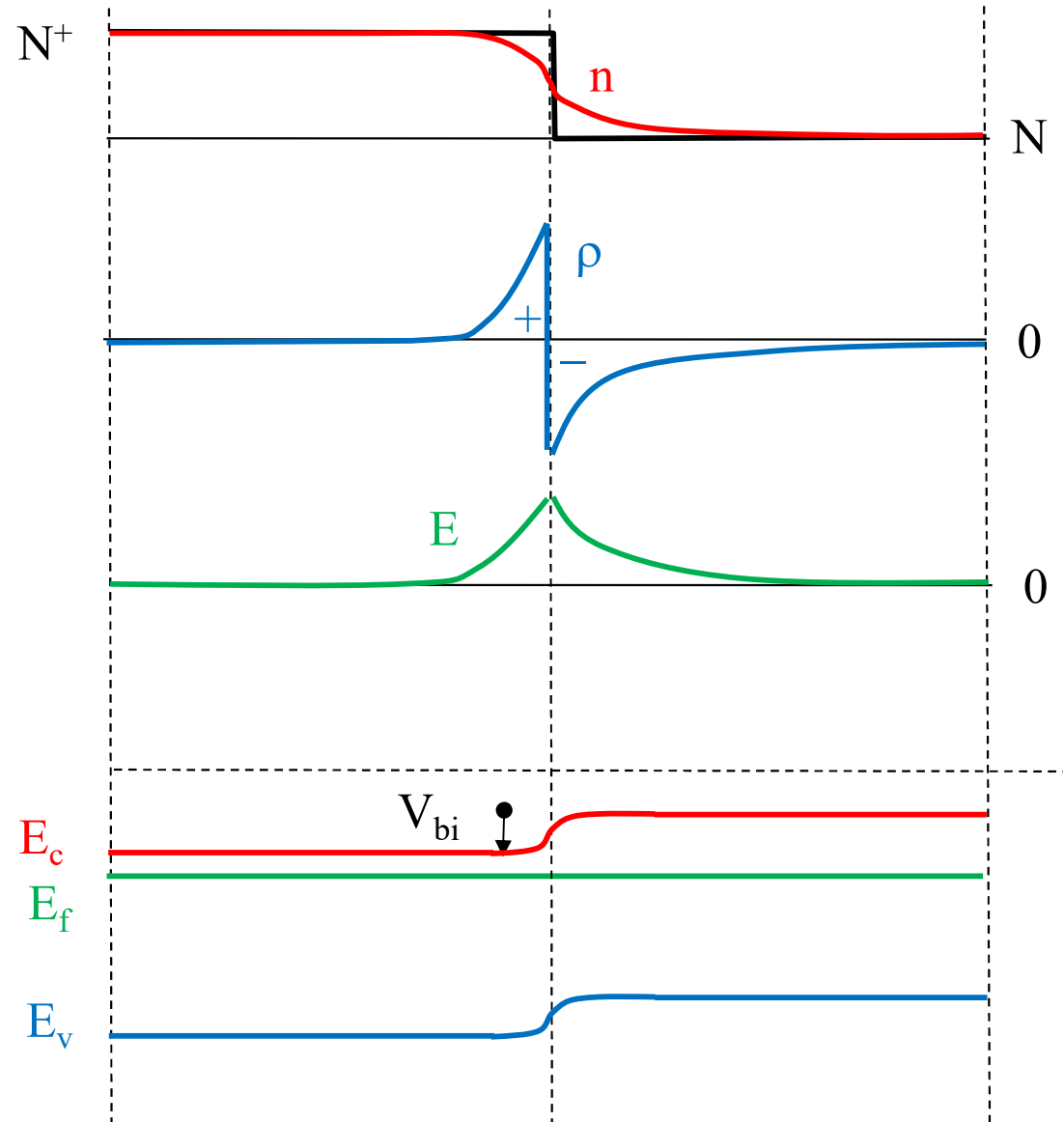
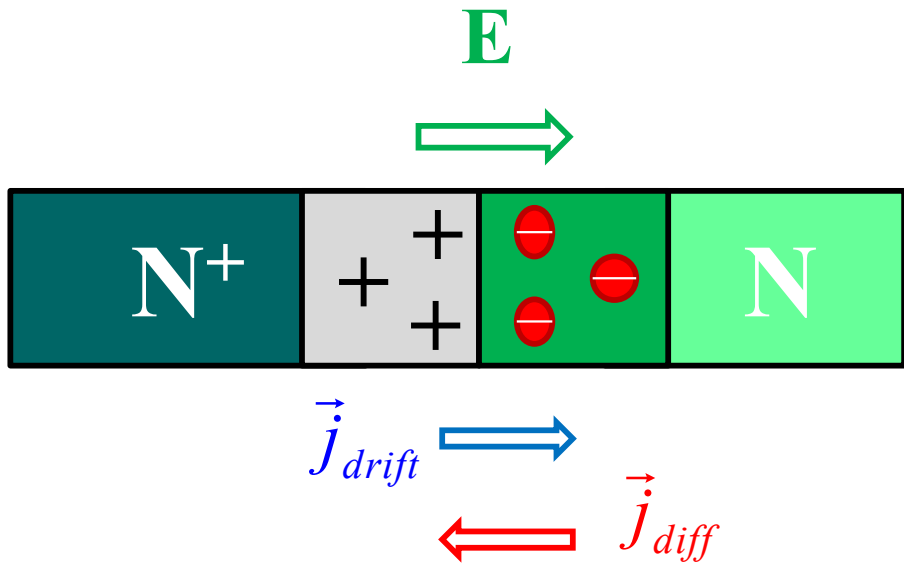
E et n

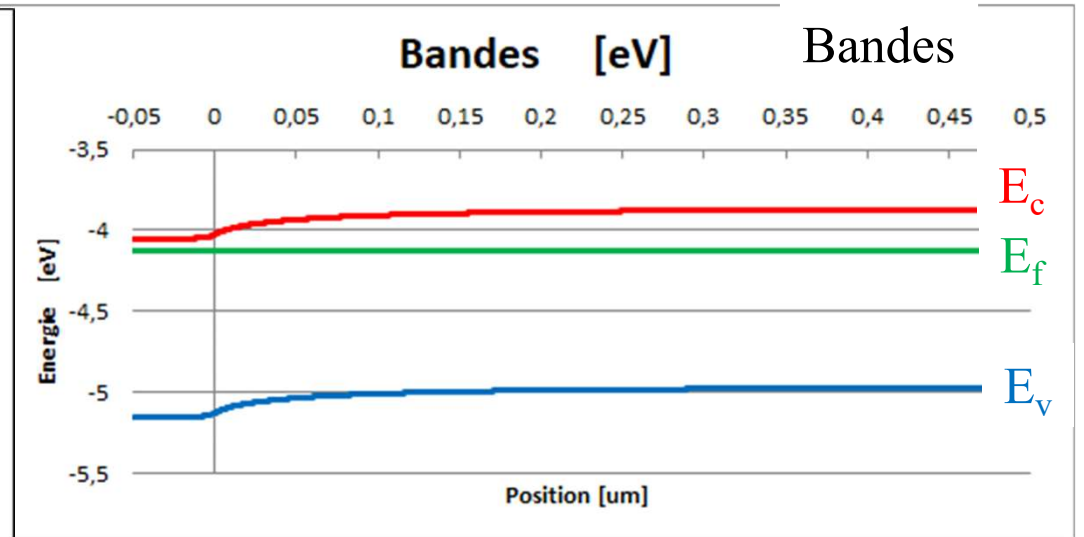
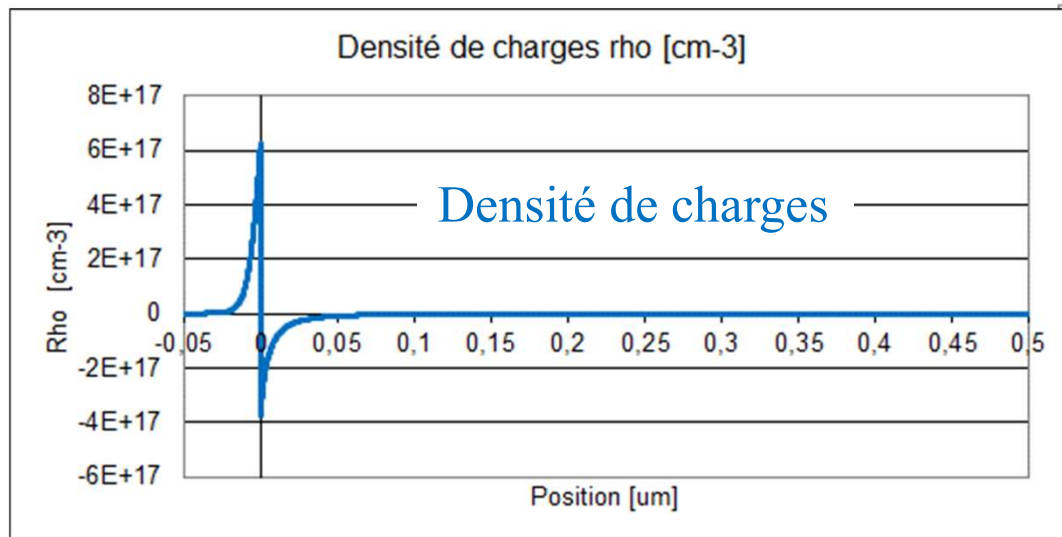
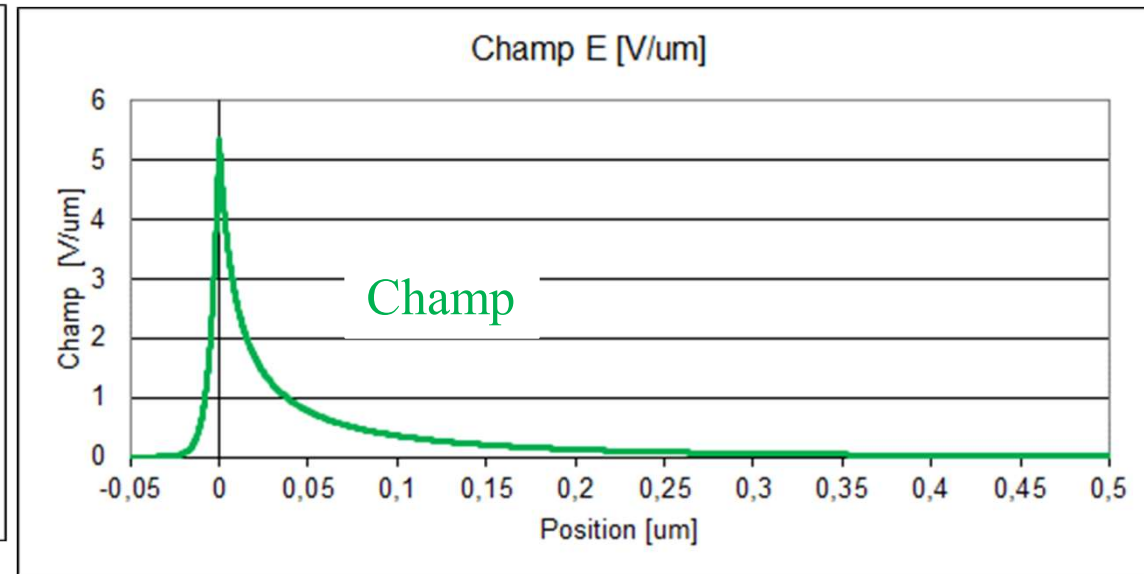
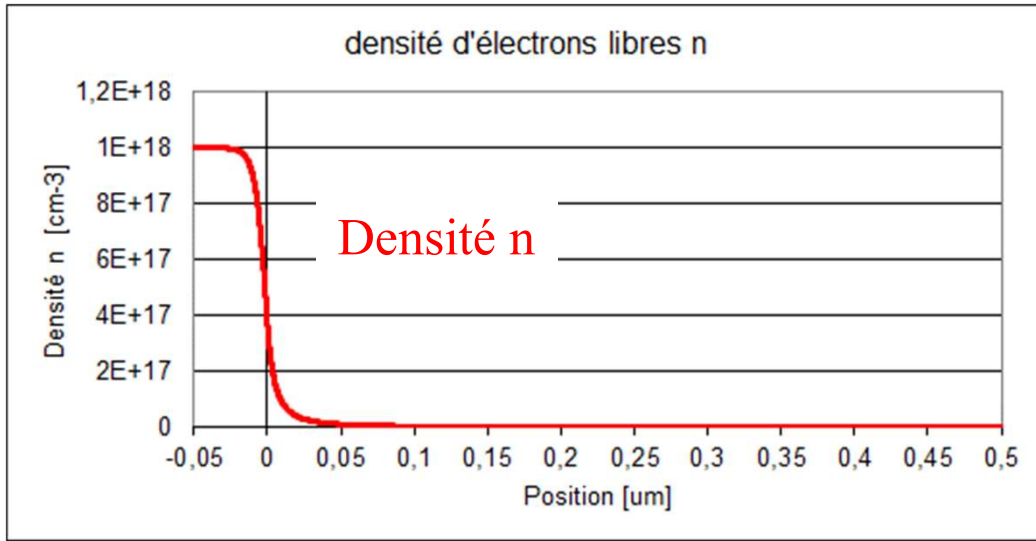
Conditions aux bords (2 conditions car 2 équ. diff. de premier ordre)

$$n(0) = N^+$$

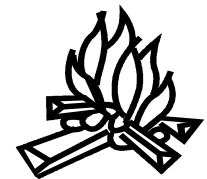
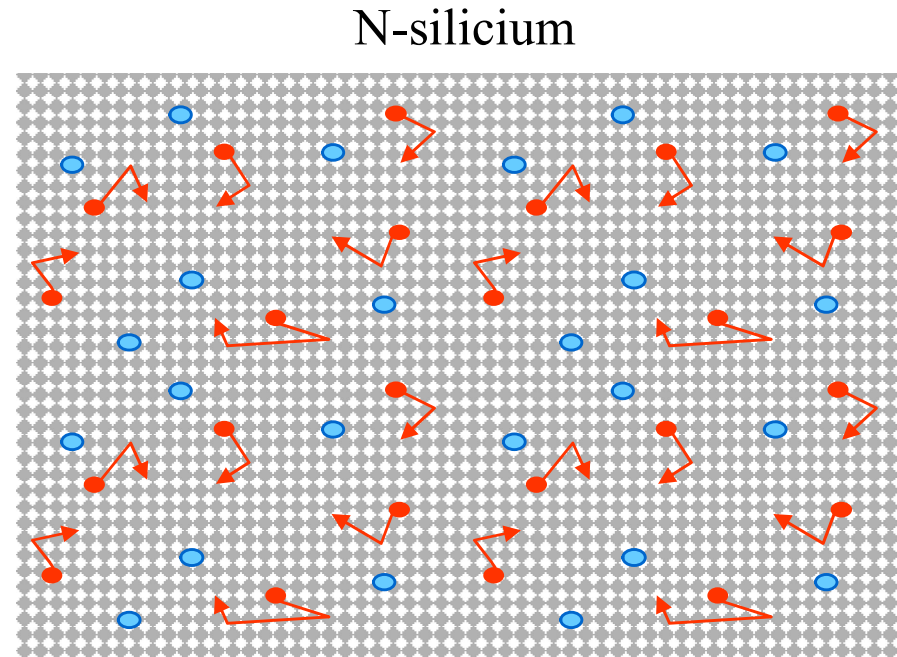
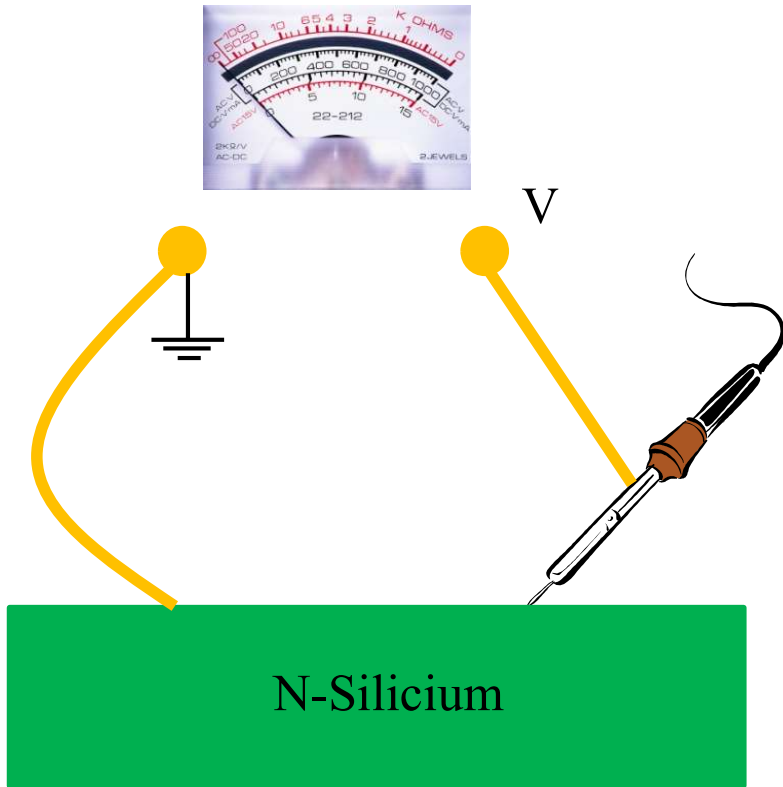
et

$$n(L) = N$$

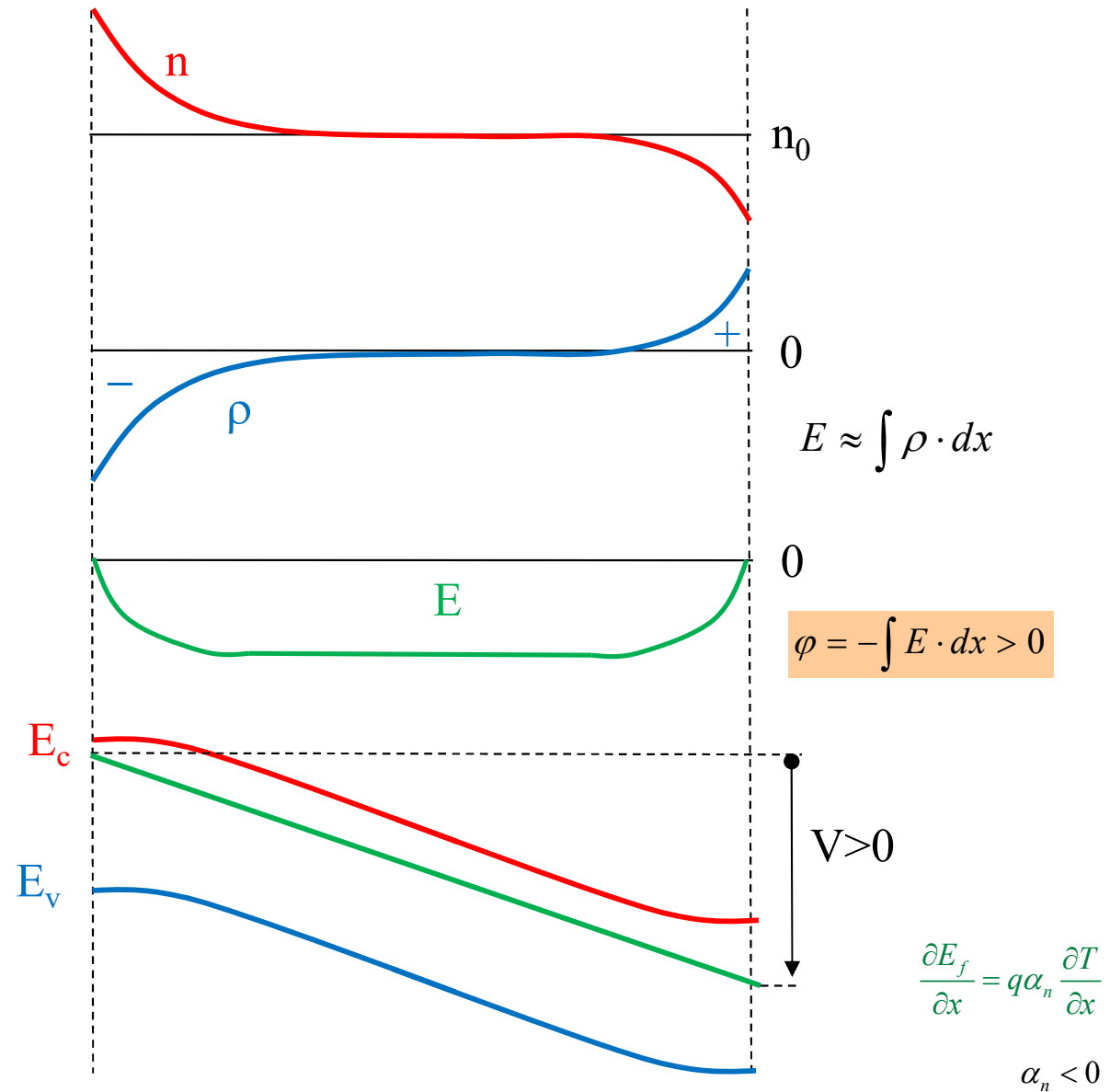
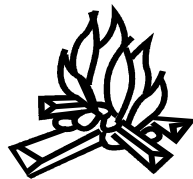
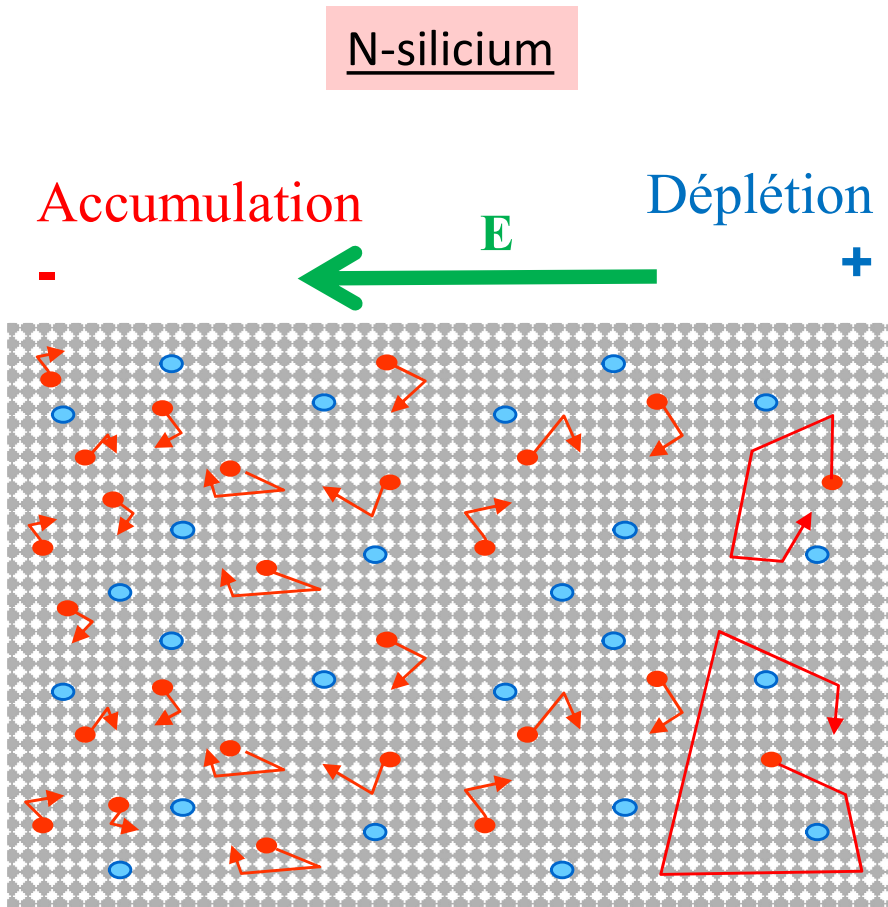




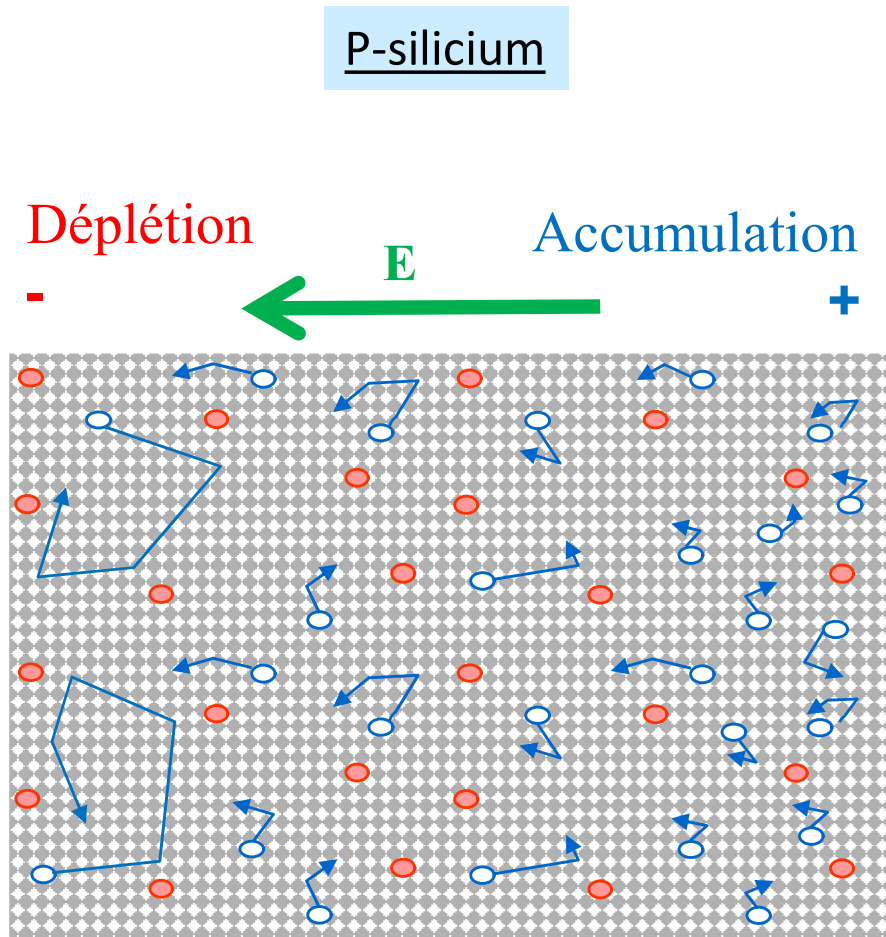
# Exercice 3.2: Hot Plate experiment



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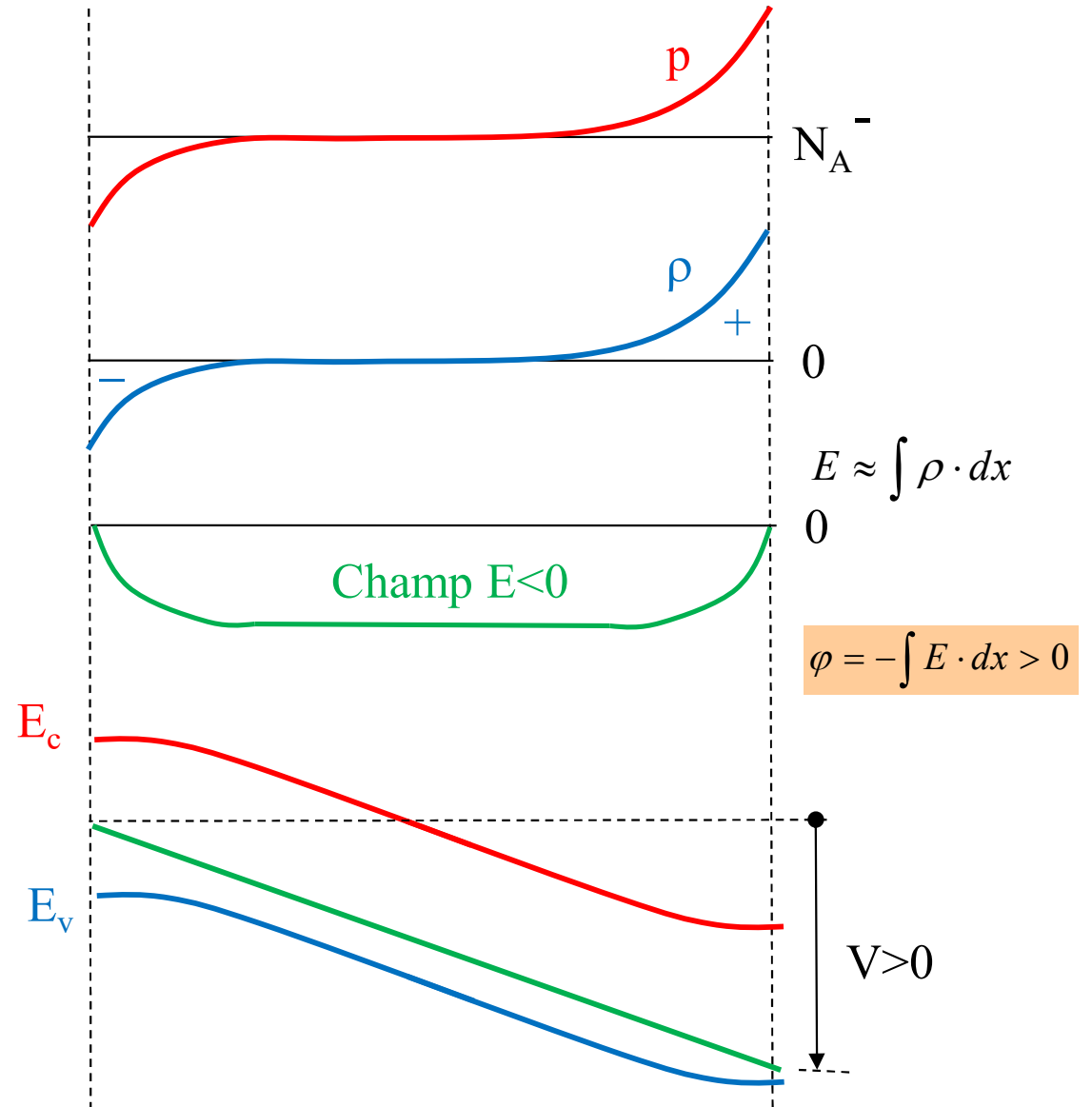


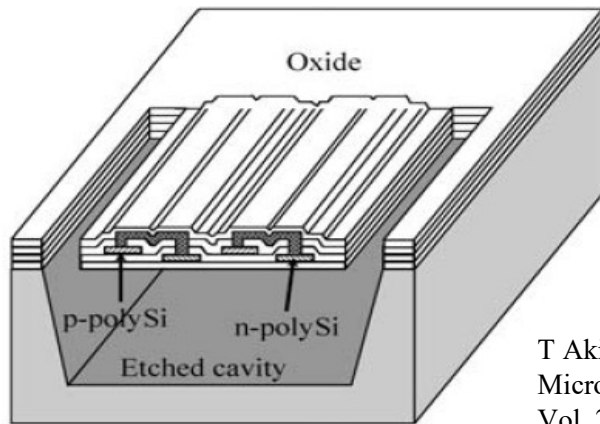
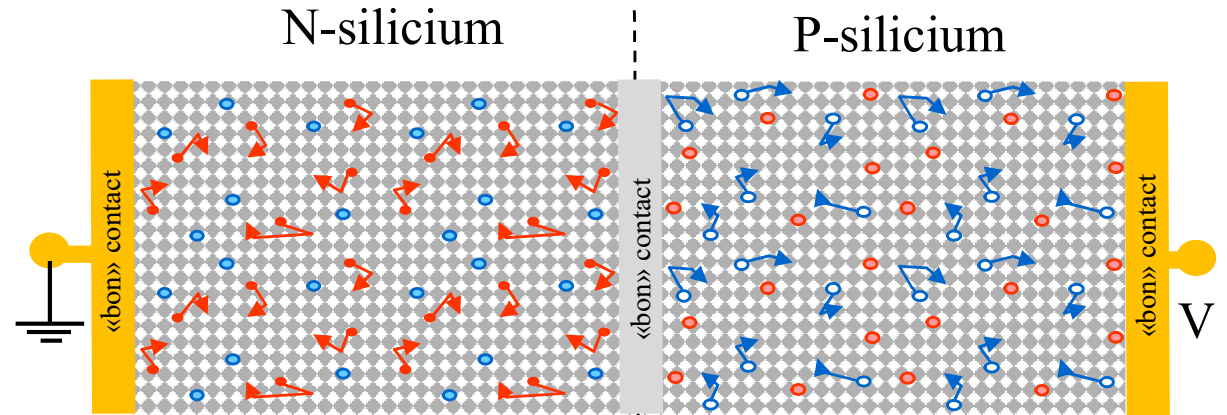
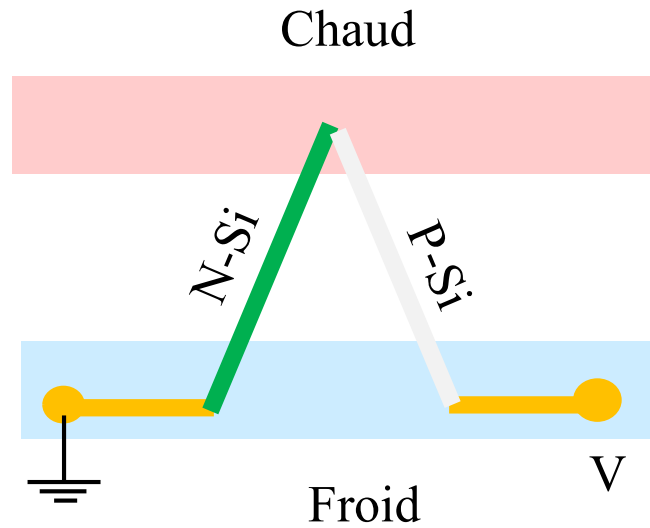
# Exercice 3.2: Hot Plate experiment



$$\frac{\partial E_f}{\partial x} = q\alpha_p \frac{\partial T}{\partial x}$$

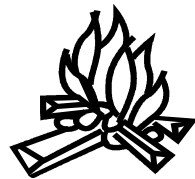
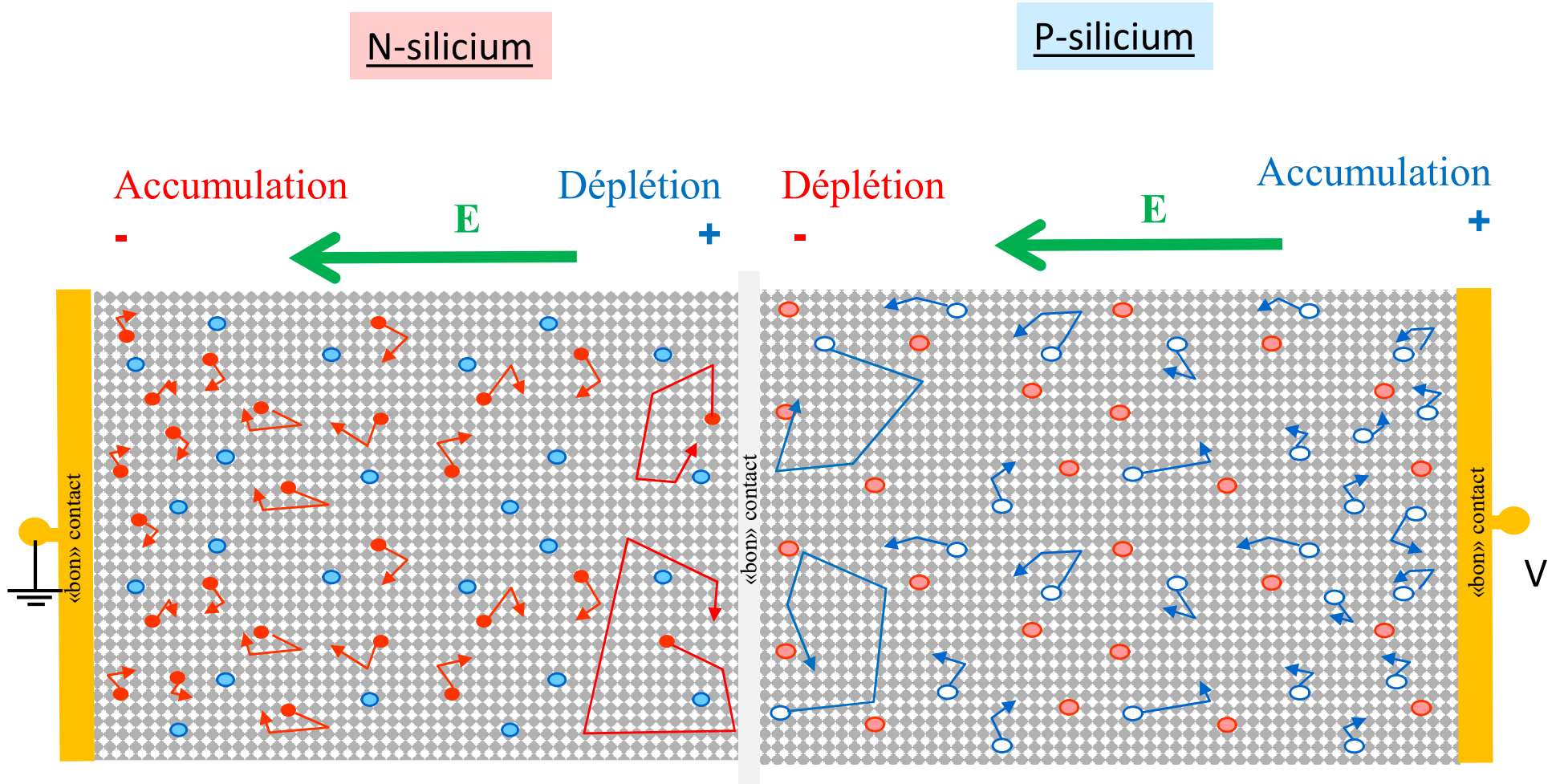
$$\alpha_p > 0$$



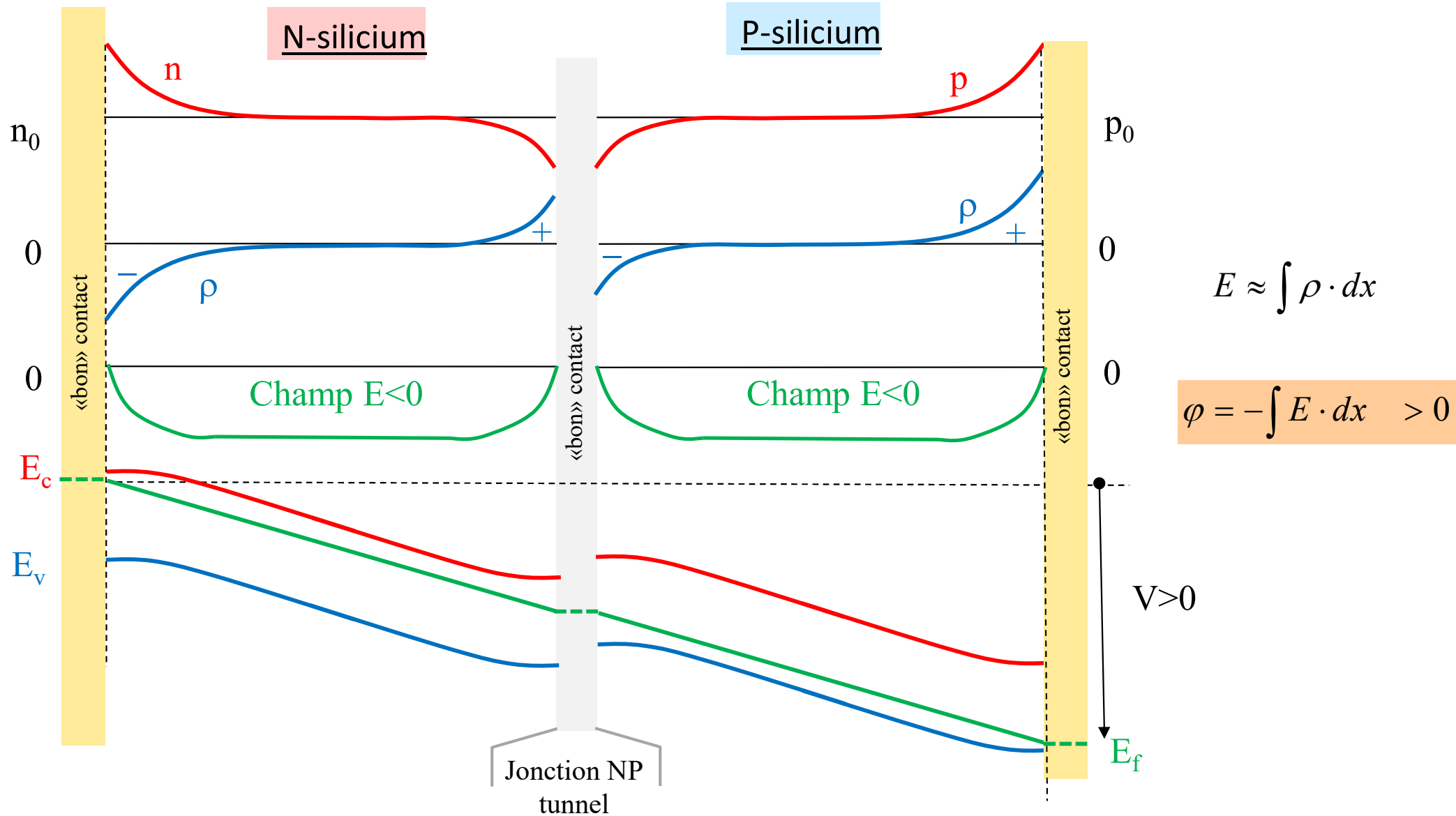


T Akin in Advanced  
Micro and Nanosystems.  
Vol. 2. CMOS – MEMS,  
Chap. 10

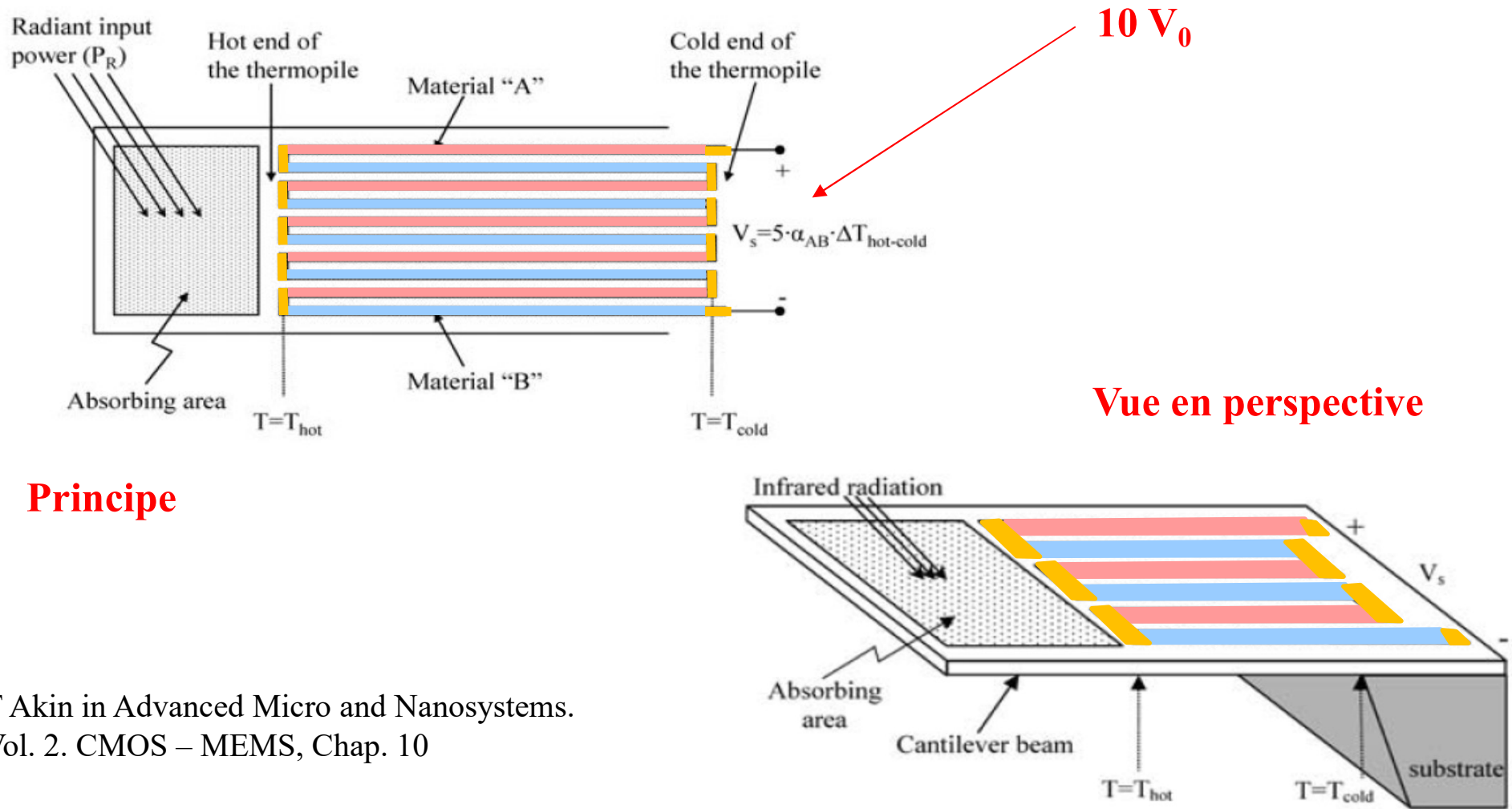
# Exercice 3.3: Thermocouple



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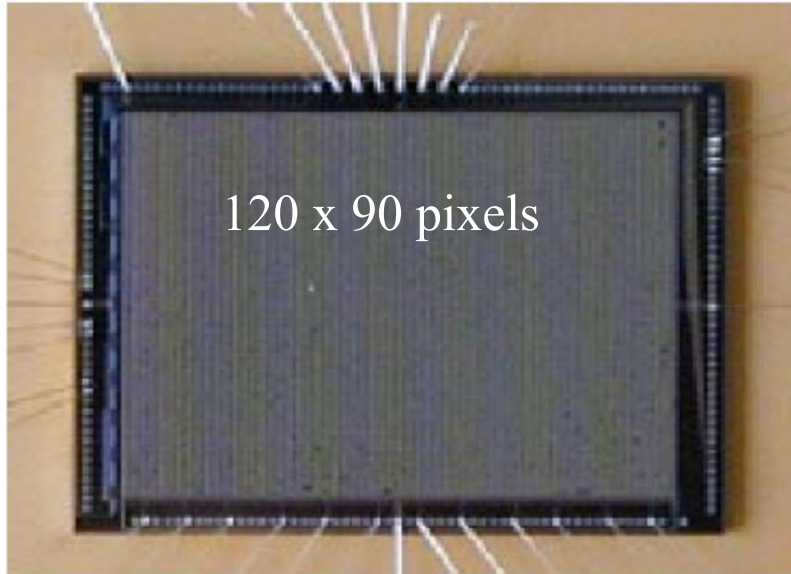
# Thermopile comme capteur IR



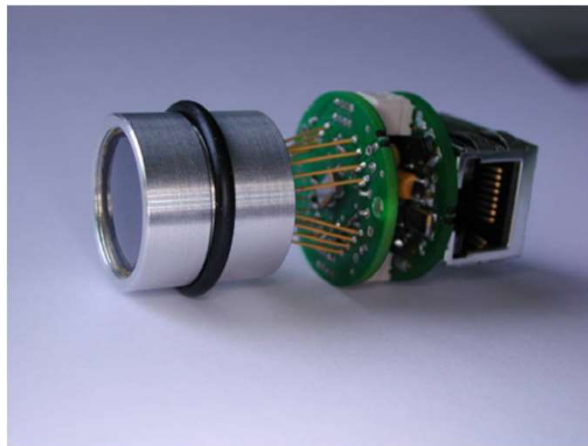
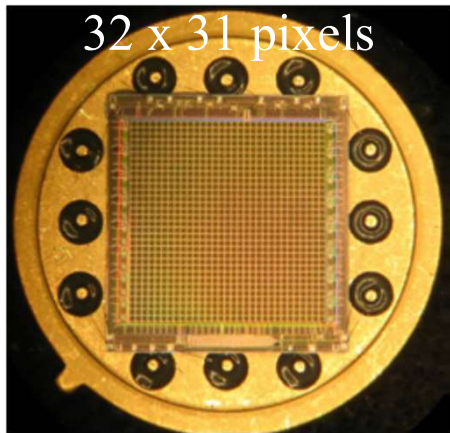
**Principe**

T Akin in Advanced Micro and Nanosystems.  
Vol. 2. CMOS – MEMS, Chap. 10

# Caméra en thermopiles



M. Hirota et al. / Sensors and Actuators A 135 (2007) 146–151



Heimann Sensor GMBH



[http://www.heimannsensor.com/HS\\_Posters\\_Array\\_2009.pdf](http://www.heimannsensor.com/HS_Posters_Array_2009.pdf)

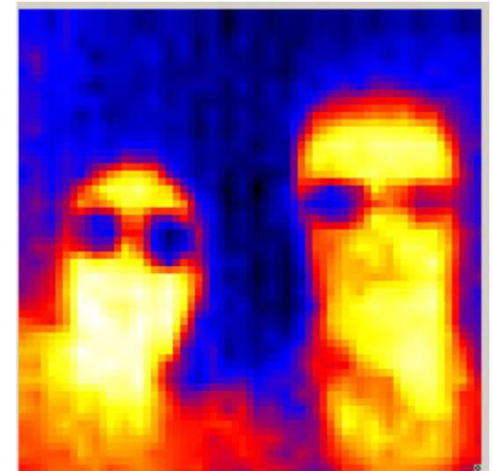


Table 1  
Seebeck coefficients of metals relative to platinum

Material	Seebeck coefficient ( $\mu\text{V}/^\circ\text{C}$ )
Antimony	+48.9
Chromel	+29.8
Tungsten	+11.2
Gold	+7.4
Copper	+7.6
Silver	+7.4
Aluminum	+4.2
p-Silicon, $\rho = 0.0035 \Omega \text{ cm}$	+450
p-Germanium, $\rho = 0.0083 \Omega \text{ cm}$	+420
Platinum	0.00
Calcium	-5.1
Alumel	-10.85
Cobalt	-13.3
Nickel	-14.5
Constantan	-37.25
Bismuth	-73.4
n-Silicon, $\rho = 0.0035 \Omega \text{ cm}$	-450
n-Germanium, $\rho = 0.69 \Omega \text{ cm}$	-548

Allison, sensors and actuators  
A 104, 2003, pp. 32-39

$$\Delta V = -\alpha \cdot \Delta T$$

$$1^\circ\text{C} \rightarrow \cong \pm 450 \mu\text{V}$$

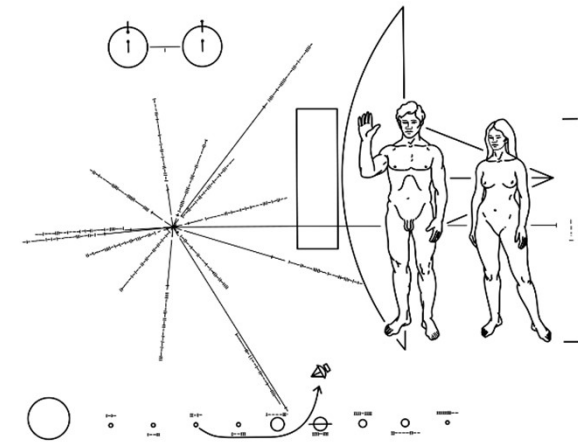
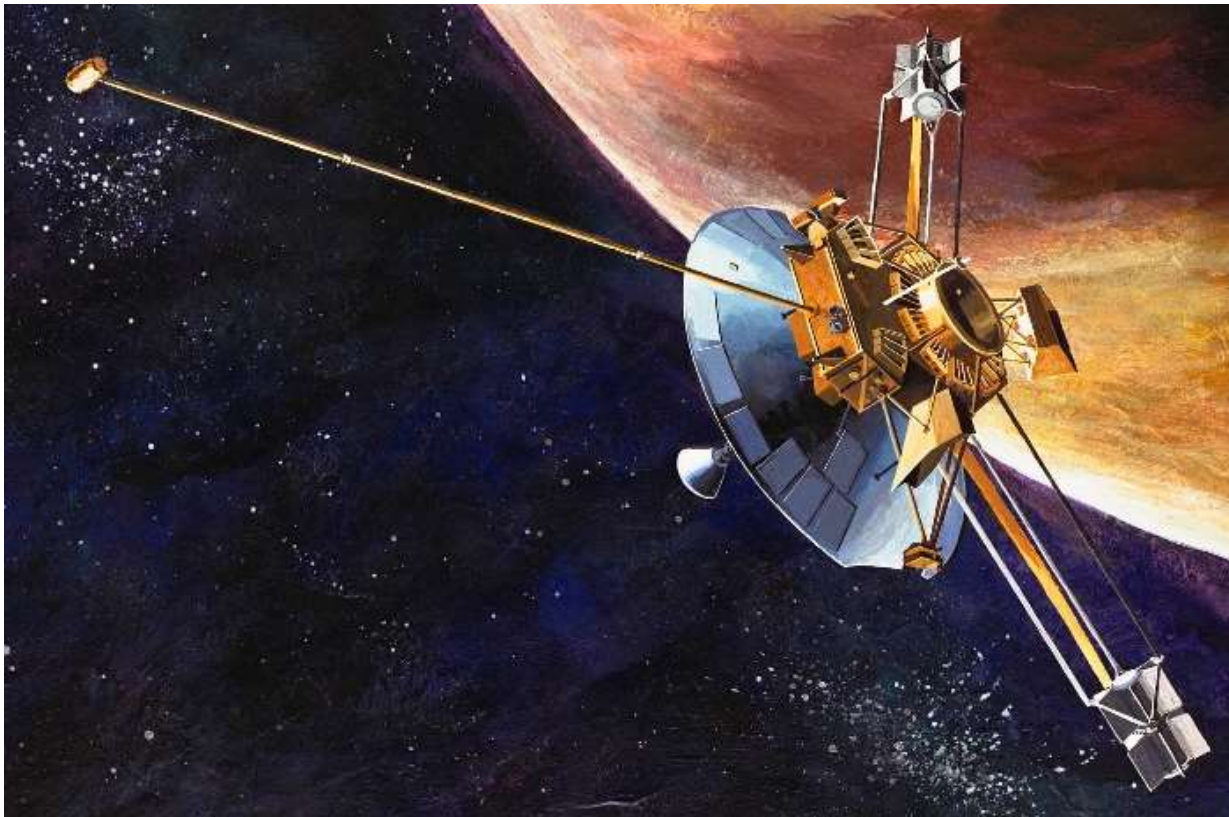
Measurements were made with the reference junction at  $0^\circ\text{C}$  and the hot junction at  $100^\circ\text{C}$  [25].

[25] D.R. Lide, CRC Handbook of chemistry and physics, 2000

## Le problème:

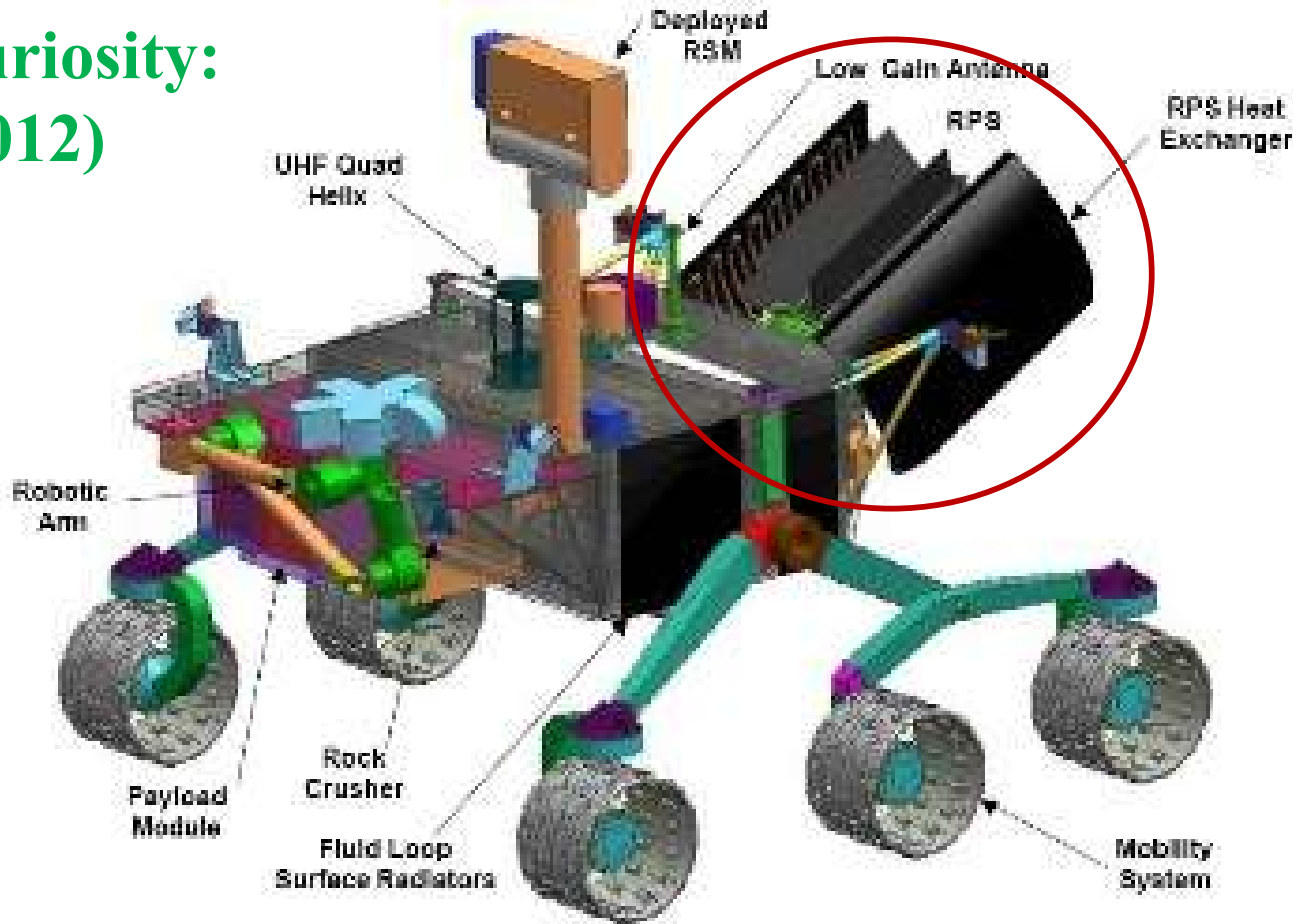
Alimenter en courant électrique la sonde Pioneer 10 (1972-2003)  
qui ira visiter les confins du système solaire.

Le soleil n'est qu'une petite étoile trop faible pour des panneaux solaires !!!



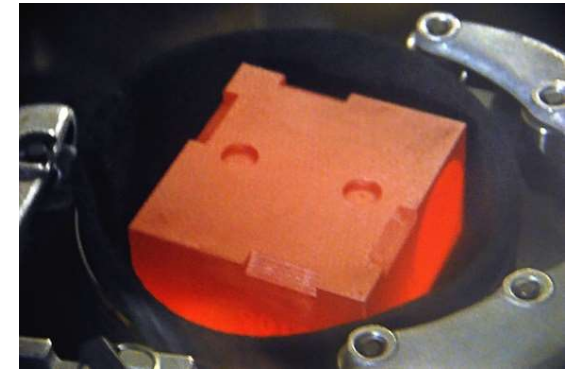
? Votre solution ?

Curiosity:  
(2012)

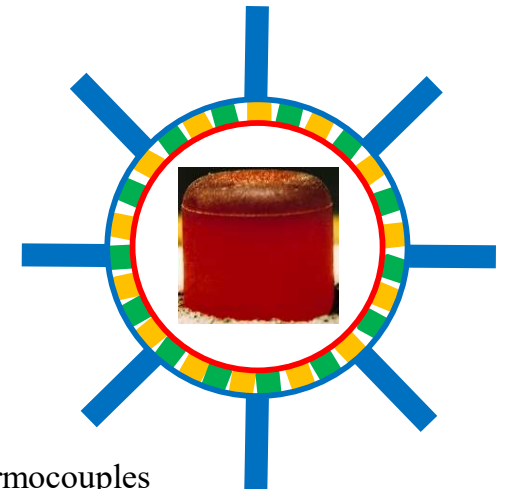


Plutonium 238  
 $^{238}\text{PuO}_2$

Decay: 88 years



$\approx 1000^{\circ}\text{K}$



> 500 thermocouples

[https://fr.wikipedia.org/wiki/G%C3%A9n%C3%A9rateur\\_thermo%C3%A9lectrique\\_%C3%A0\\_radioisotope\\_multi-mission](https://fr.wikipedia.org/wiki/G%C3%A9n%C3%A9rateur_thermo%C3%A9lectrique_%C3%A0_radioisotope_multi-mission)

**Efficiency: 6% – 8%**





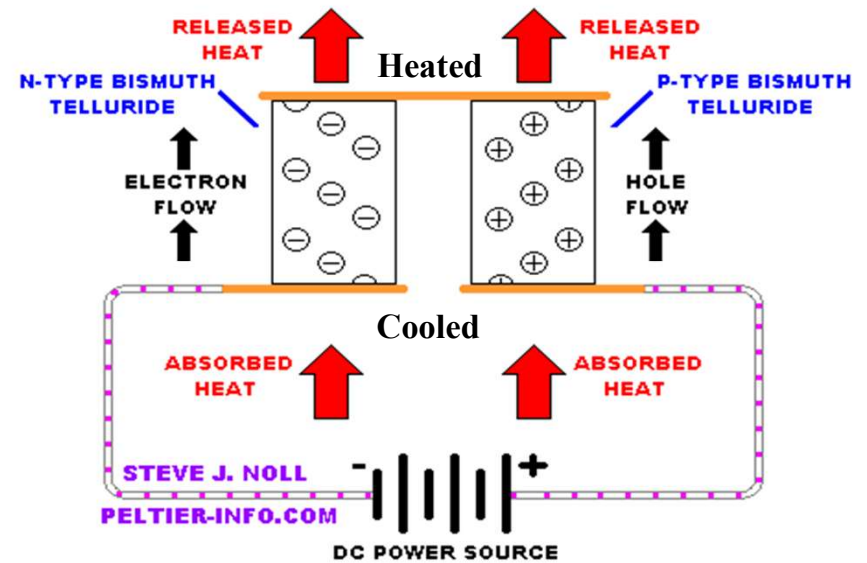
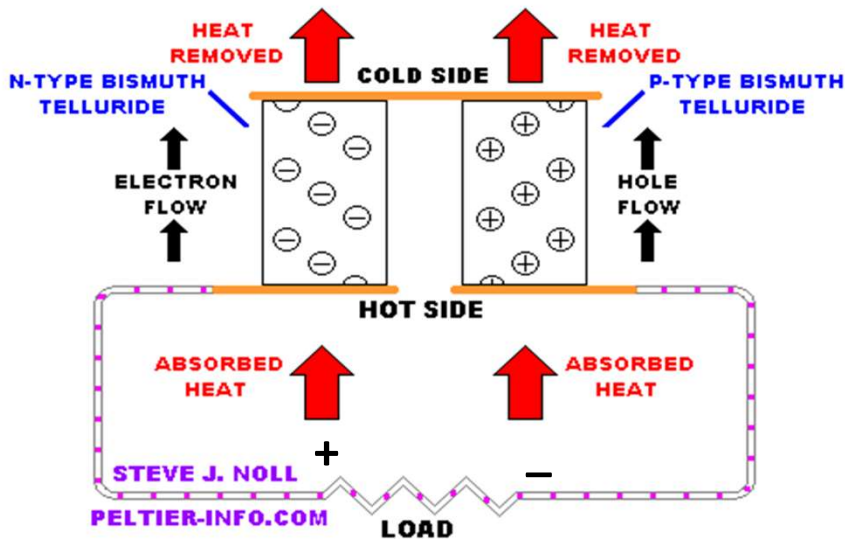
## Générateur Seebeck



## Peltier cooler

ONE SEEBECK DEVICE "COUPLE" CONSISTS OF ONE N-TYPE AND ONE P-TYPE SEMICONDUCTOR PELLET

ONE PELTIER DEVICE "COUPLE" CONSISTS OF ONE N-TYPE AND ONE P-TYPE SEMICONDUCTOR PELLET



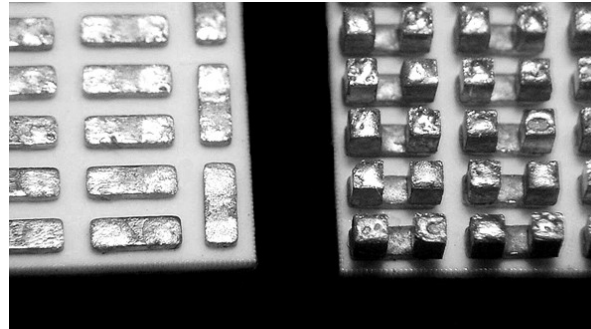
THERE MUST BE A TEMPERATURE DIFFERENCE BETWEEN THE HOT AND COLD SIDES FOR POWER TO BE GENERATED

THE CHARGE CARRIERS, NEGATIVE ELECTRONS AND POSITIVE HOLES, TRANSPORT THE HEAT.

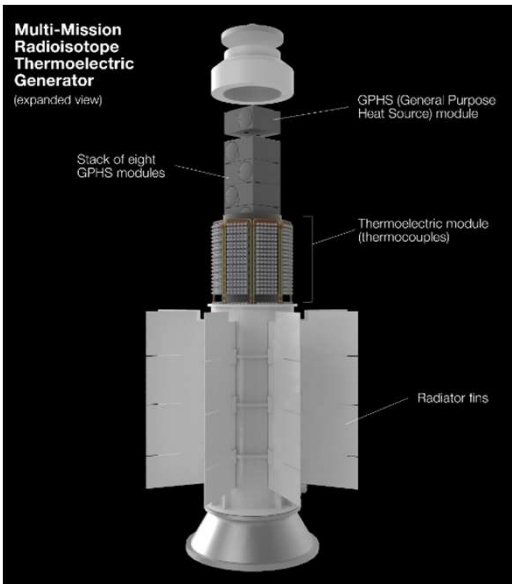
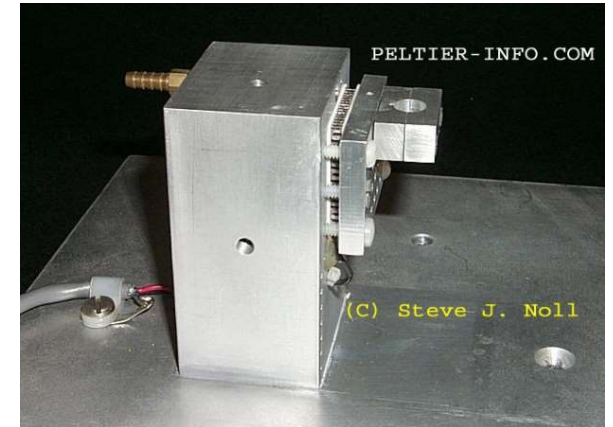


<http://www.peltier-info.com/photos.html>

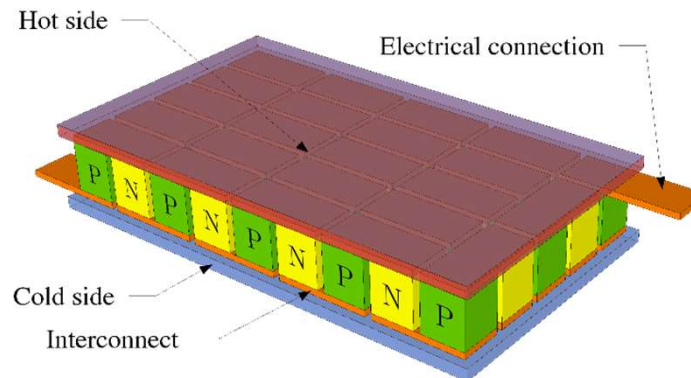
## Food thermometer: thermocouple



## Peltier cooler / heater



**Thermoelectric generator**  
actifs env. 30 ans sur la sonde Pioneer 10



**Thermoelectric water cooler**