COMPOSANTS SEMI-CONDUCTEURS

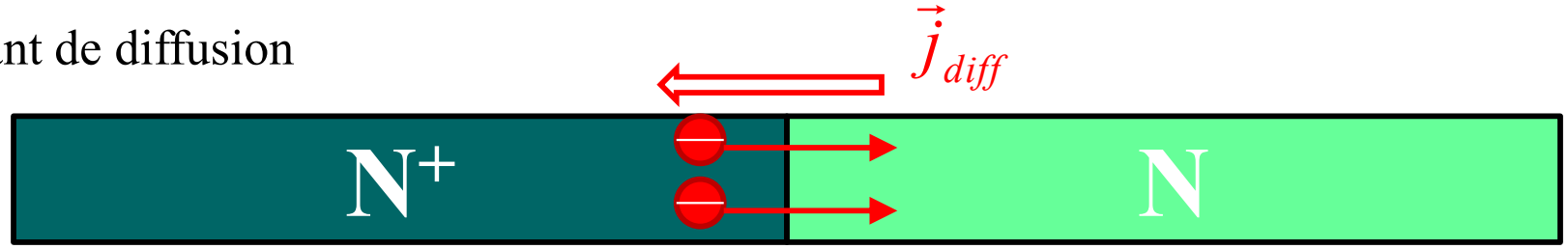
III) Solutions S3

P.A. Besse

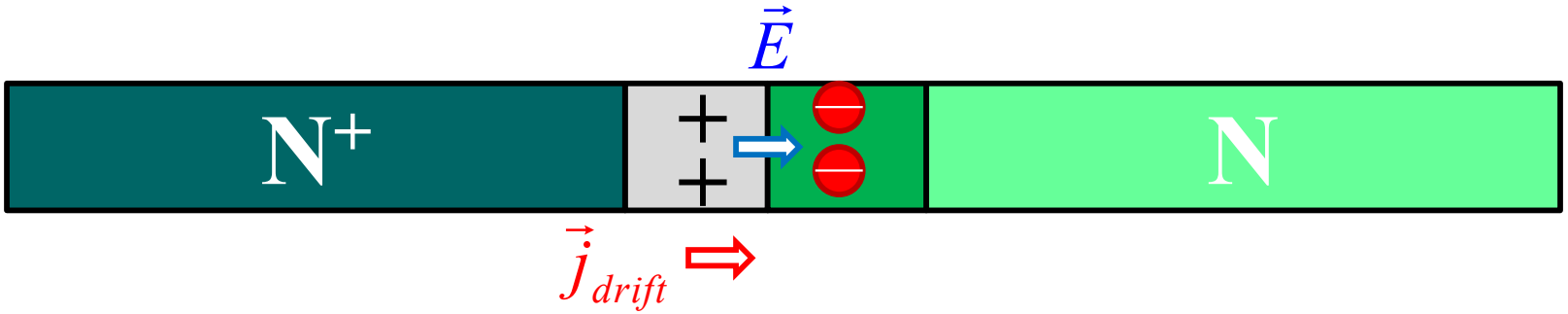
EPFL

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

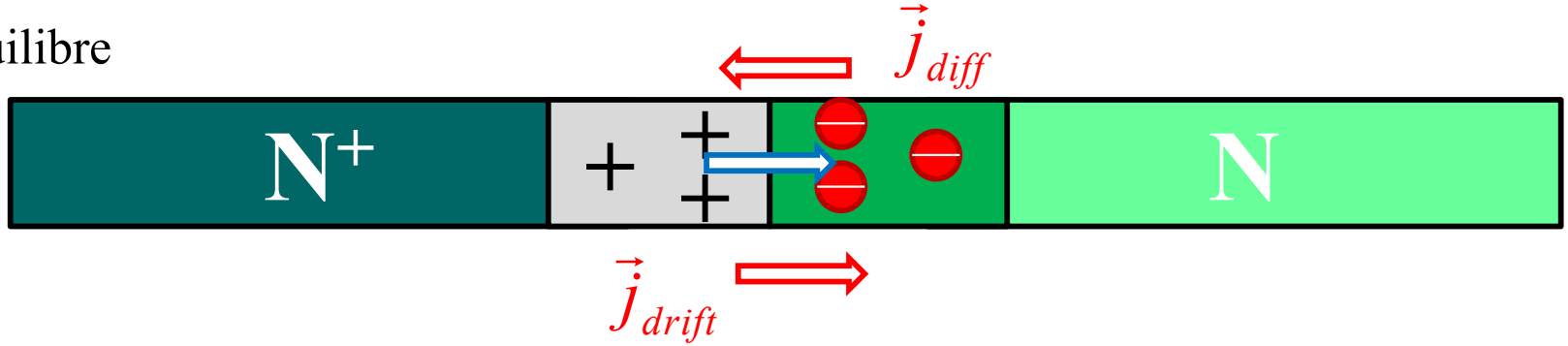
a) Courant de diffusion



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 φ)
concentration d'électrons libres n
concentration de trous p

3 équations:

1 $$div(\vec{E}) = \frac{1}{\varepsilon_0 \varepsilon} q\,(p + N_d^+ - n - N_a^-)$$

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

3 $$n \cdot p = n_i^2$$

1ère voie de calcul

$p = n_i^2 / n$ Mais p est ici négligeable ! → pas nécessaire de résoudre

$$div(\vec{E}) = \frac{1}{\varepsilon_0 \varepsilon} q\,(N_d^+ - n) \quad \rightarrow \quad \frac{\partial E}{\partial x} = \frac{q}{\varepsilon_0 \varepsilon}(N_d - n)$$

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

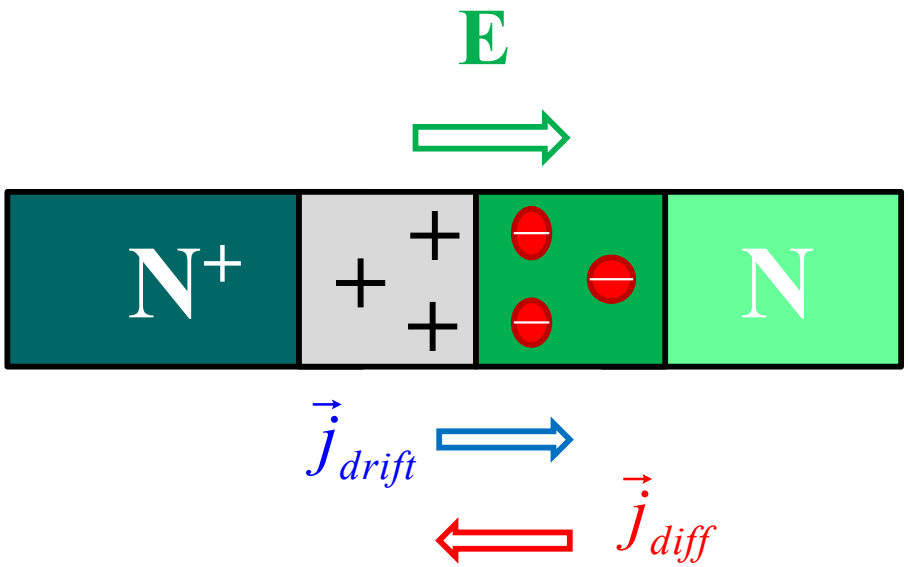
Inconnues:

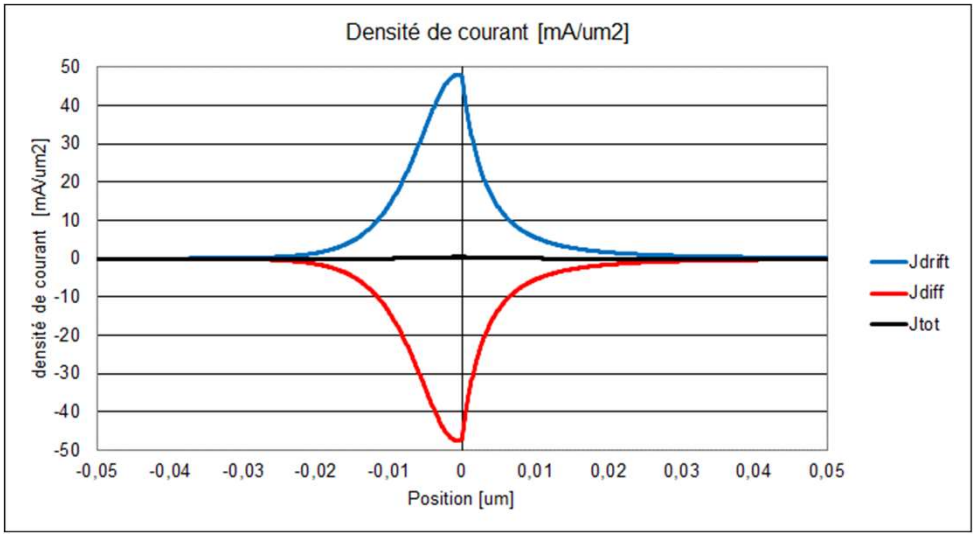
E et n

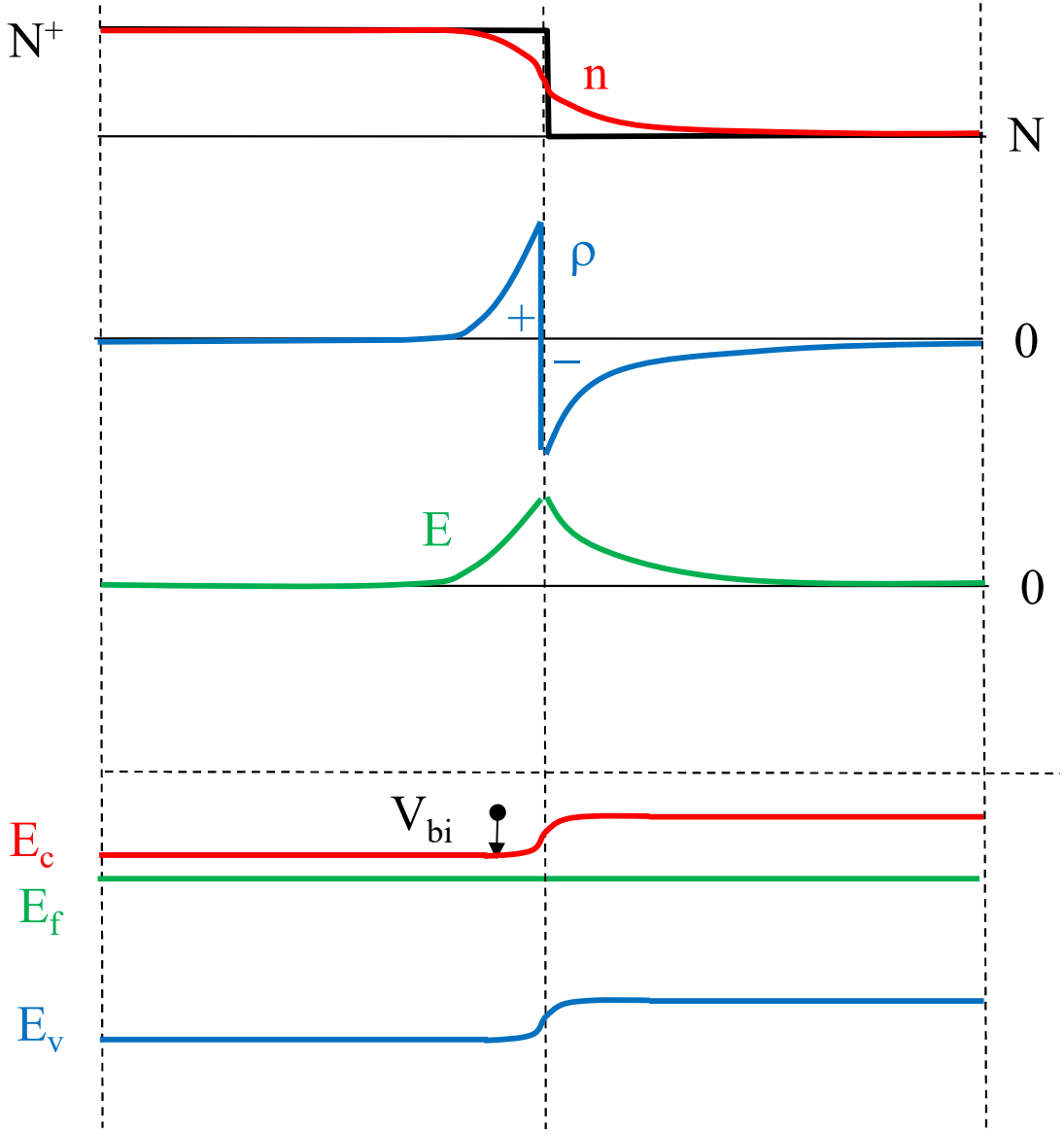
Conditions aux bords (2 conditions car 2 équa. diff. de premier ordre)

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

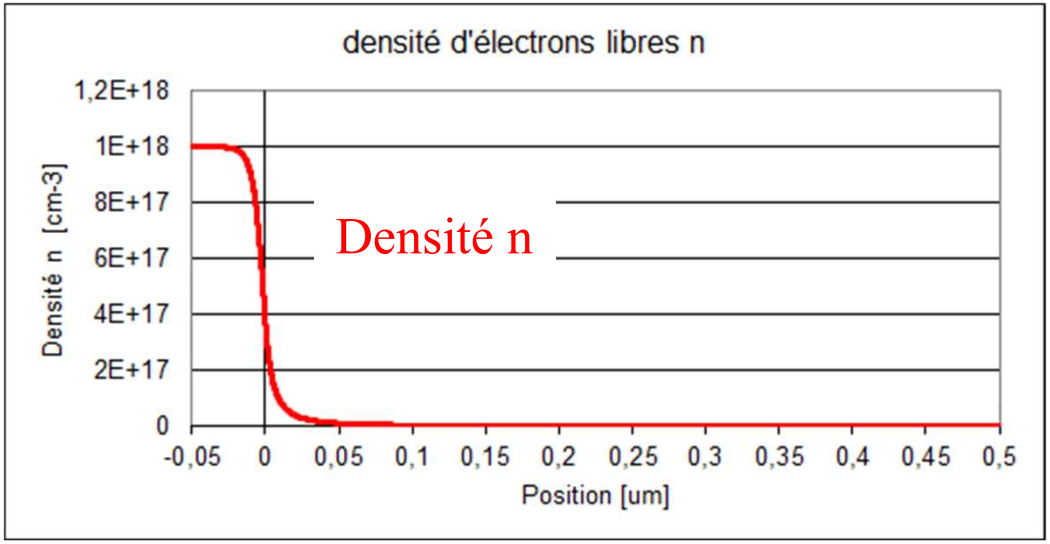
Solutions esquissées: N^+/N

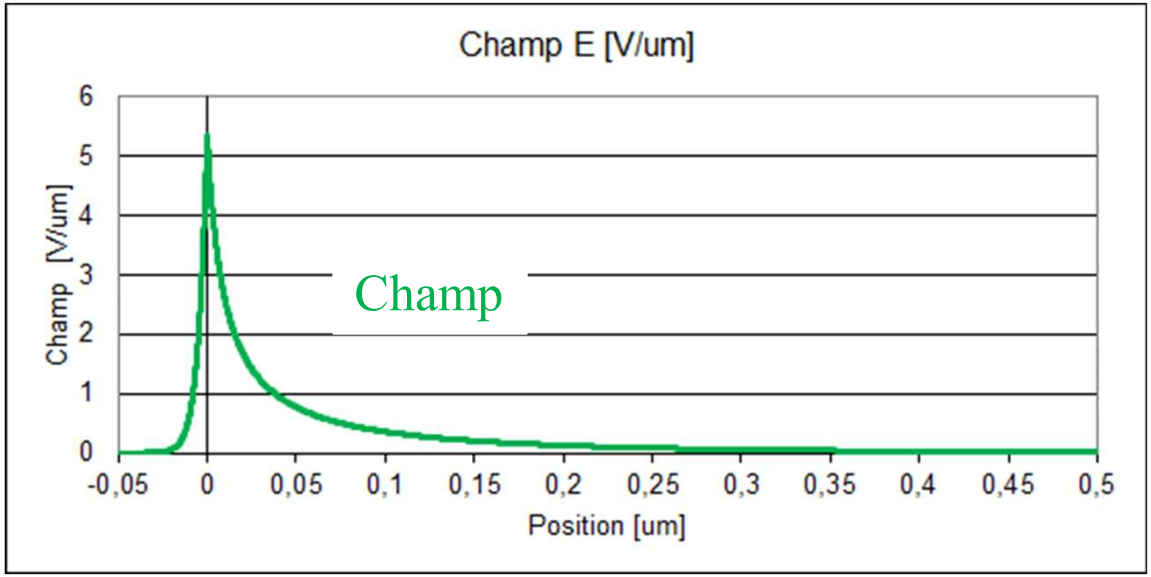


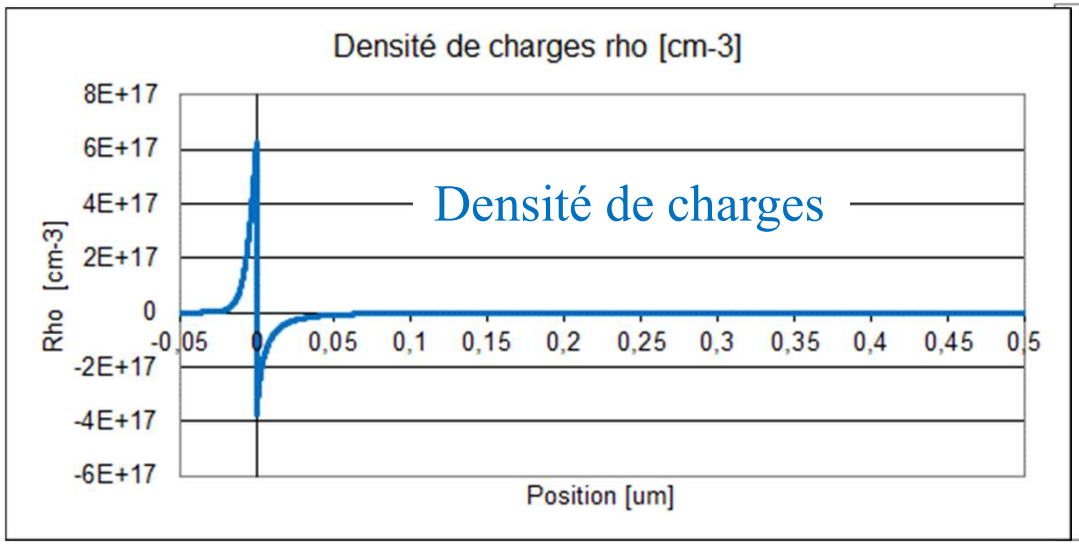


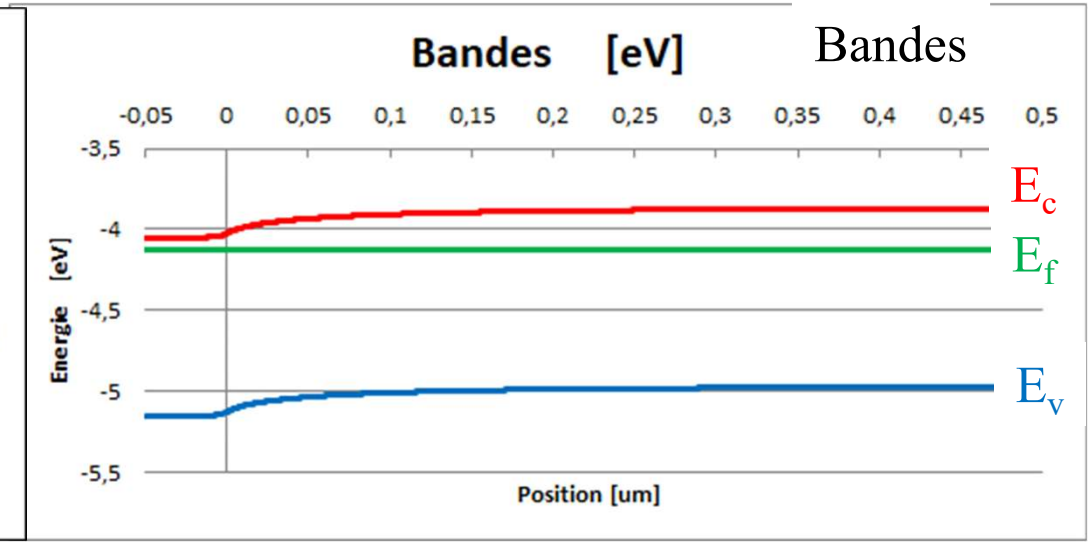


Solutions simulées N^+/N

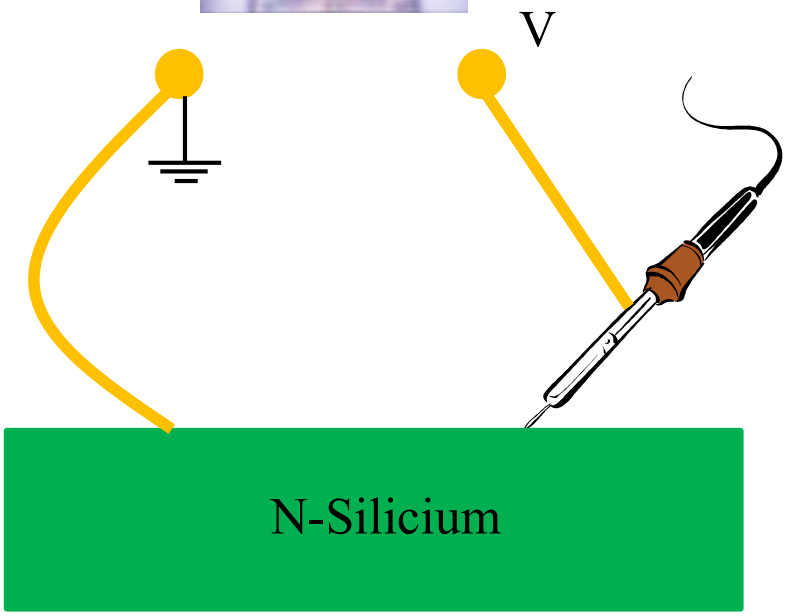




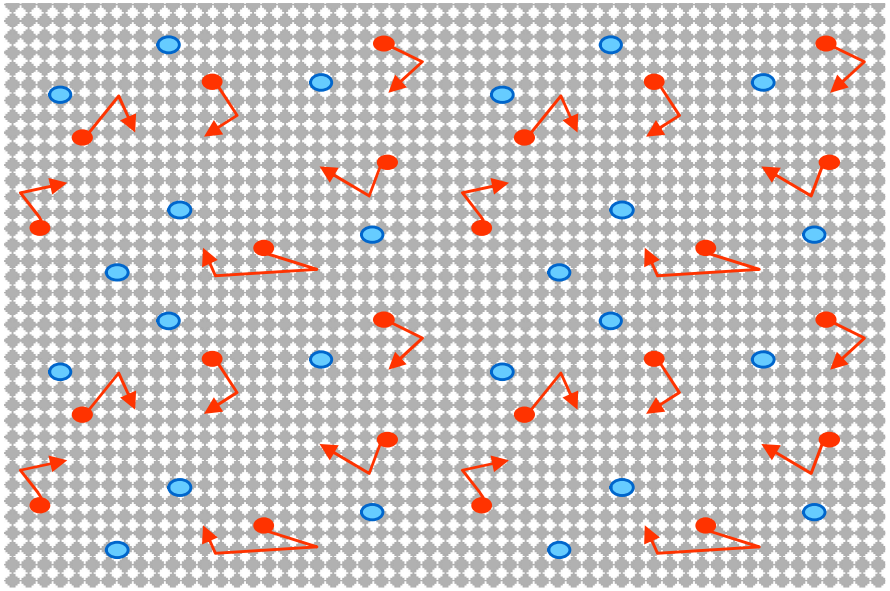


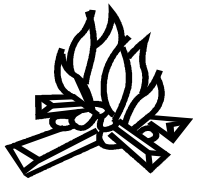


Exercice 3.2: Hot Plate experiment



N-silicium





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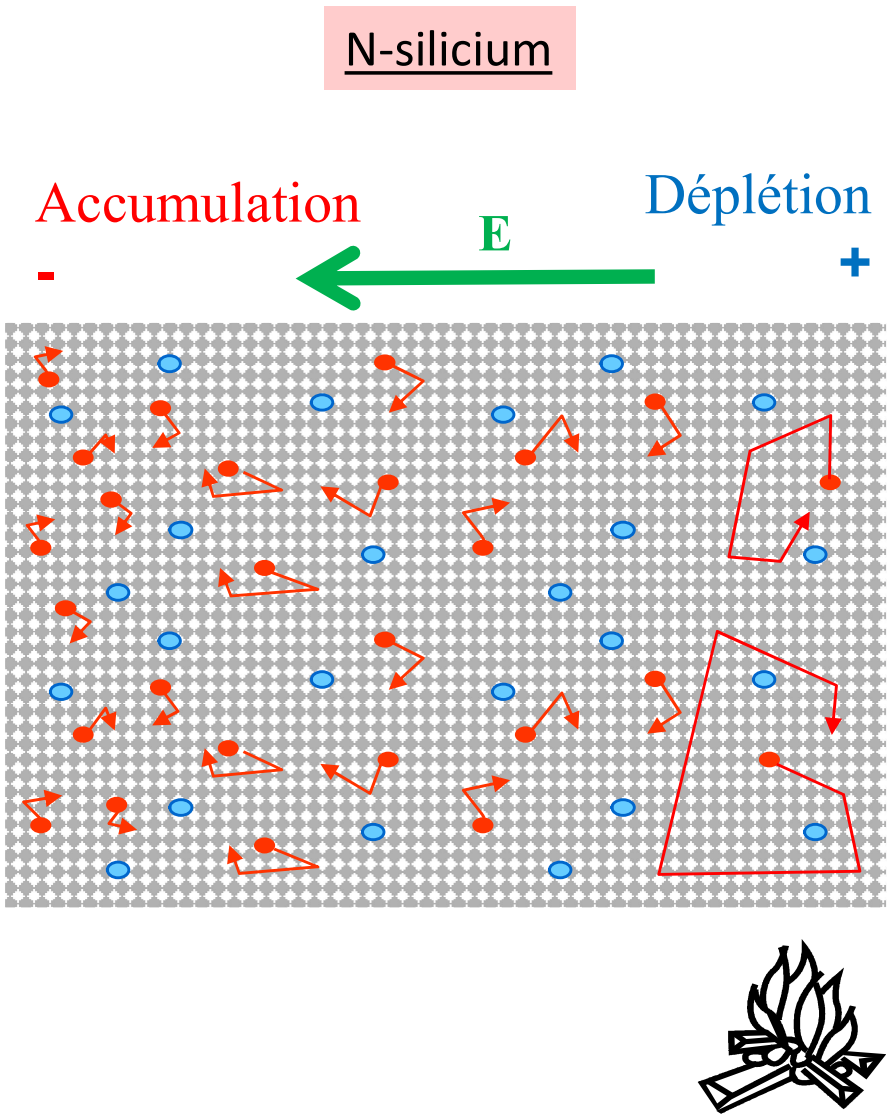
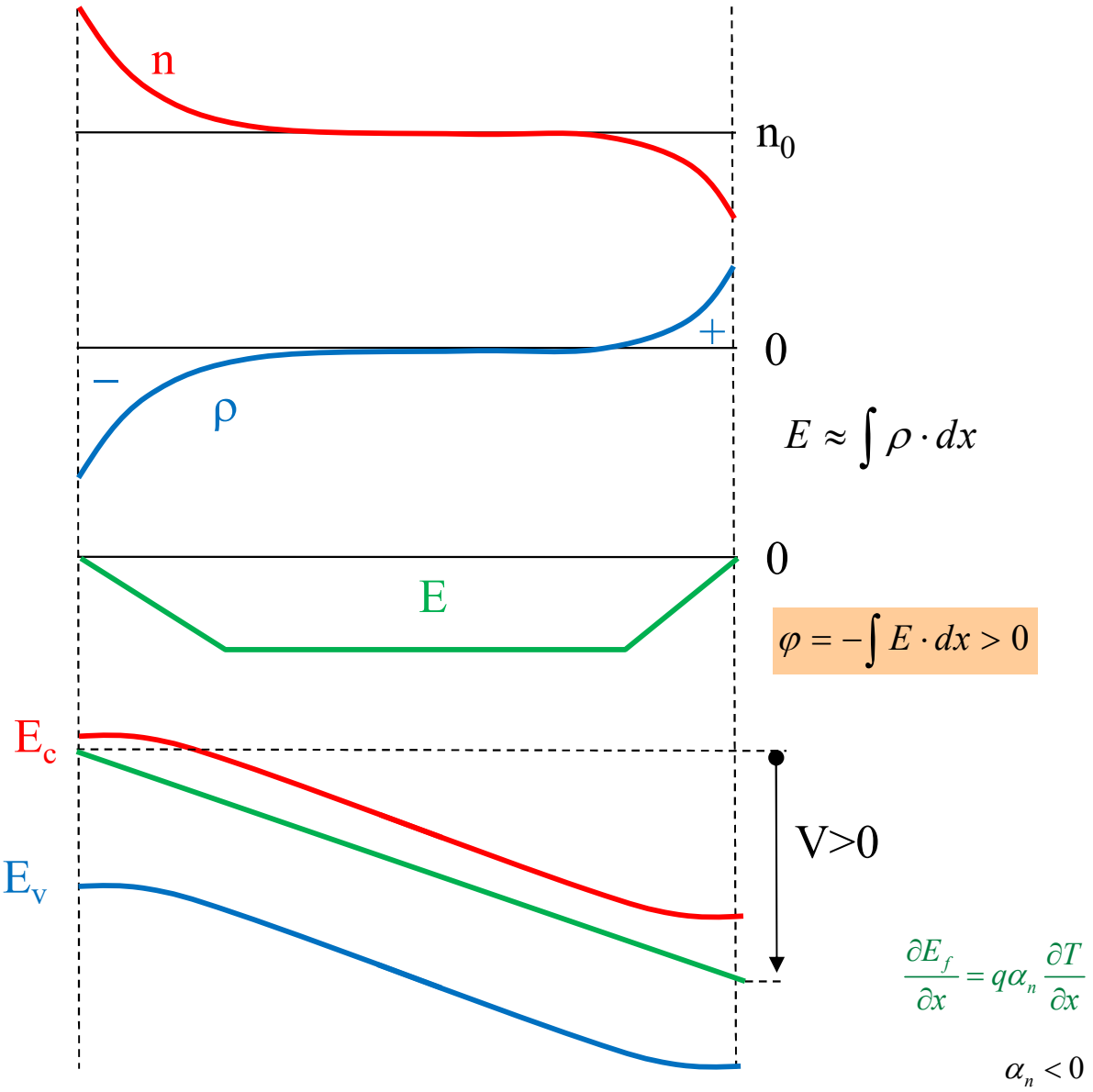
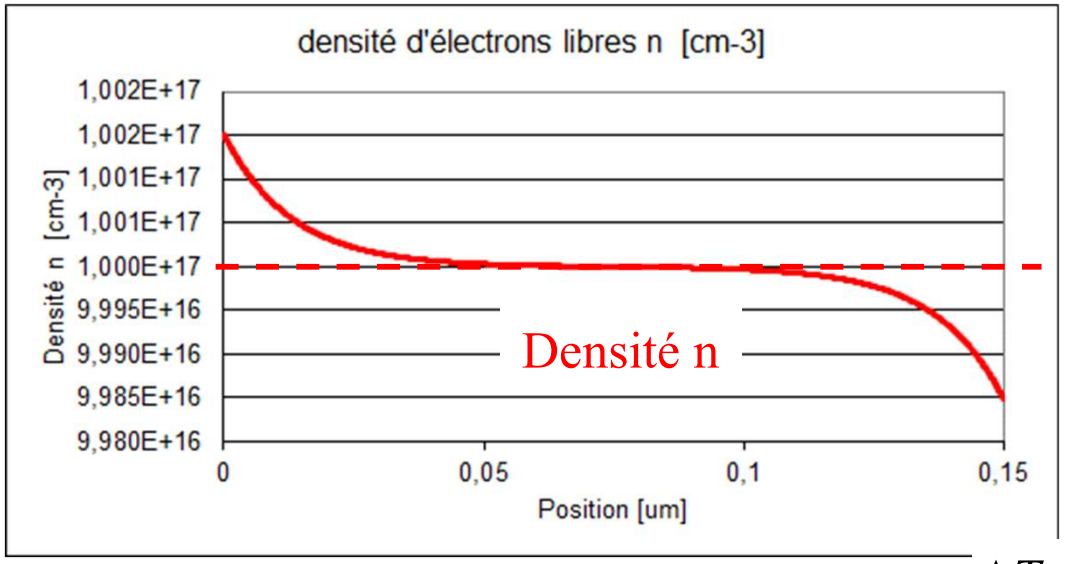
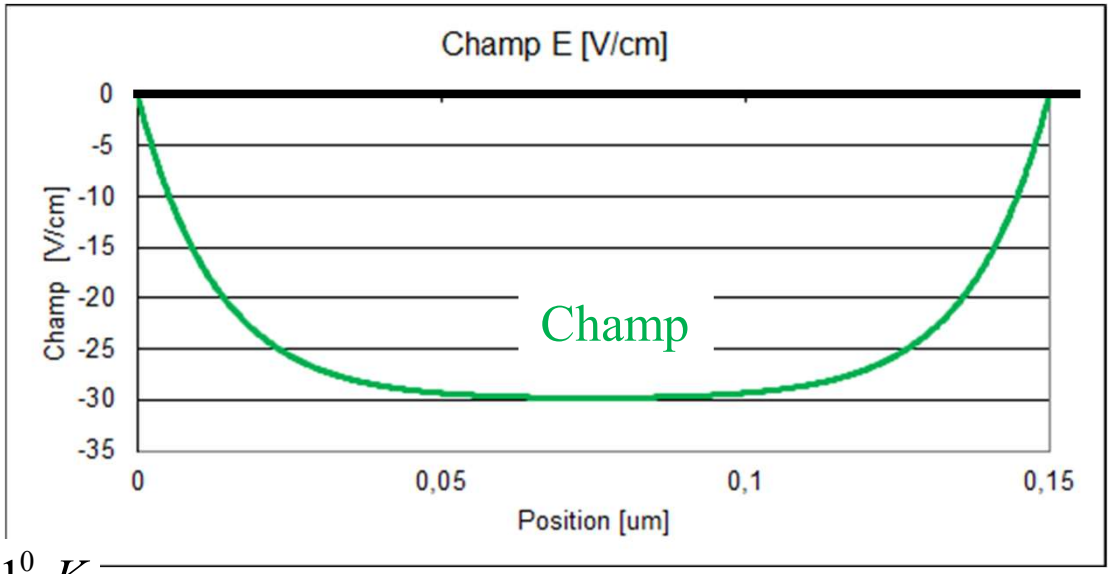


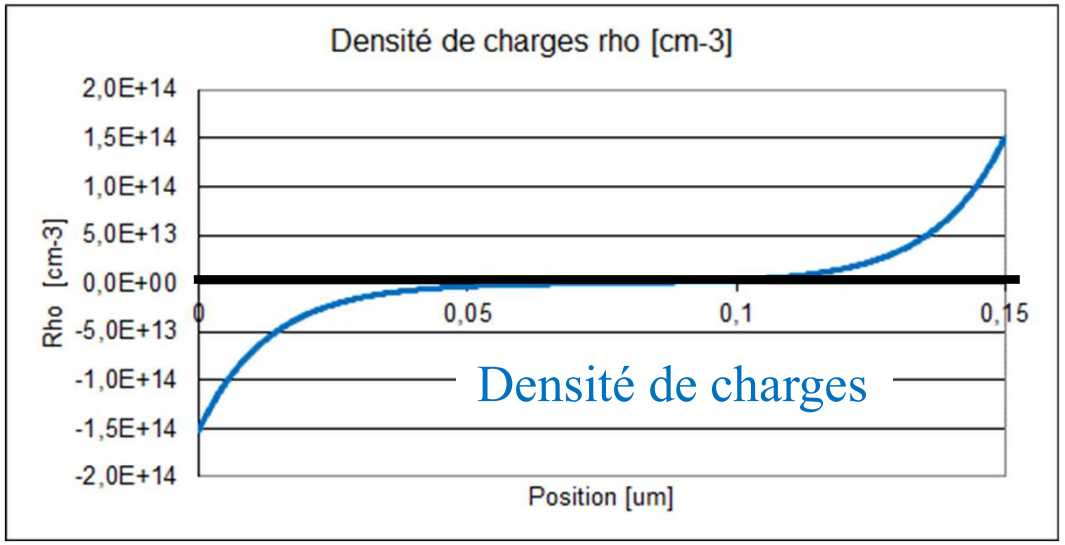


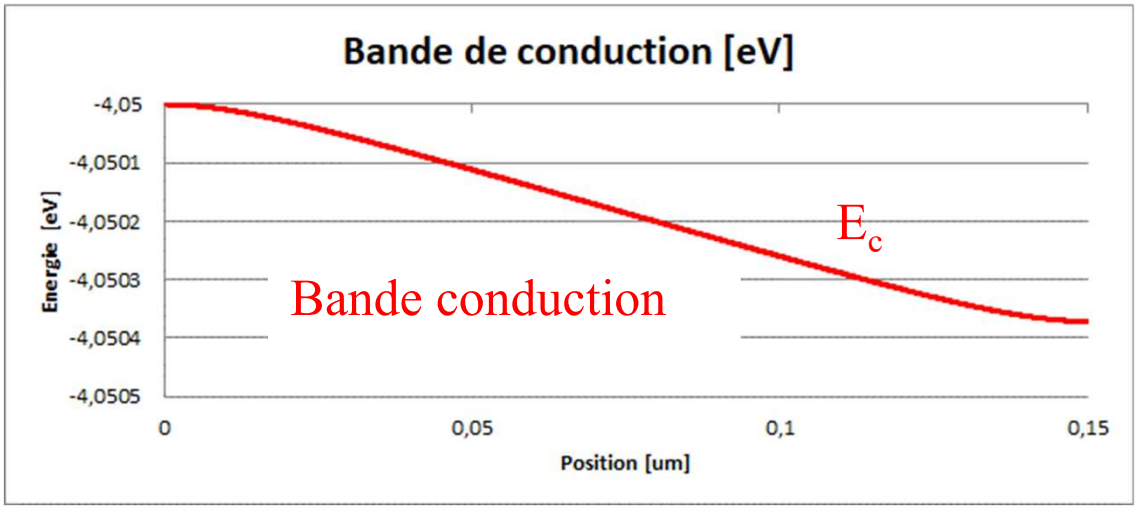
Simulation hot plate (1)





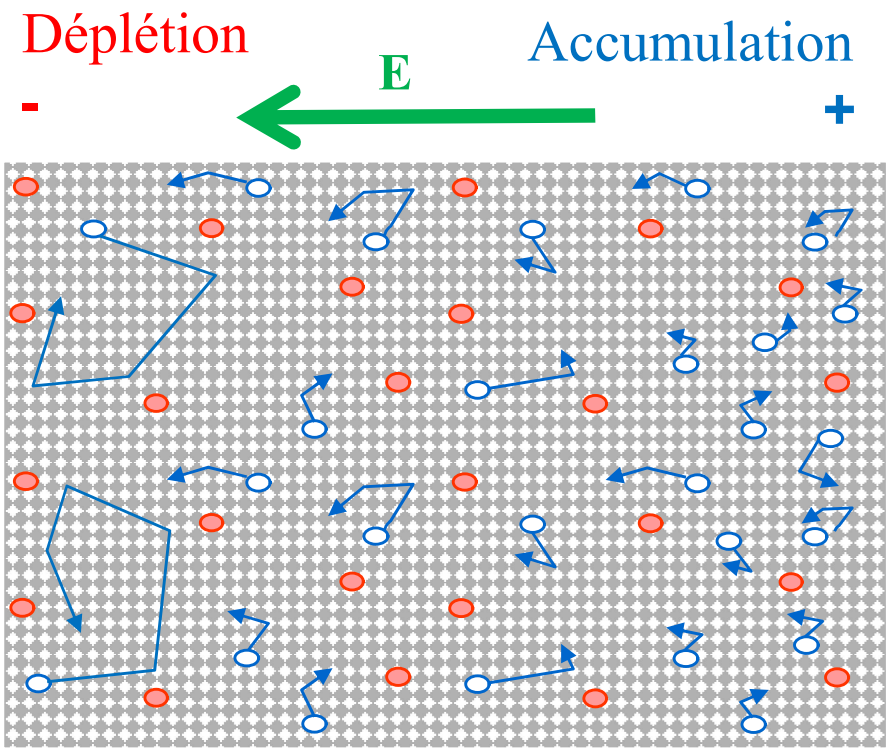
$$\Delta T = 1^0 \ K$$

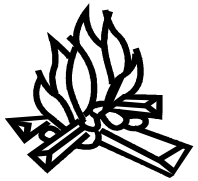




Exercice 3.2: Hot Plate experiment

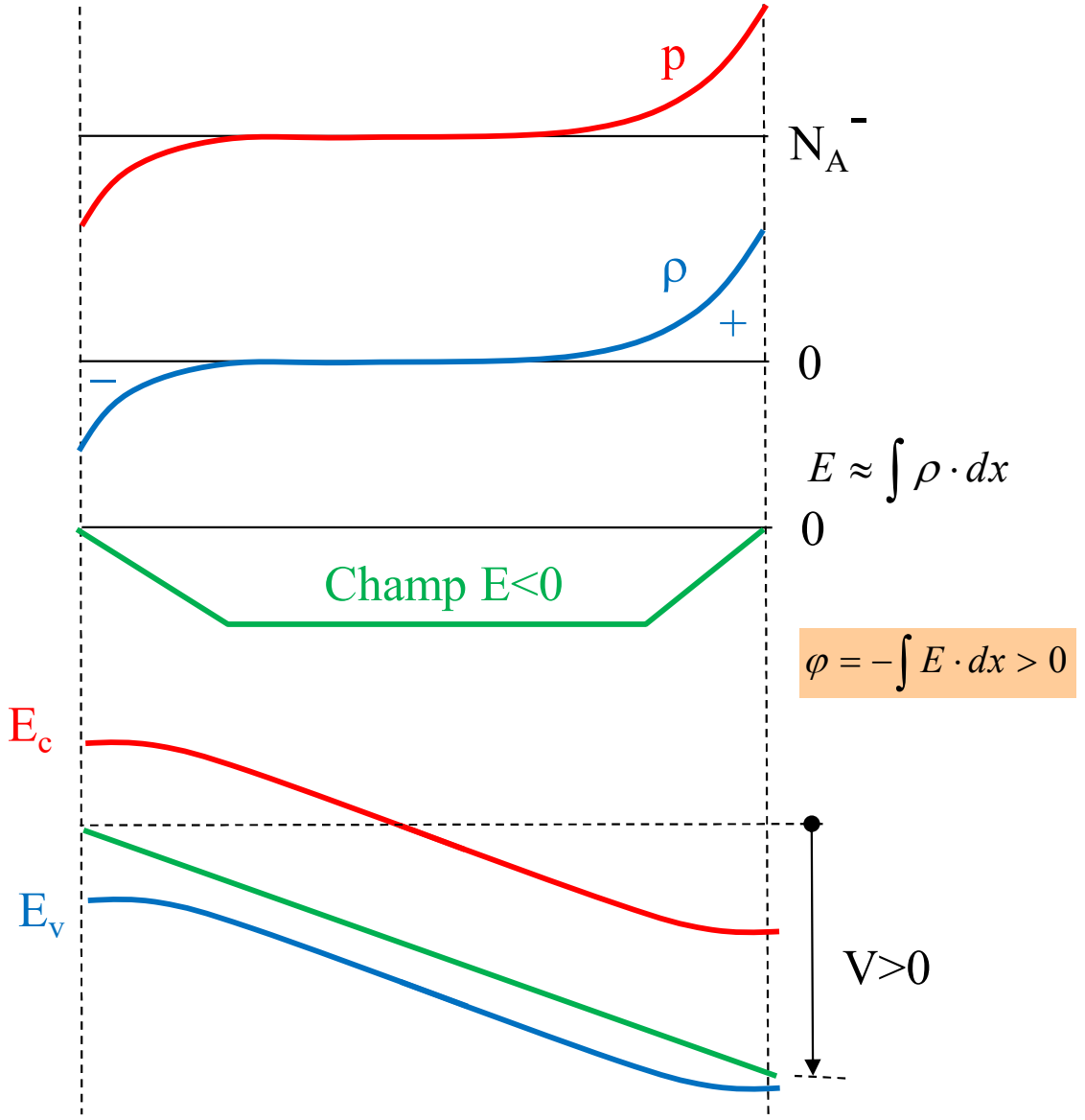
P-silicium



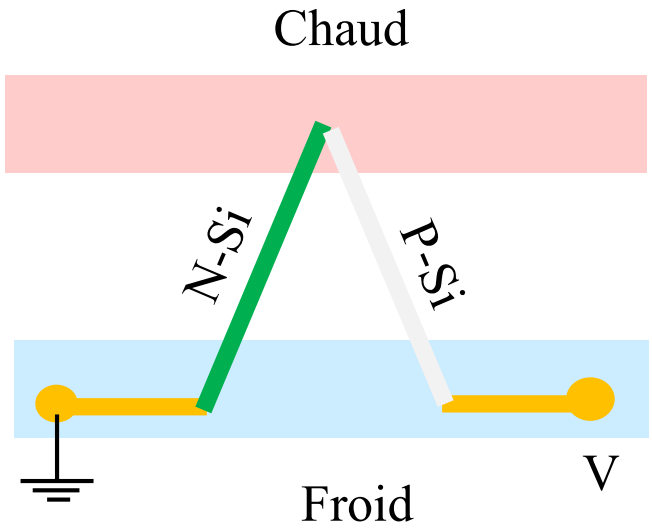


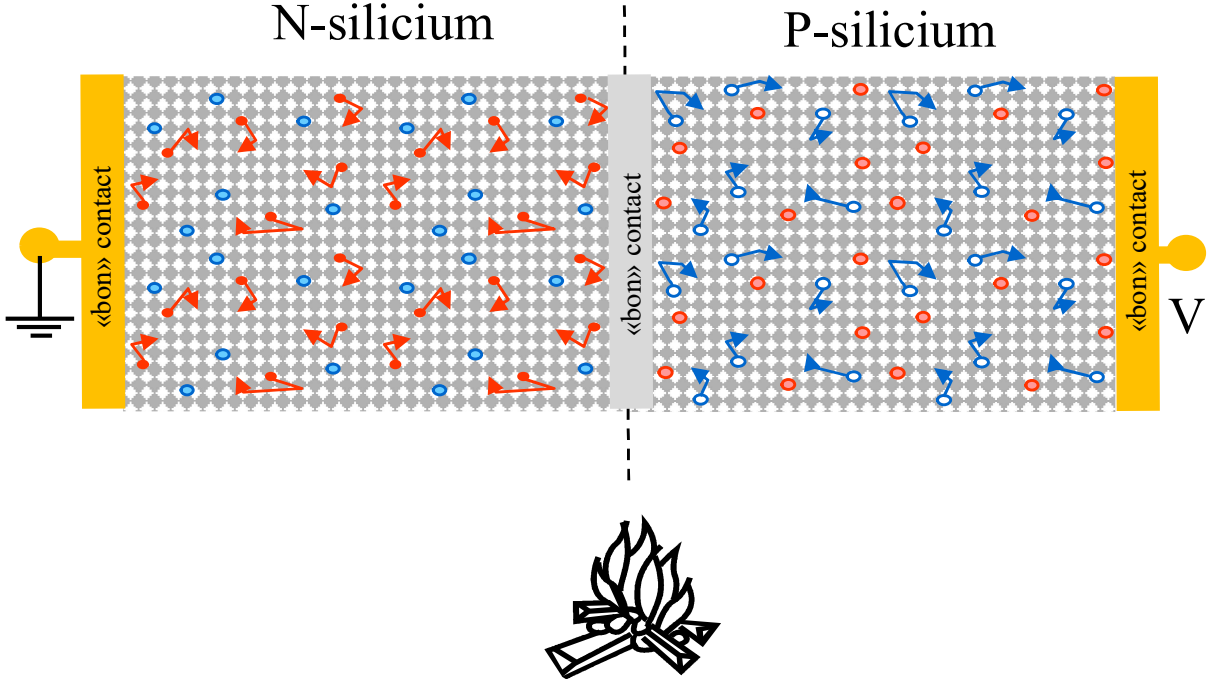
$$\frac{\partial E_f}{\partial x} = q\alpha_p \frac{\partial T}{\partial x}$$

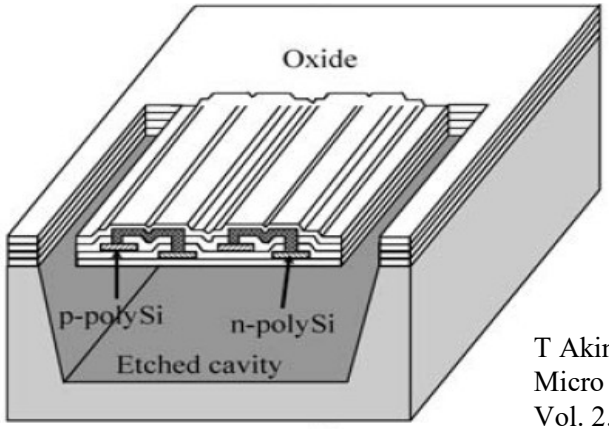
$$\alpha_p > 0$$



Exercice 3.3: Thermocouple







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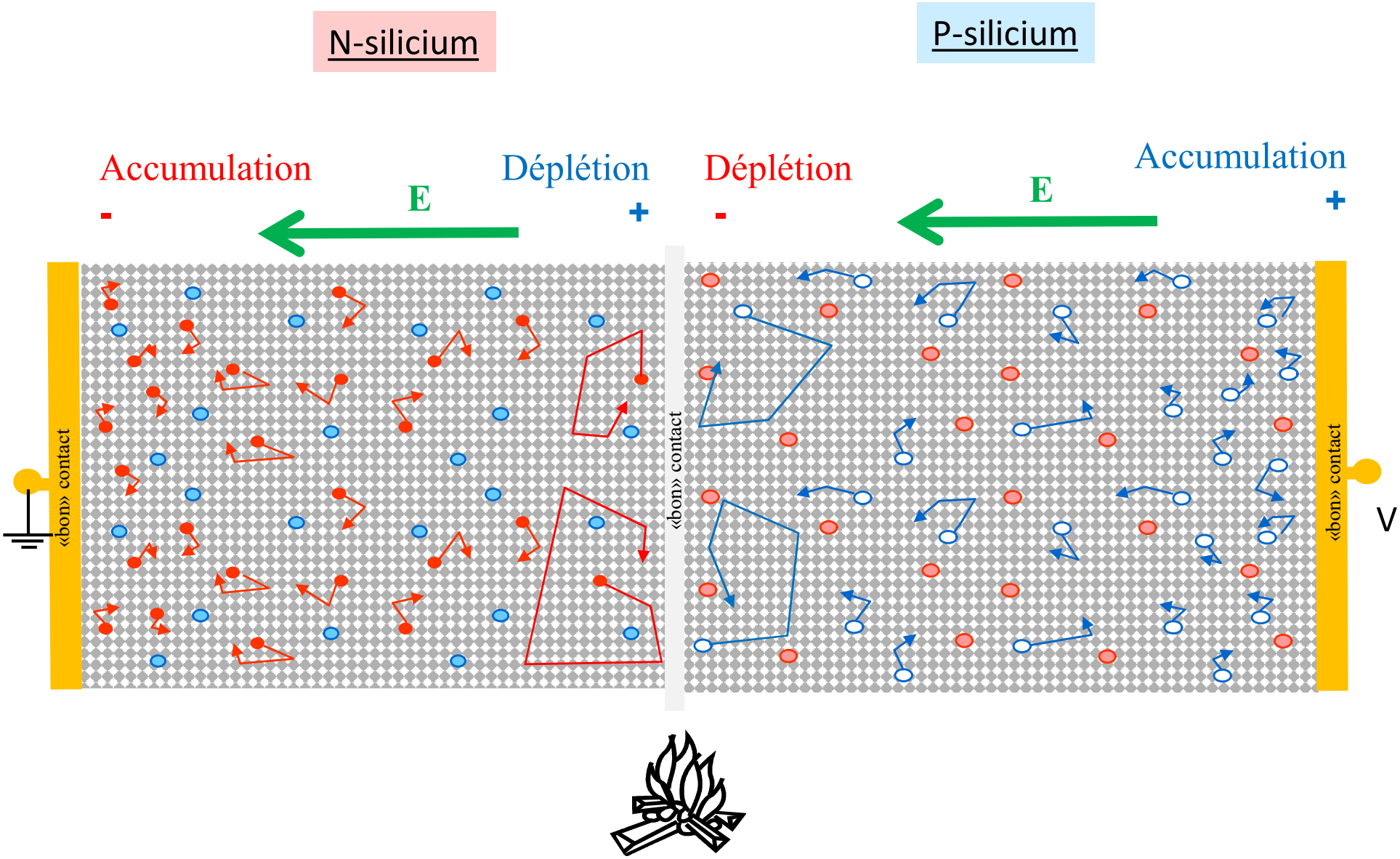
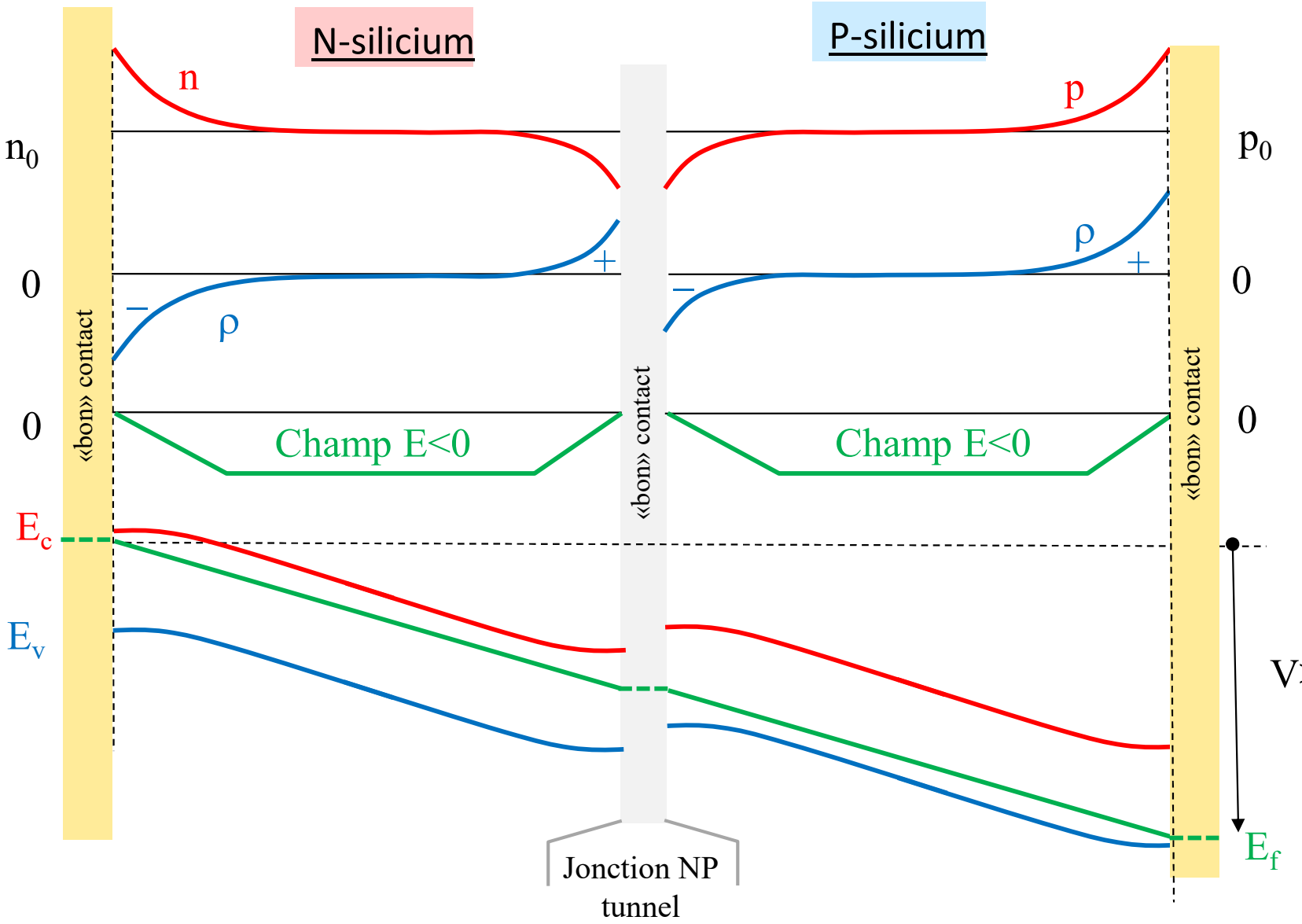
Exercice 3.3: Thermocouple



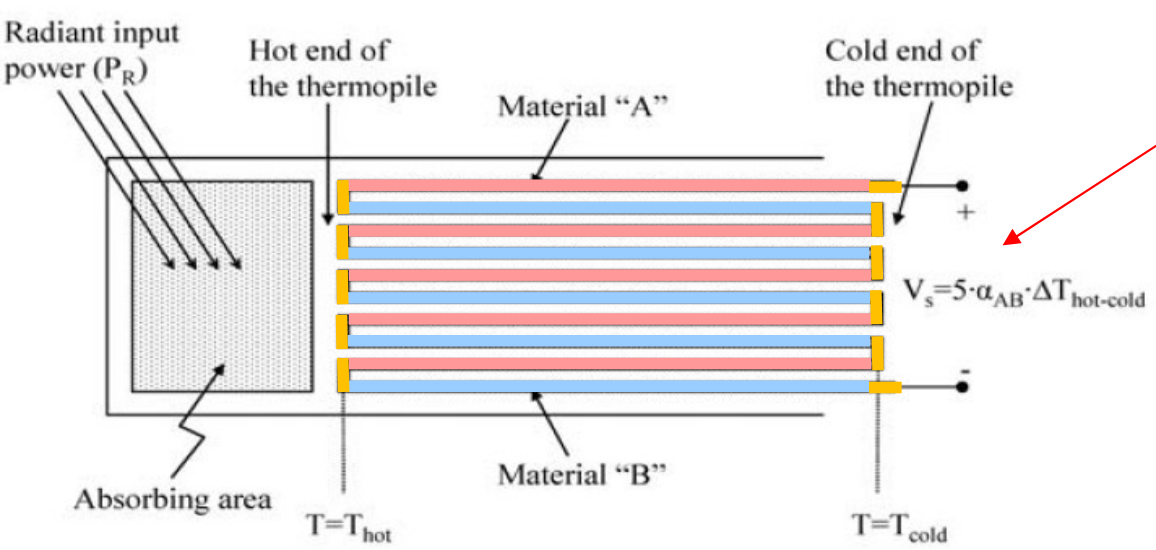
Exercice 3.3: Thermocouple



$$E \approx \int \rho \cdot dx$$

$$\varphi = -\int E \cdot dx \quad > 0$$

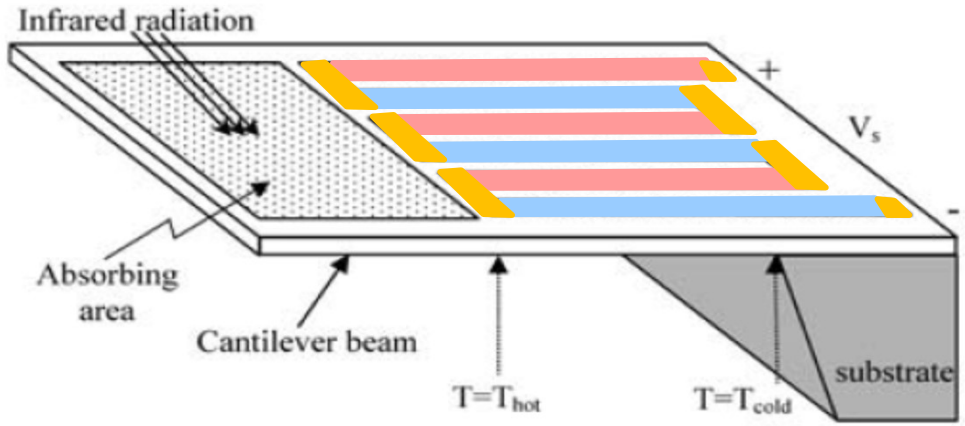
Thermopile comme capteur IR



10 V_0

Principe

Vue en perspective



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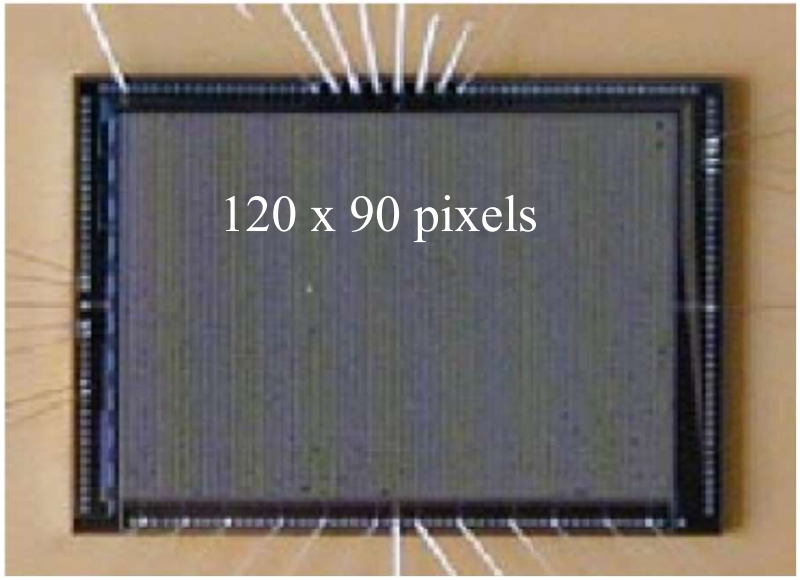
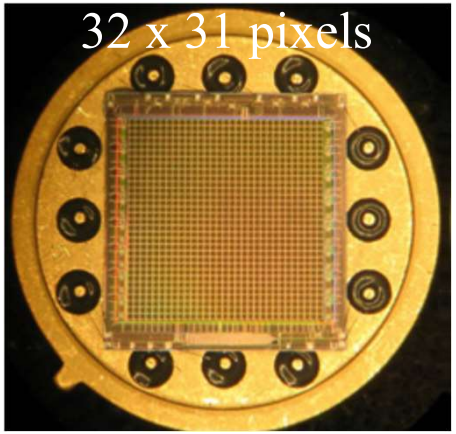
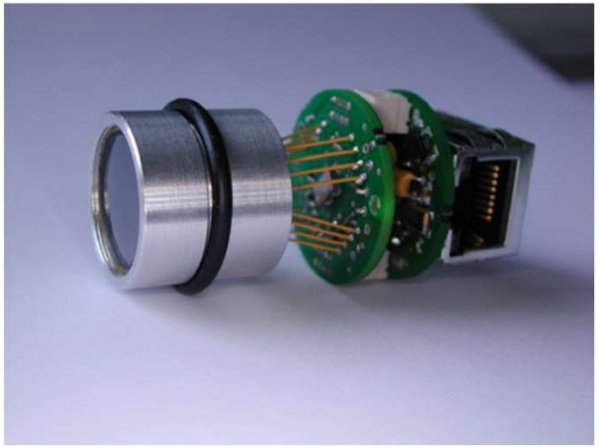
Vol. 2. CMOS – MEMS, Chap. 10

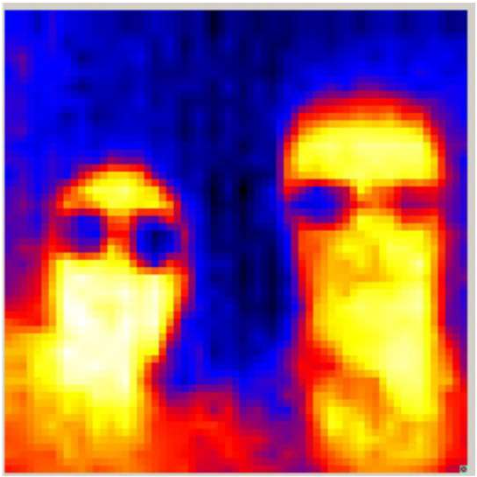
Caméra en thermopiles



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







Heimann Sensor GMBH

http://www.heimannsensor.com/HS_Poster_Array_2009.pdf

Pouvoir thermo-électrique

Table 1
Seebeck coefficients of metals relative to platinum

Material	Seebeck coefficient (μV/°C)
Antimony	+48.9
Chromel	+29.8
Tungsten	+11.2
Gold	+7.4
Copper	+7.6
Silver	+7.4
Aluminum	+4.2
p-Silicon, $\rho = 0.0035\ \Omega$ cm	+450
p-Germanium, $\rho = 0.0083\ \Omega$ 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, $\rho = 0.0035\ \Omega$ cm	−450
n-Germanium, $\rho = 0.69\ \Omega$ cm	−548

Measurements were made with the reference junction at 0 °C and the hot junction at 100 °C [25].

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

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

$$1^0 C \rightarrow \cong \pm 450 \mu V$$

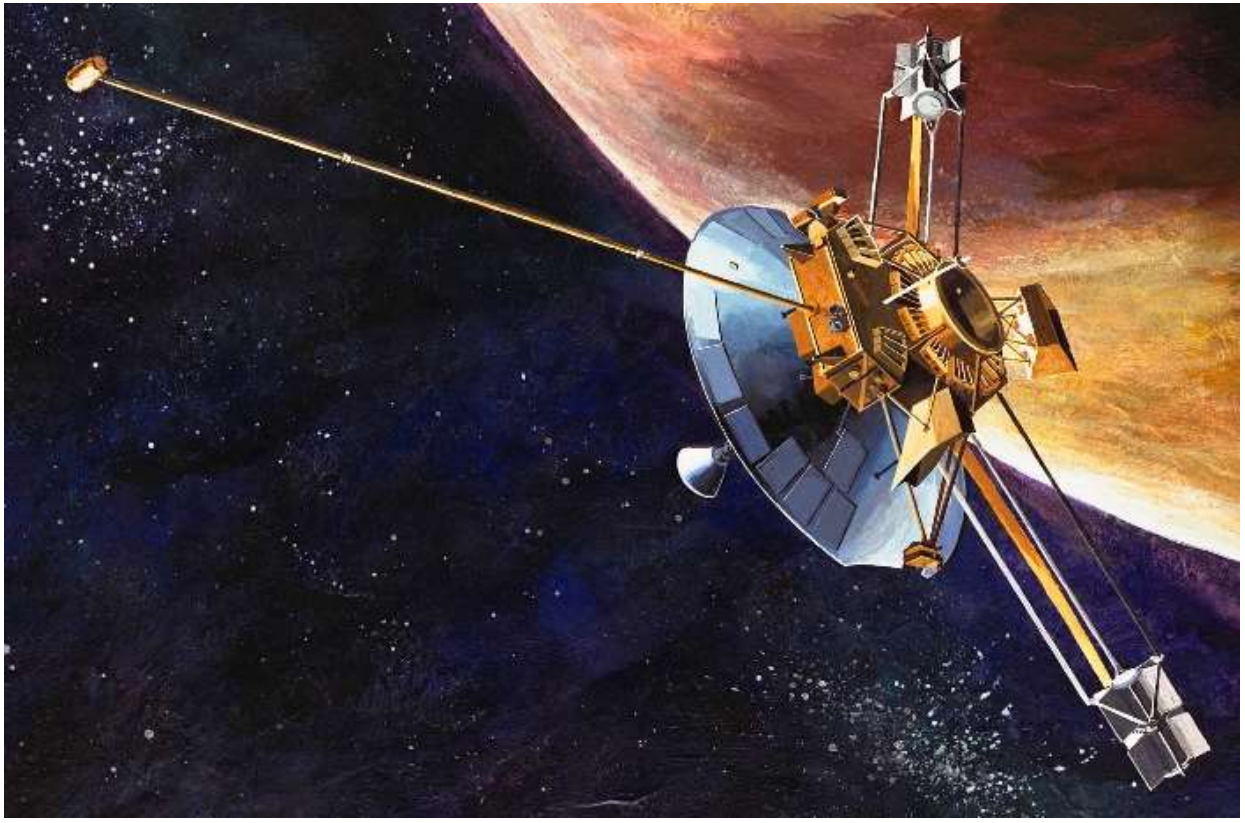
[25] D.R. Lide, CRC Handbook of chemistry and physics, 2000

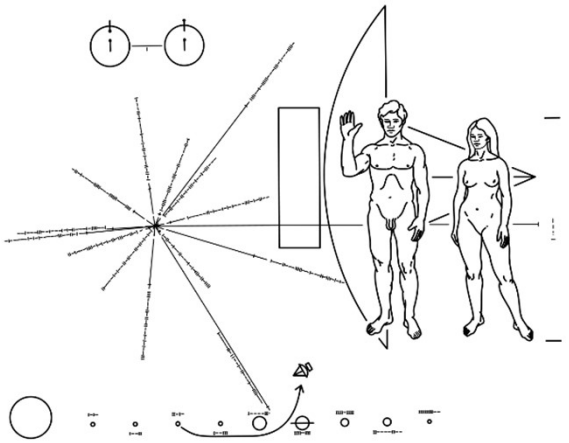
Sonde Pioneer 10

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 !!!

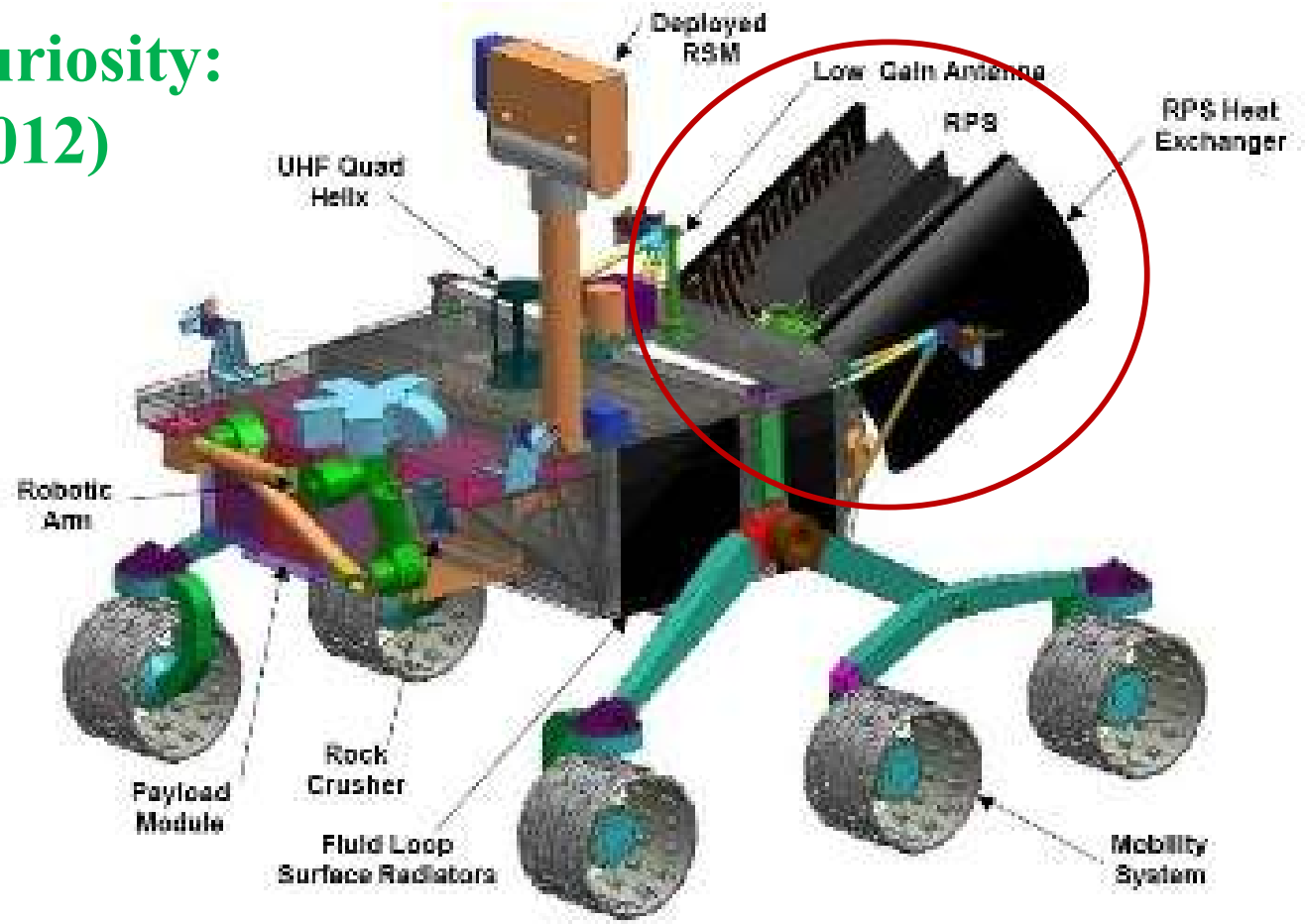




? Votre solution ?

Thermoelectric generator

Curiosity: (2012)



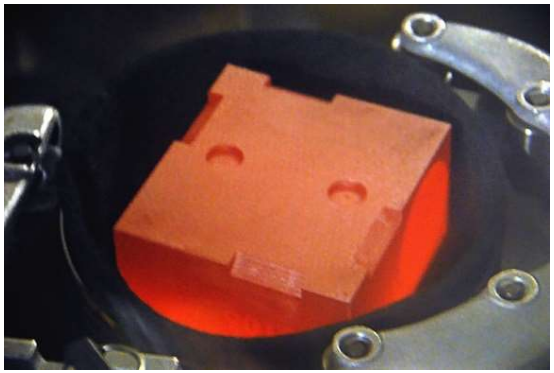
https://fr.wikipedia.org/wiki/Générateur_thermoélectrique_à_radioisotope_multi-mission

Efficiency: 6% – 8%

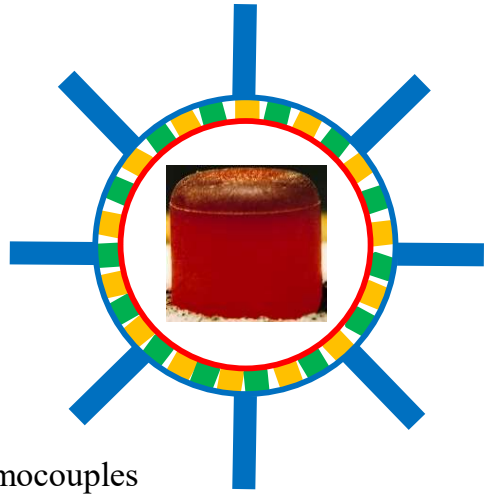
Plutonium 238

$^{238}PuO_2$

Decay: 88 years

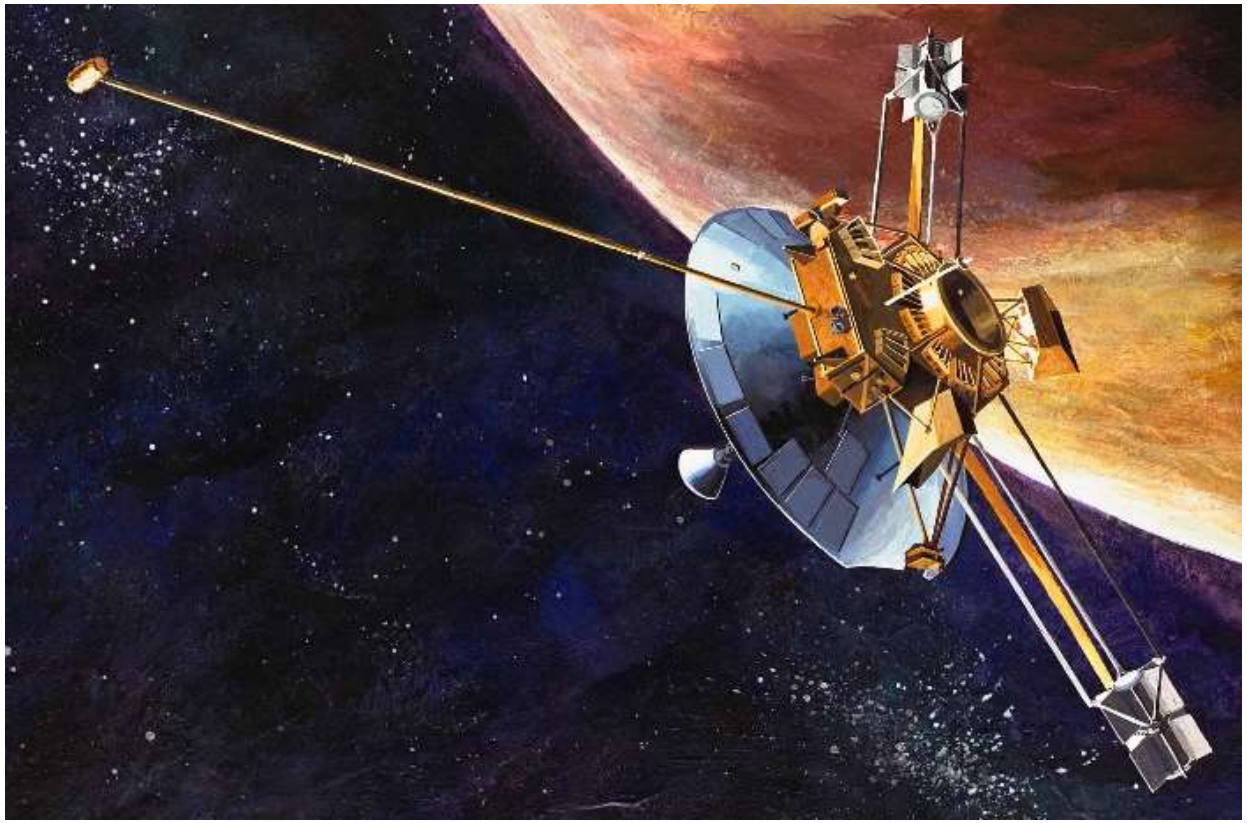


$\simeq 1000^0\,K$



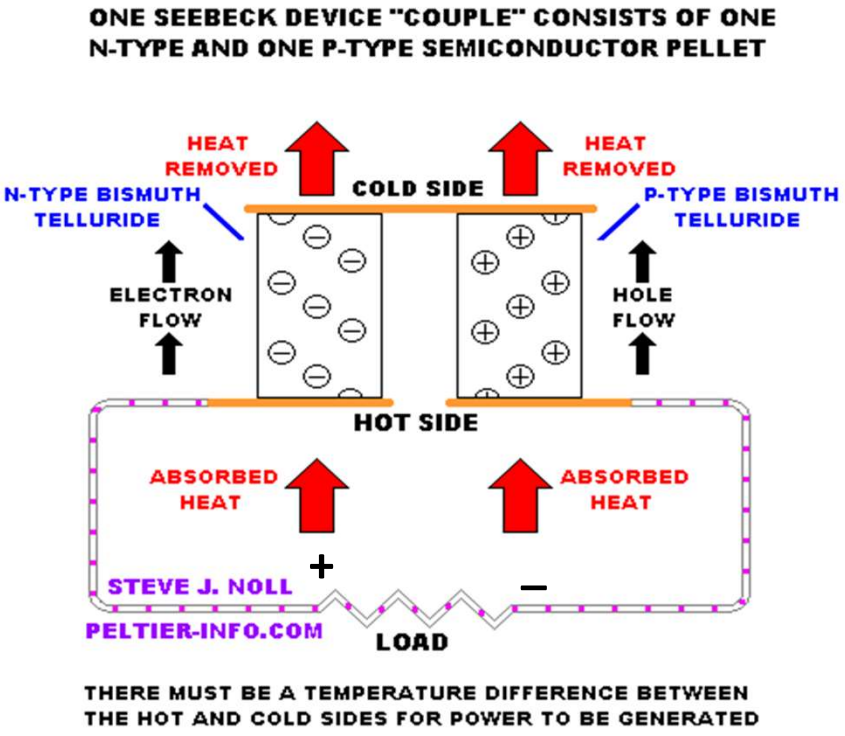
> 500 thermocouples

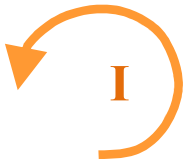
!!! Trouvez le lien !!!



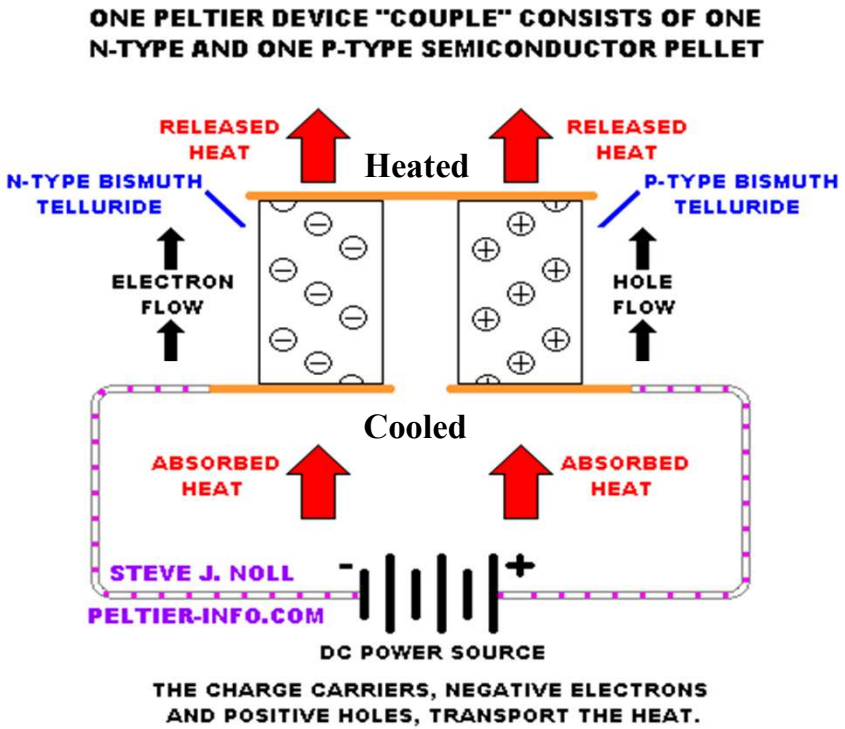
Comparaison effet Seeback et Peltier

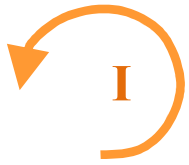
Générateur Seeback





Peltier cooler

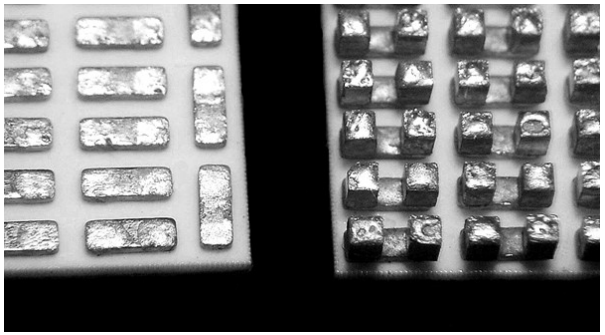


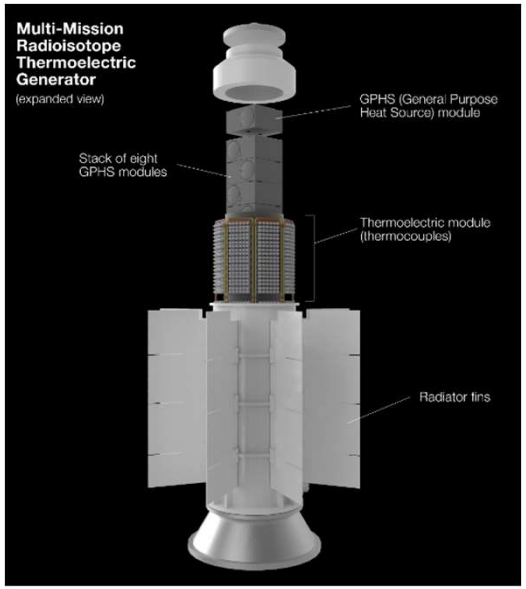


http://www.peltier-info.com/photos.html

Effets Seeback et Peltier

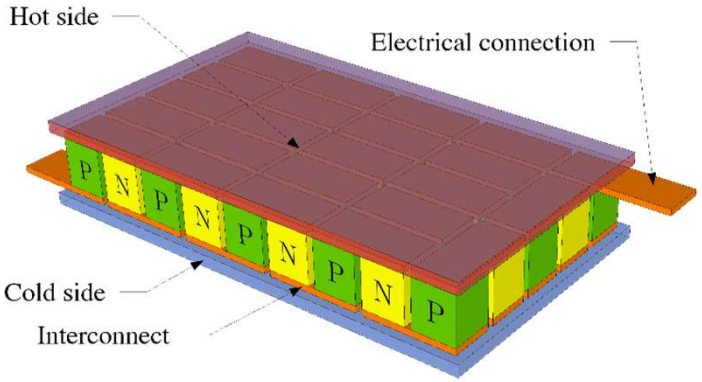
Food thermometer: thermocouple



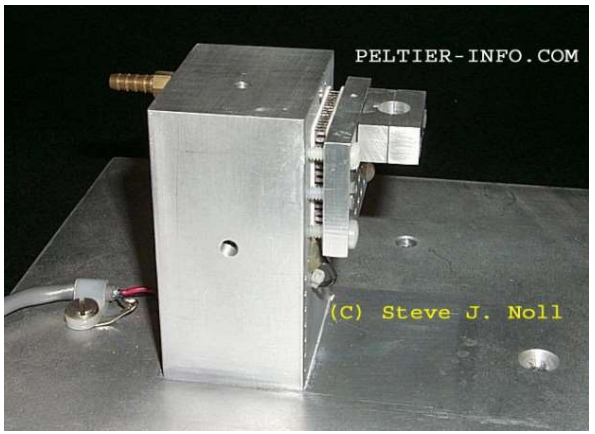


Thermoelectric generator

actifs env. 30 ans sur la sonde Pioneer 10



Peltier cooler / heater



Thermoelectric water cooler