Semiconductor Materials

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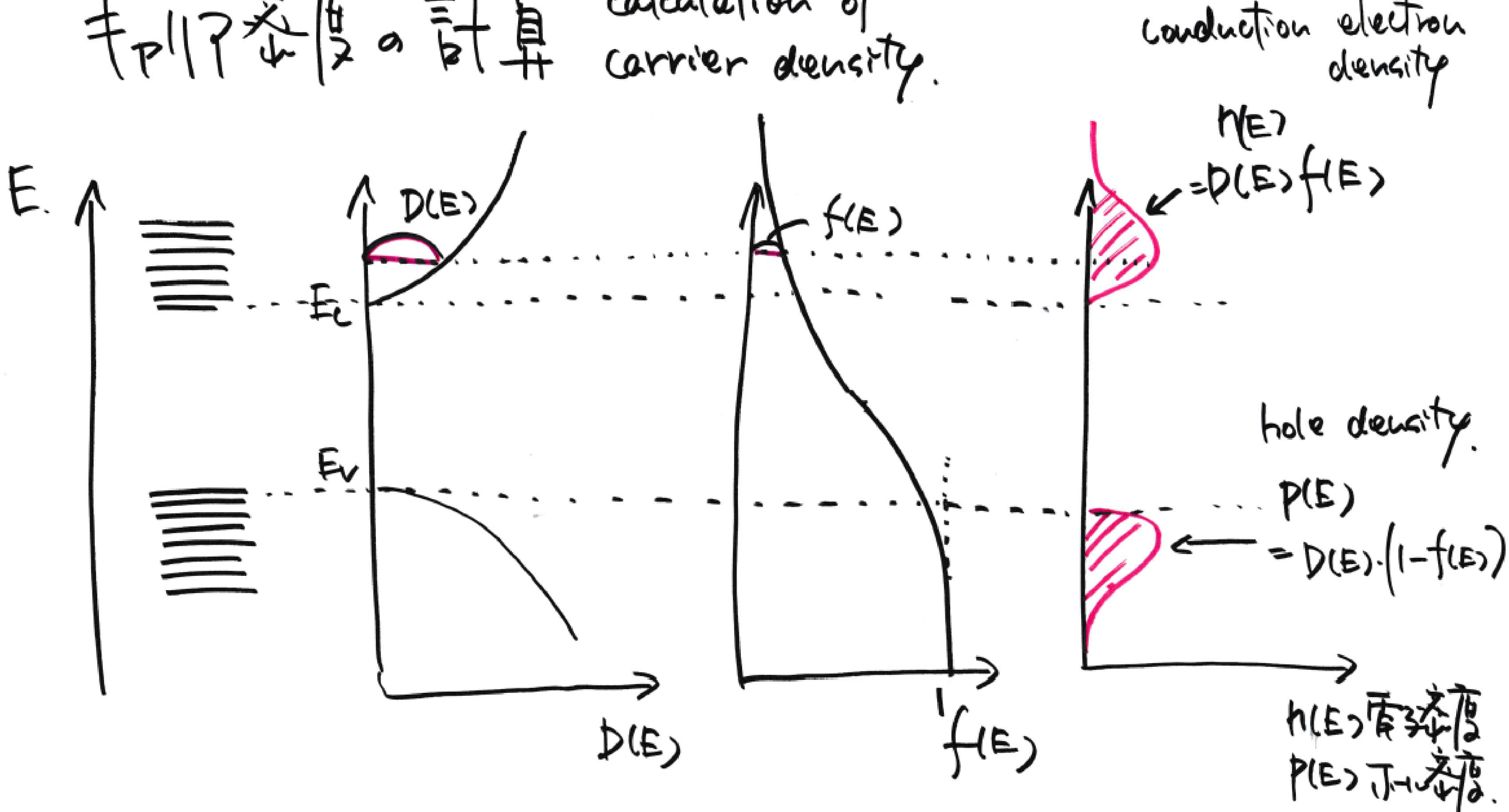
Exercise 1.

Prove $p = N_V \exp\left(-\frac{E_F - E_V}{kT}\right)$.

$p = N_V \exp\left(-\frac{E_F - E_V}{kT}\right)$ となることを示せ。

キャリア密度の計算 calculation of carrier density



hole density

ホール密度

$$p = \int_{-\infty}^{E_V} D(E)\cdot\{1-f(E)\}\,dE$$

$$= \frac{2N_V}{\sqrt{\pi(kT)^3}}\int_{-\infty}^{E_V}\sqrt{E_V-E}\cdot\exp\left(\frac{E-E_F}{kT}\right)dE$$

$$\frac{E-E_V+E_V-E_F}{kT}$$

$$\left(\frac{E_V-E}{kT}\equiv x,\quad -\frac{dE}{kT}=dx,\quad \begin{array}{c|c} E & -\infty \longrightarrow E_V \\ \hline x & \infty \longrightarrow 0 \end{array}\right)$$

$$= \frac{2N_V}{\sqrt{\pi(kT)^3}}\exp\left(-\frac{E_F-E_V}{kT}\right)\sqrt{kT}\int_{\infty}^{0}\sqrt{x}\cdot\exp(-x)\cdot(-kT\,dx)$$

$$= \frac{2}{\sqrt{\pi}}N_V\exp\left(-\frac{E_F-E_V}{kT}\right)\underbrace{\int_0^{\infty}\sqrt{x}\,e^{-x}\,dx}_{\frac{\sqrt{\pi}}{2}}$$

$$= N_V\exp\left(-\frac{E_F-E_V}{kT}\right) \quad //.$$

伝導電子密度
Conduction electron density

$$n = N_c \exp\left(-\frac{E_c - E_{Fn}}{kT}\right)$$

ホール密度
Hole density

$$p = N_v \exp\left(-\frac{E_{Fp} - E_v}{kT}\right)$$

Mass action law

質量作用の法則.

$$n\times p = N_cN_v \exp\left(\frac{-E_c+\cancel{E_F}-\cancel{E_F}+E_v}{kT}\right)$$

$$= N_cN_v\exp\left(-\frac{E_c-E_v}{kT}\right).$$

bandgap

E_g バンドギャップ

半導体の性質のみに依存
（不純物の種類量に依らない）

Intrinsic semiconductor

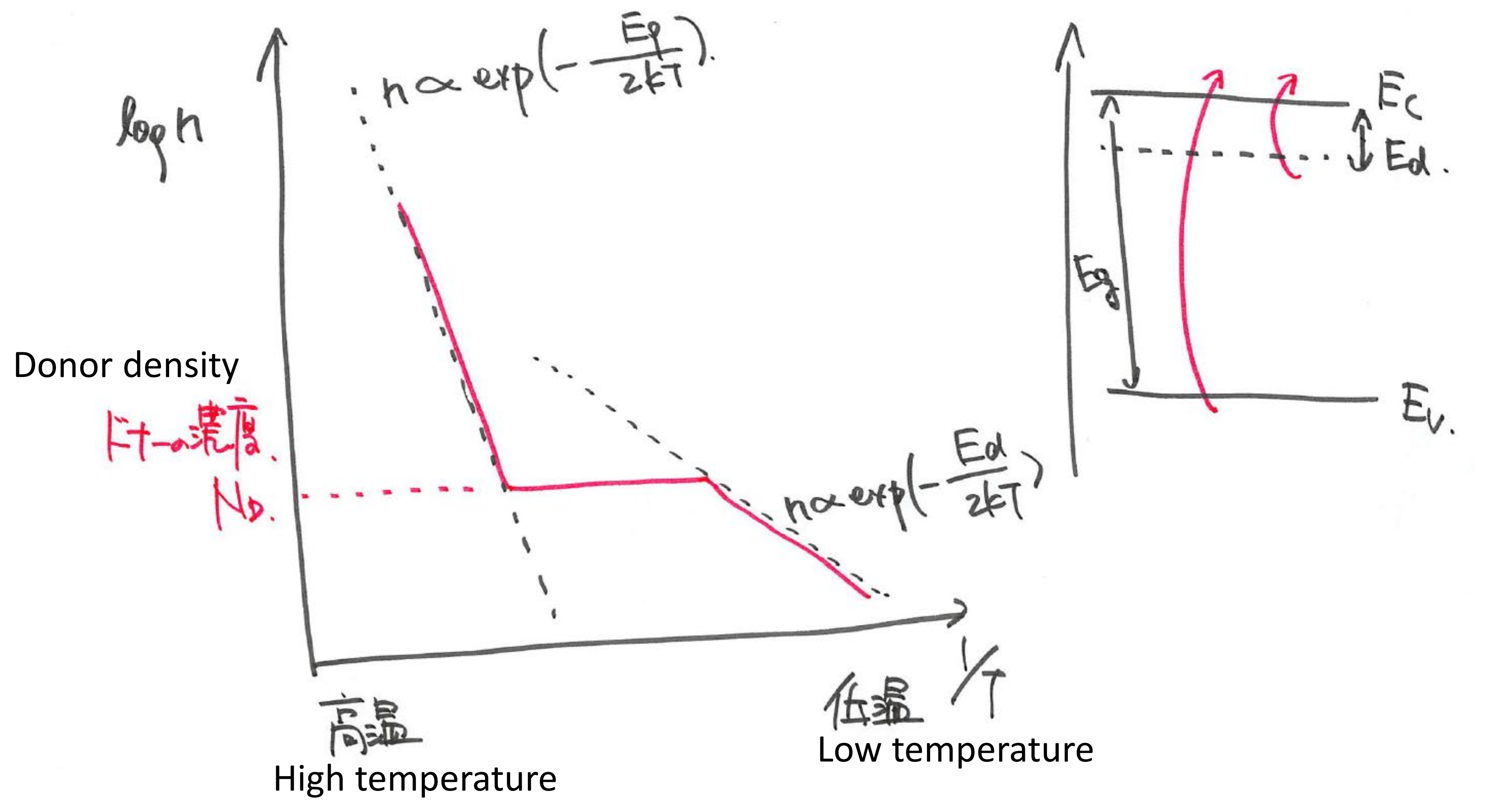
真性半導体

$$n=p=\sqrt{N_cN_v}\exp\left(-\frac{E_g}{2kT}\right)$$

$$\left(\begin{array}{l} \mathrm{Si}\ \ E_g=1.12\,\mathrm{eV} \\ \quad n=p\sim 1\times10^{10}/\mathrm{cm}^3\ (300\mathrm{K}). \end{array}\right)$$

Temperature dependence of carrier density

キャリア密度の温度依存性.



Fermi level

E_F（フェルミレベルの位置）.

真性半導体　$n = p$

Intrinsic semiconductor

$$N_c \exp\left(-\frac{E_c - E_F}{kT}\right) = N_v \exp\left(-\frac{E_F - E_v}{kT}\right)$$

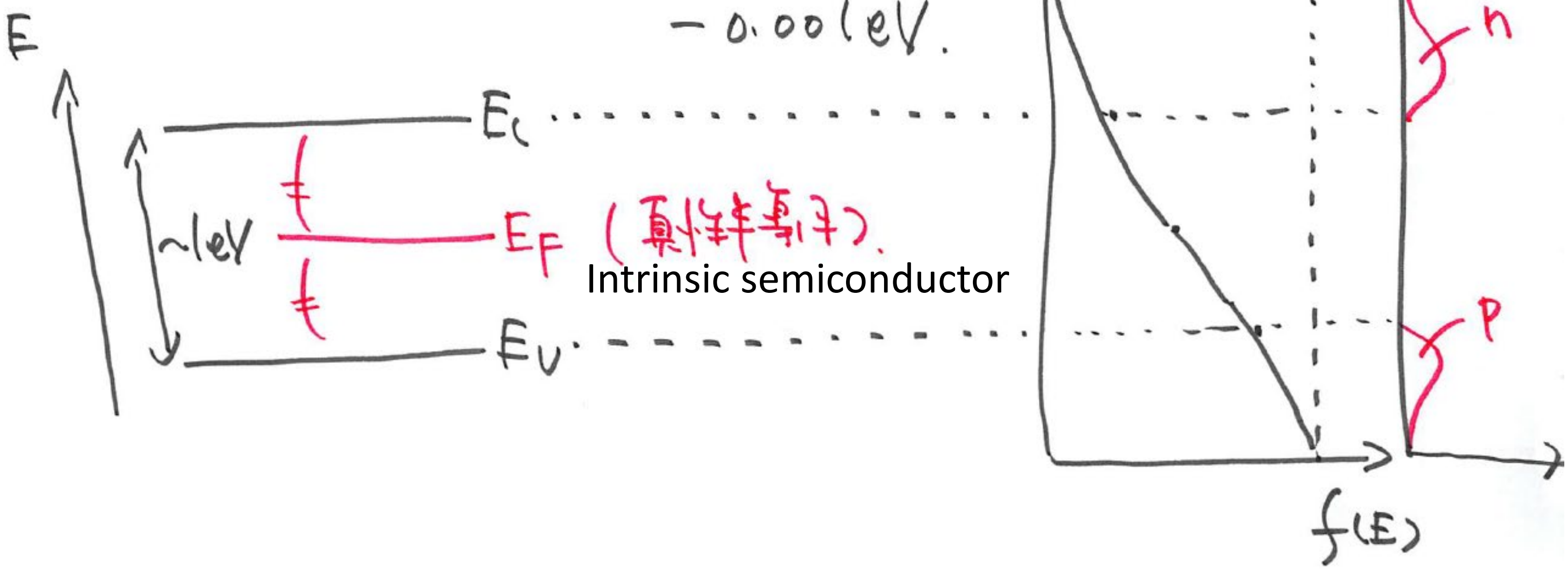
$$\downarrow$$

$$E_F = \frac{E_c + E_v}{2} + \frac{kT}{2} \log \frac{N_v}{N_c} \qquad \text{①}$$

演習 1.　式①が成り立つことを示せ.

Exercise 1　　Prove equation ①.

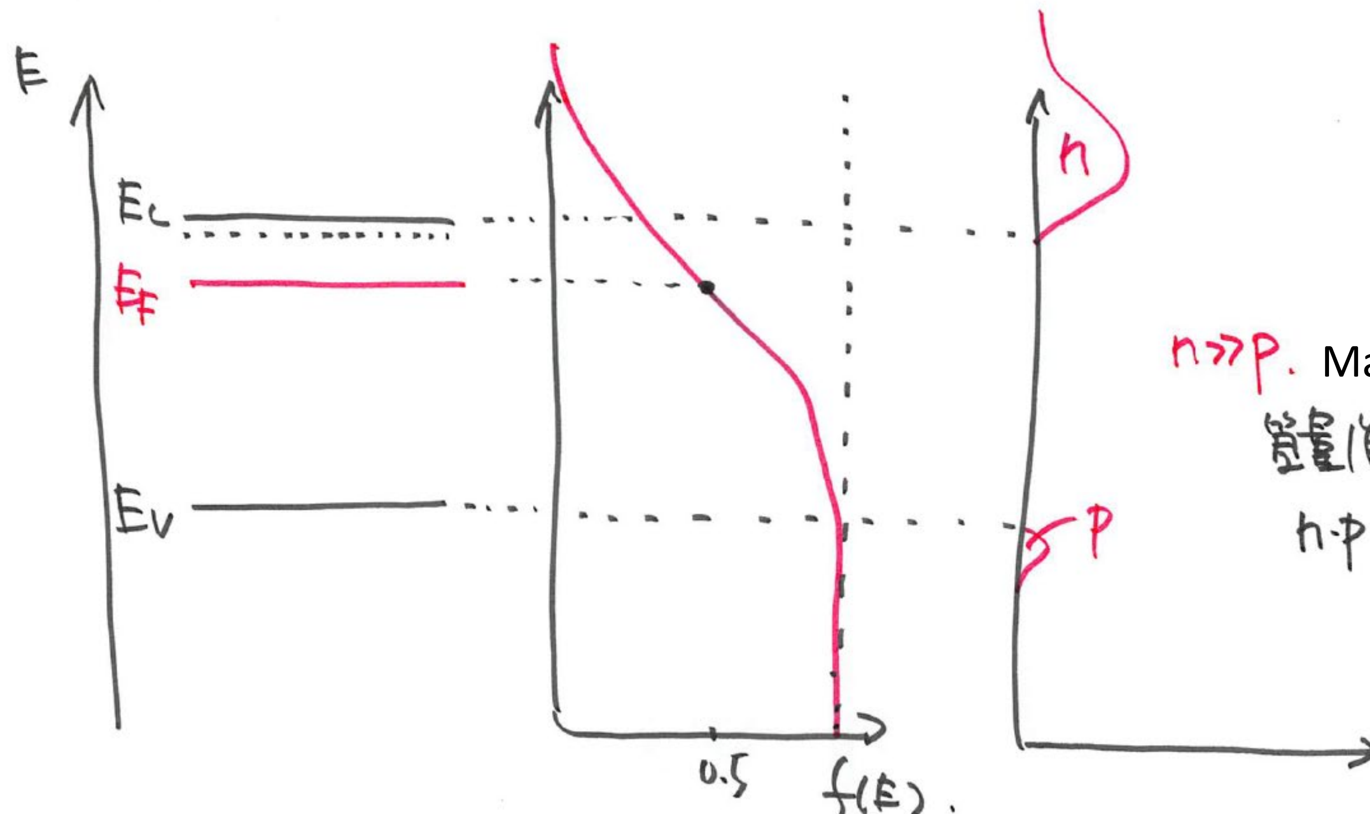
$$E_F = \frac{E_c + E_v}{2} + \underbrace{\frac{kT}{2}\log\frac{N_v}{N_c}}_{\sim 0.001\,eV}$$



Intrinsic semiconductor

n-type semiconductor

n型半導体.



Fermi distribution

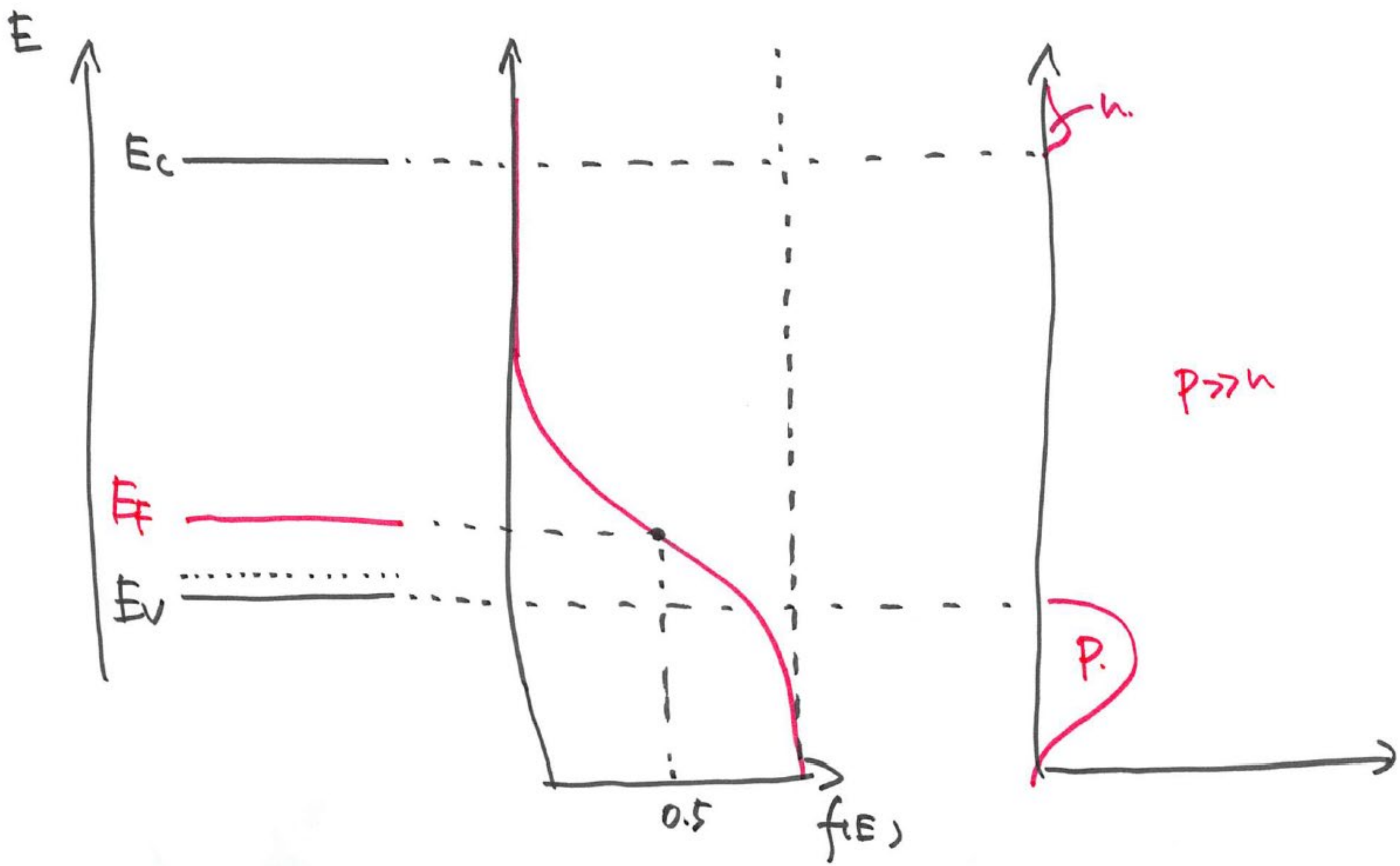
$n \gg p$. Mass action law

質量作用の法則

$n \cdot p = \text{const.}$

p-type semiconductor

P型半導体



Fermi distribution

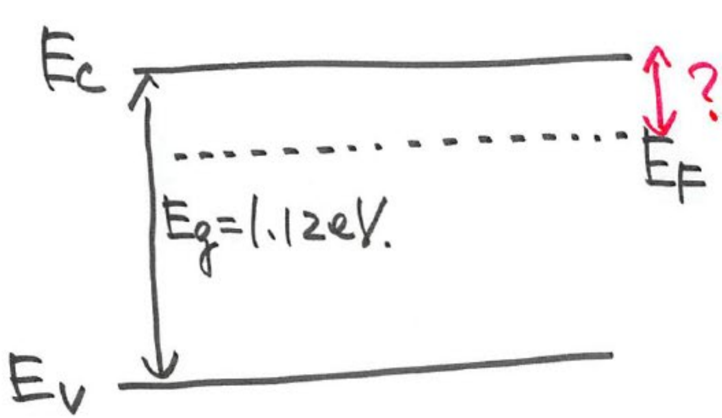
Exercise 2

演習 2

Siの結晶を$1\times10^{16}/cm^3$のAsでドープした。

室温(300K)におけるホール密度，伝導電子密度，フェルミ準位を求めよ。

($kT = 0.026\,eV$ at $T=300K$)



$N_c = 2.86\times10^{19}/cm^3$

$N_v = 2.66\times10^{19}/cm^3$

Si is doped with 1×10^{16} /cm^3 of As.
Derive the hole density, conduction electron density and E_F (Fermi level) at T=300(K).