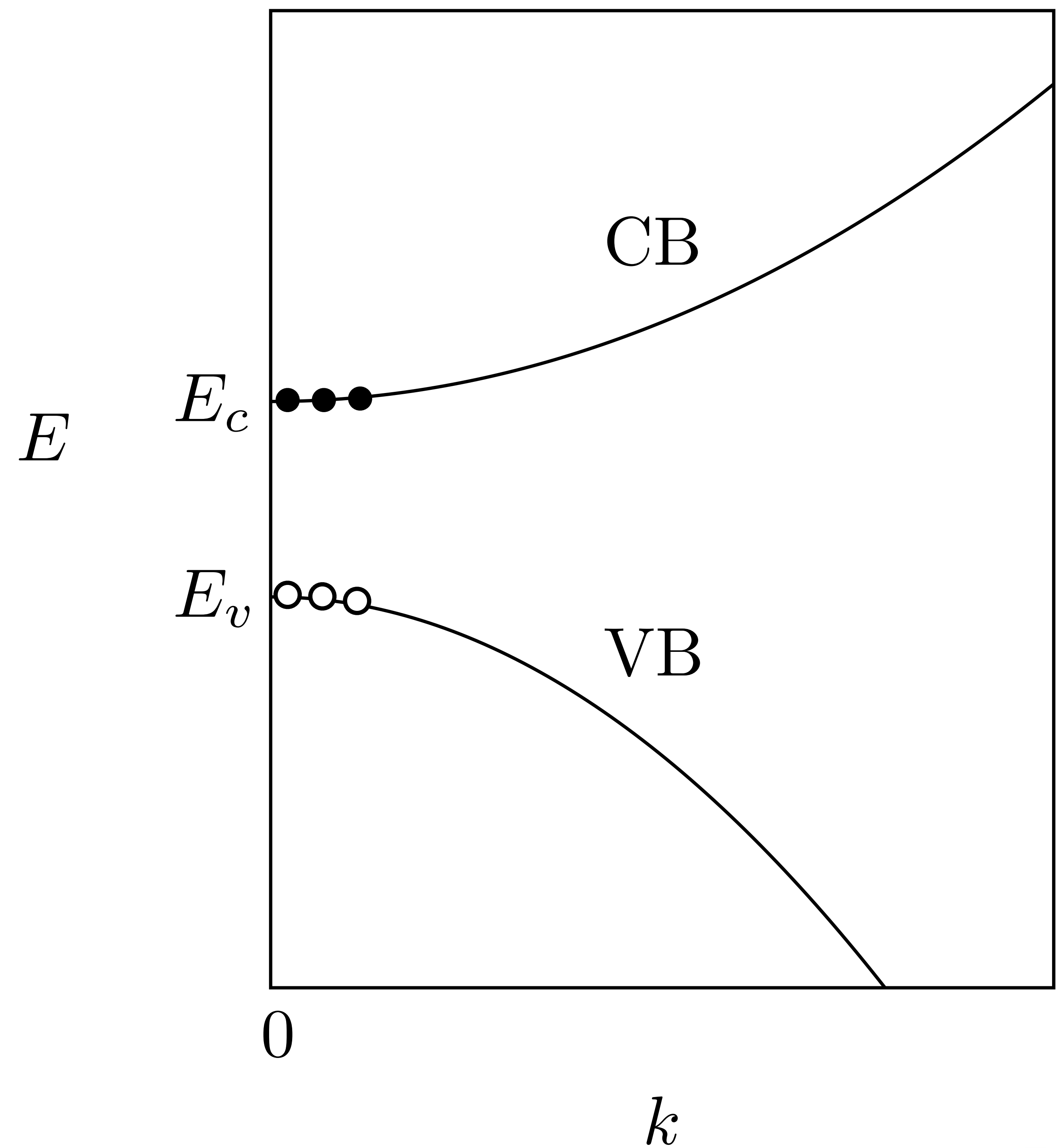
Typical semiconductor bands

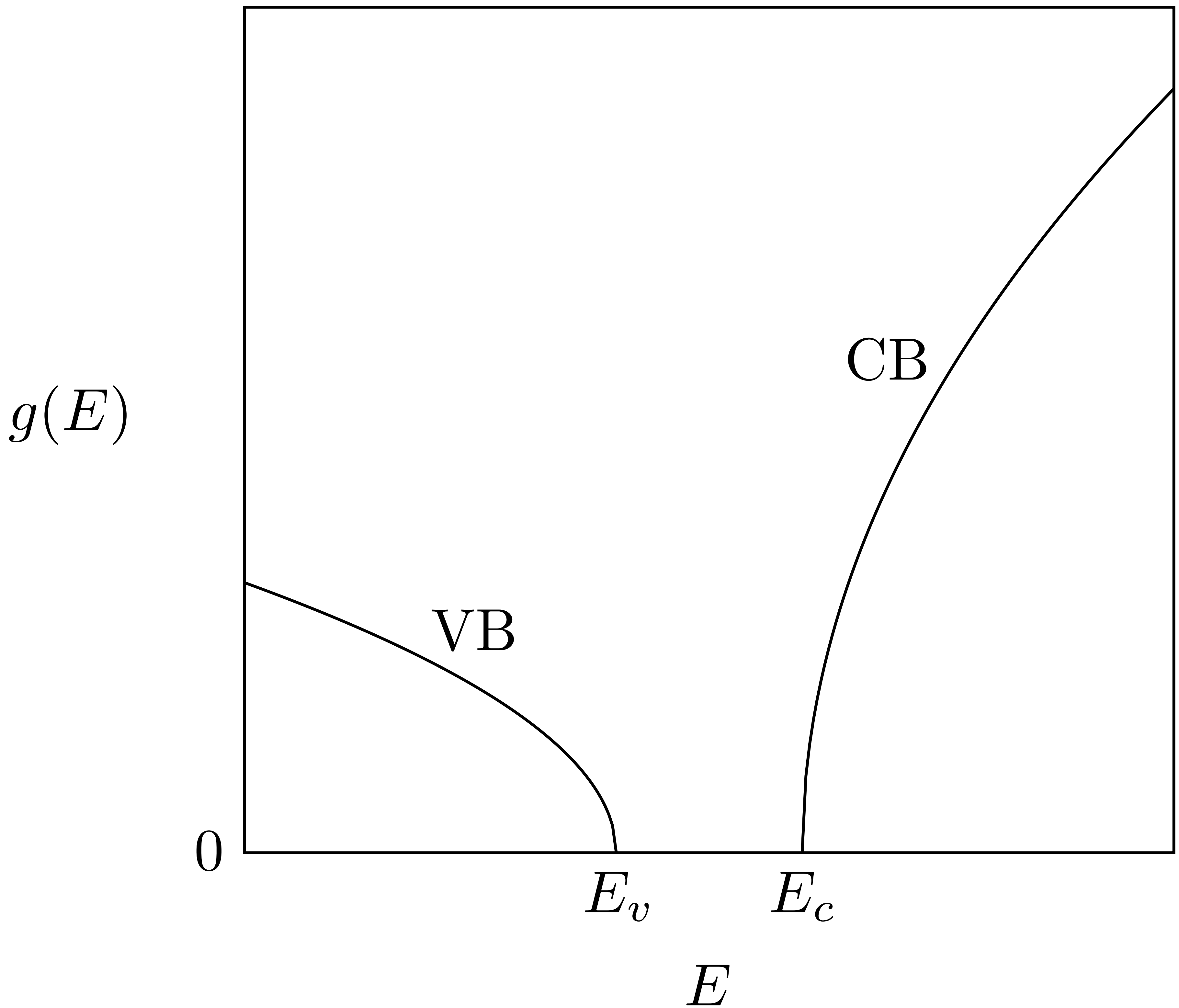
$$E(k) = E(0) + \left.\frac{dE}{dk}\right|_{k=0} k + \frac{1}{2}\left.\frac{d^2E}{dk^2}\right|_{k=0} k^2 + \cdots$$

$$E = E_c + \frac{\hbar^2}{2m_n^*}k^2$$

$$E = E_v - \frac{\hbar^2}{2m_p^*}k^2$$

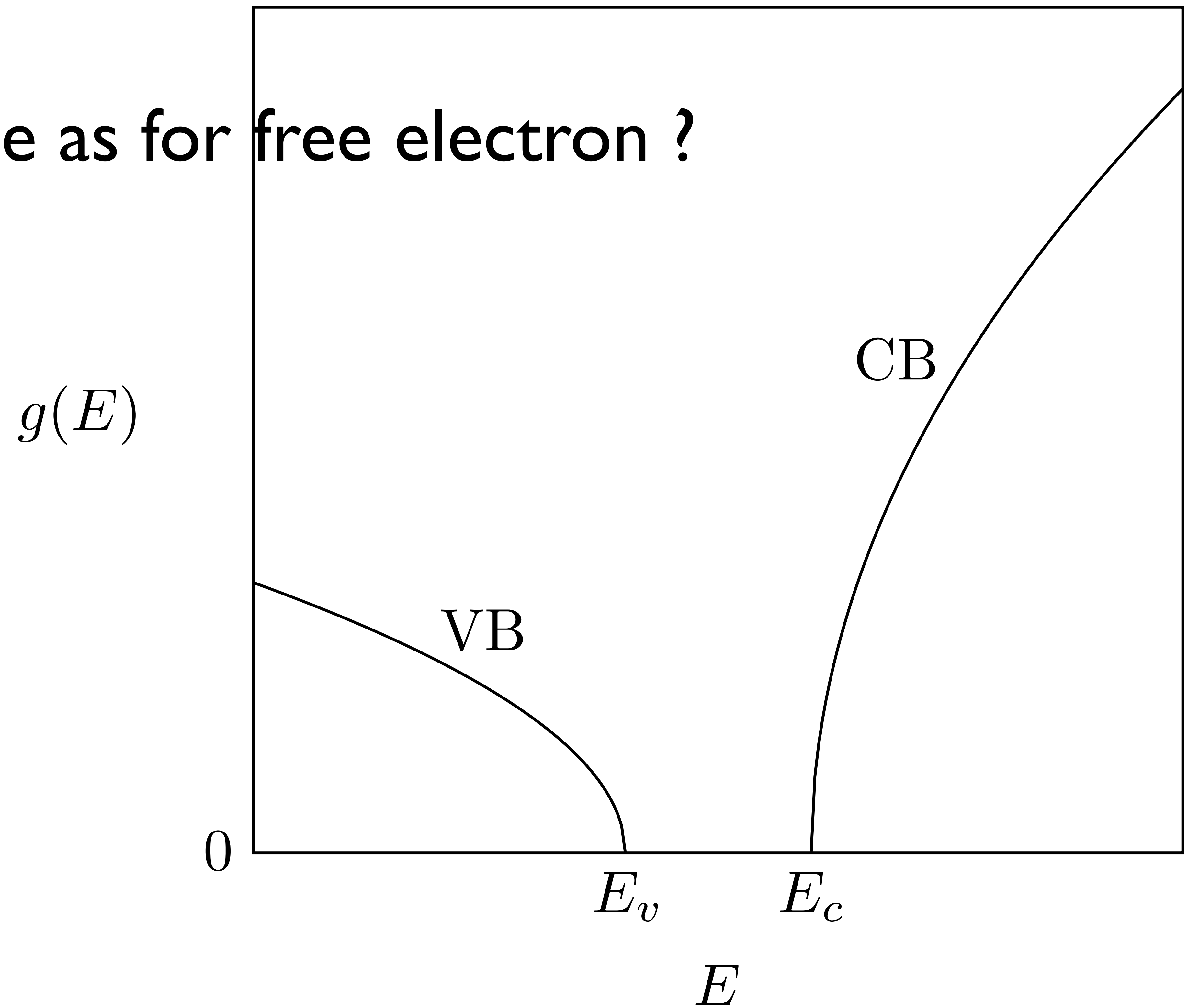


Density of states

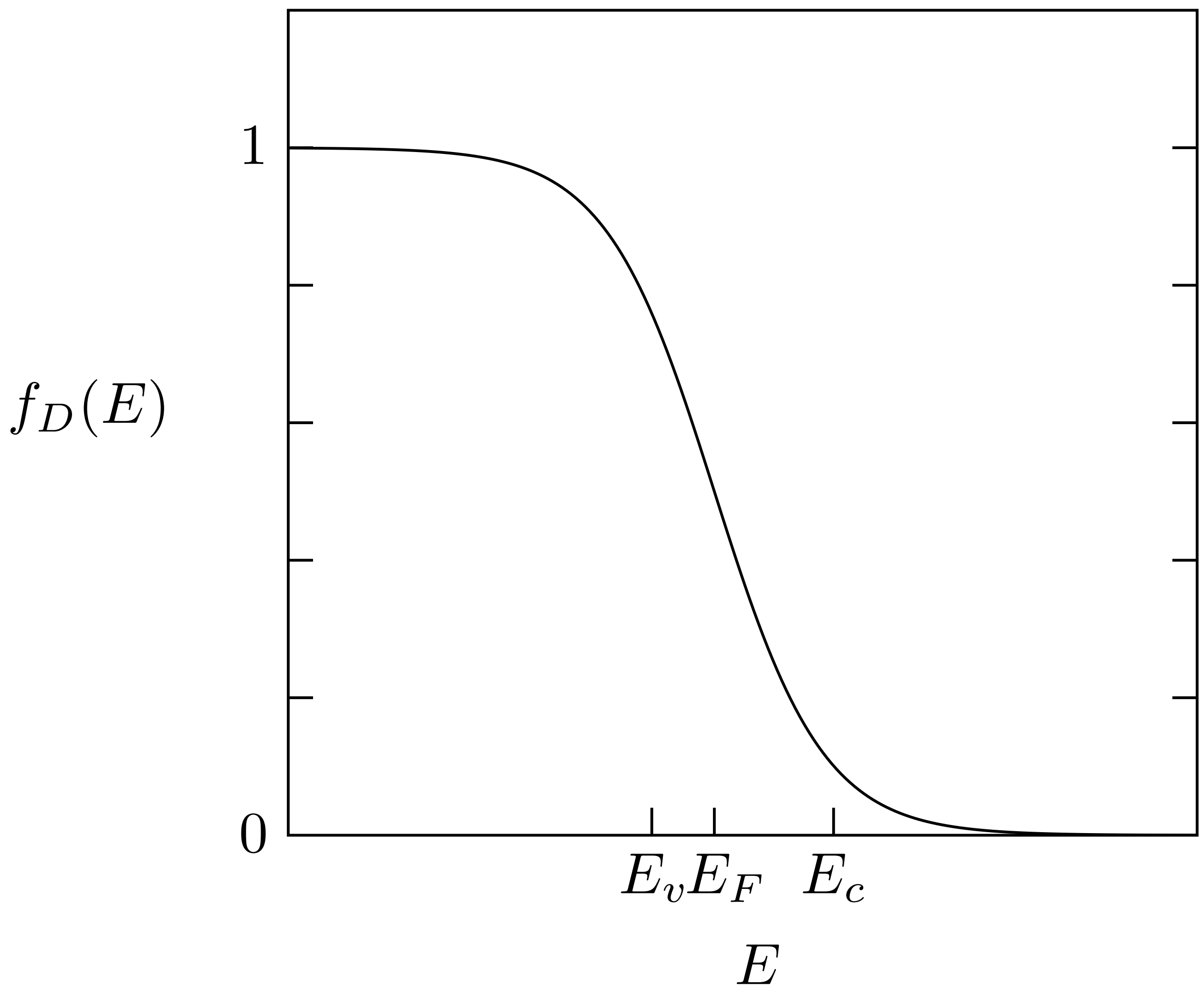


Density of states

Same as for free electron ?



Band occupation at $T \neq 0$



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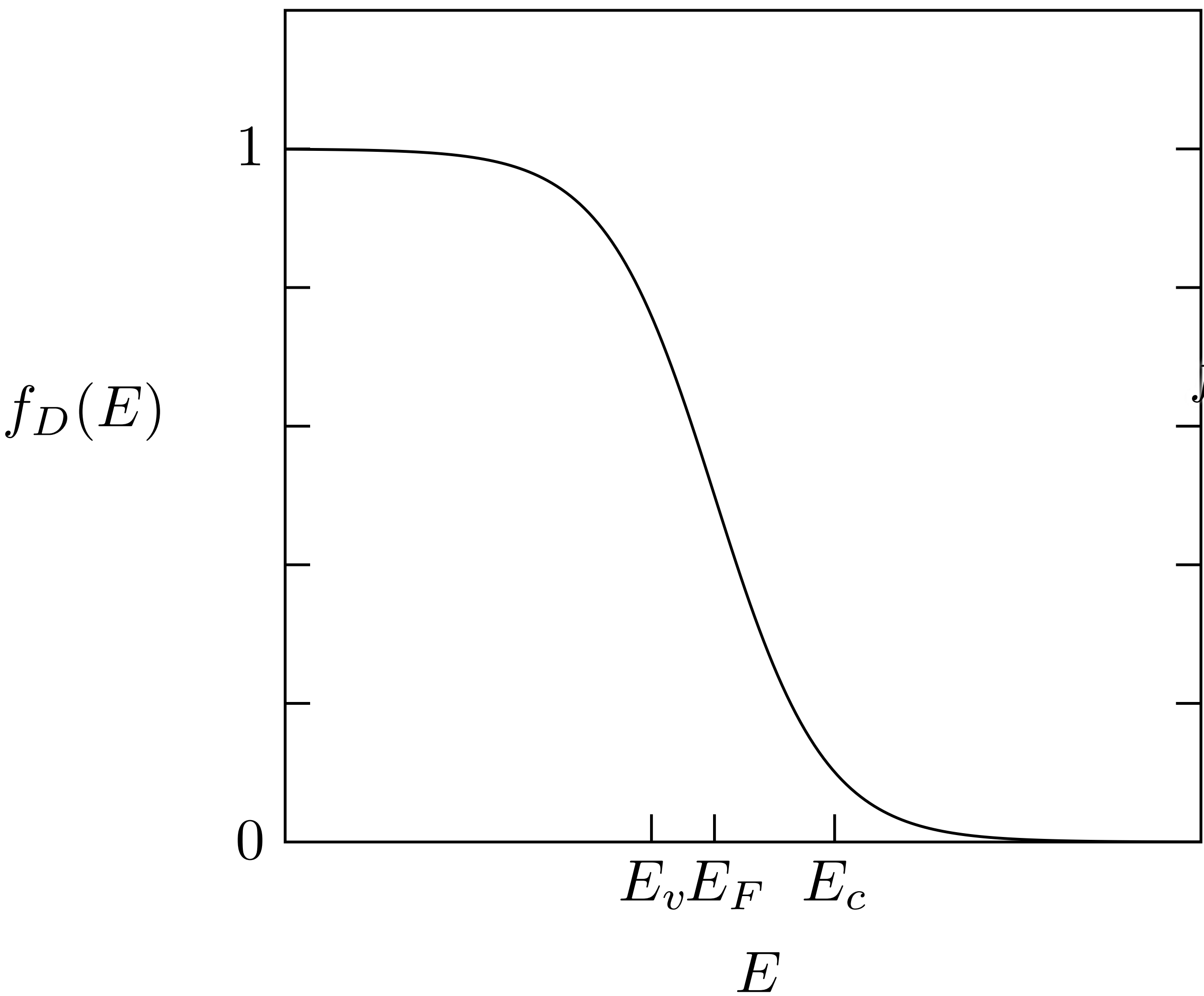

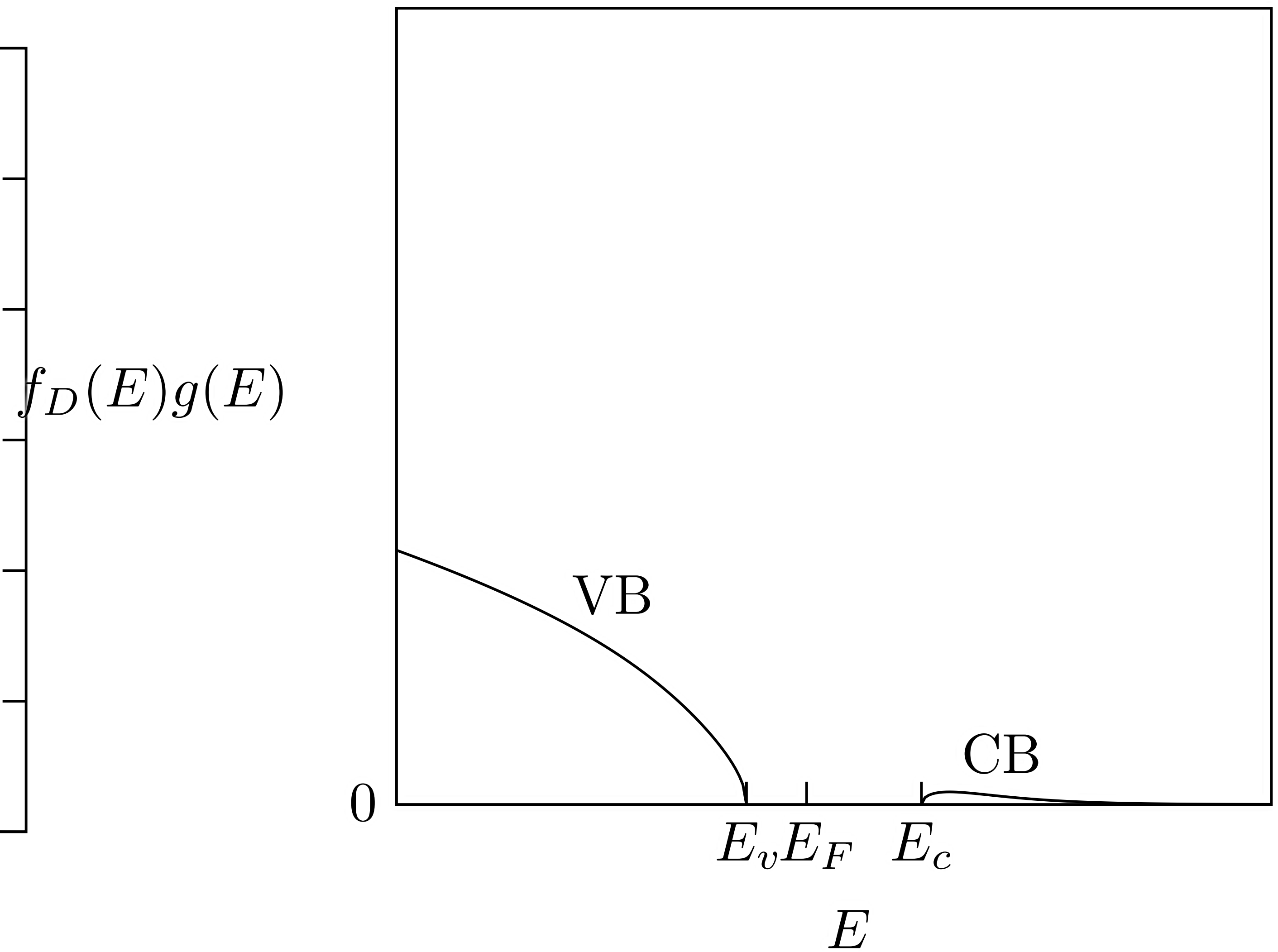

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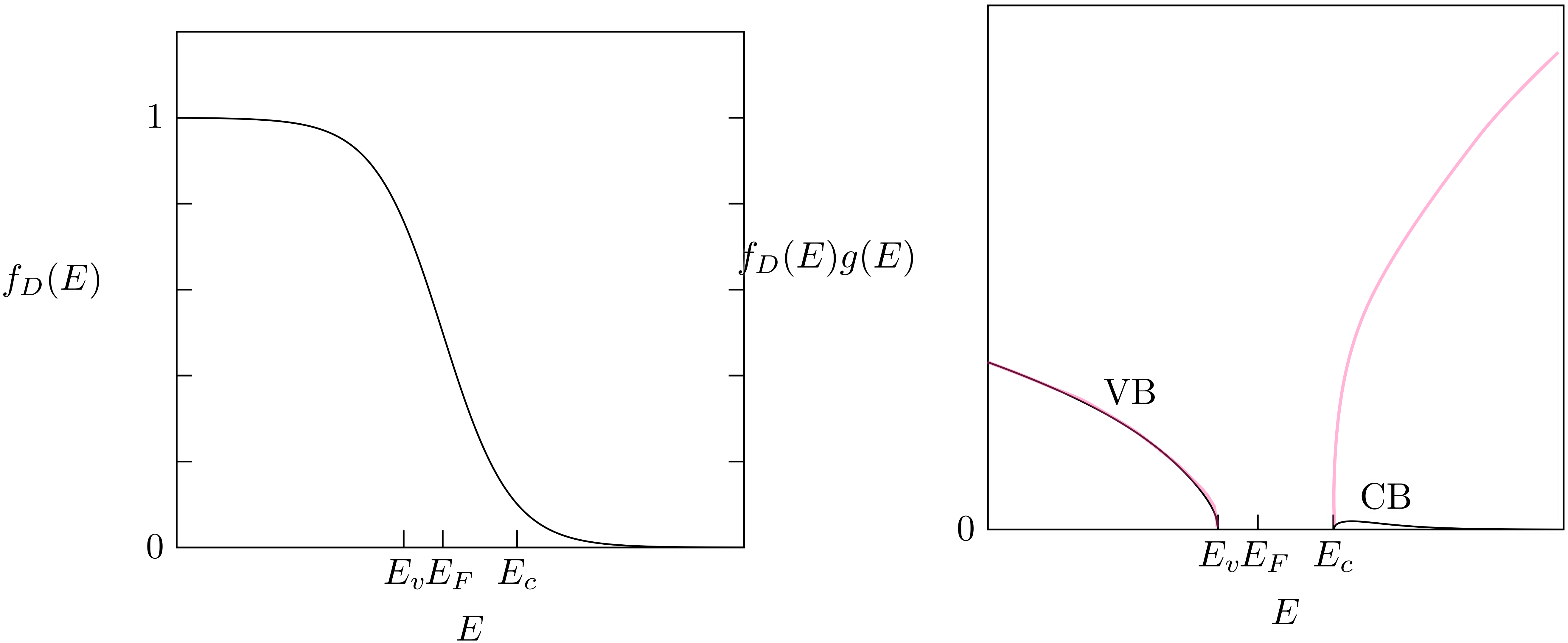

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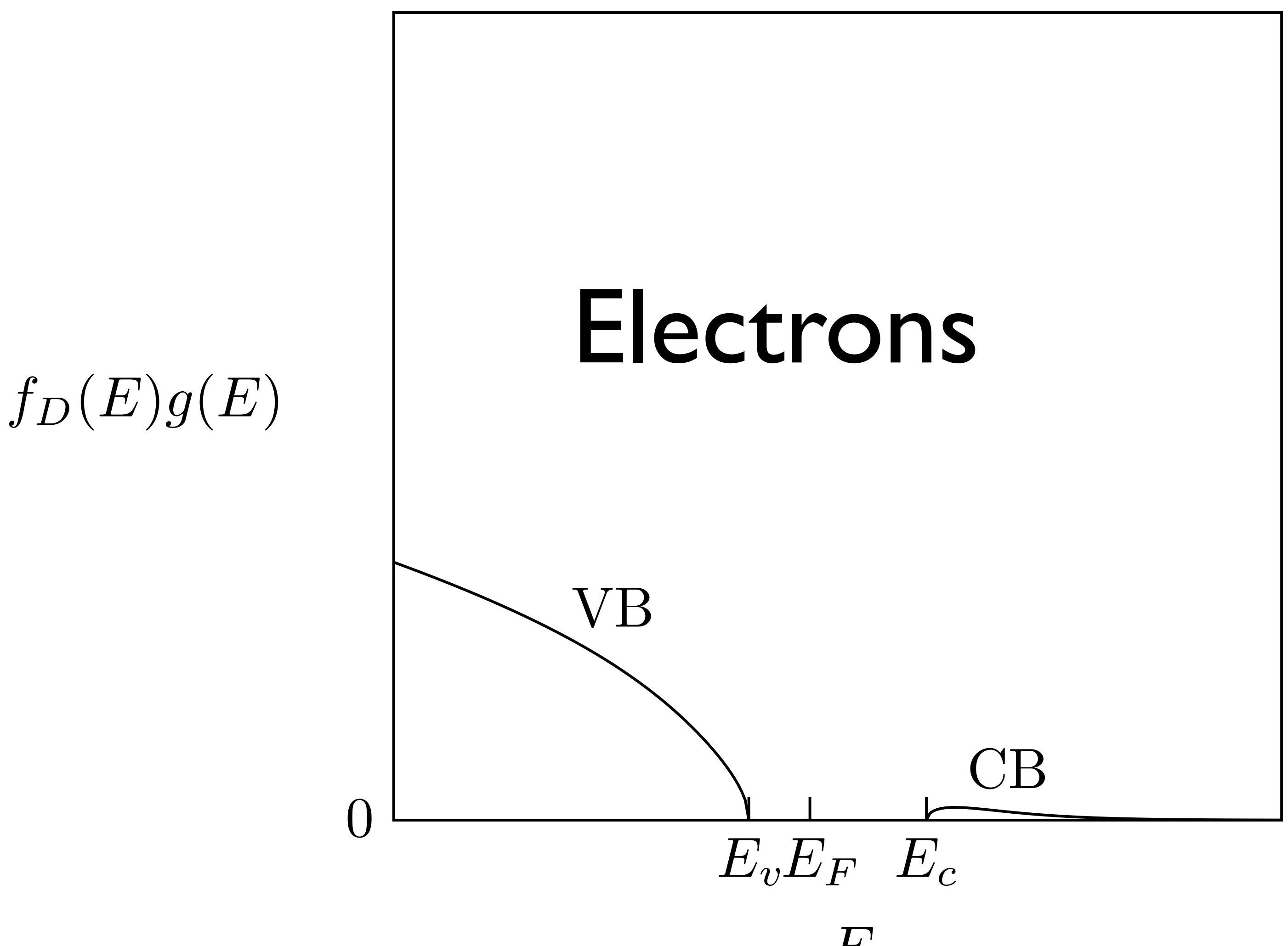

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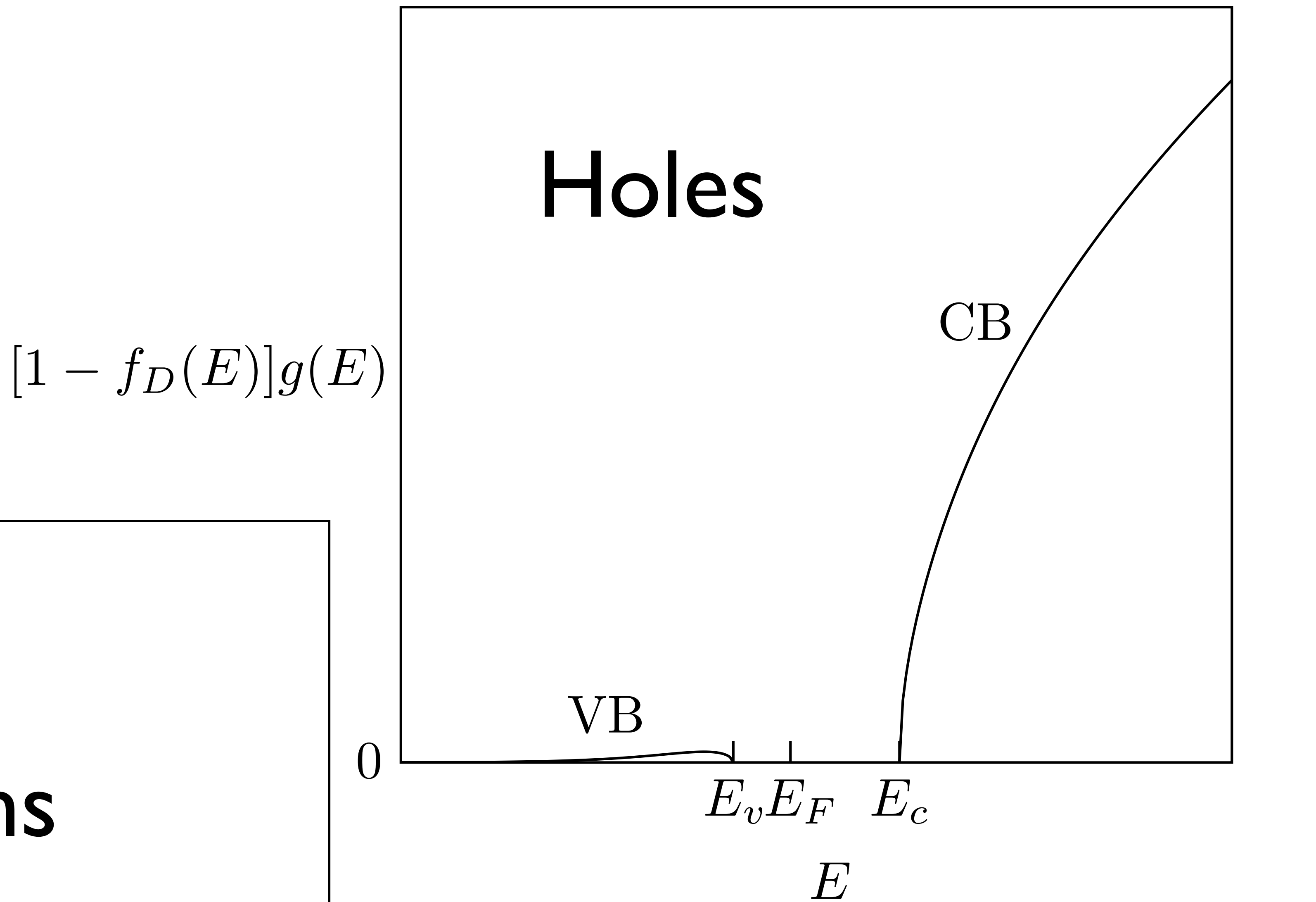
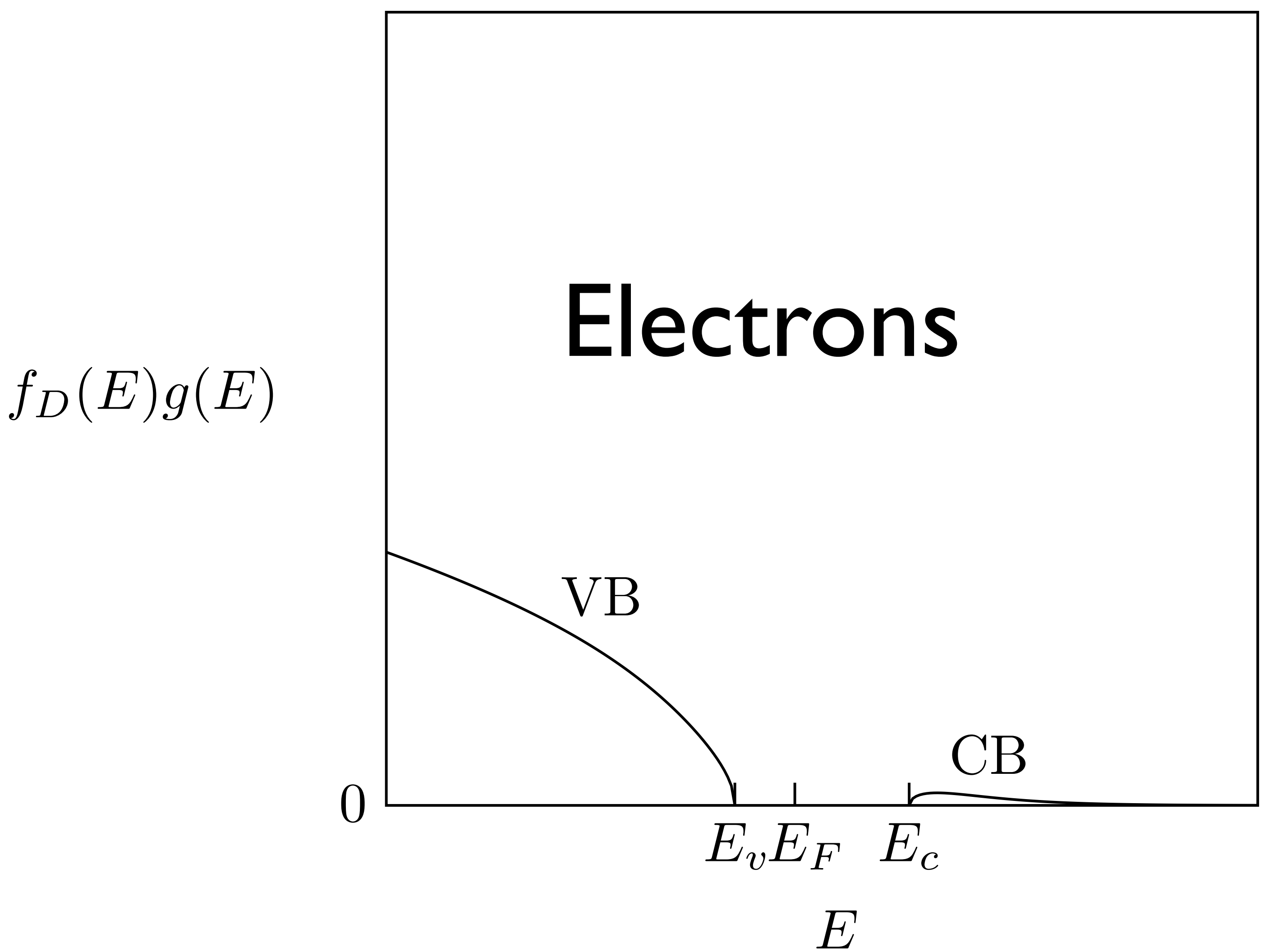
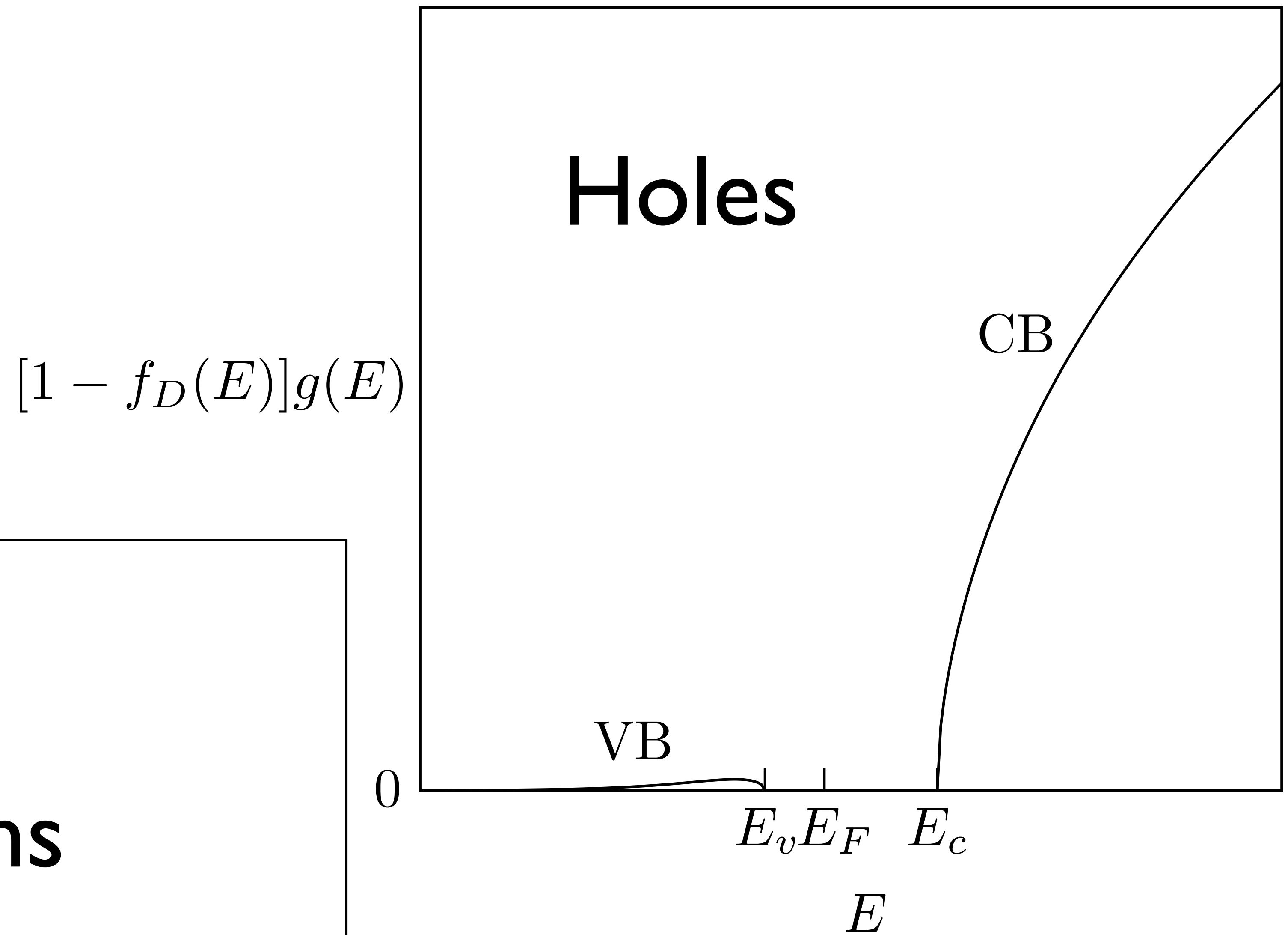
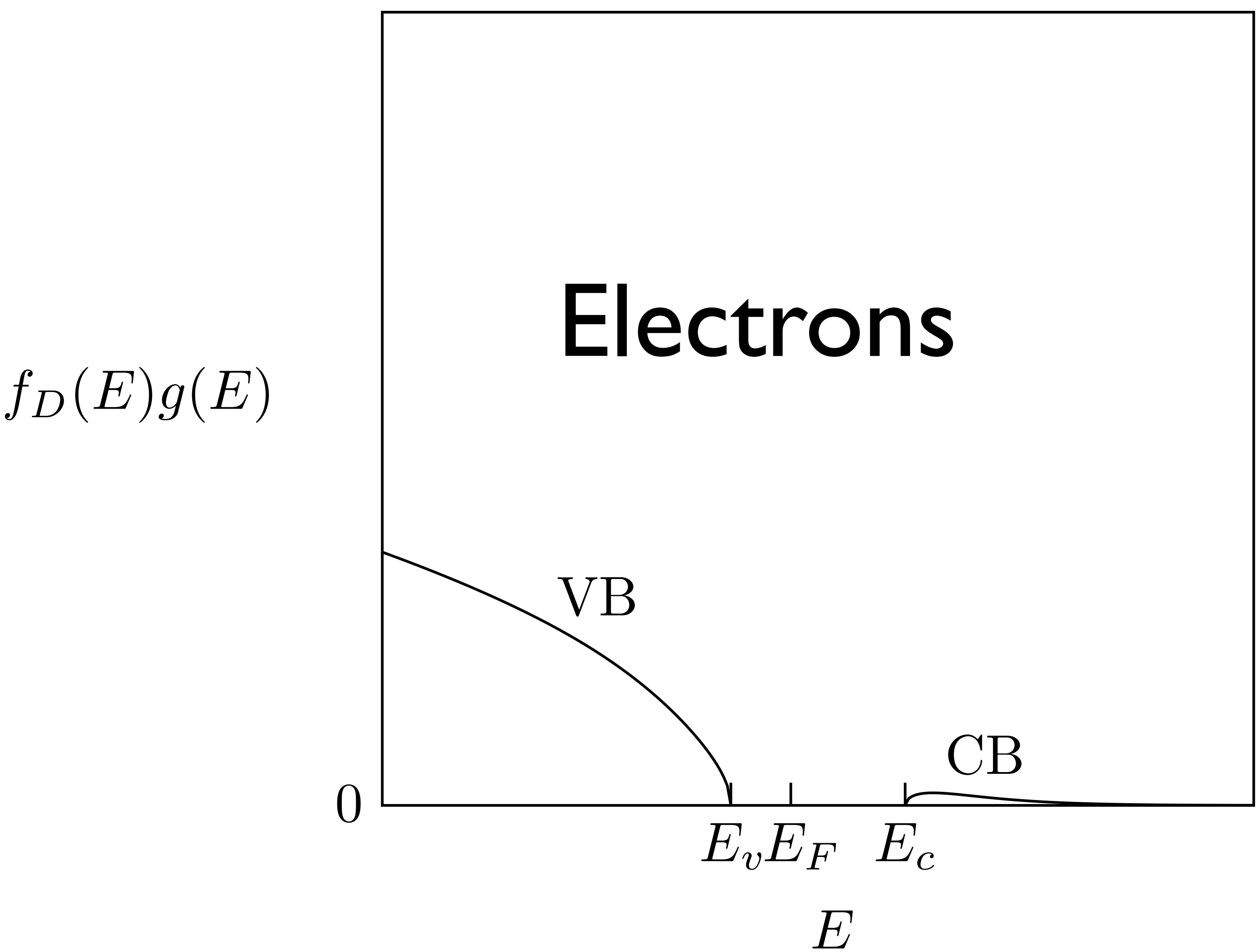




Band occupation at $T \neq 0$

Why $1 - f_D$?





$$n = \frac{1}{V}\int f_D(E)g(E)dE$$

$$= 2\left(\frac{m_n^* k_B T}{2\pi\hbar^2}\right)^{3/2} \exp\left(-\frac{E_c - E_F}{k_B T}\right)$$

$$p = 2\left(\frac{m_p^* k_B T}{2\pi\hbar^2}\right)^{3/2} \exp\left(-\frac{E_F - E_v}{k_B T}\right)$$

Set n = p

$$E_f \approx \frac{1}{2}\left(E_c + E_v\right)$$

$$n_i = \sqrt{N_c N_v} \exp\left(-\frac{E_g}{2k_B T}\right)$$

At 300 K

$$n_i = 9.8 \times 10^{15}$$

At 373 K

$$n_i = 9.5 \times 10^{17}$$

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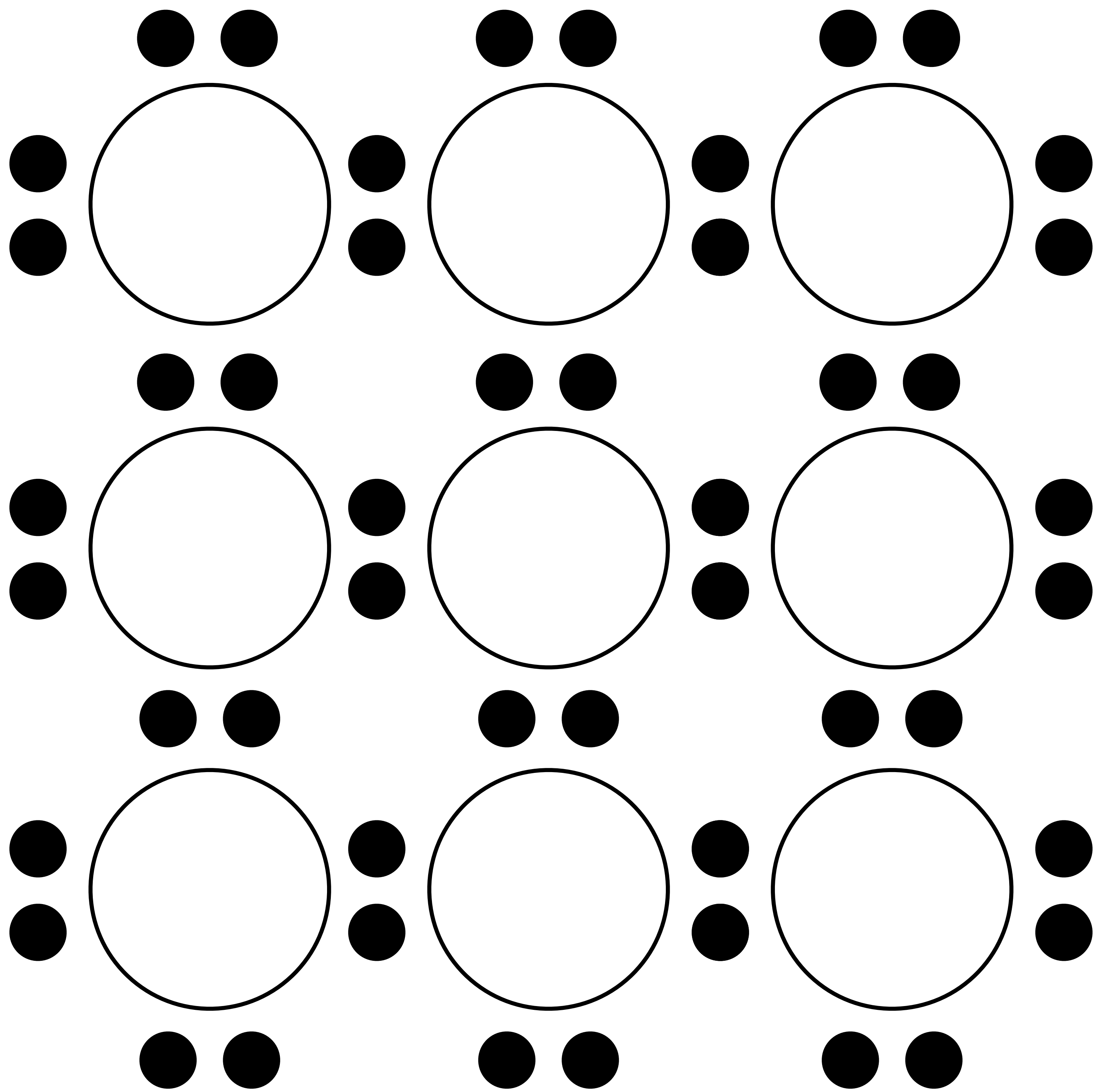
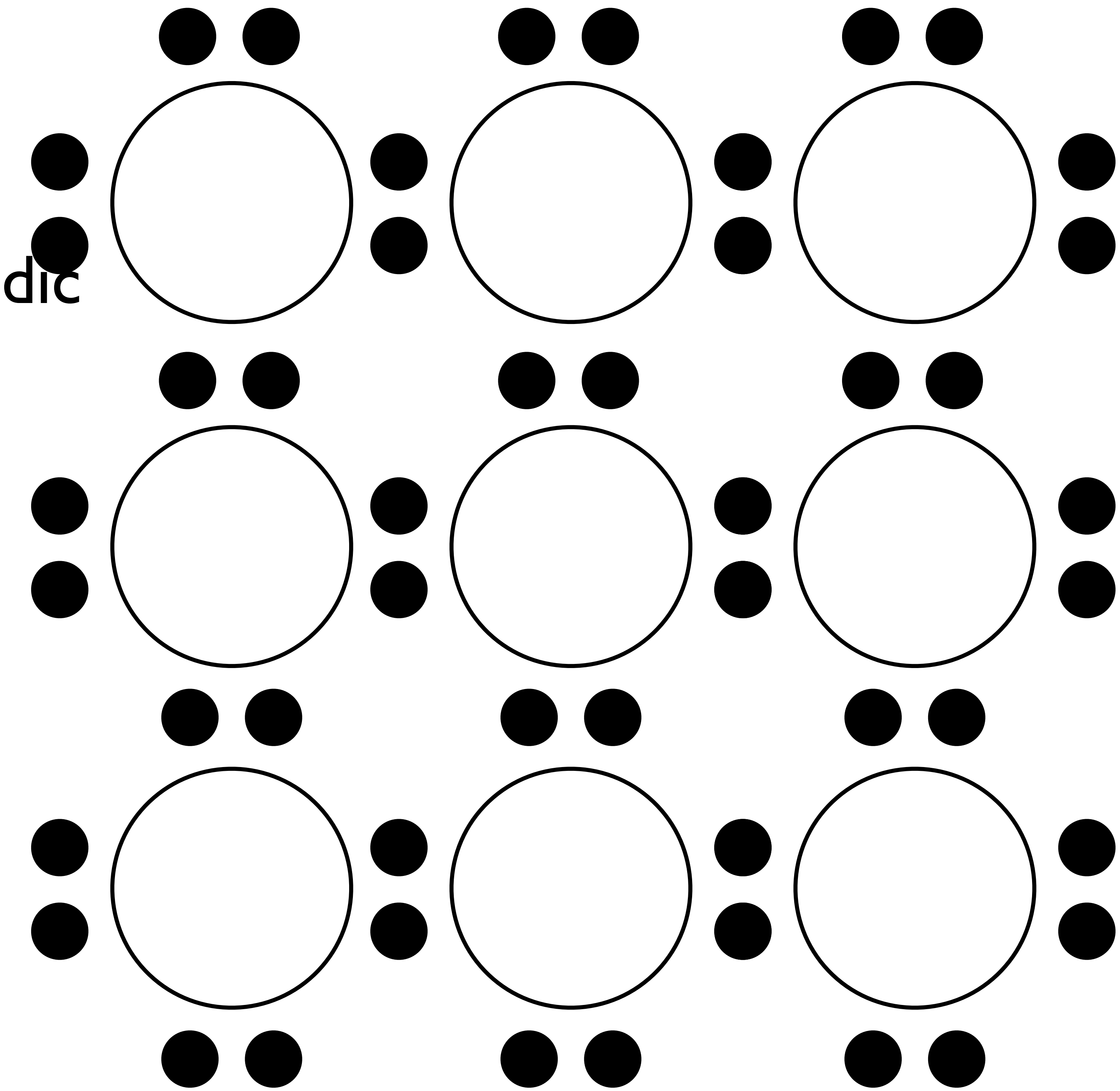
2D Model of a Semiconductor



2D Model of a Semiconductor

Where is silicon on the periodic table?



2D Model of a Semiconductor

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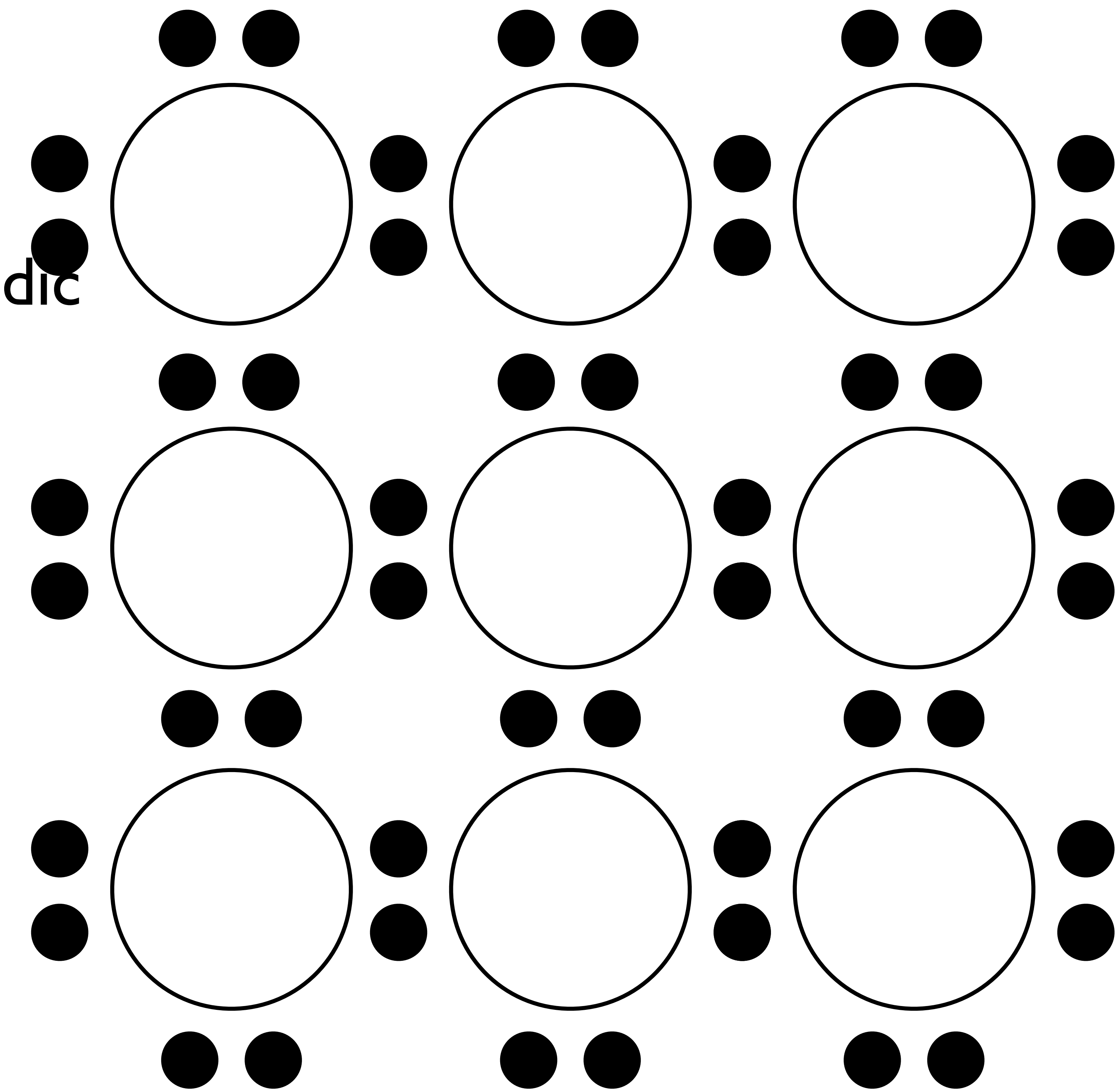

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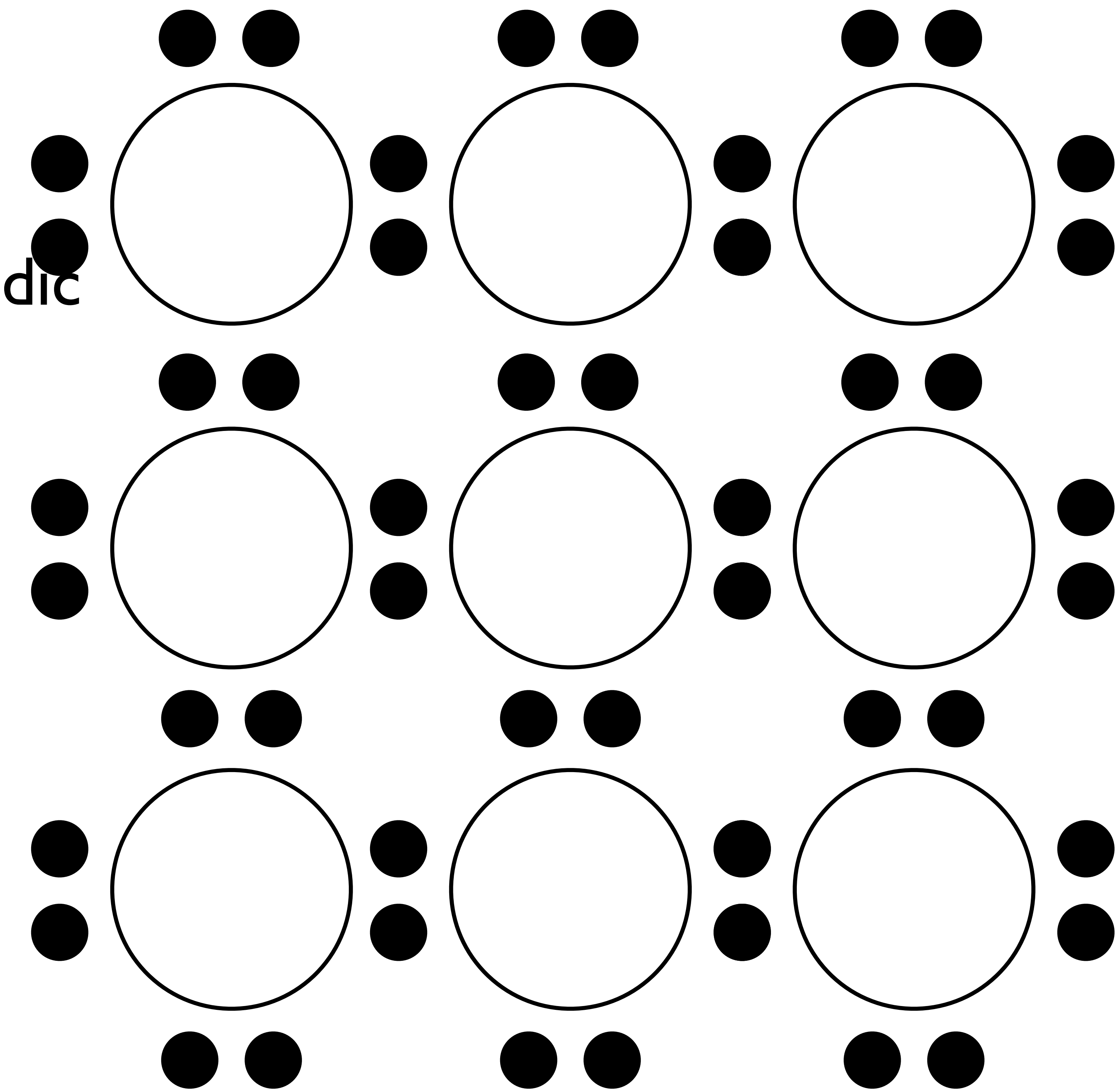
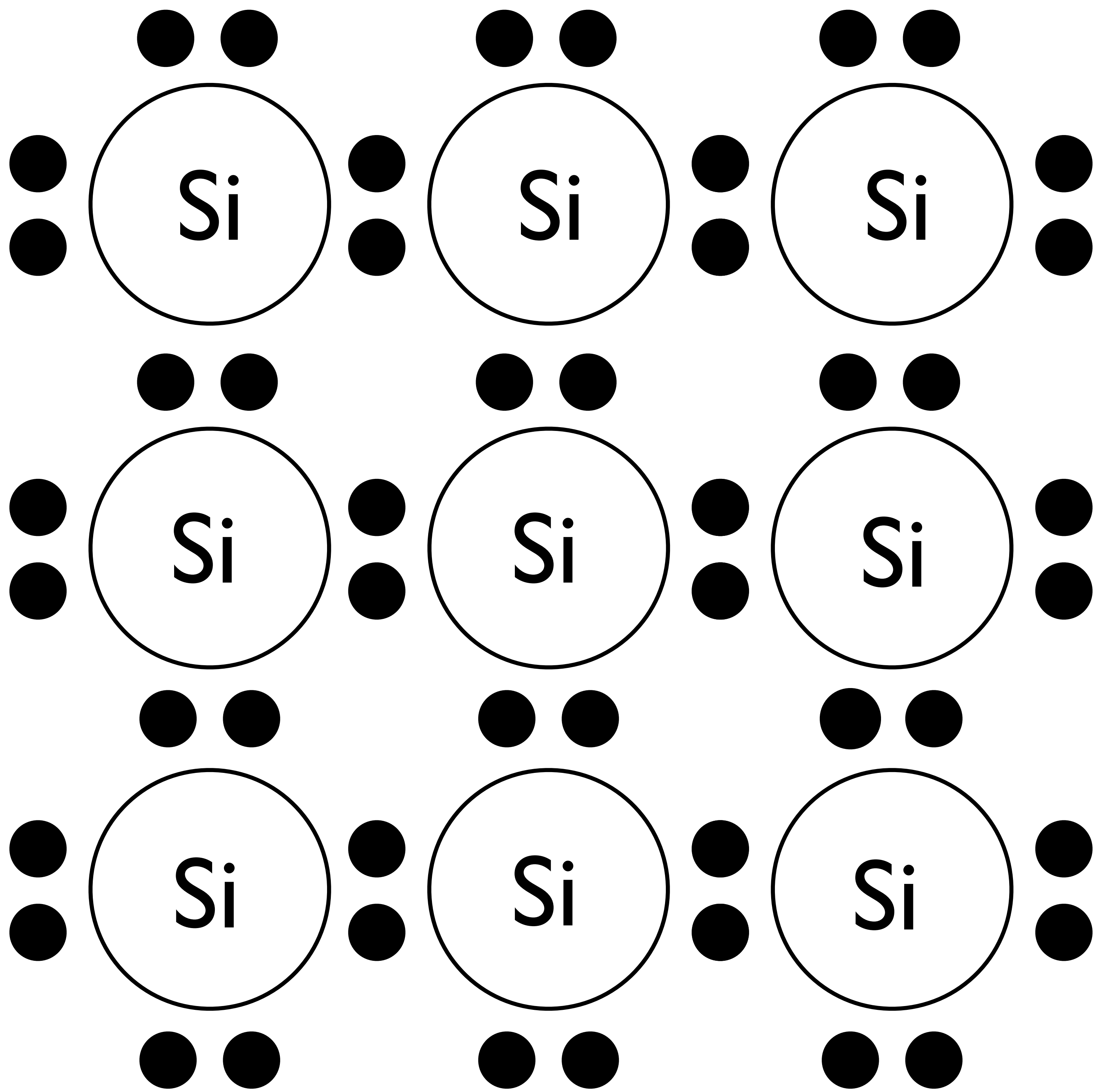


What role does temper-ature play?

Why is that significant?

Intrinsic semiconductor



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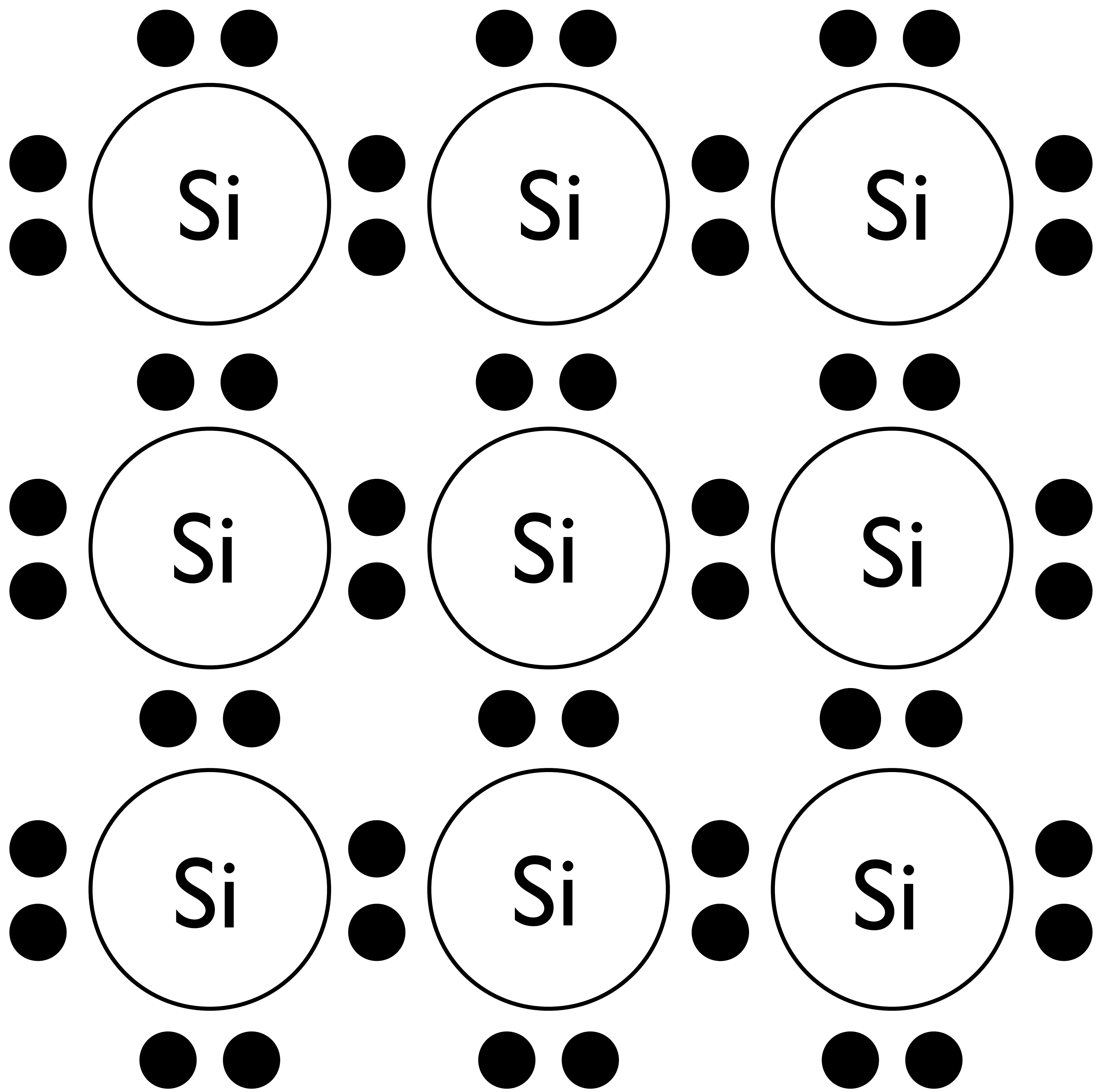
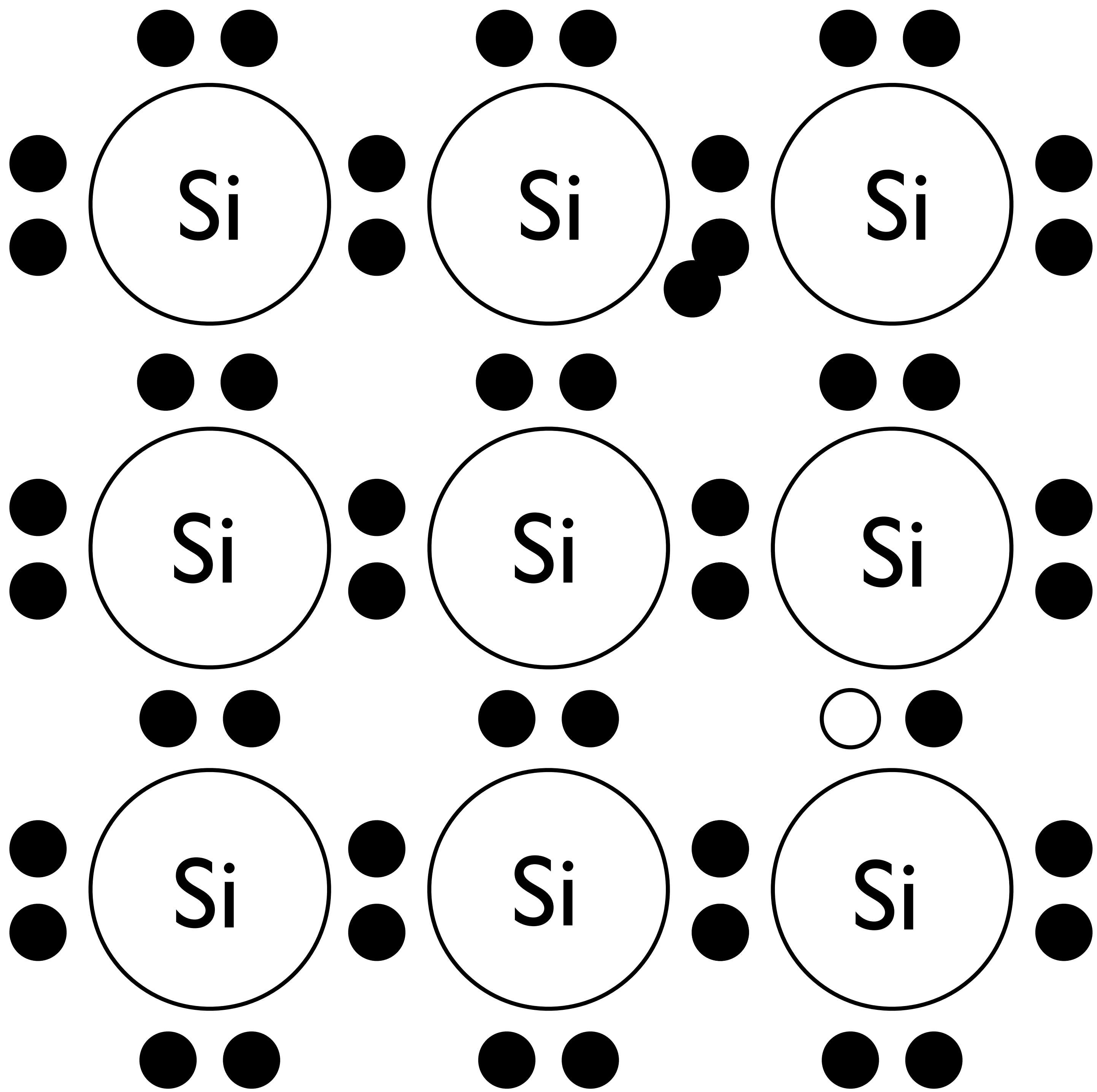


e-h pair creation

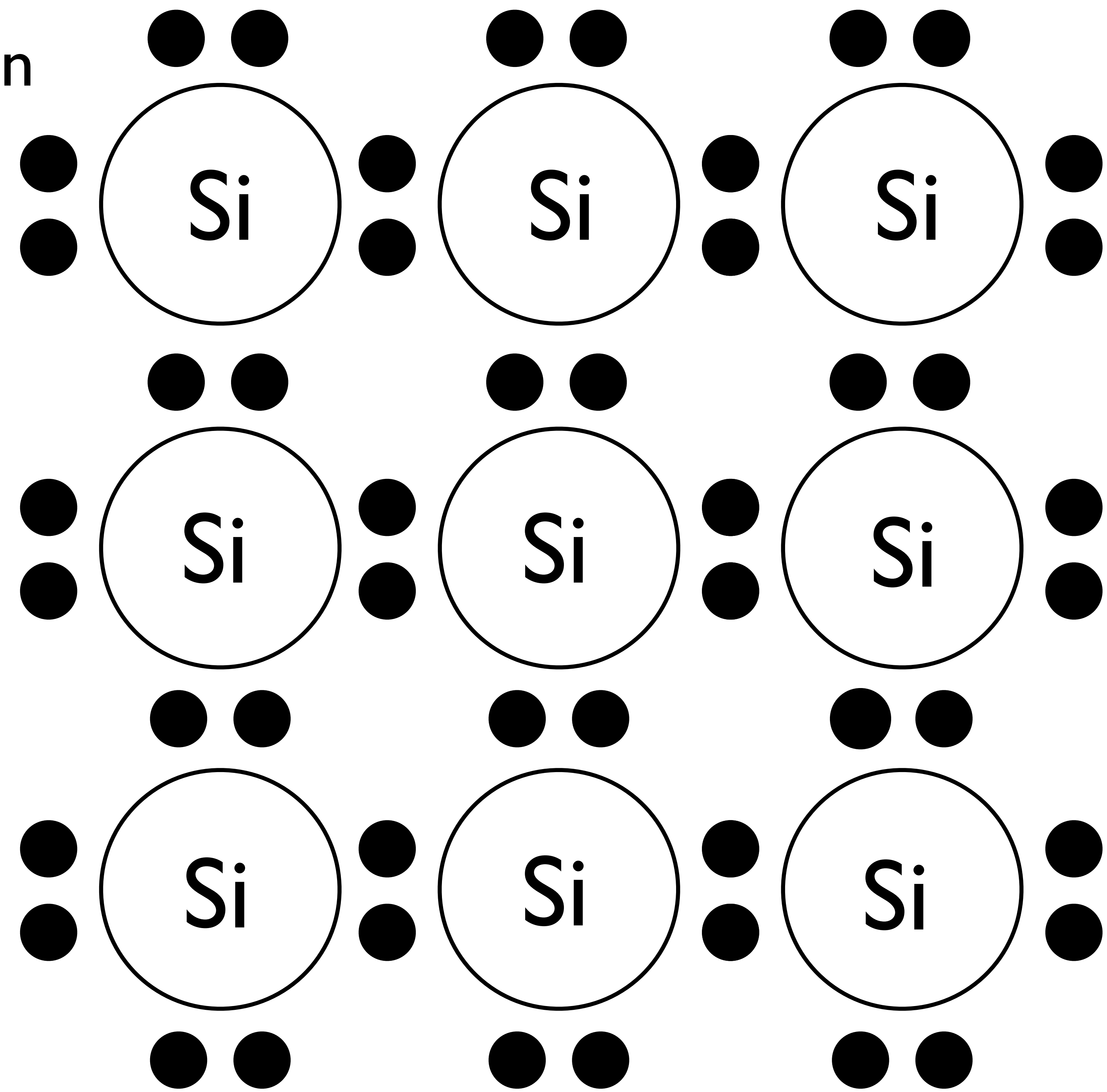
Intrinsic semiconductor



e-h pair creation

Intrinsic semiconductor

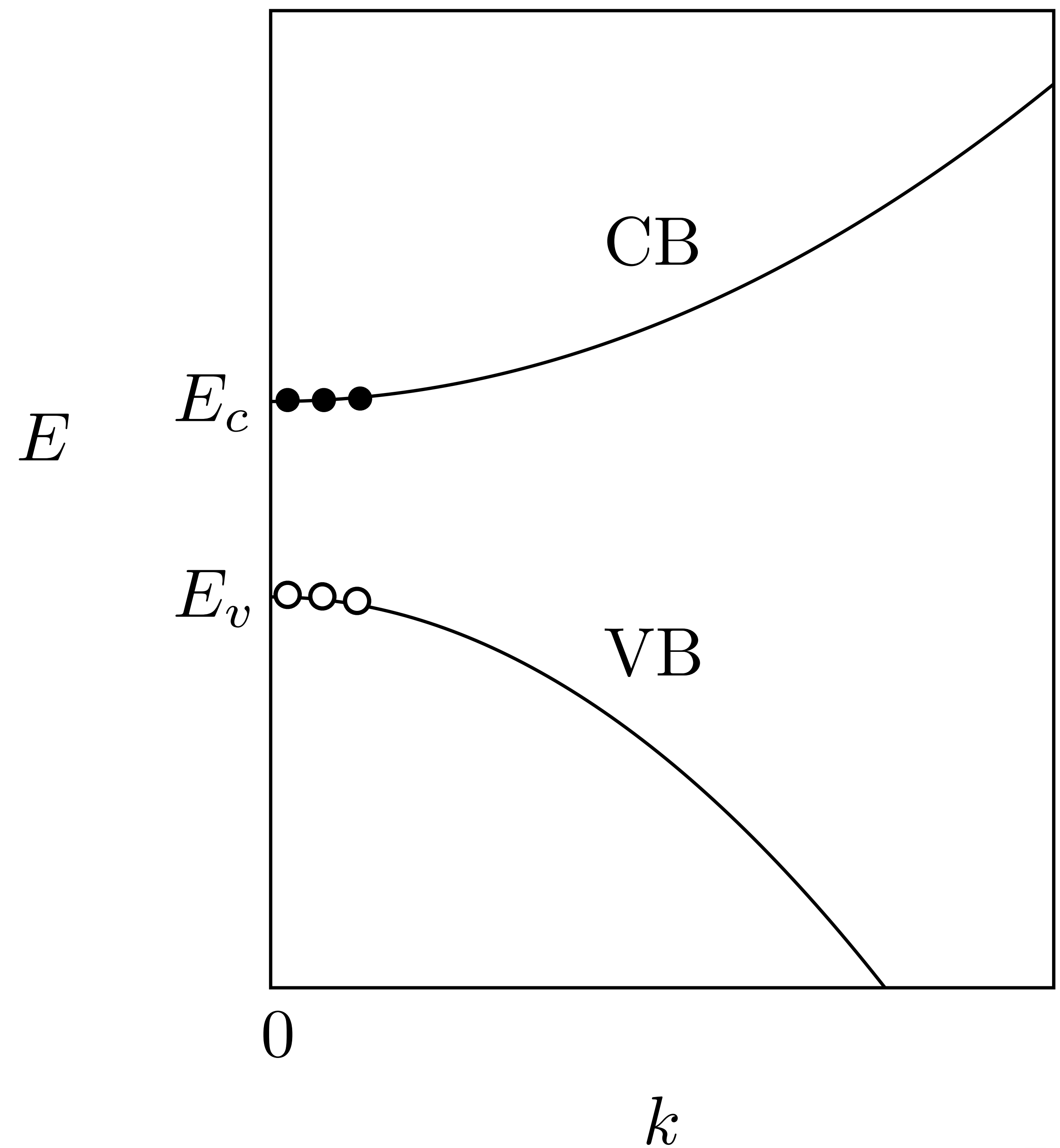
Recombination



e-h pair creation

Dynamic Equilibrium

$$\text{rate}_{\text{recomb}} = \text{rate}_{\text{e-h creation}}$$



Dynamic Equilibrium

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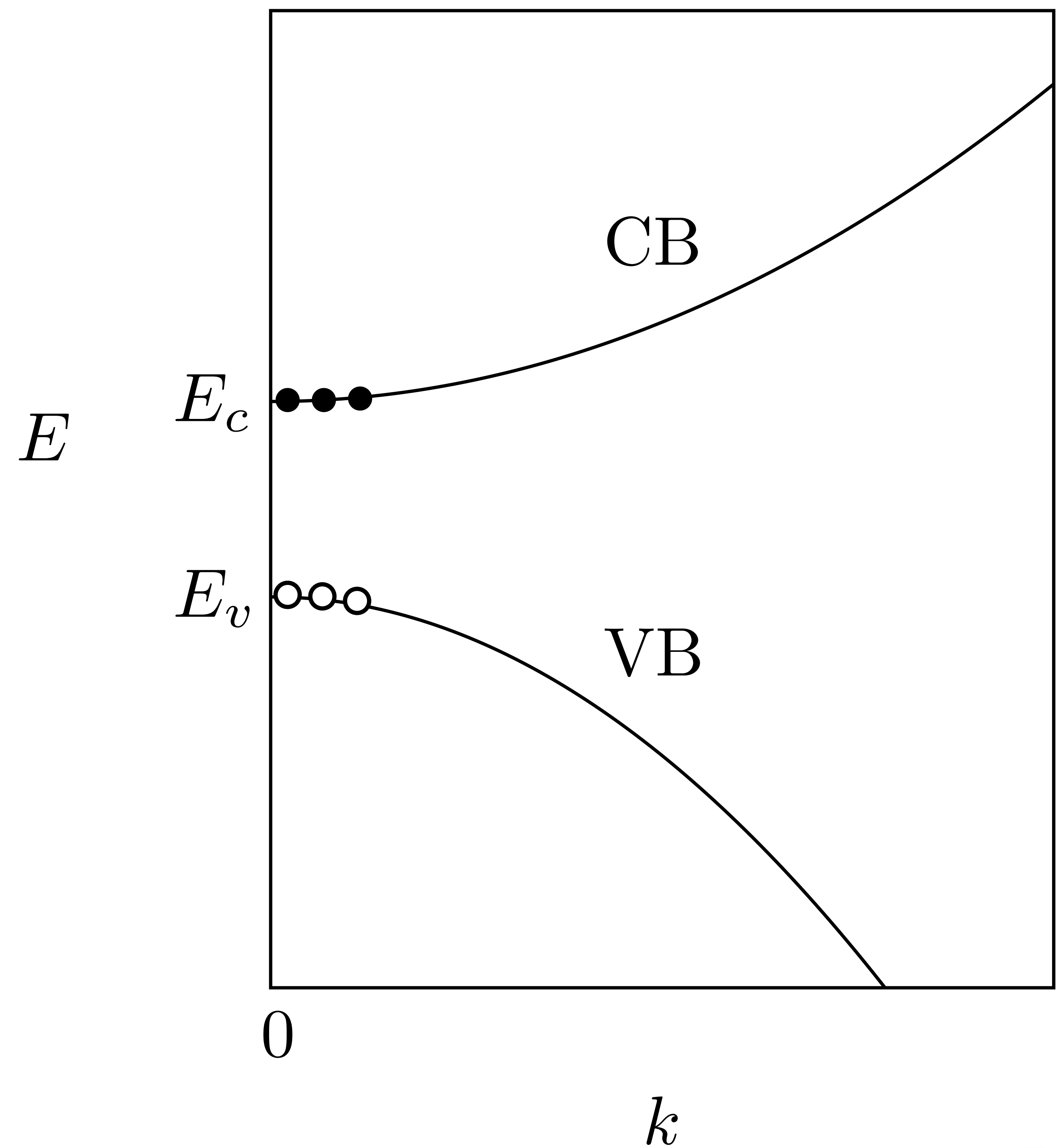
Electrons tunnel into the neighboring hole



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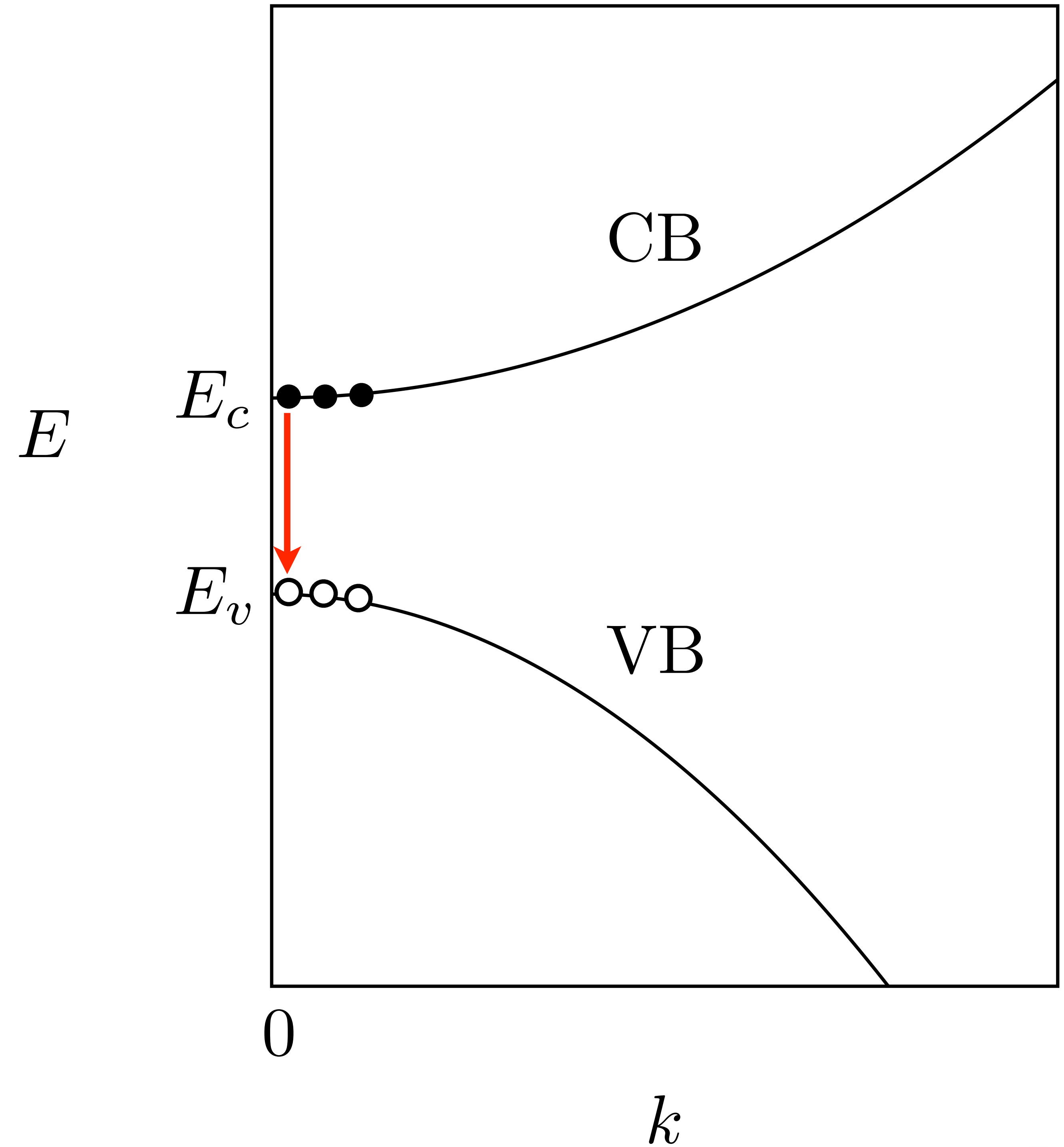

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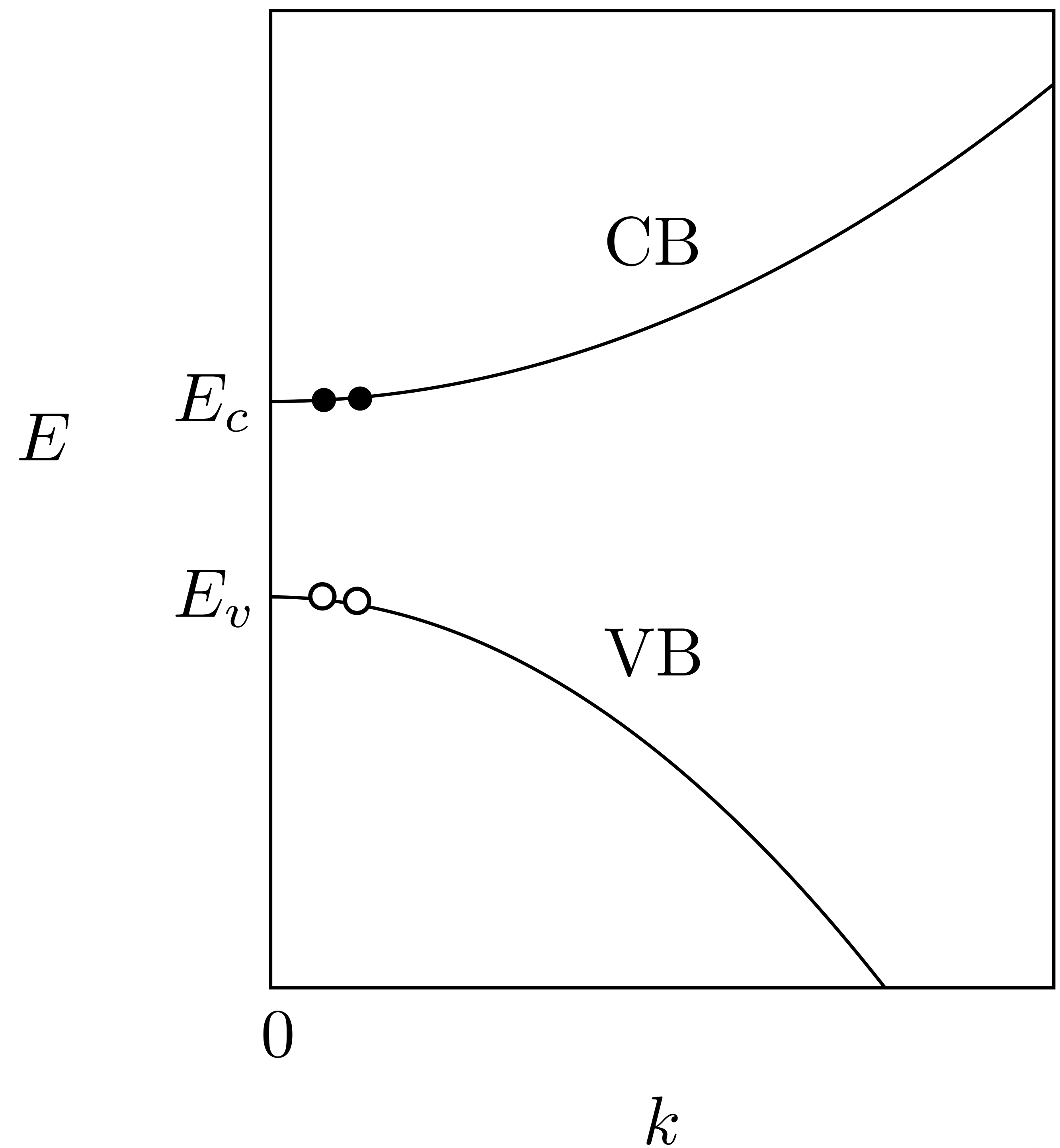
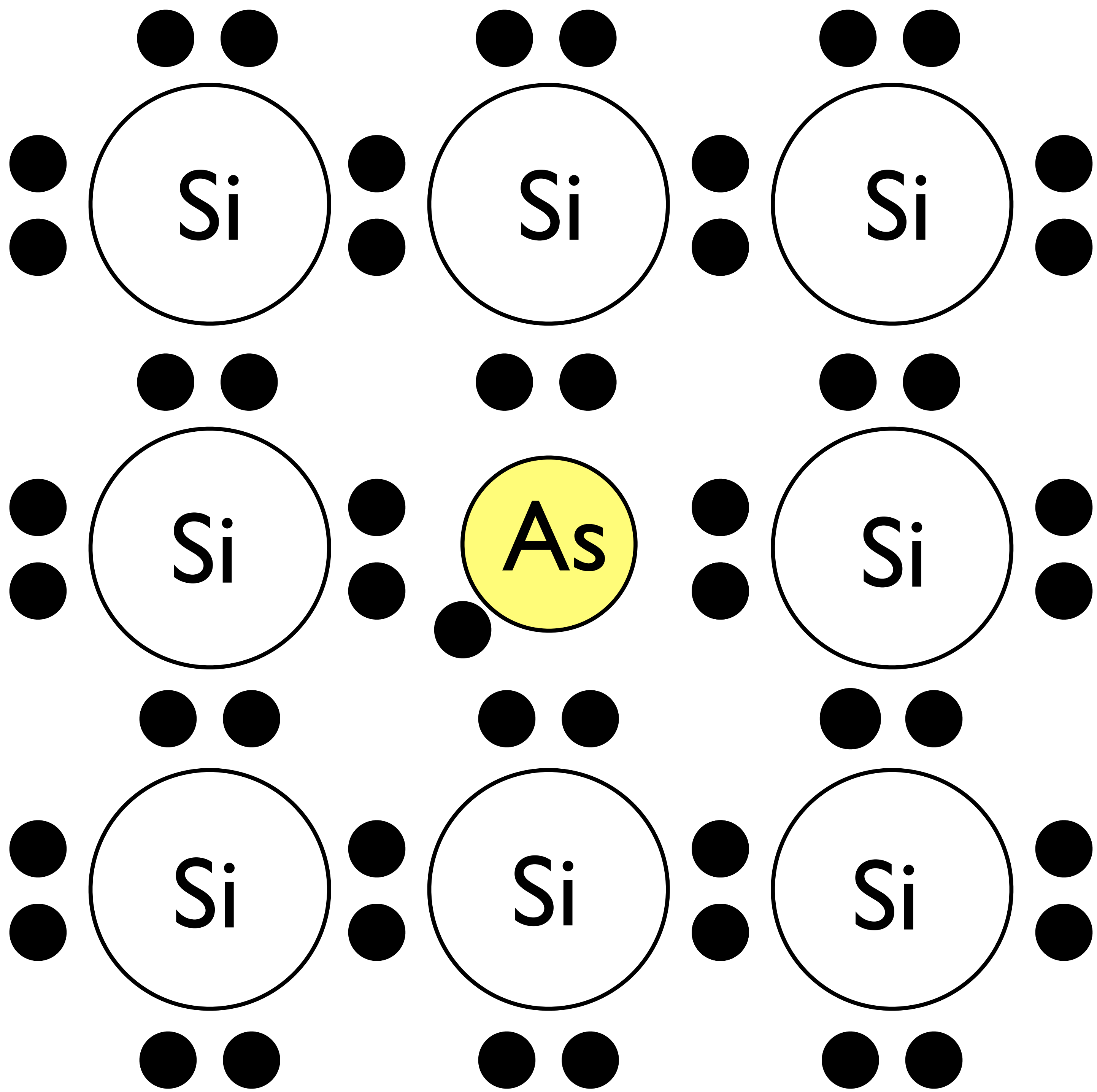
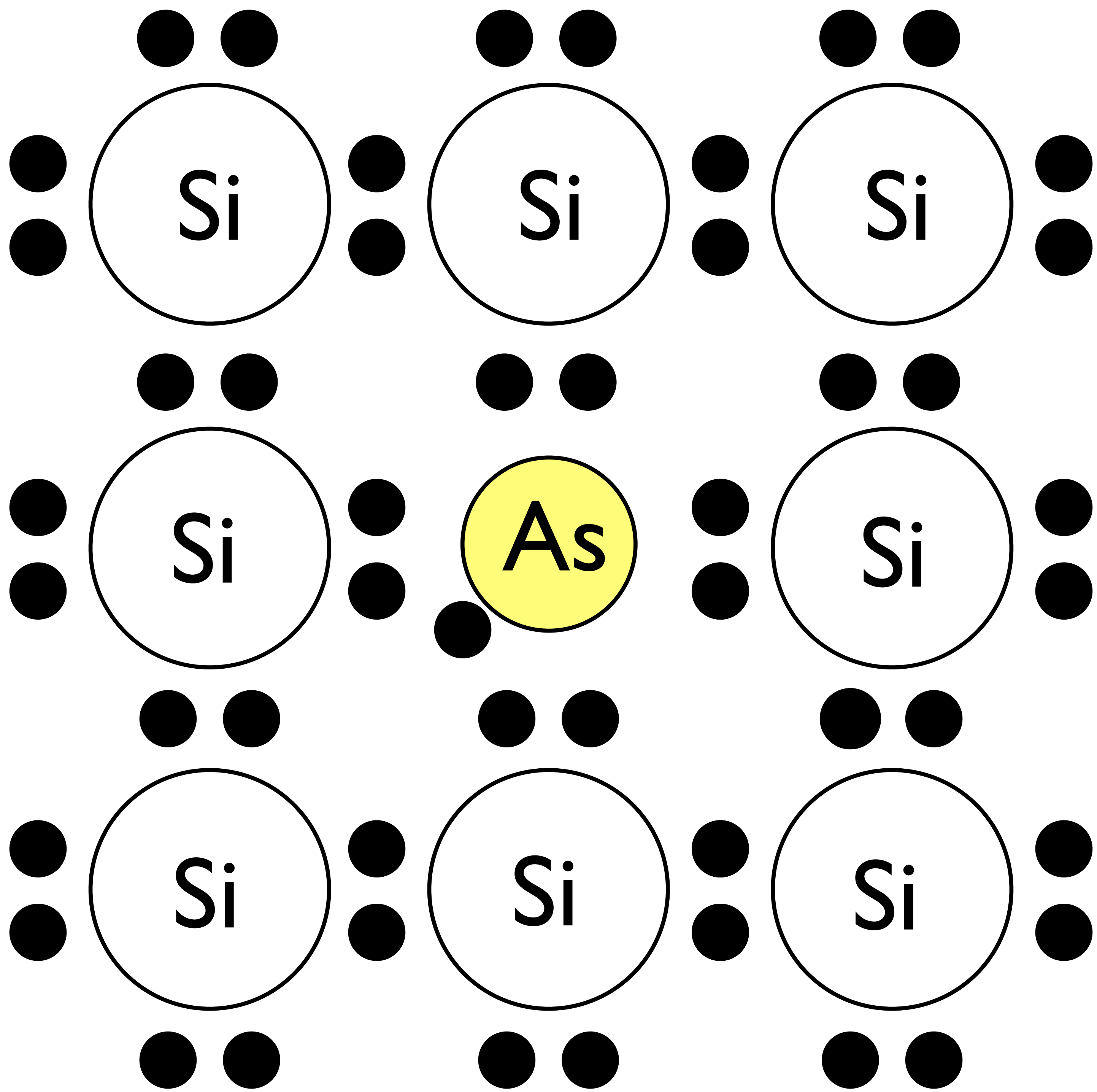


A doped semiconductor



A doped semiconductor

Why is there an "extra" electron?



A doped semiconductor

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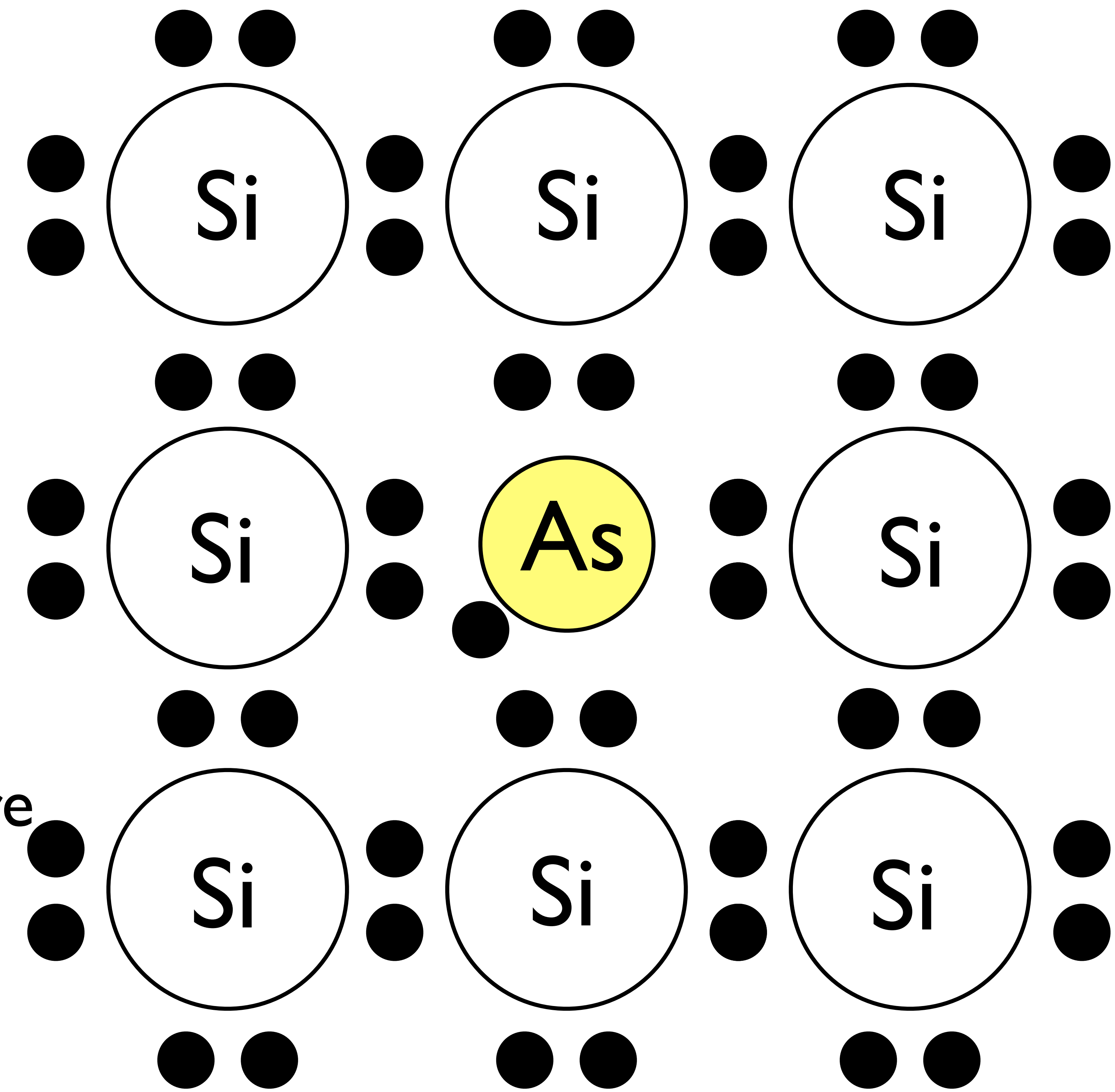
Why does it stay by the arsenic atom? (The bonds are full after all...)



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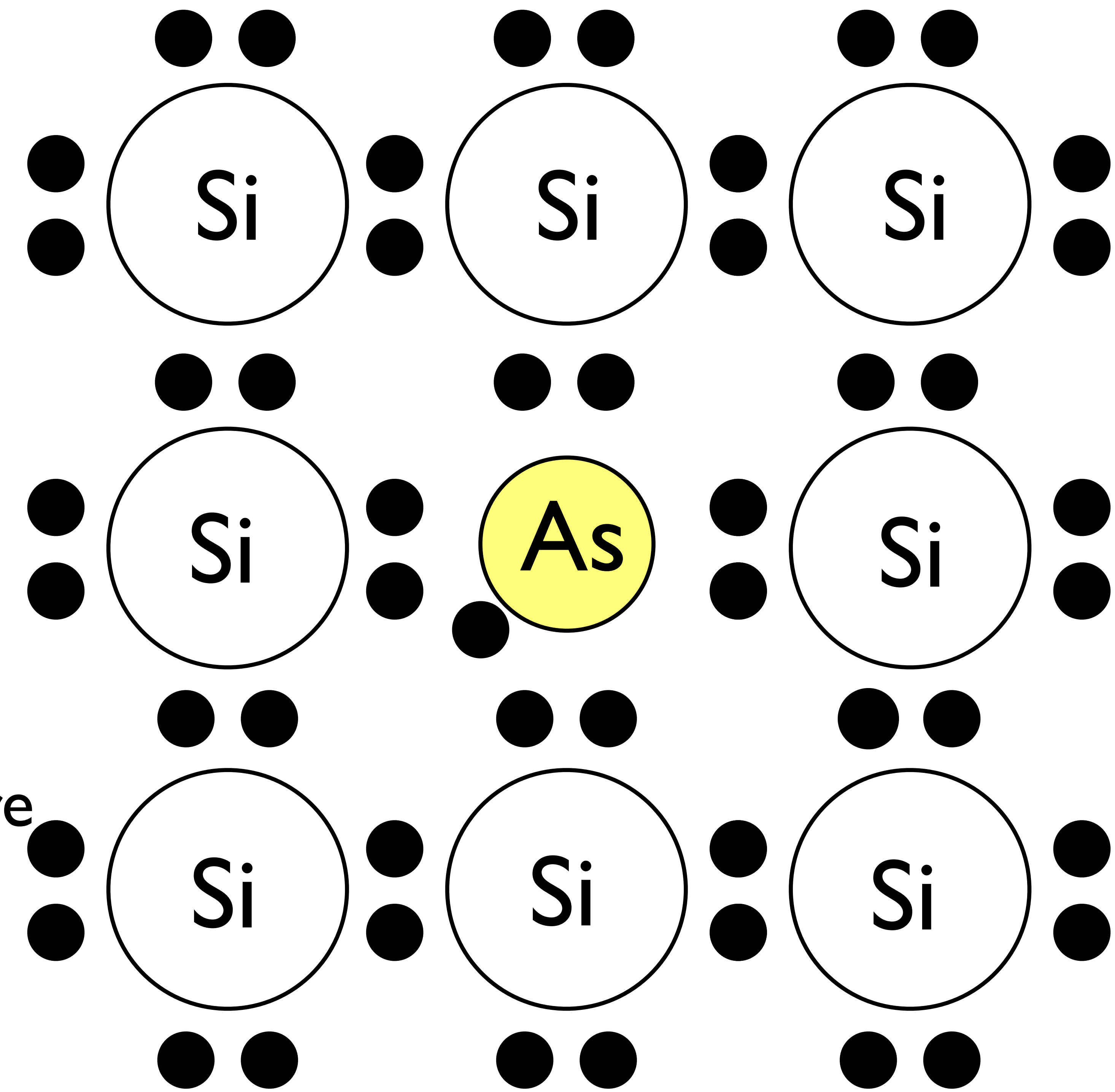

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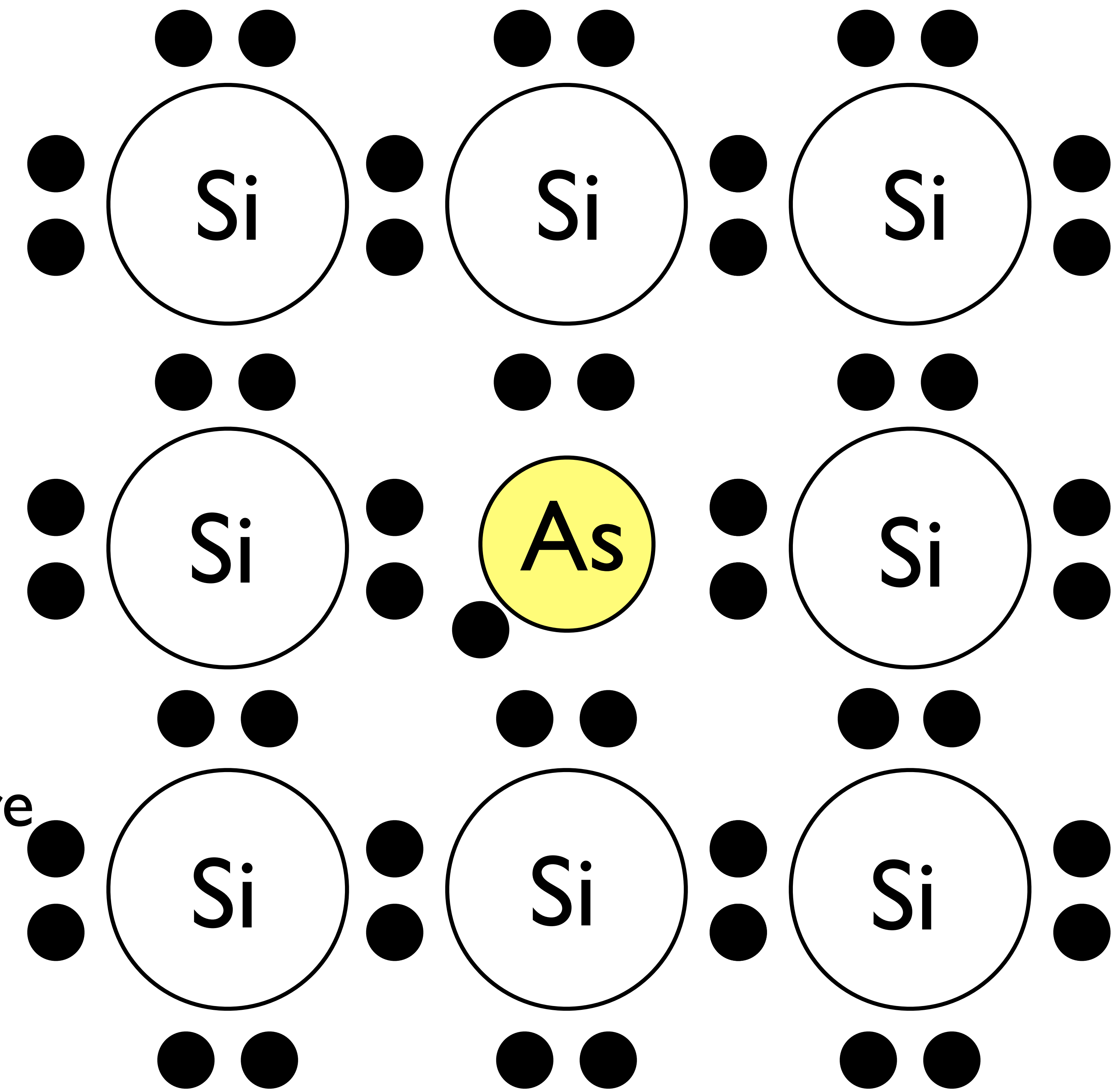

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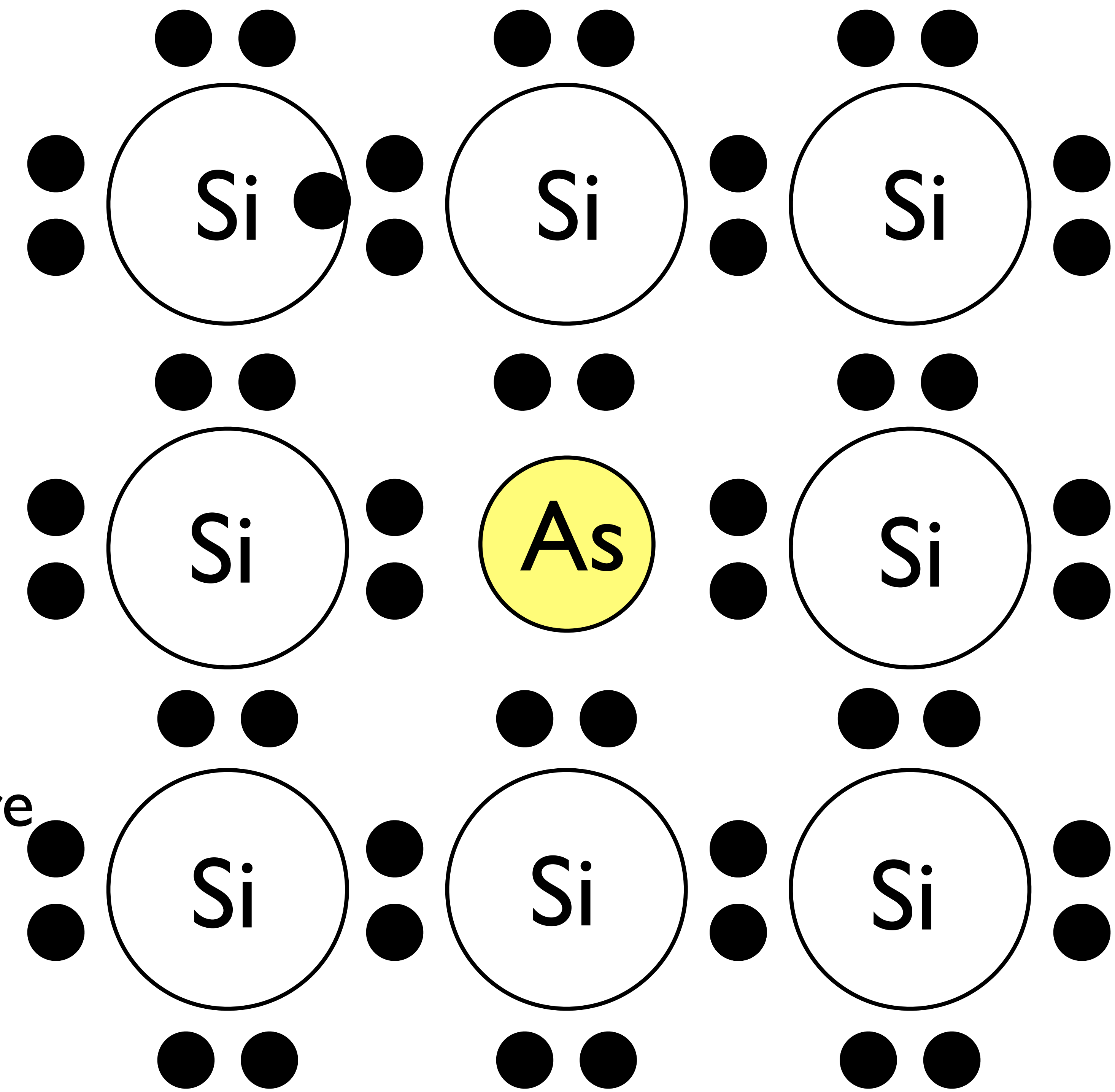

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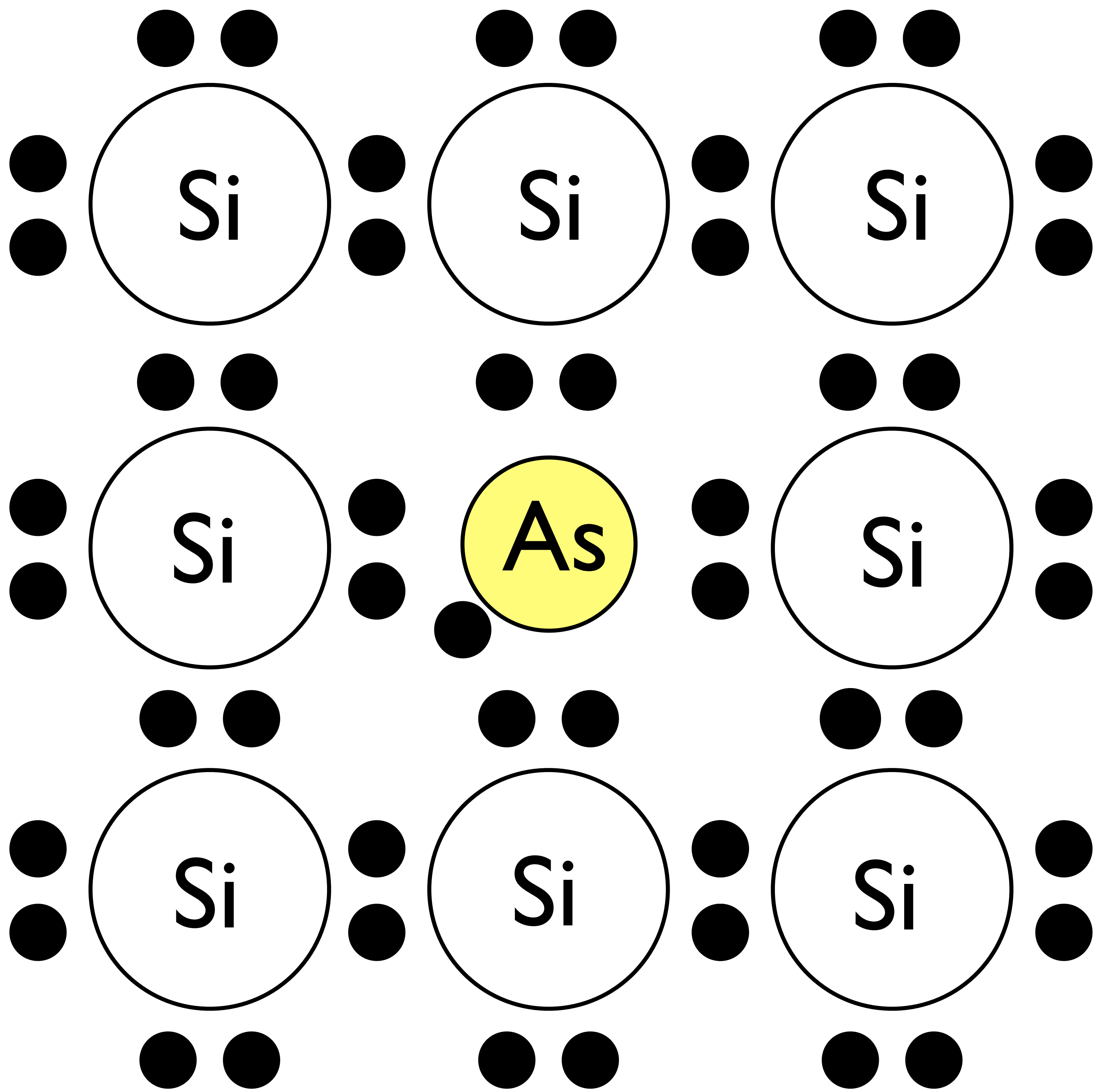
What about holes?



A doped semiconductor

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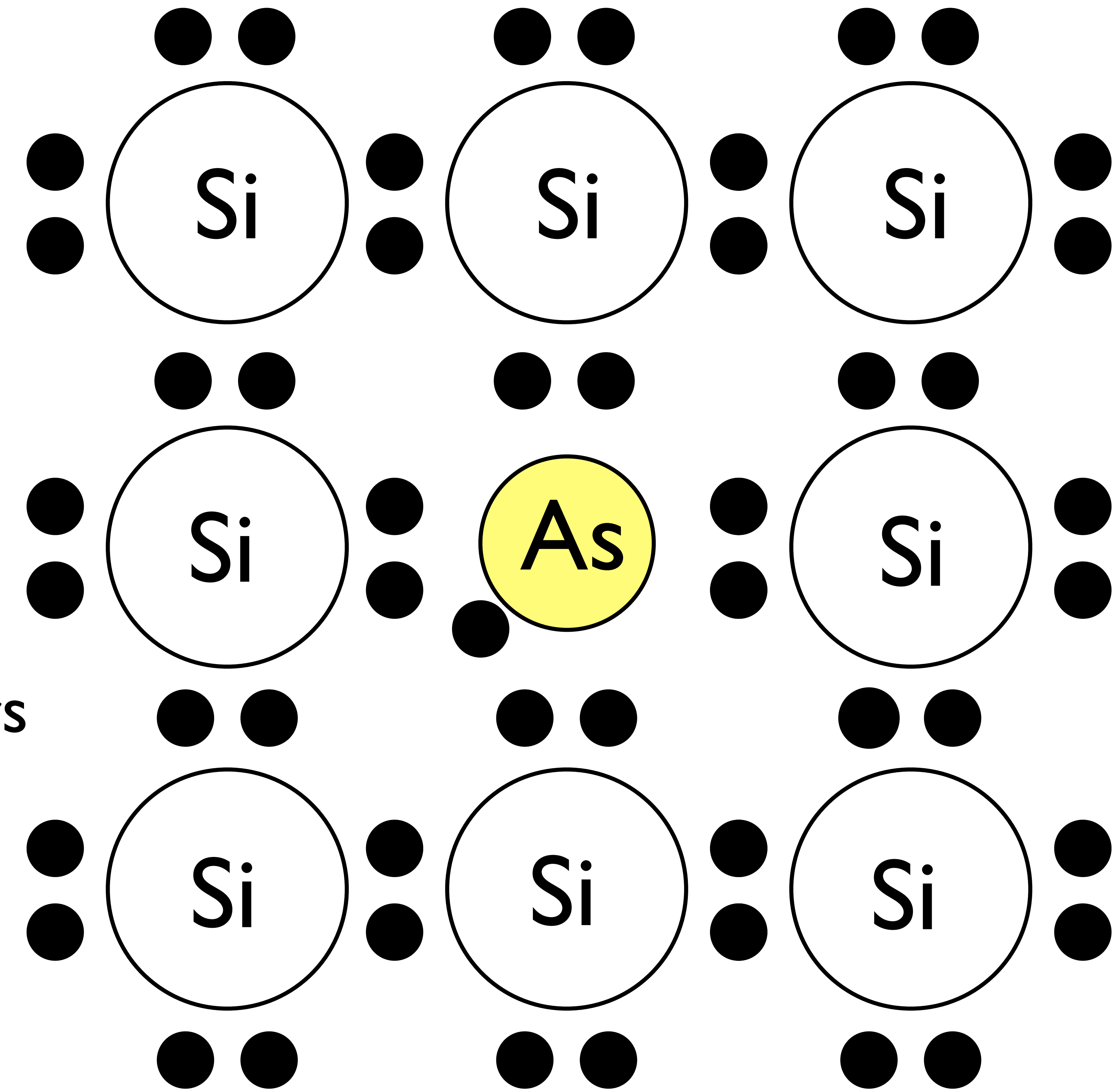
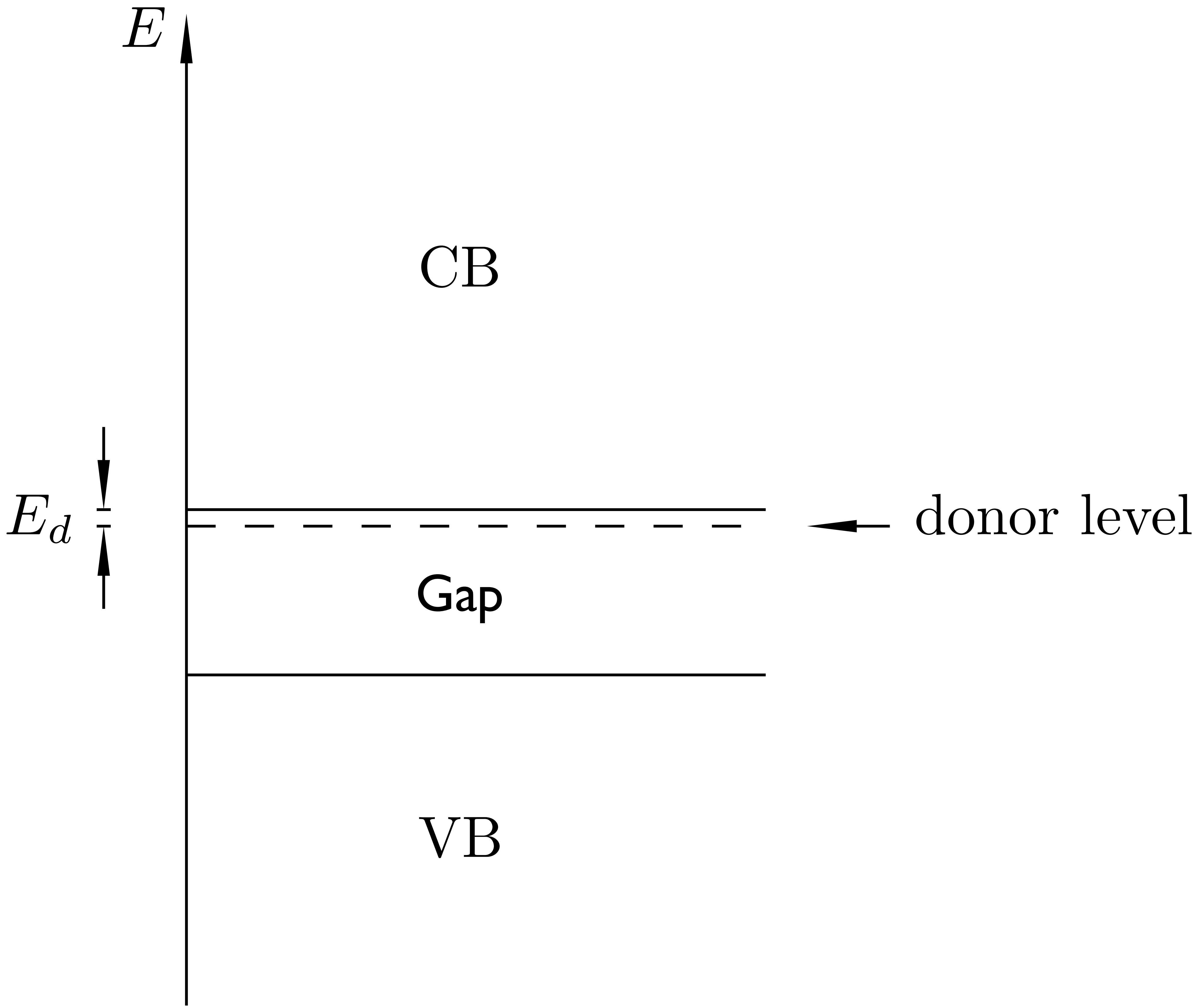
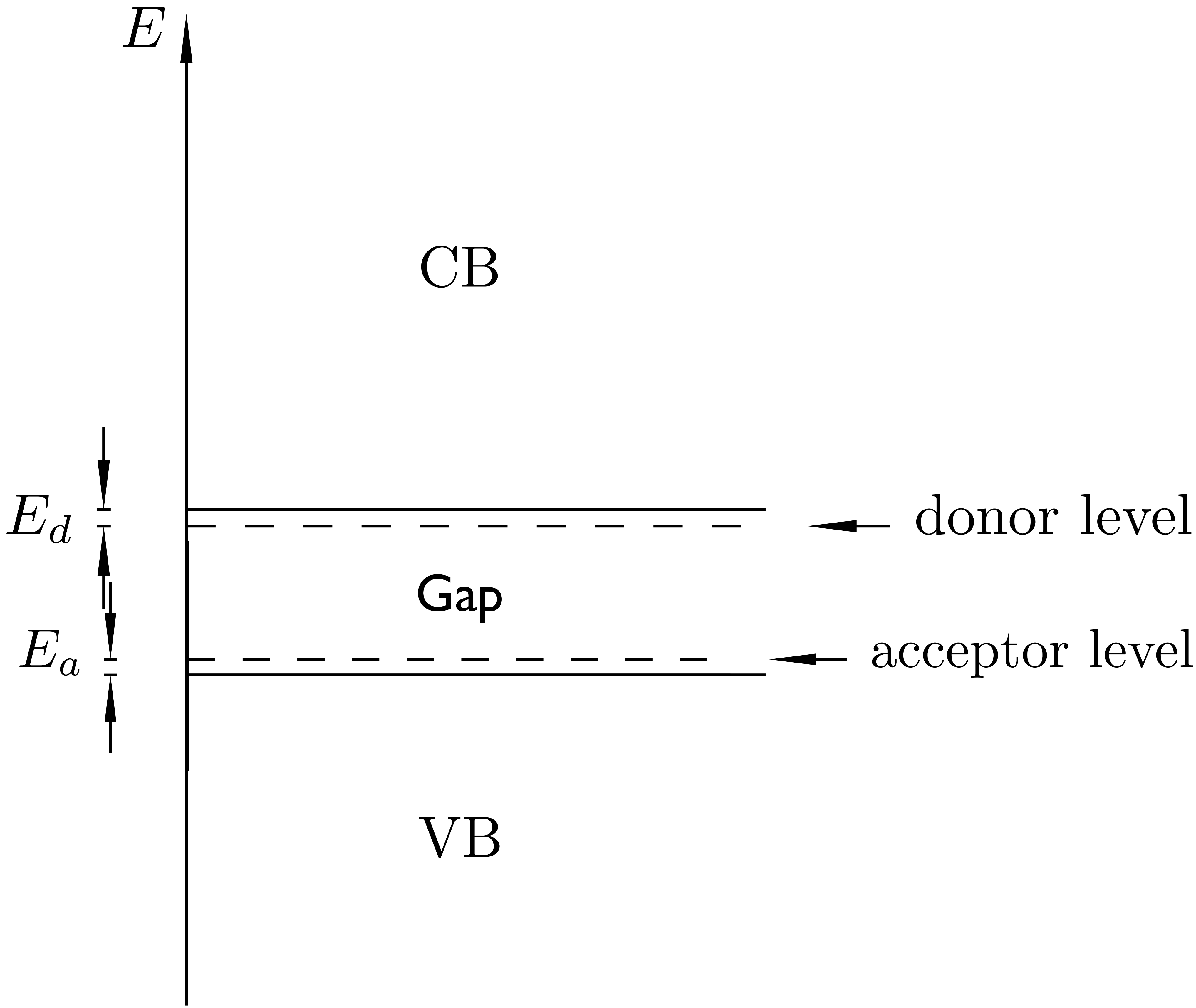
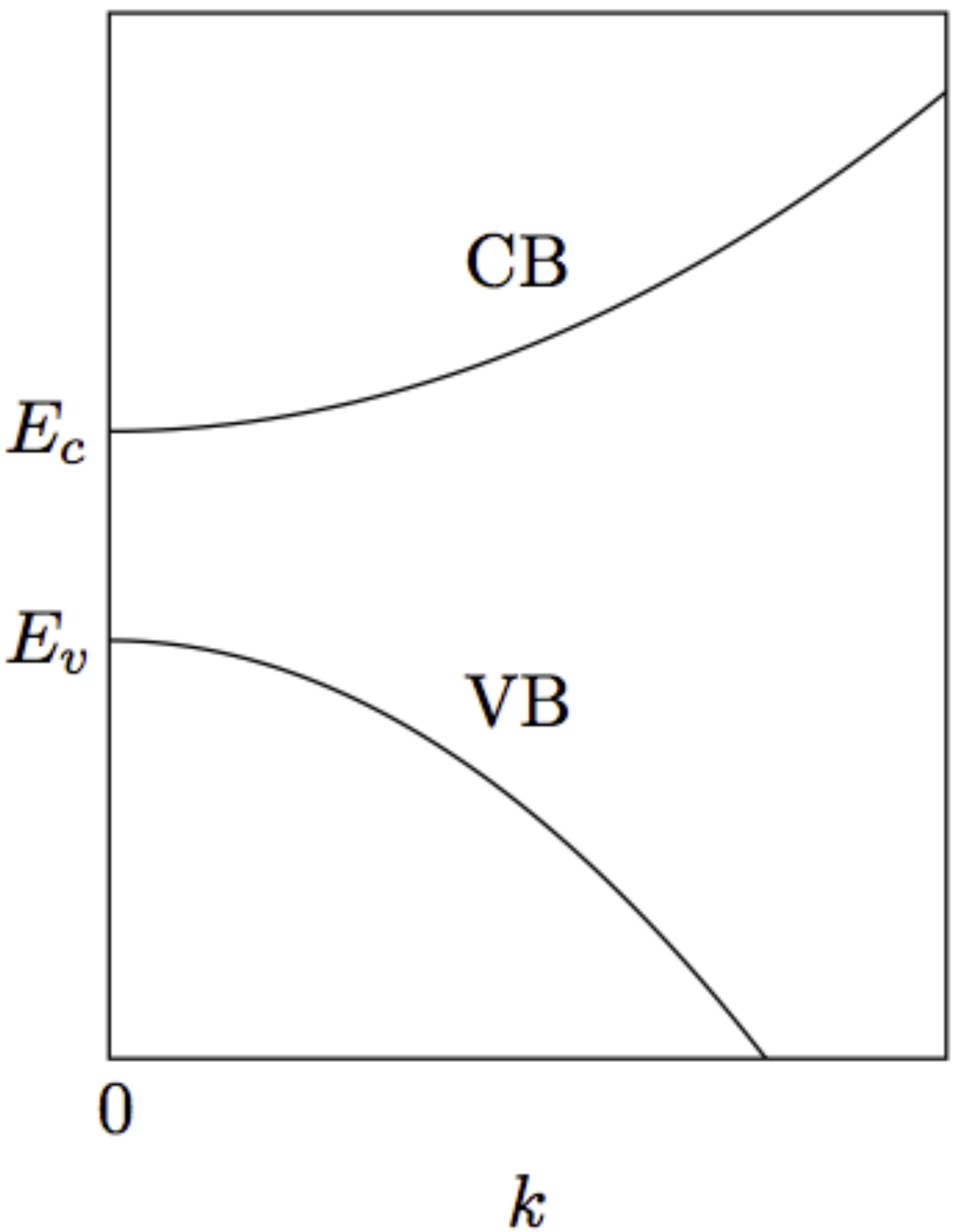
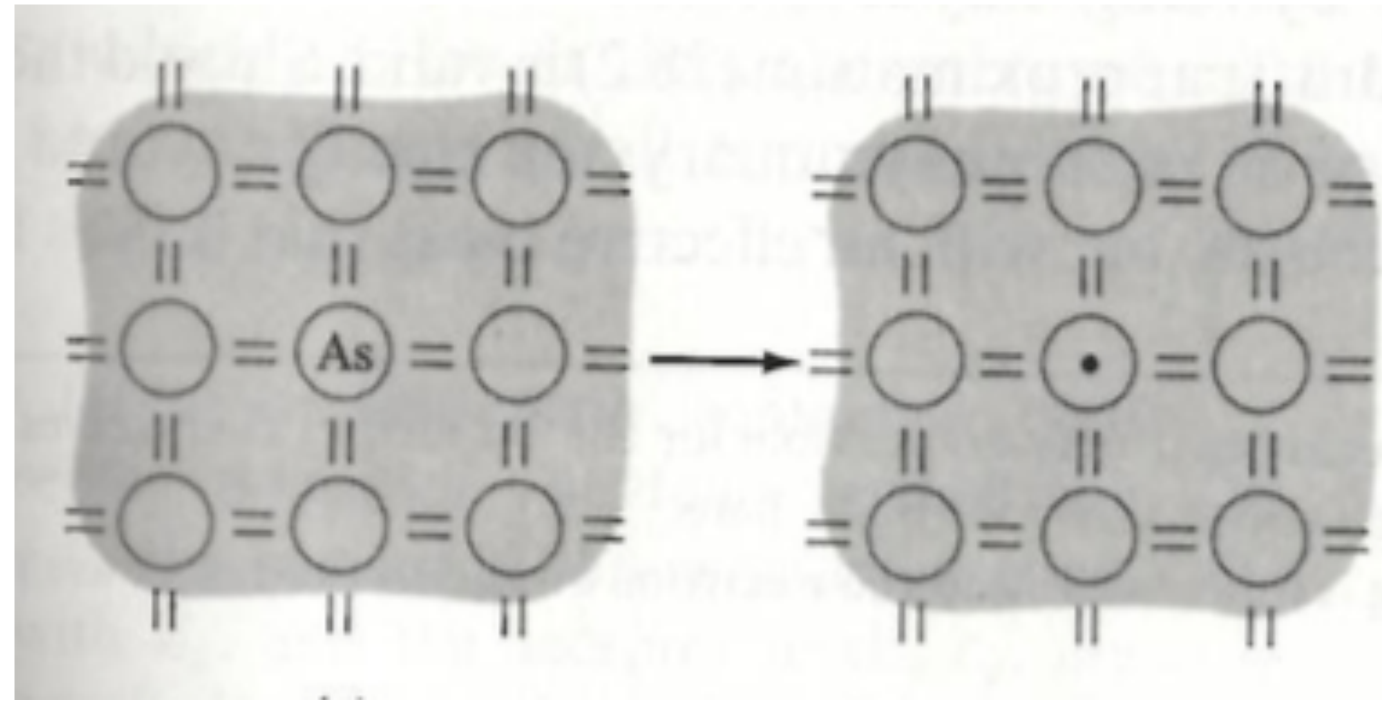


Having donors kills all the holes

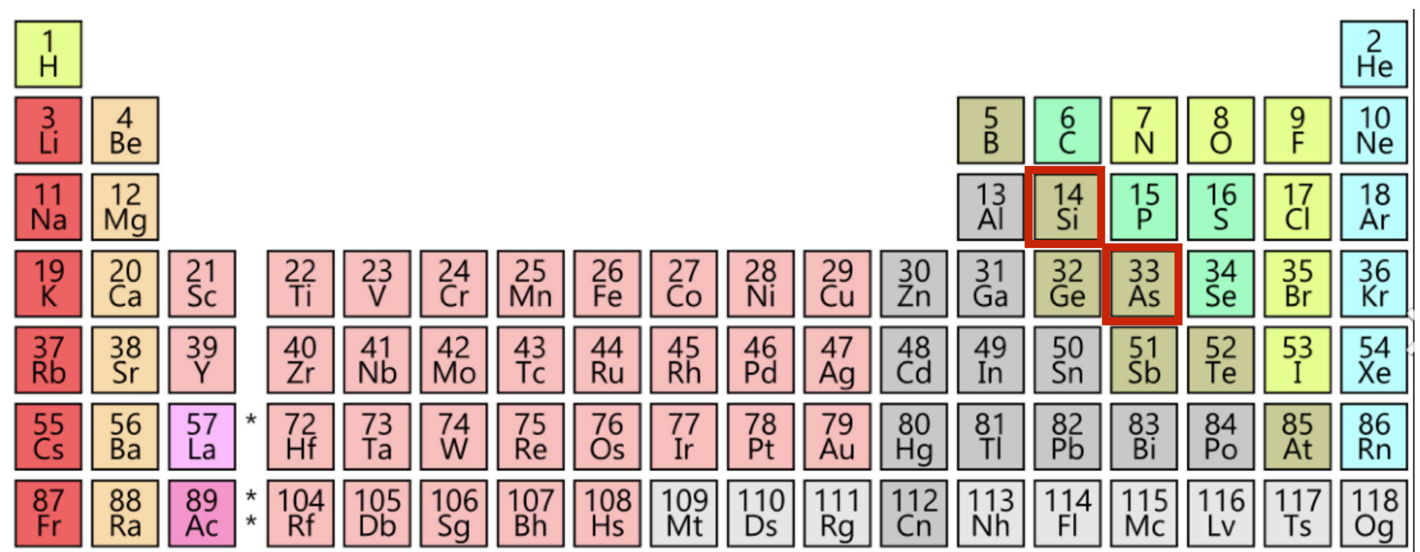

E
CB
E_d
donor level
Gap
VB


E
CB
E_d
donor level
Gap
E_a
acceptor level
VB

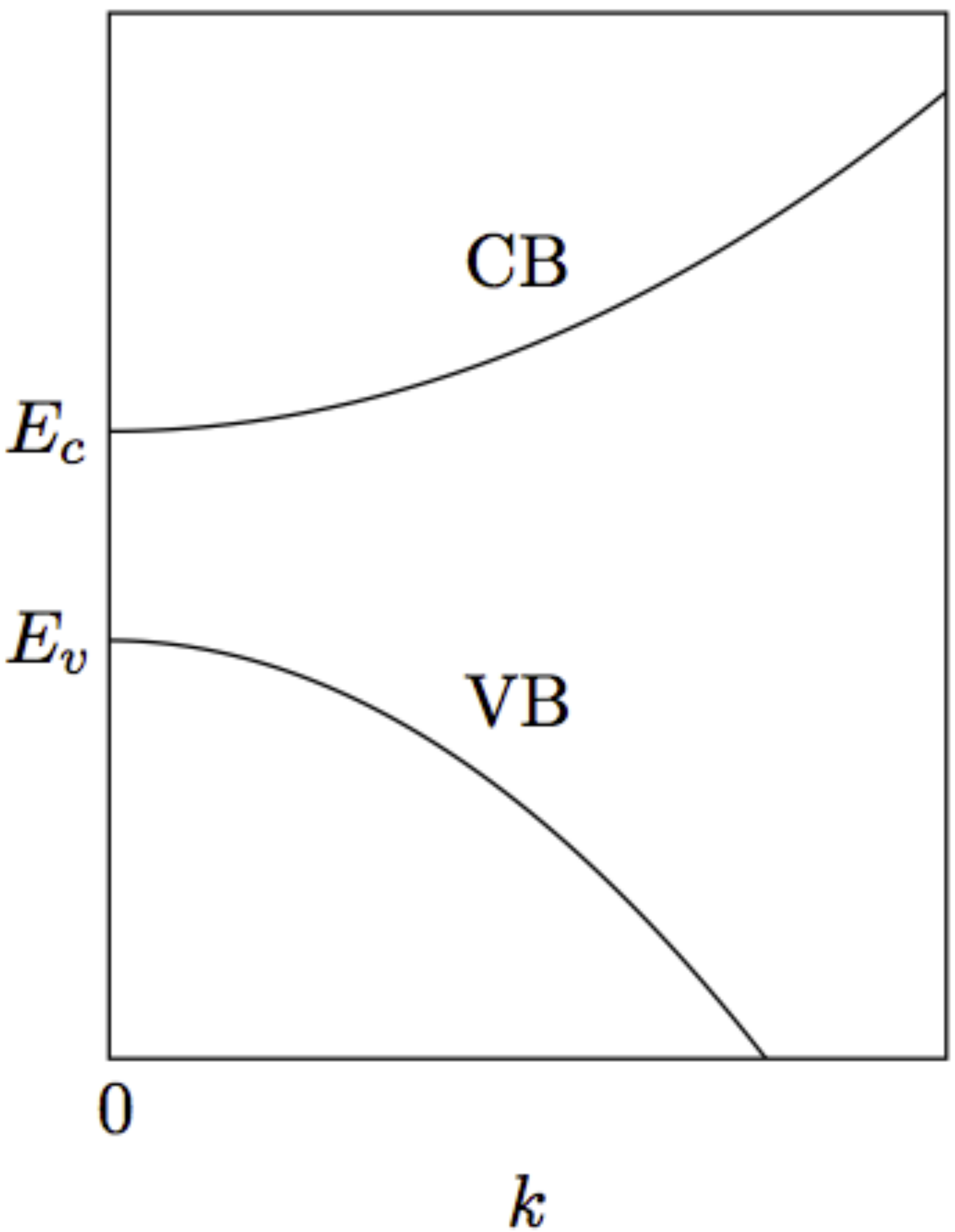


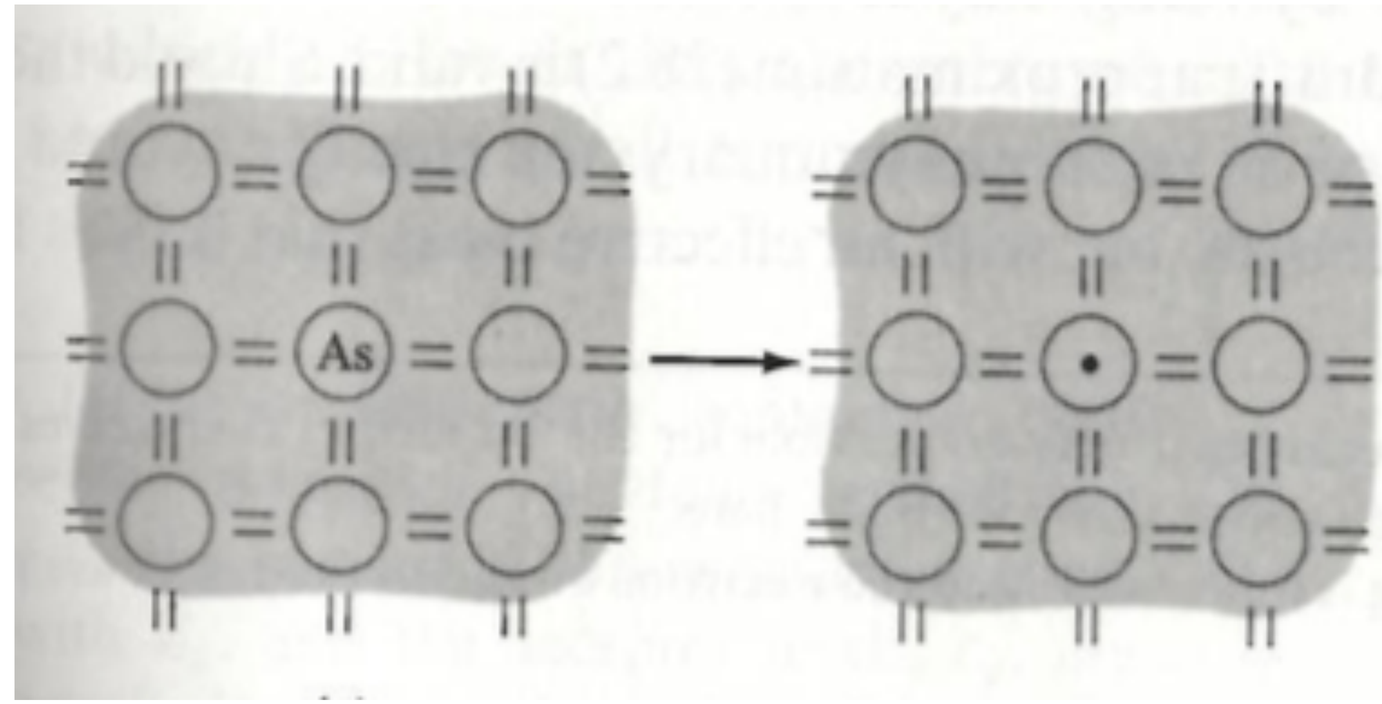


=Silicon atom



Now these aren't equal to each other!





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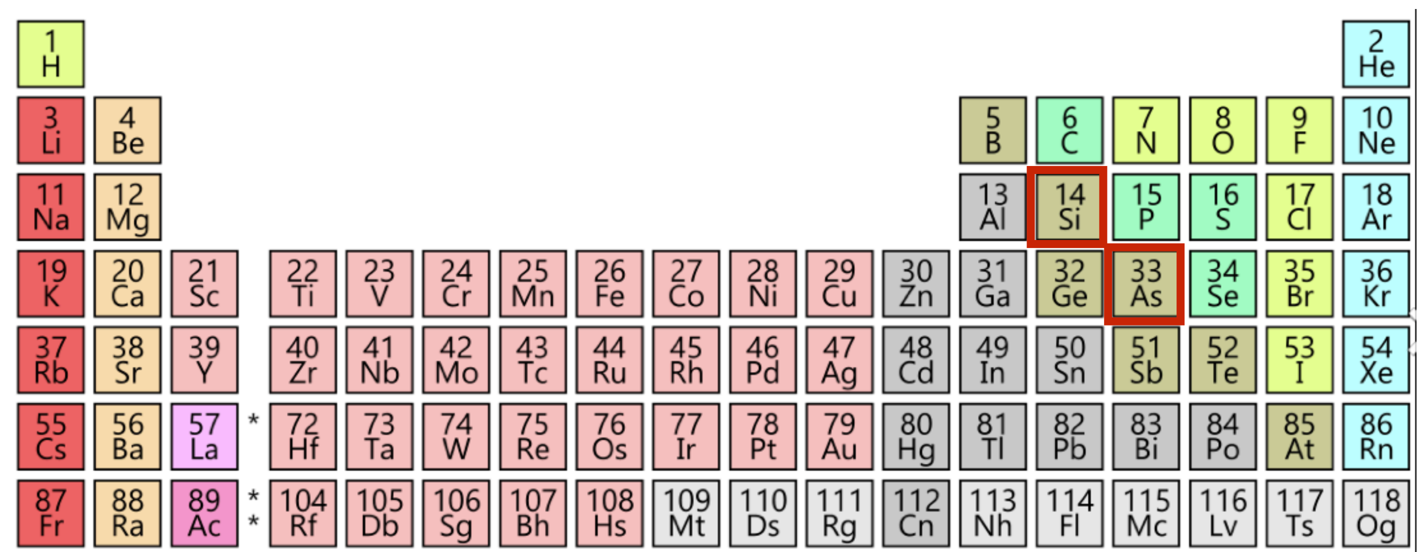

$$n = 2\left(\frac{m_n^* k_B T}{2\pi\hbar^2}\right)^{3/2} e^{-\frac{E_c - E_F}{k_B T}} \qquad p = 2\left(\frac{m_p^* k_B T}{2\pi\hbar^2}\right)^{3/2} e^{-\frac{E_F - E_v}{k_B T}}$$

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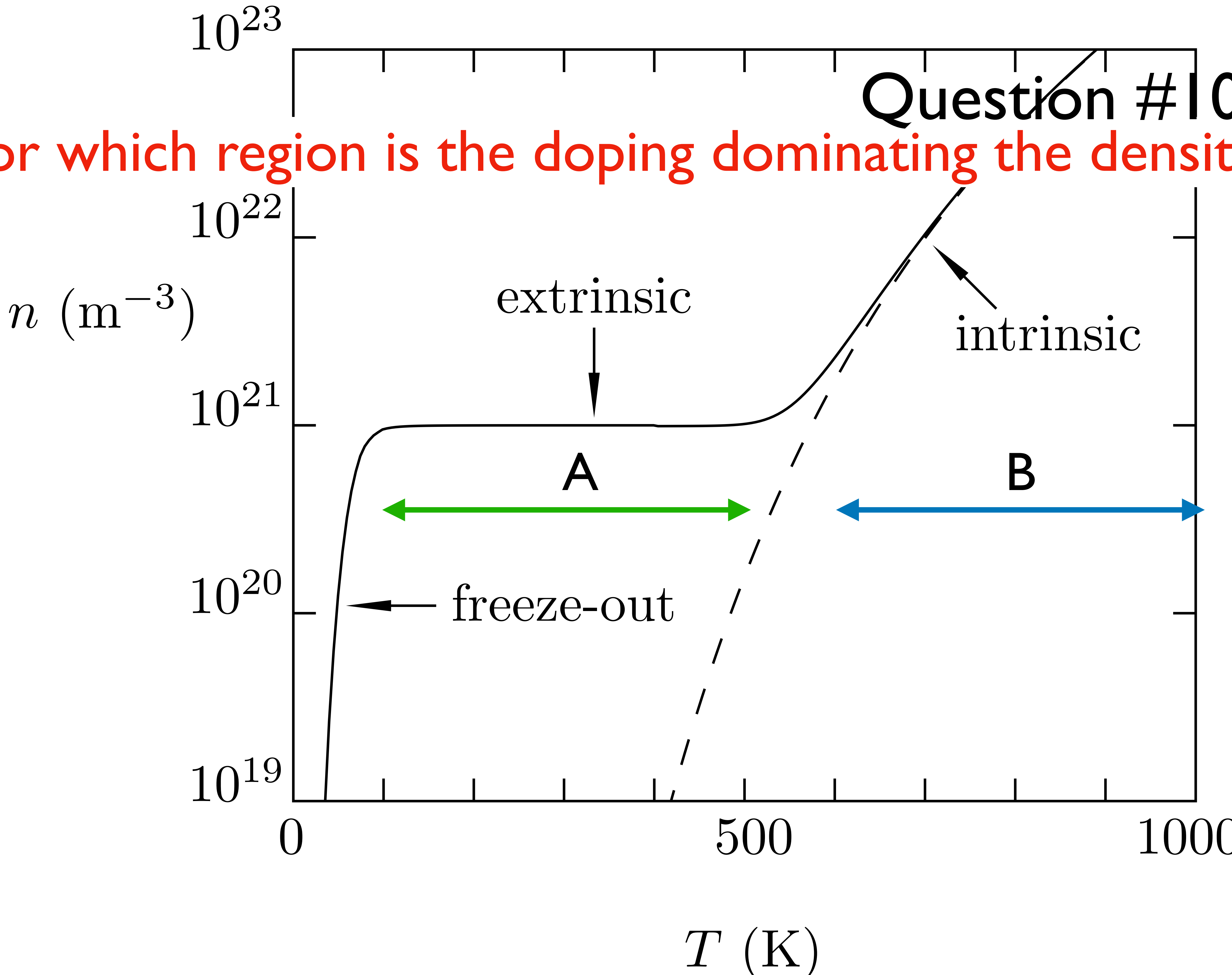
$$np = N_c N_v e^{-\frac{E_g}{k_B T}}$$

Question #10

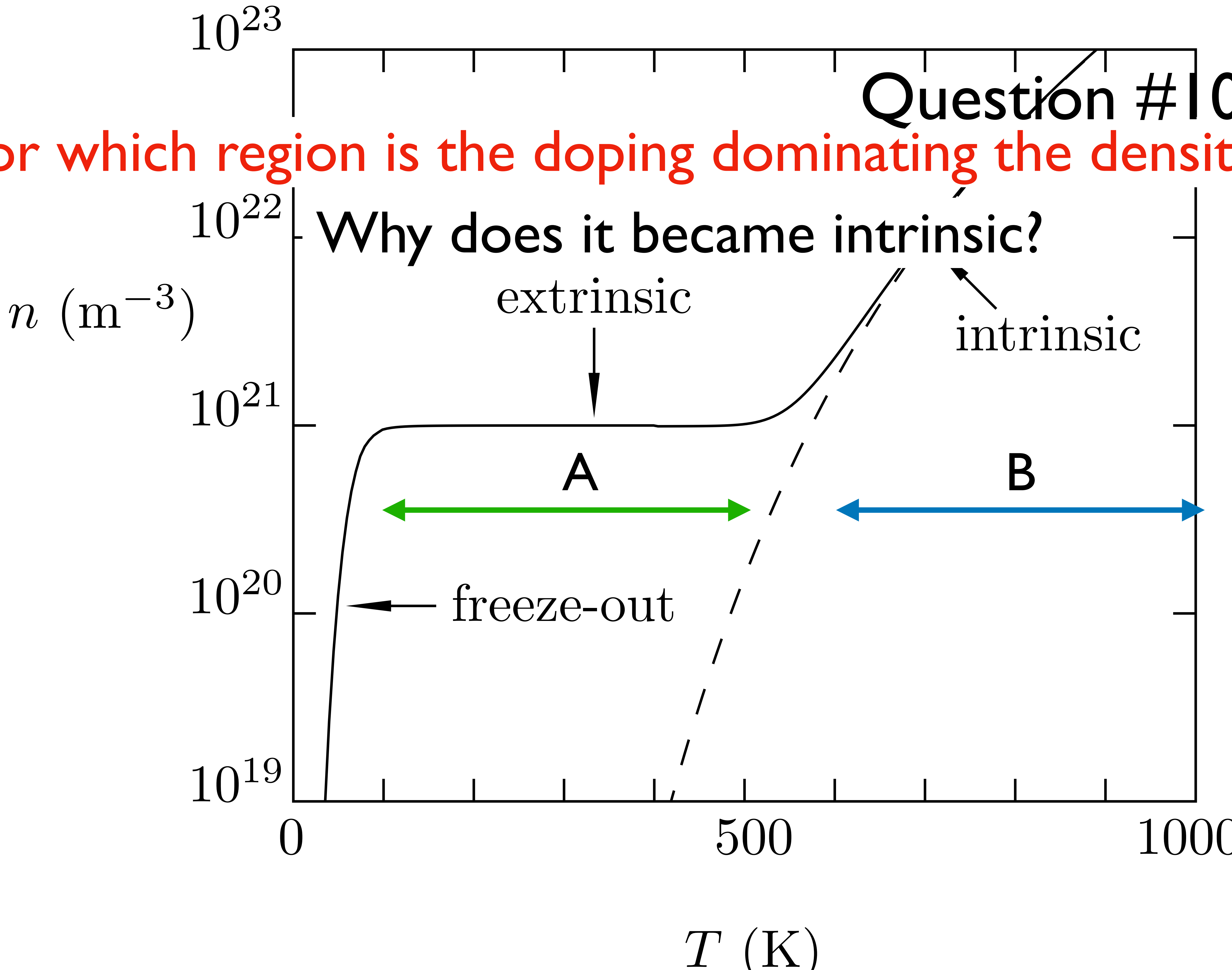
For which region is the doping dominating the density?



Question #10

For which region is the doping dominating the density?

Why does it became intrinsic?



How big of an affect is it?

1 atom in 5×10^7

$n_i = 10^{16}\ \mathrm{m}^{-3} \rightarrow$

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$$n_i = 10^{16} \text{ m}^{-3} \rightarrow n \approx 10^{21} \text{ m}^{-3}$$

$$\frac{dq}{dt} = I = -eNv \qquad \boxed{1}$$

$$\vec{J} = -en\vec{v} \overset{\boxed{2}}{=} \sigma\vec{\mathcal{E}} \overset{\boxed{3}}{=} \frac{ne^2\tau}{m^*}\vec{\mathcal{E}} \qquad \boxed{4}$$

$$\vec{v}_d = -\frac{e\tau}{m^*}\vec{\mathcal{E}} \overset{\boxed{5}}{\Rightarrow} \mu_n = \frac{e\tau}{m^*} \qquad \boxed{6}$$

$\boxed{7}$

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$\boxed{2}$ $\boxed{3}$ $\boxed{4}$

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$\boxed{5}$ $\boxed{6}$

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Why bother with mobility?
How is it useful?

$\boxed{7}$

$$\frac{dq}{dt} = I = -eNv$$

1

2 3 4

$$\vec{J} = -en\vec{v} = \sigma\vec{\mathcal{E}} = \frac{ne^2\tau}{m^*}\vec{\mathcal{E}}$$

5 6

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7

$$\sigma_n = ne\mu_n$$

Which of the following are intrinsic semiconductors

Question #12

a) A cool doped semiconductor.
b) A hot, doped semiconductor.
c) A cool pure (undoped) semiconductor.
d) A hot pure (undoped) semiconductor.
e) b, c, and d.
f) Both b and d.

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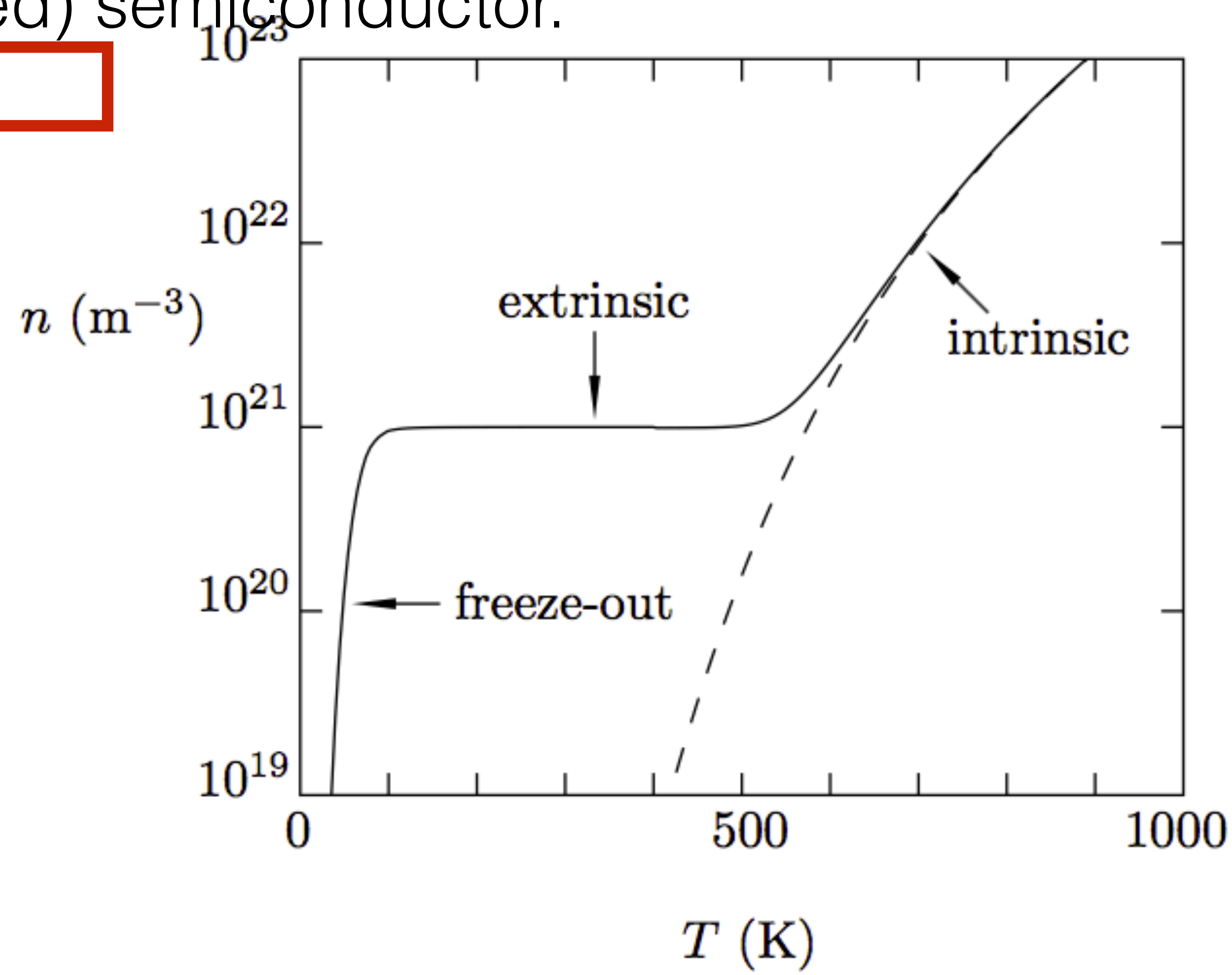

At low temperature, what kind of semiconductor has a higher electrical conductivity?

Question #13

a) Extrinsic because it has less charge carriers.
b) Extrinsic because it has more charge carriers.
c) Intrinsic because it has more charge carriers.
d) Intrinsic because it has less charge carriers.
e) They will have the same electrical conductivity.

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Question #13

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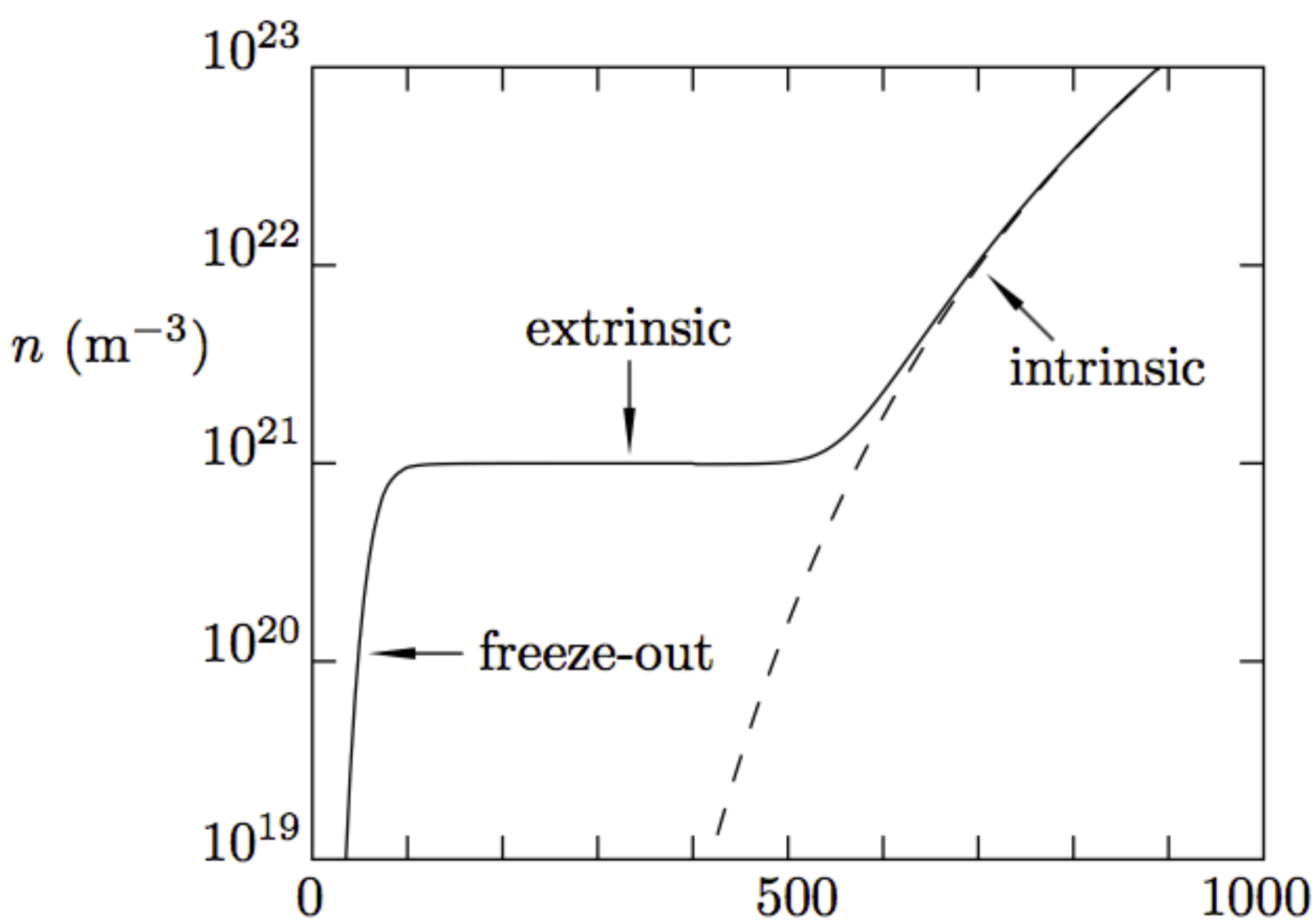
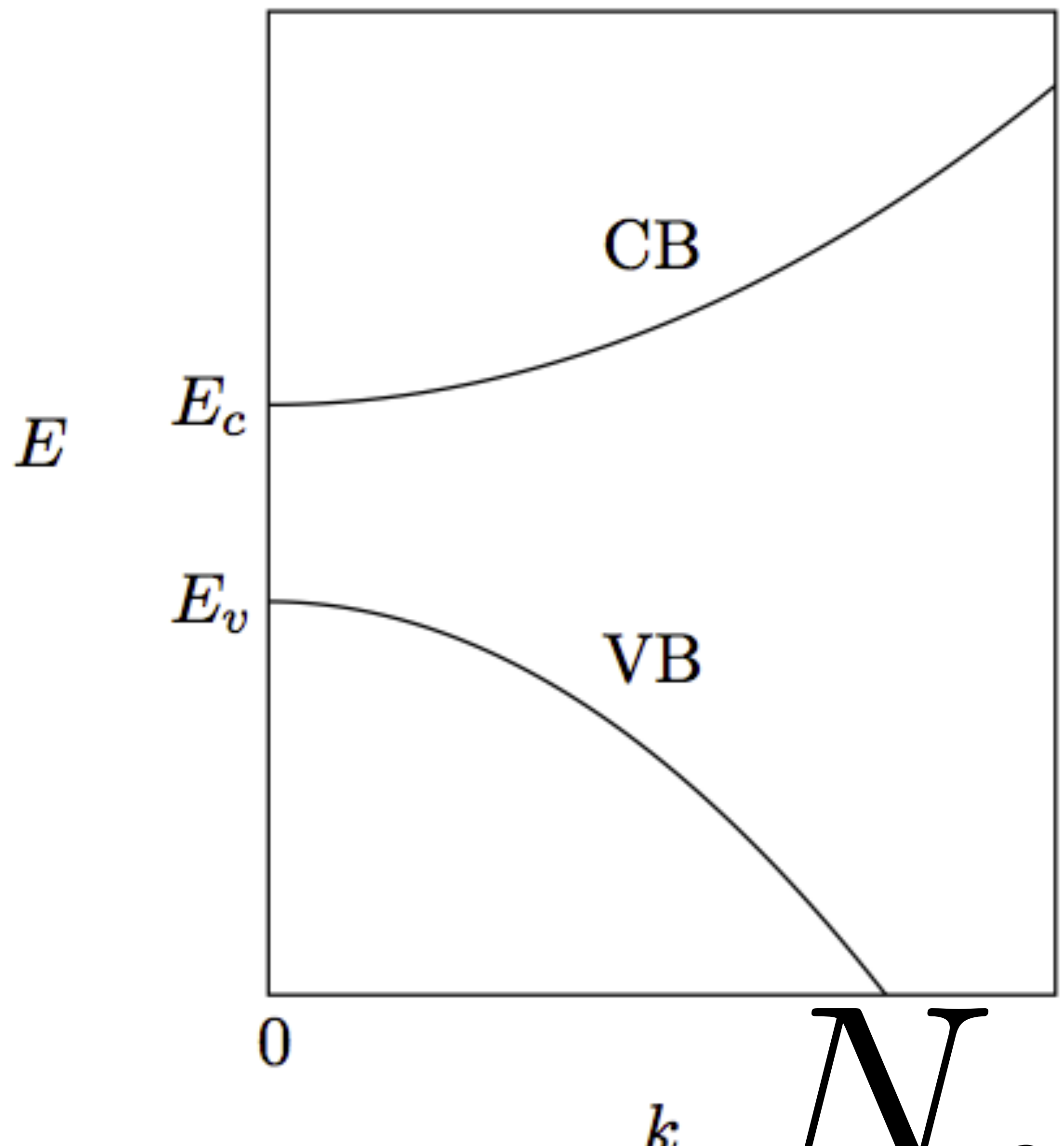


E_g n_i

n E_d



p_i E_a

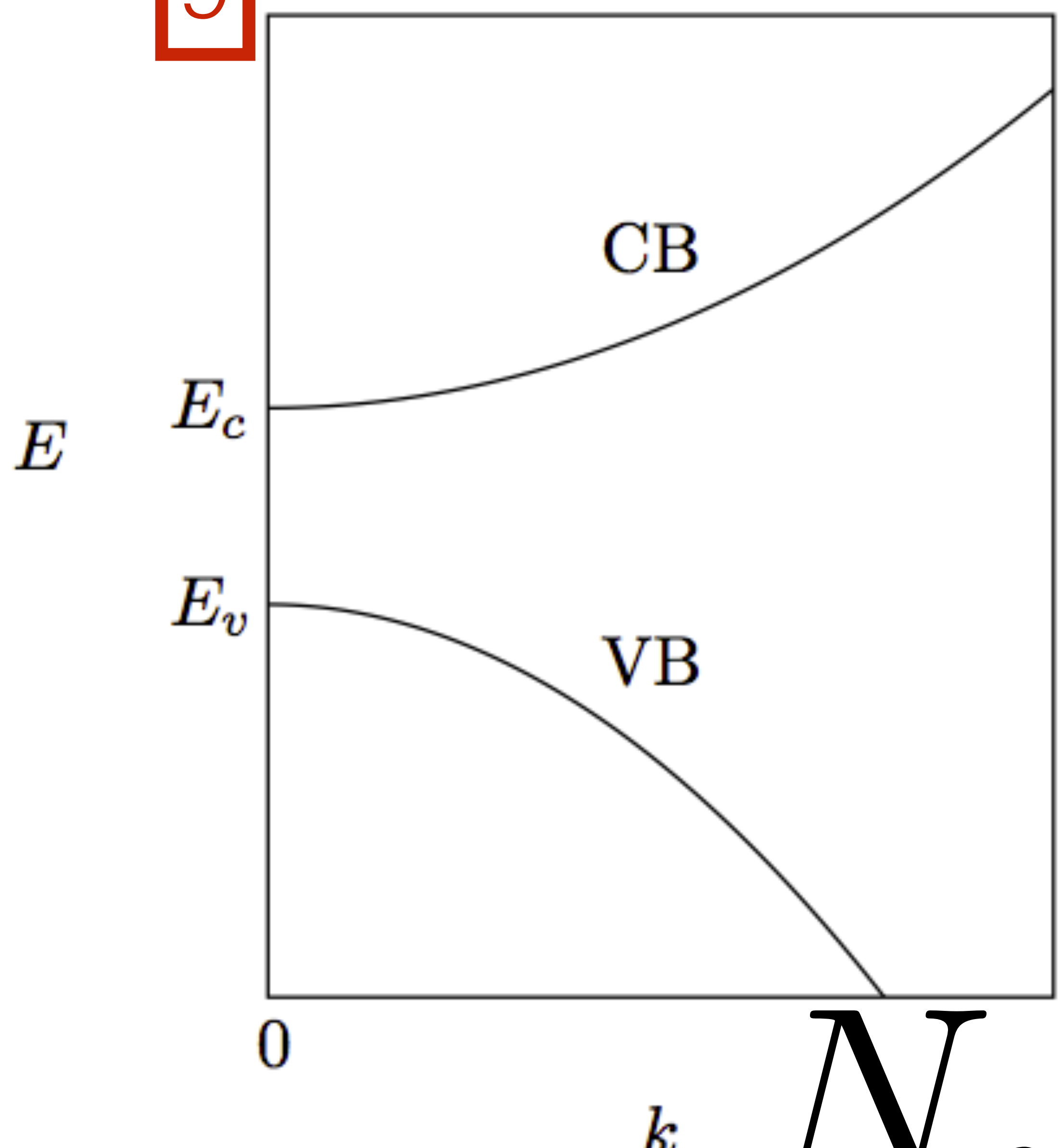
N_d N_a p

E_g 9

n_i 4

E_d 8

n 2



6 p_i

E_a 1

N_d 5

N_a 3

p 7

Consider an n-type semiconductor at low temperature (with donor density N_d), what will be the value of p?

Question #14

d) $p \approx 0$
a) $p \approx n_i$
c) $p \approx N_d$

Consider an n-type semiconductor at low temperature (with donor density N_d), what will be the value of p?

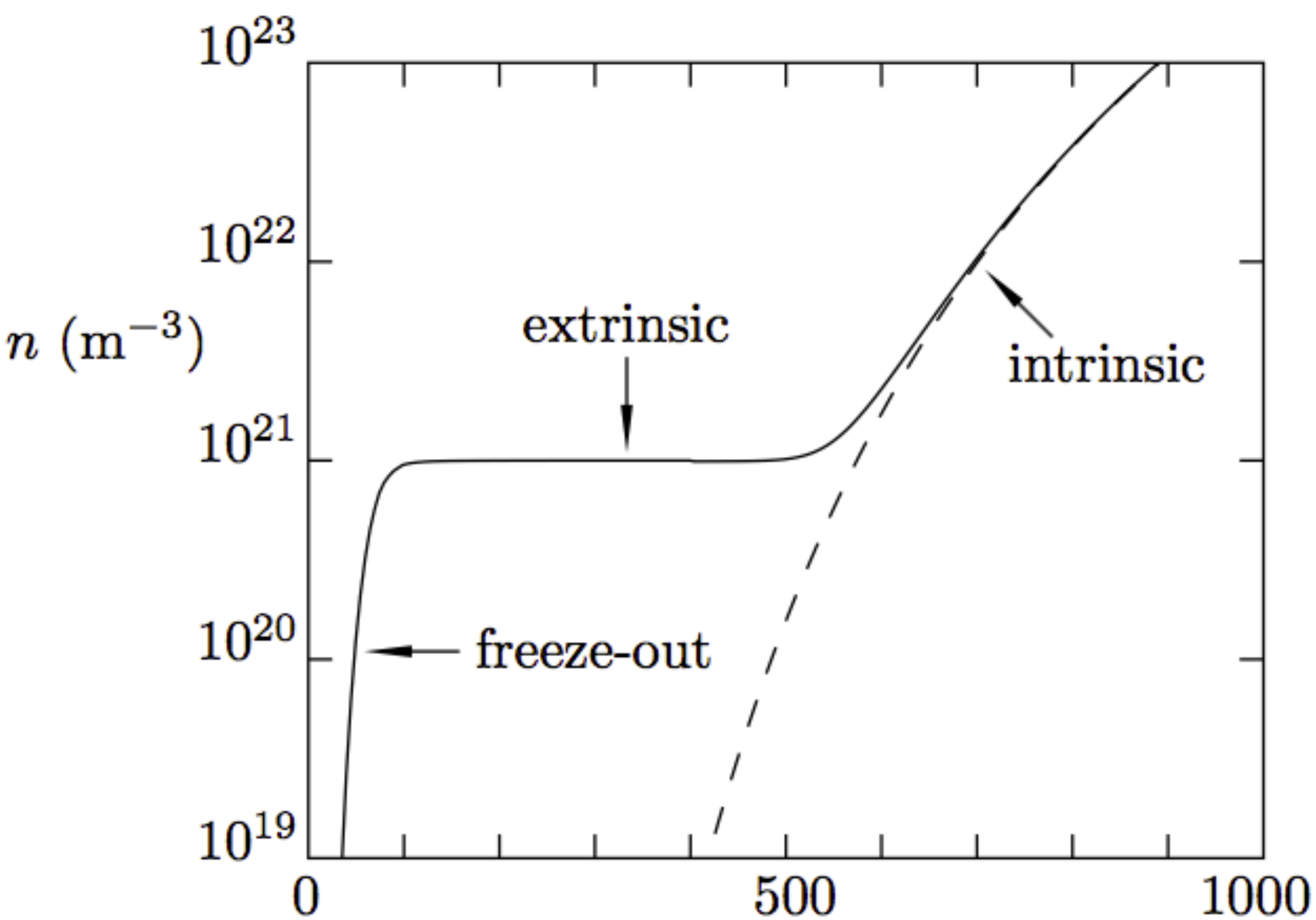
Question #14

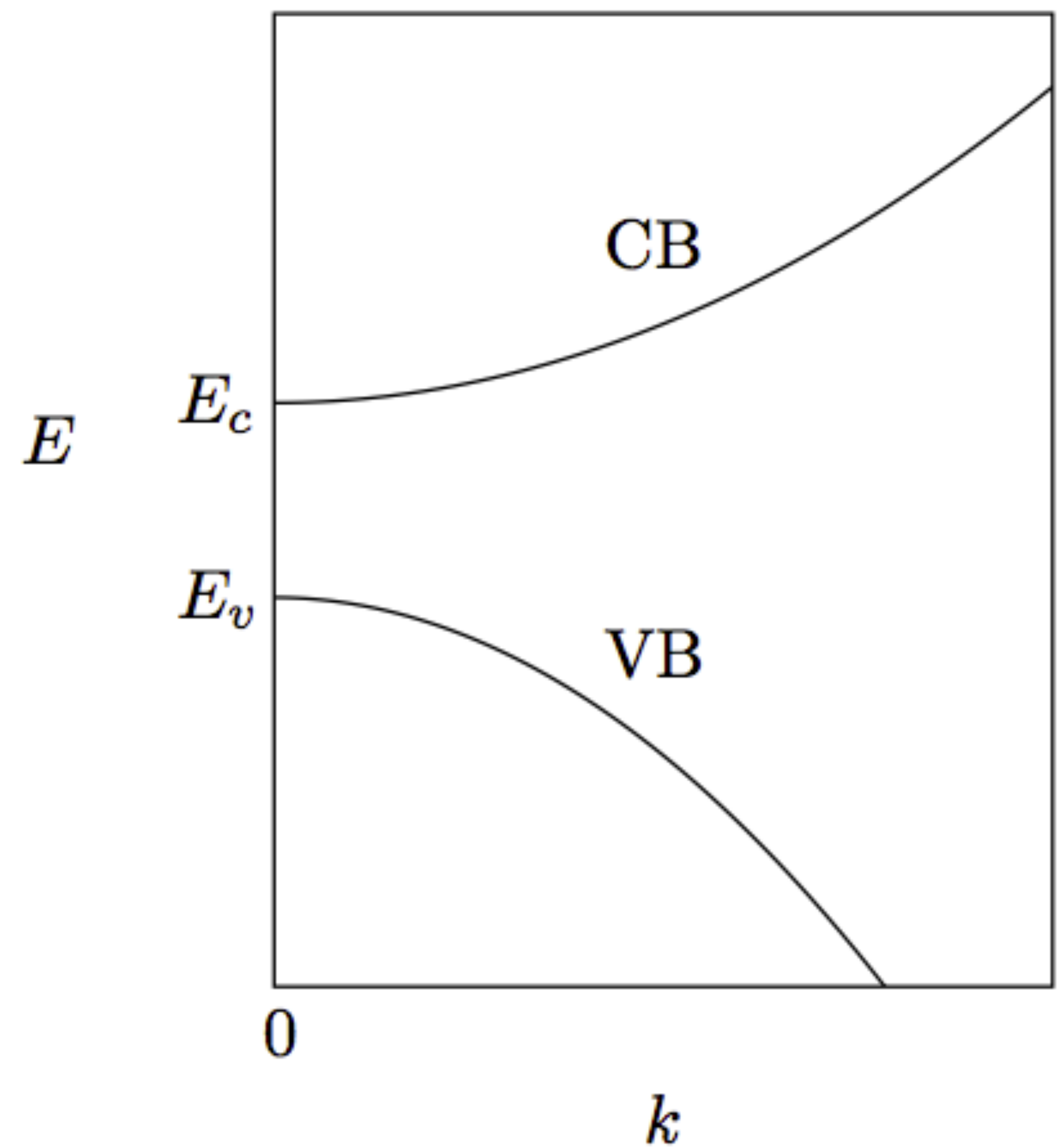
d) $\boxed{p \approx 0}$

a) $p \approx n_i$

c) $p \approx N_d$

$$p \approx \frac{p_i^2}{N_d}$$





Consider a p-type semiconductor at high temperature (with donor density N_a), what will be the value of n?

Question #15

c) $n \approx 0$

d) $n \approx p_i$

e) $n \approx N_a$

Consider a p-type semiconductor at high temperature (with donor density N_a), what will be the value of n?

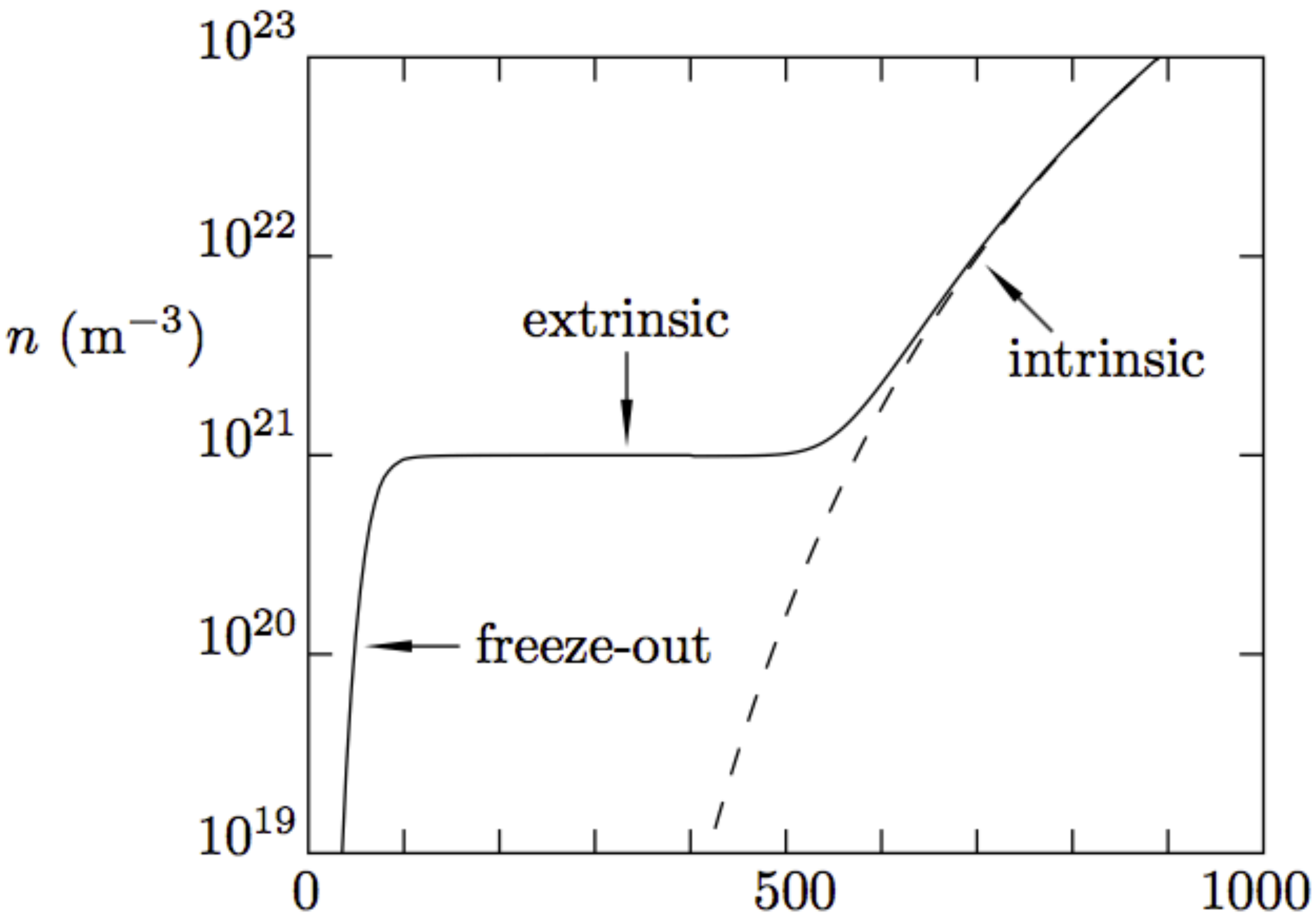
Question #15

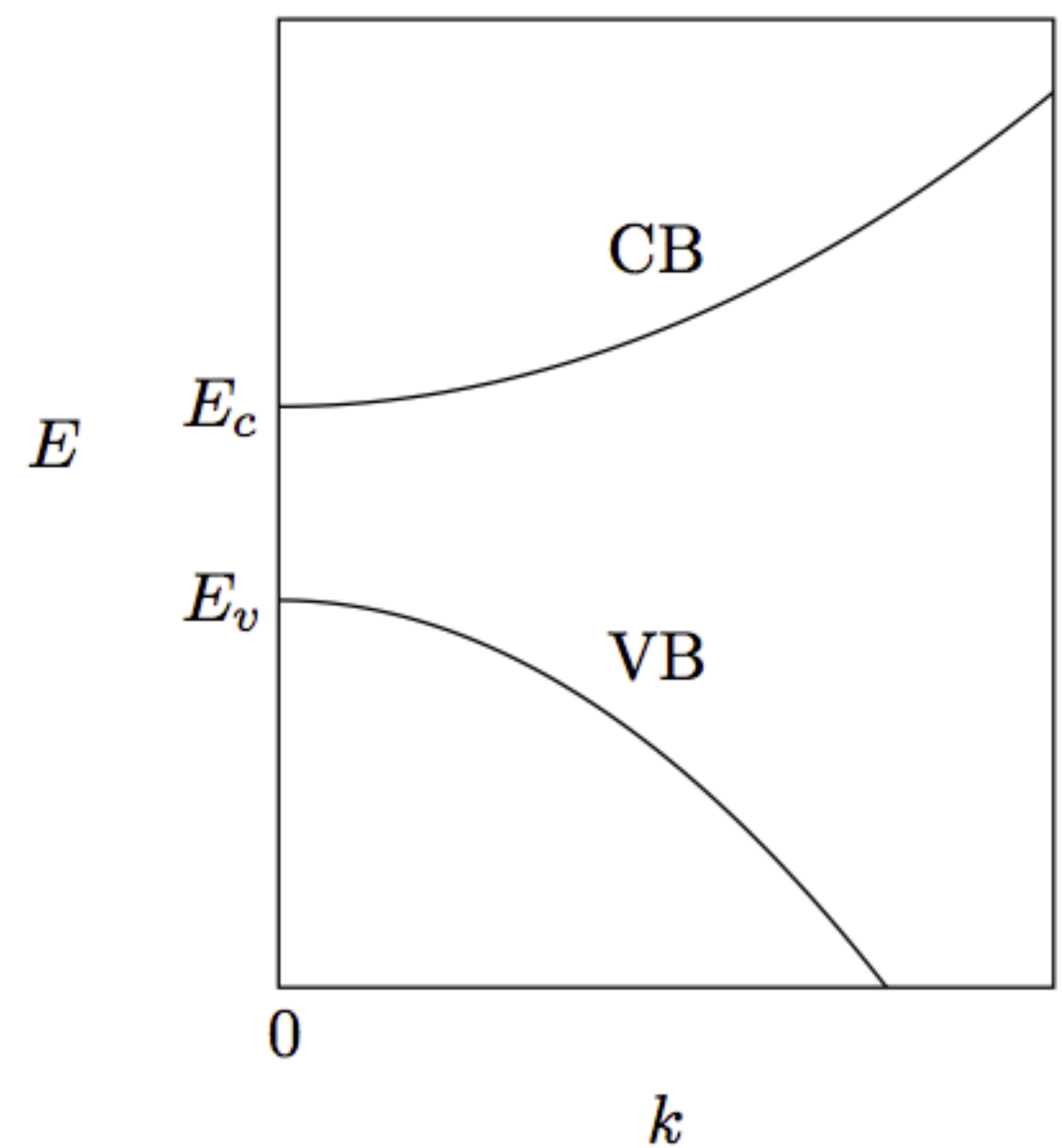
c) $n \approx 0$

d) $\boxed{n \approx p_i}$

e) $n \approx N_a$

$$n \approx \frac{n_i^2}{N_a}$$





Question #16

If the we raise the temperature of a semiconductor, what happens to the mobility of the electrons and holes?

Question #16

If the we raise the temperature of a semiconductor, what happens to the mobility of the electrons and holes?

Question #16

(A) Mobility of holes goes up;
for electrons, goes down.
(B) Mobility of holes goes down;
for electrons, goes up.
(C) both decrease.
(D) both increase.
(E) Nothing, unless the semiconductor is doped.

If the we raise the temperature of a semiconductor, what happens to the mobility of the electrons and holes?

If the we raise the temperature of a semiconductor, what happens to the mobility of the electrons and holes?

Answer: Mobility of both decreases

Why?

Question #17

Consider an n-type semiconductor at room temperature. If we increase the density of donor atoms, the mobility of the electrons in the conduction band

Question #17

Consider an n-type semiconductor at room temperature. If we increase the density of donor atoms, the mobility of the electrons in the conduction band

Question #17

(A) remains the same.
(B) decreases.
(C) increases.
(D) is irrelevant—only the holes are moving.

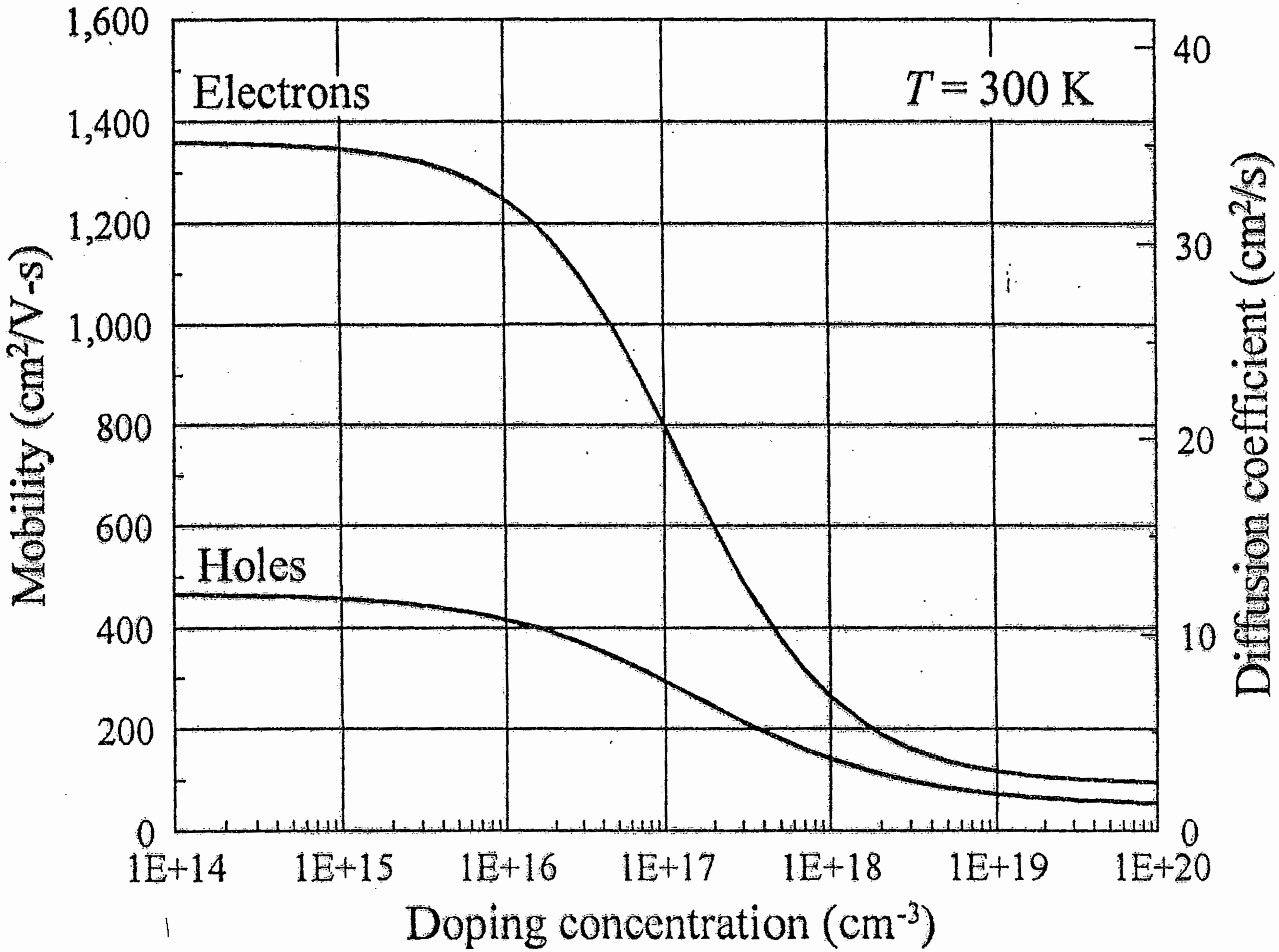


FIGURE 2.7. Electron and hole mobilities in bulk silicon at 300 K as a function of doping concentration.

Question #18

If we raise the temperature of an extrinsic semiconductor, what happens to its electrical conductivity? (Assume that the semiconductor remains extrinsic at the higher temperature.)

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Question #18

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(B) conductivity increases.
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(D) Irrelevant, only the holes are moving.

If we raise the temperature of an extrinsic semiconductor, what happens to its electrical conductivity? (Assume that the semiconductor remains extrinsic at the higher temperature.) **Question #18**

(A) conductivity remains the same.
(B) conductivity increases.
(C) conductivity decreases.
(D) Irrelevant, only the holes are moving.

$$\mu_n = \frac{e\tau}{m^*} \qquad \sigma_n = ne\mu_n$$

Question #19

If we raise the temperature of an intrinsic semiconductor, what happens to its electrical conductivity?

Question #19

If we raise the temperature of an intrinsic semiconductor, what happens to its electrical conductivity?

Question #19

(A) conductivity remains the same.
(B) conductivity increases.
(C) conductivity decreases.
(D) Irrelevant, only the holes are moving.

If we raise the temperature of an intrinsic semiconductor, what happens to its electrical conductivity?

Question #19

(A) conductivity remains the same.
(B) conductivity increases.
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(D) Irrelevant, only the holes are moving.

$$\mu_n = \frac{e\tau}{m^*} \qquad \sigma_n = ne\mu_n$$