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

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

$$\vec{v}_d = -\frac{e\tau}{m^*}\vec{\mathcal{E}} \Rightarrow \mu_n = \frac{e\tau}{m^*}$$

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How is it useful?

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Question #17

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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(C) conductivity remains the same.
(D) Irrelevant, only the holes are moving.

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

Question #18

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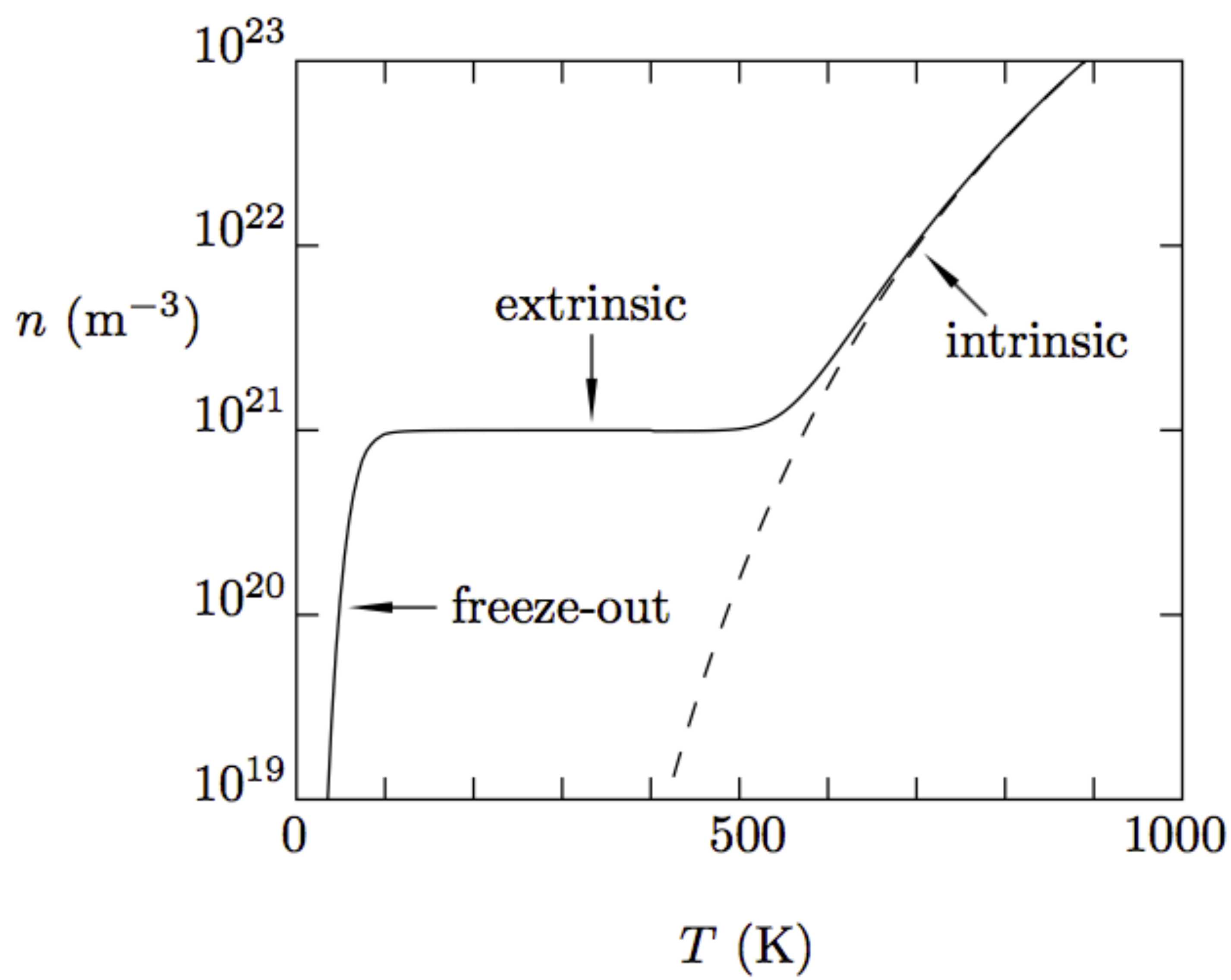
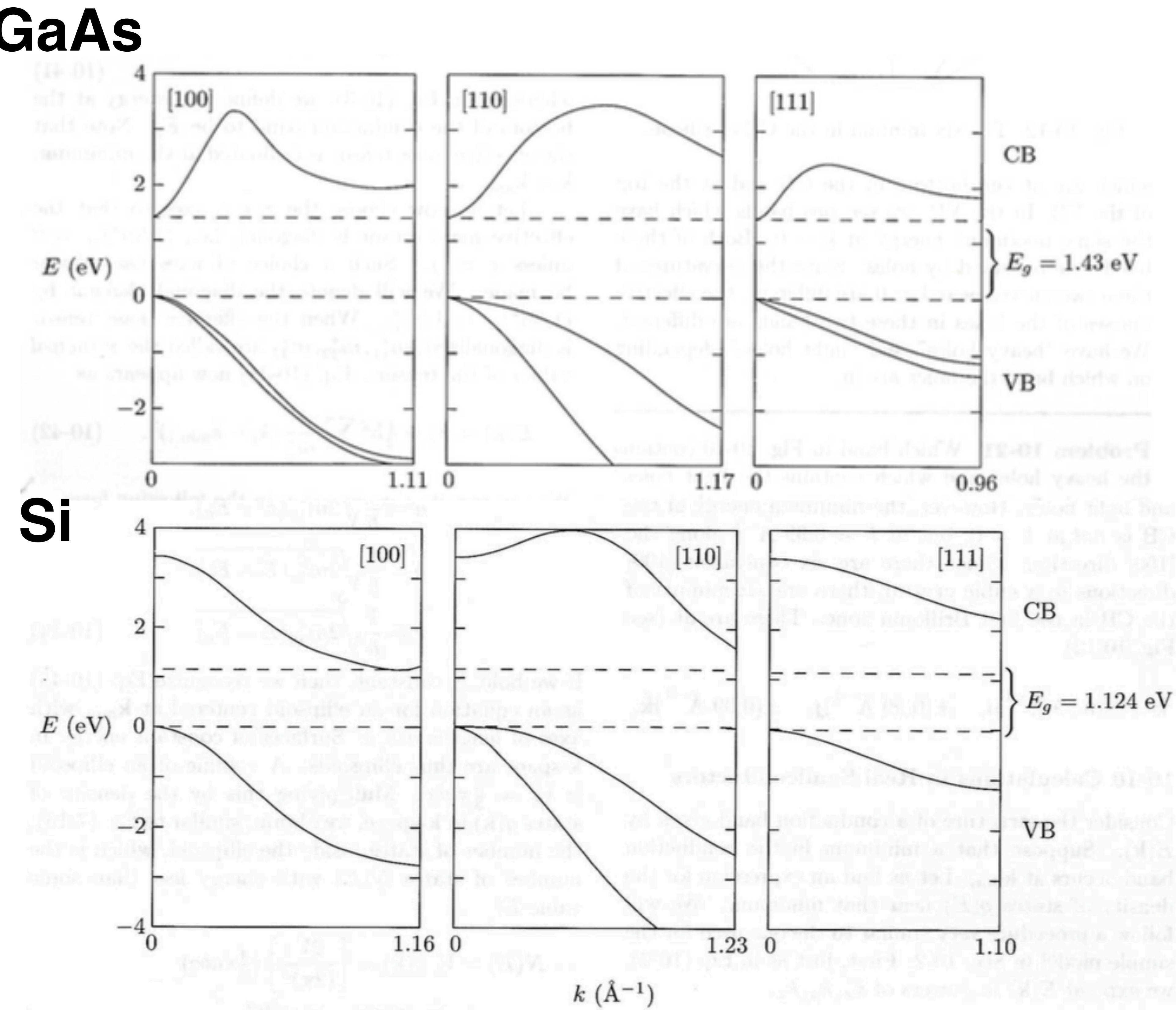
$$\mu_n = \frac{e}{m}$$



Briefly discuss differences between the ideal semiconductors we have been working with and the realistic semiconductors shown below.



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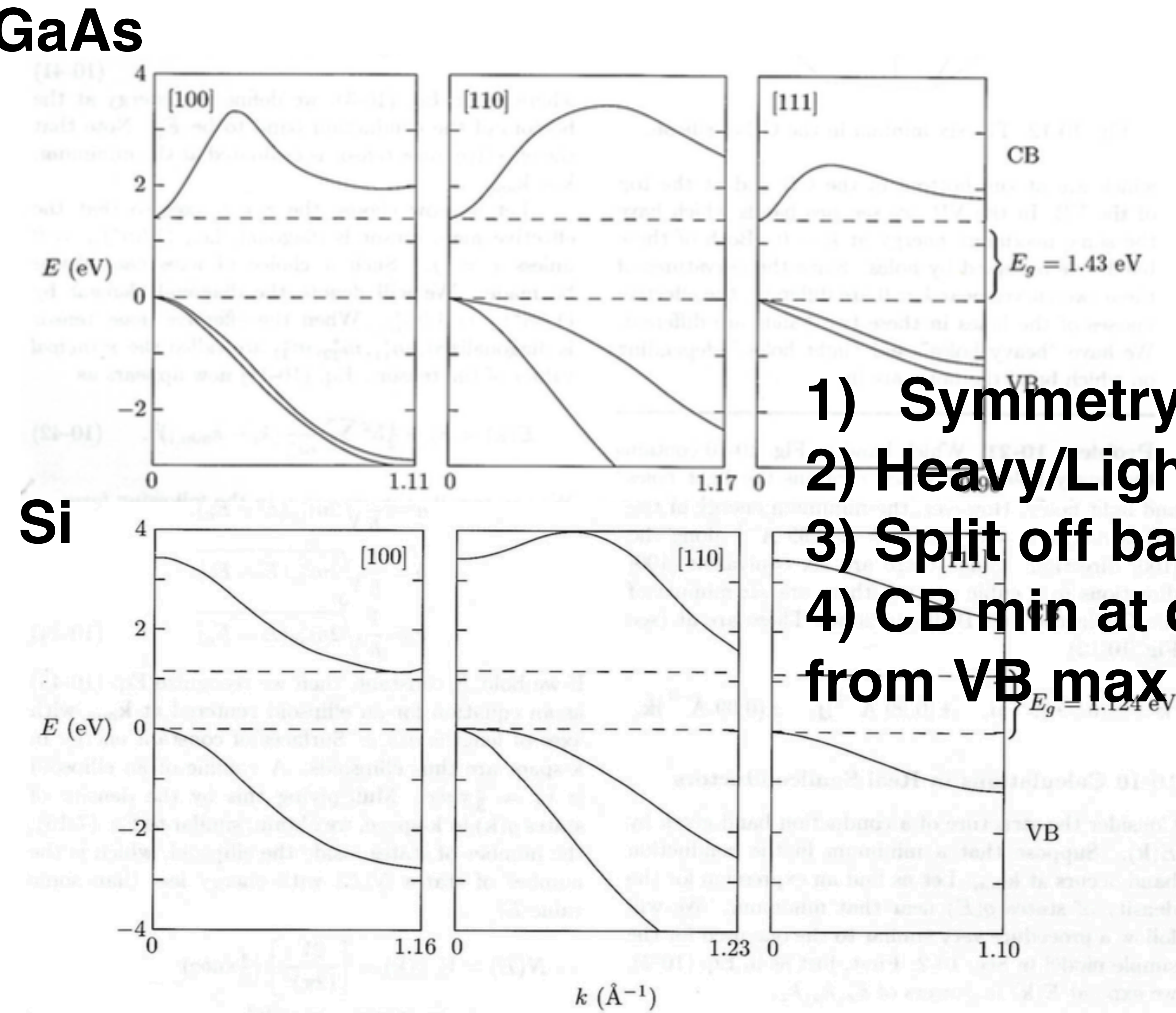

1) Symmetry

2) Heavy/Light holes

3) Split off bands

4) CB min at different location from VB max

$$g(E) = \frac{V}{2\pi^2}\left(\frac{2m_n^*}{\hbar^2}\right)^{3/2}\sqrt{E - E_c}$$ One-dimensional

What's different?

Three-dimensional

$$g(E) = \frac{V}{2\pi^2}\left(\frac{2}{\hbar^2}\right)^{3/2}(m_{11}^* m_{22}^* m_{33}^*)^{1/2}\sqrt{E - E_c}$$

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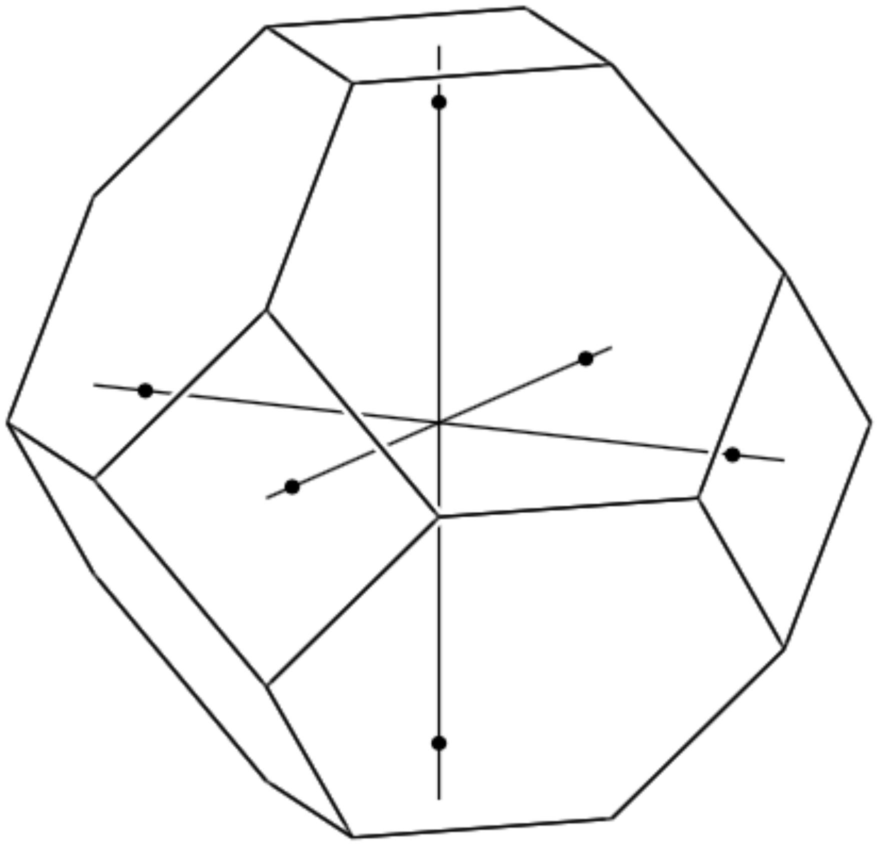
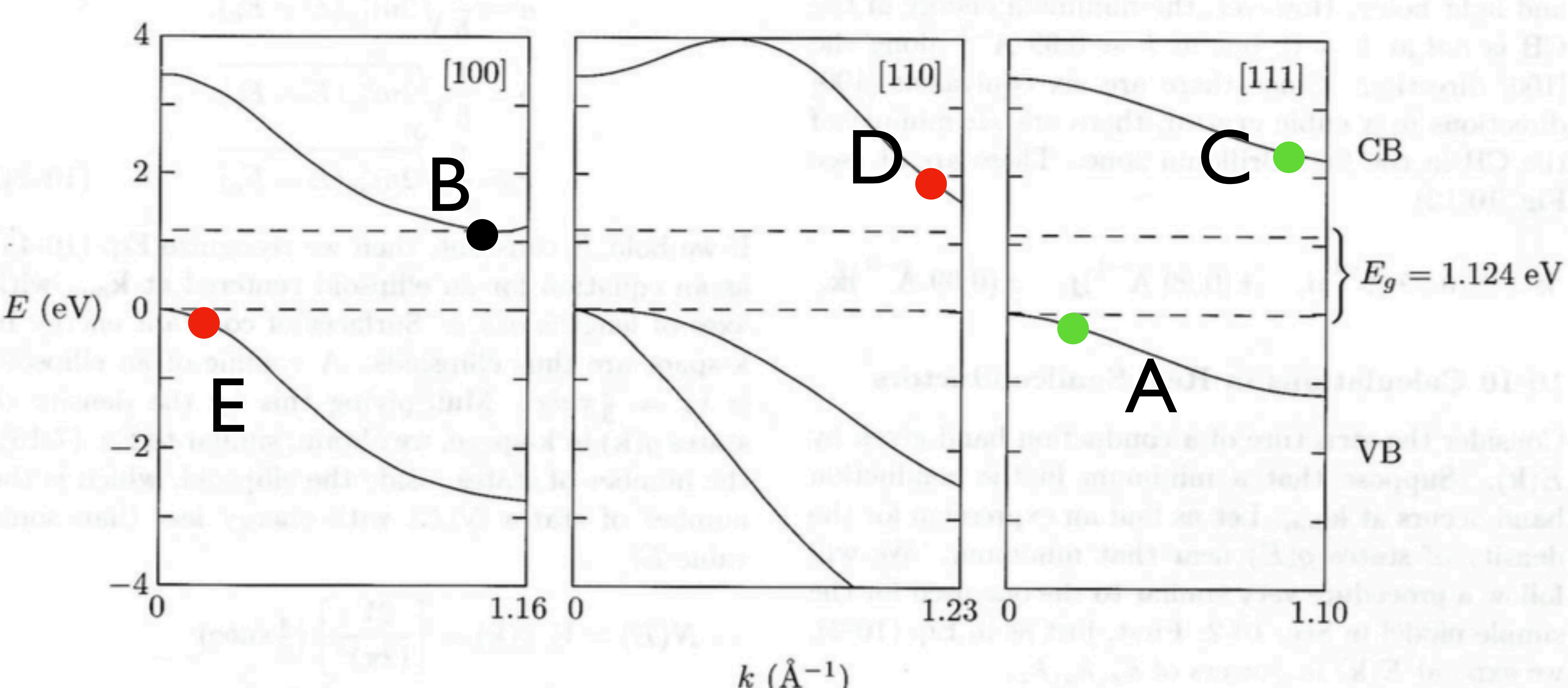
What should I set m_n^* to so that the two are equivalent?

$$m_n^* = (m_{11}^* m_{22}^* m_{33}^*)^{1/3}$$



Which point on the b.s. diagram corresponds to the black dots in the f.b.z?

Question #19



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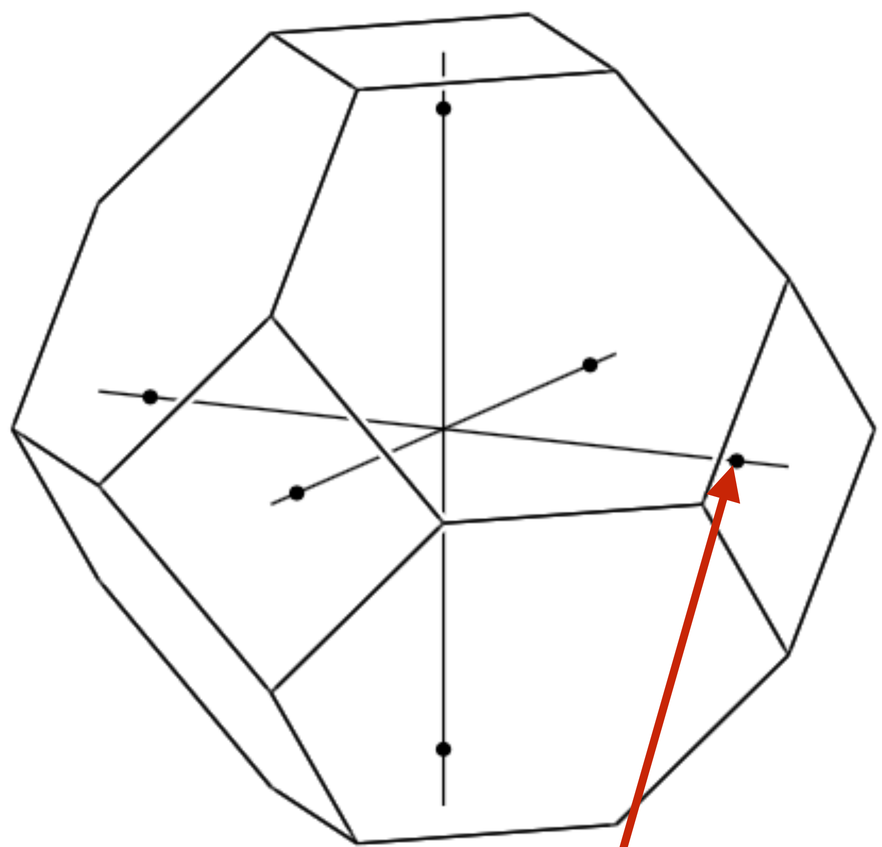

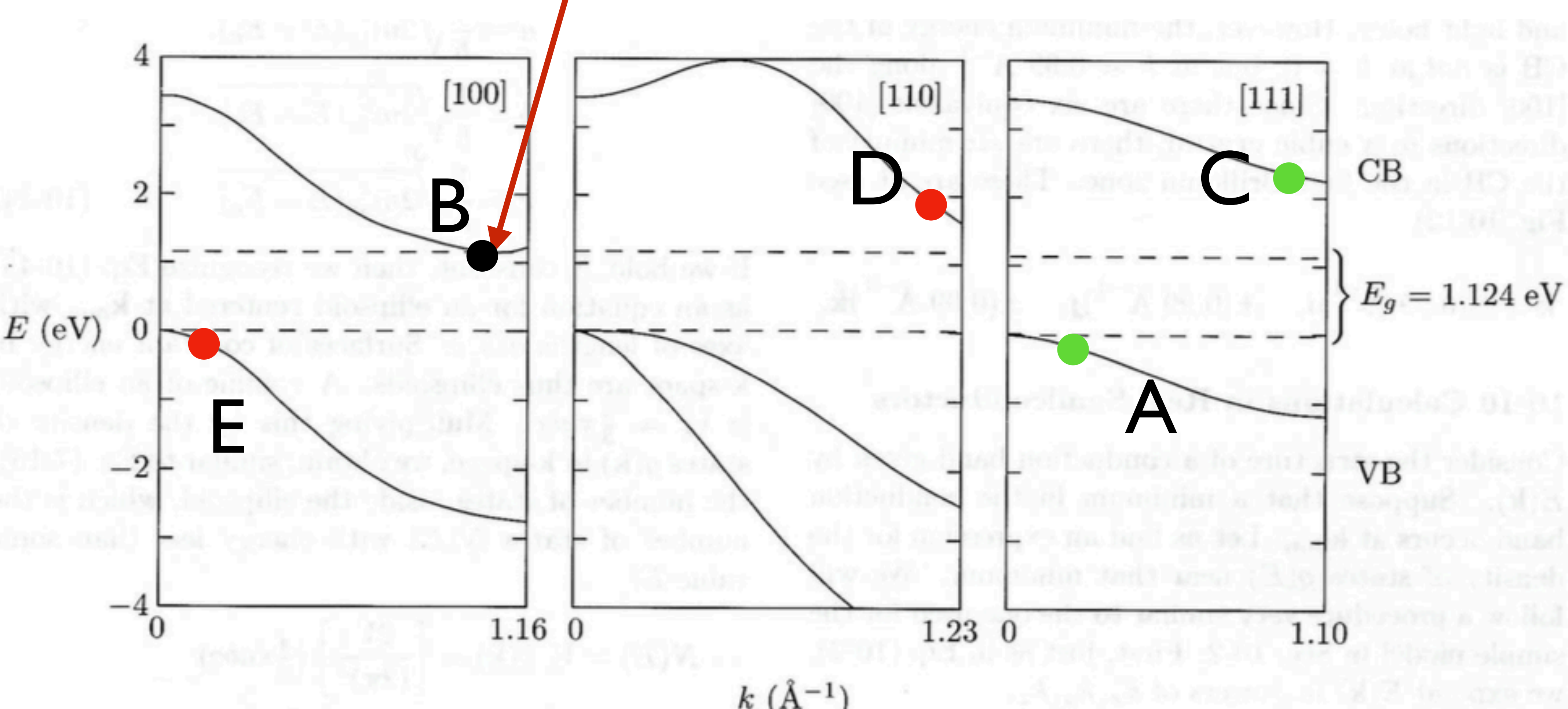

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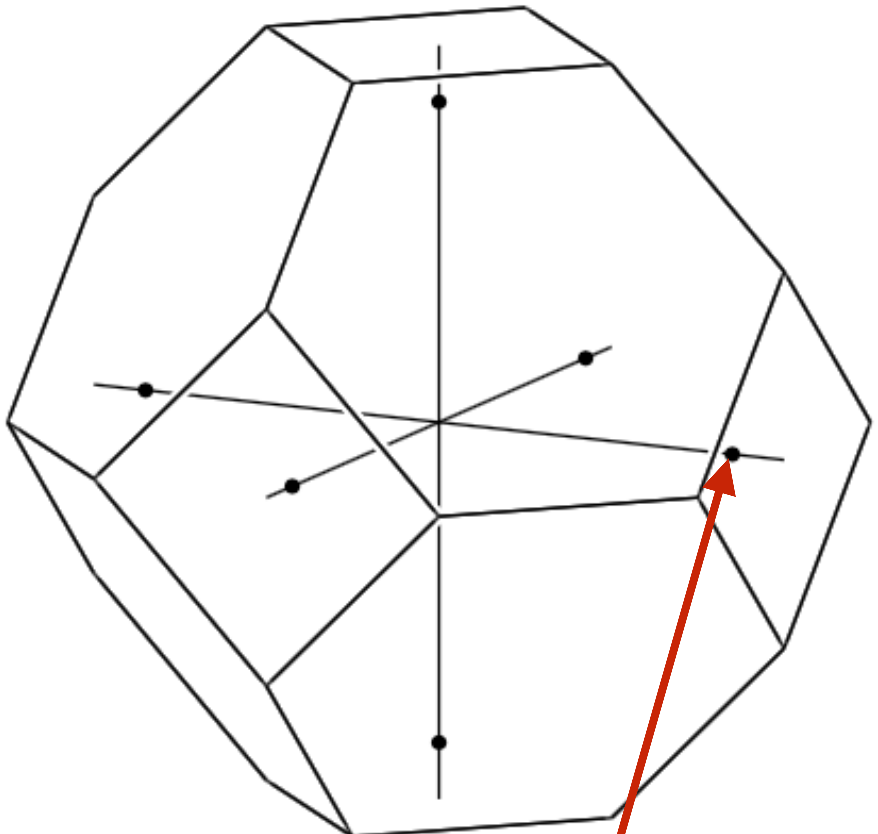
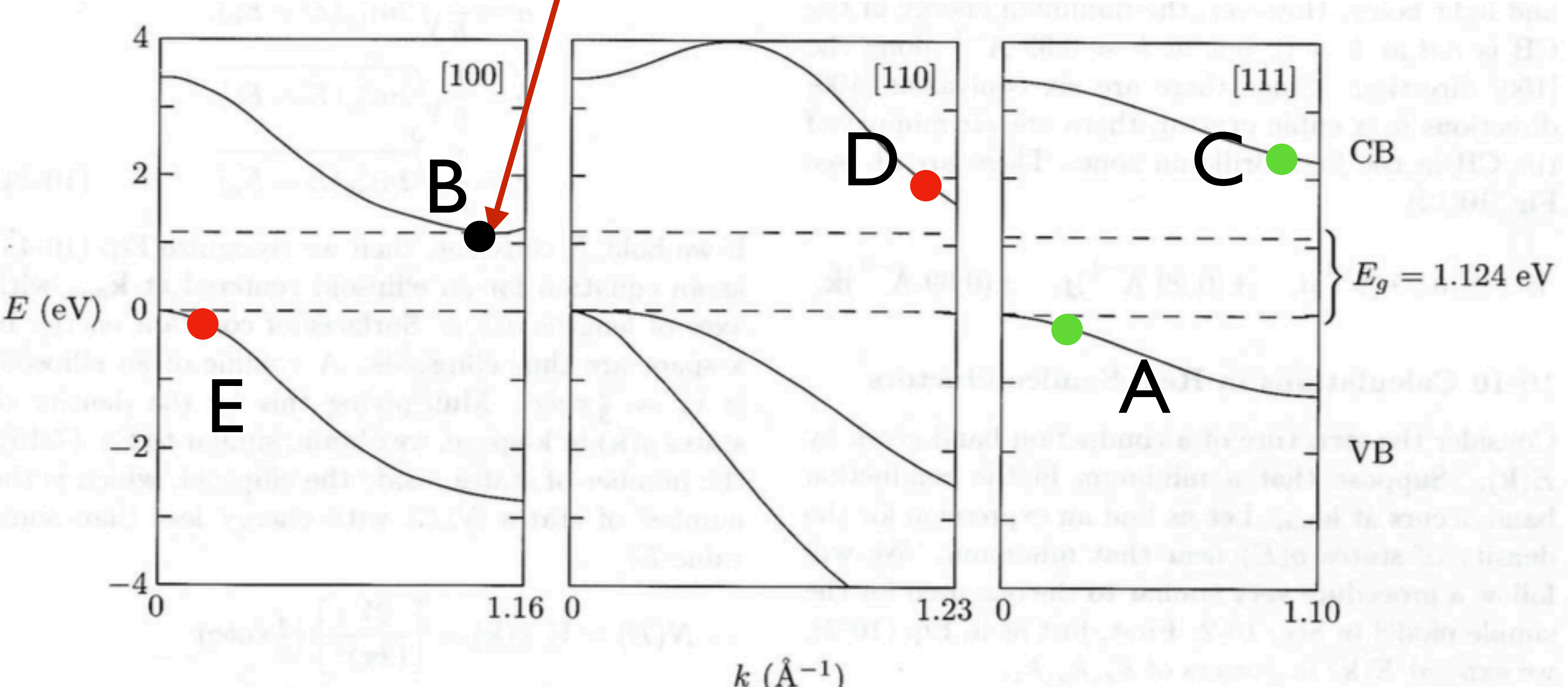
Question #19

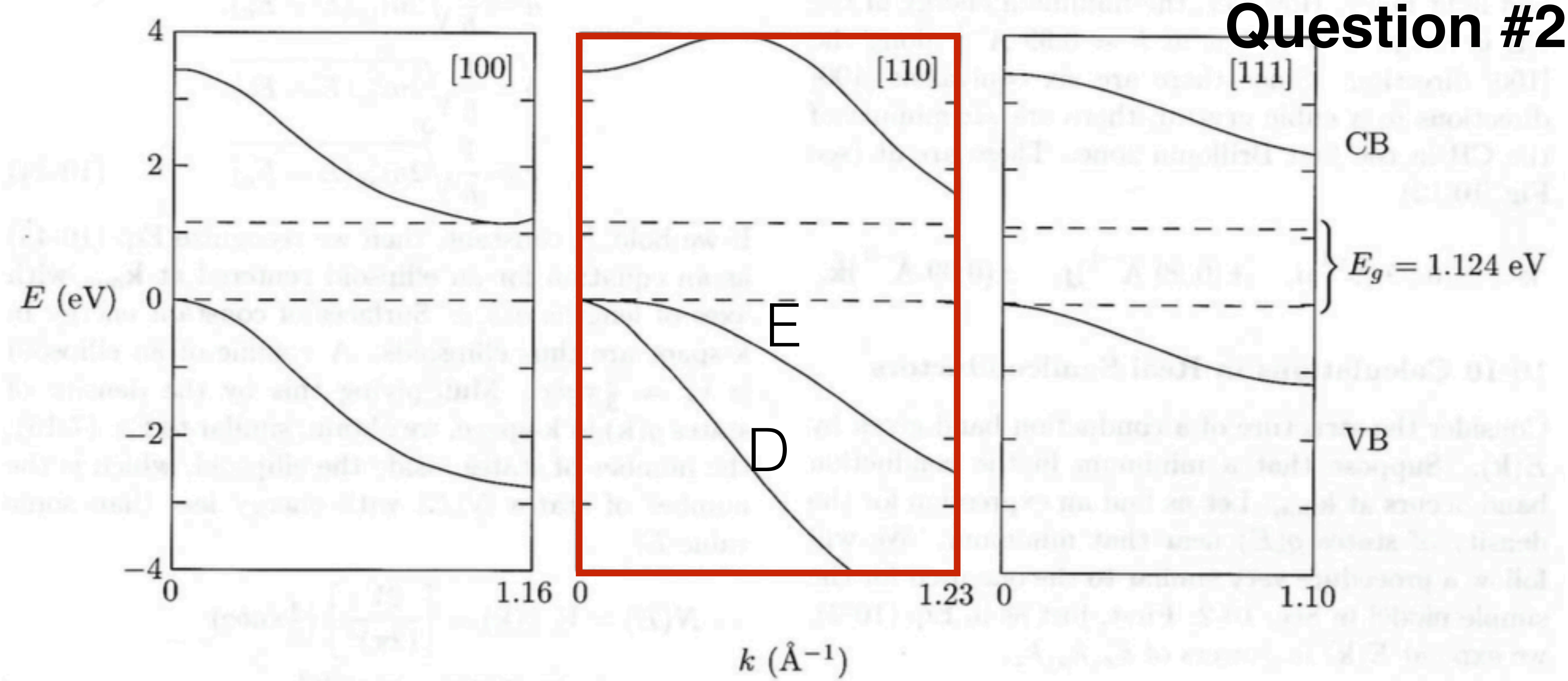
$$g(E) = \frac{V}{2\pi^2}\left(\frac{2m_n^*}{\hbar^2}\right)^{3/2}\sqrt{E - E_c}$$

$$g(E) = 6\frac{V}{2\pi^2}\left(\frac{2m_n^*}{\hbar^2}\right)^{3/2}\sqrt{E - E_c}$$



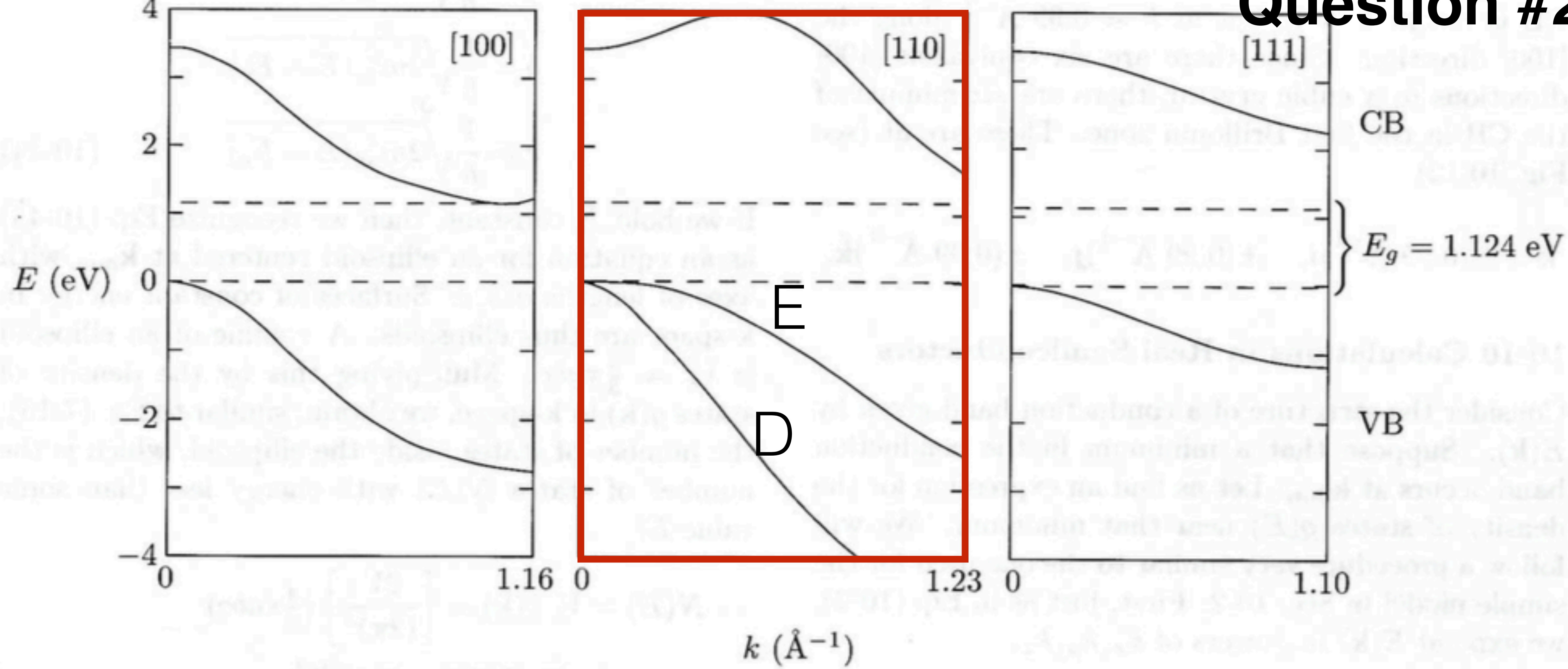


Question #20



Which band has the heavy holes?

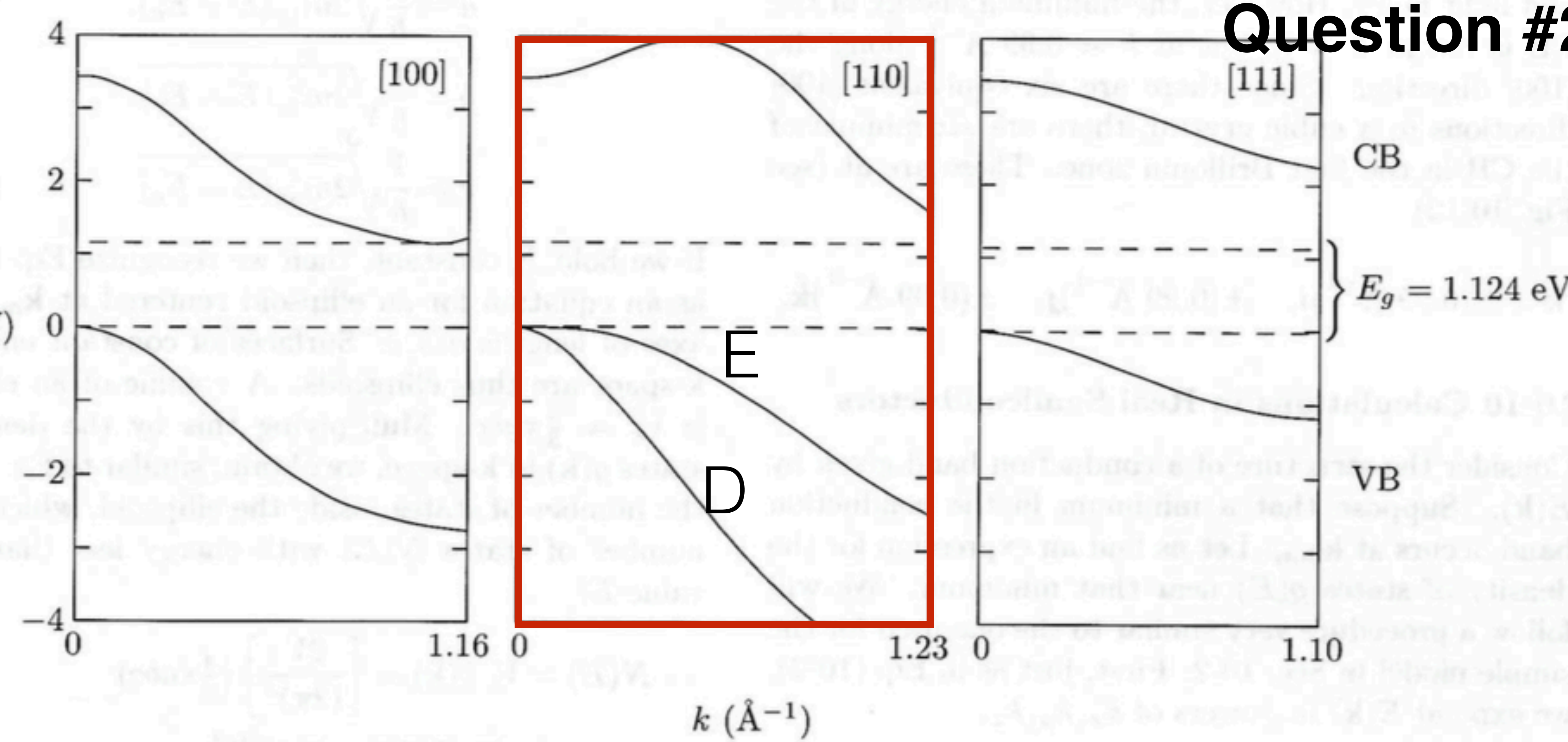
Question #20



Which band has the heavy holes?

$$m^* = \left(\frac{1}{\hbar^2} \frac{d^2 E}{dk^2} \right)^{-1}$$

Question #20



Which band has the heavy holes?

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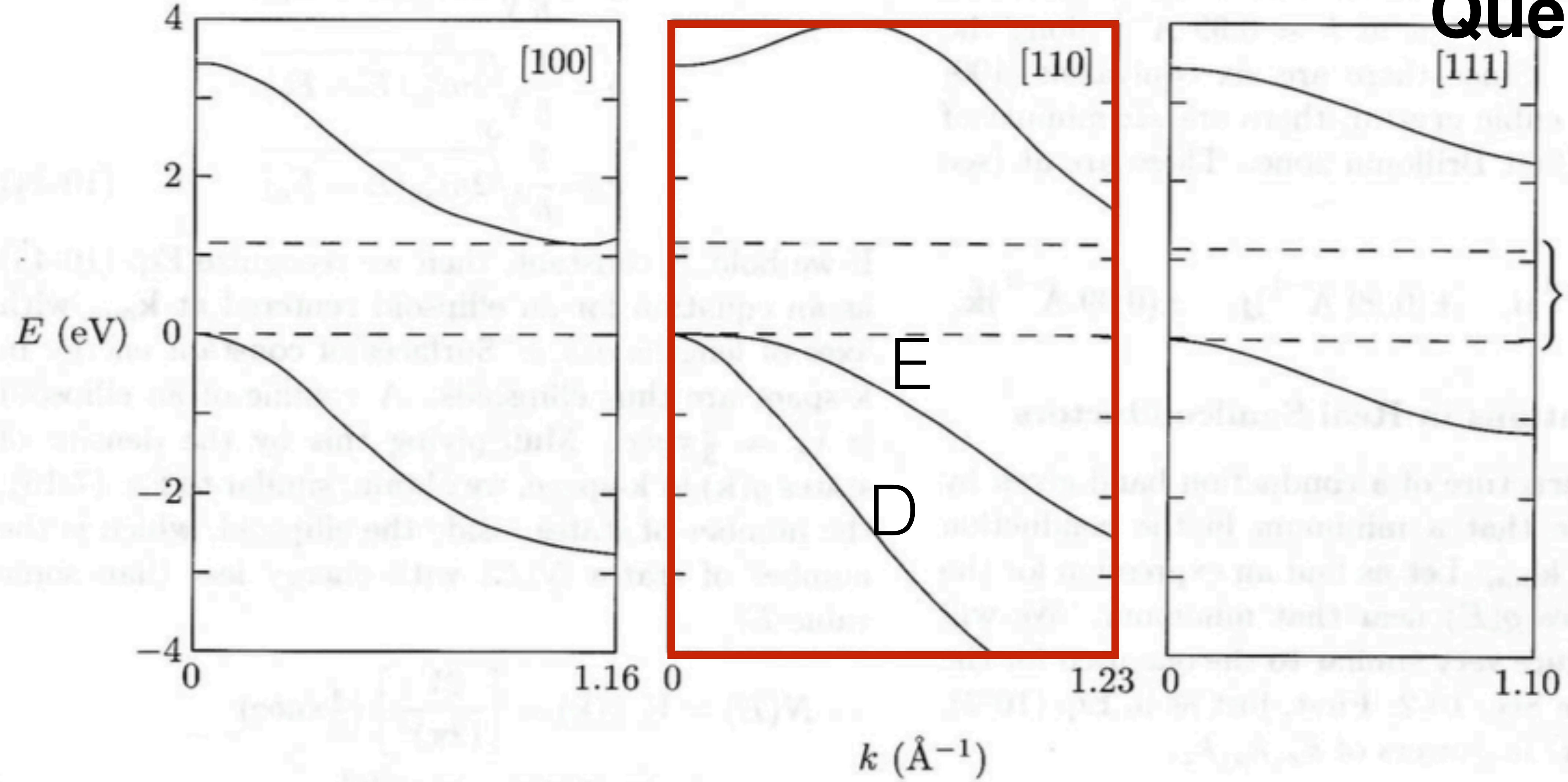

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Question #21

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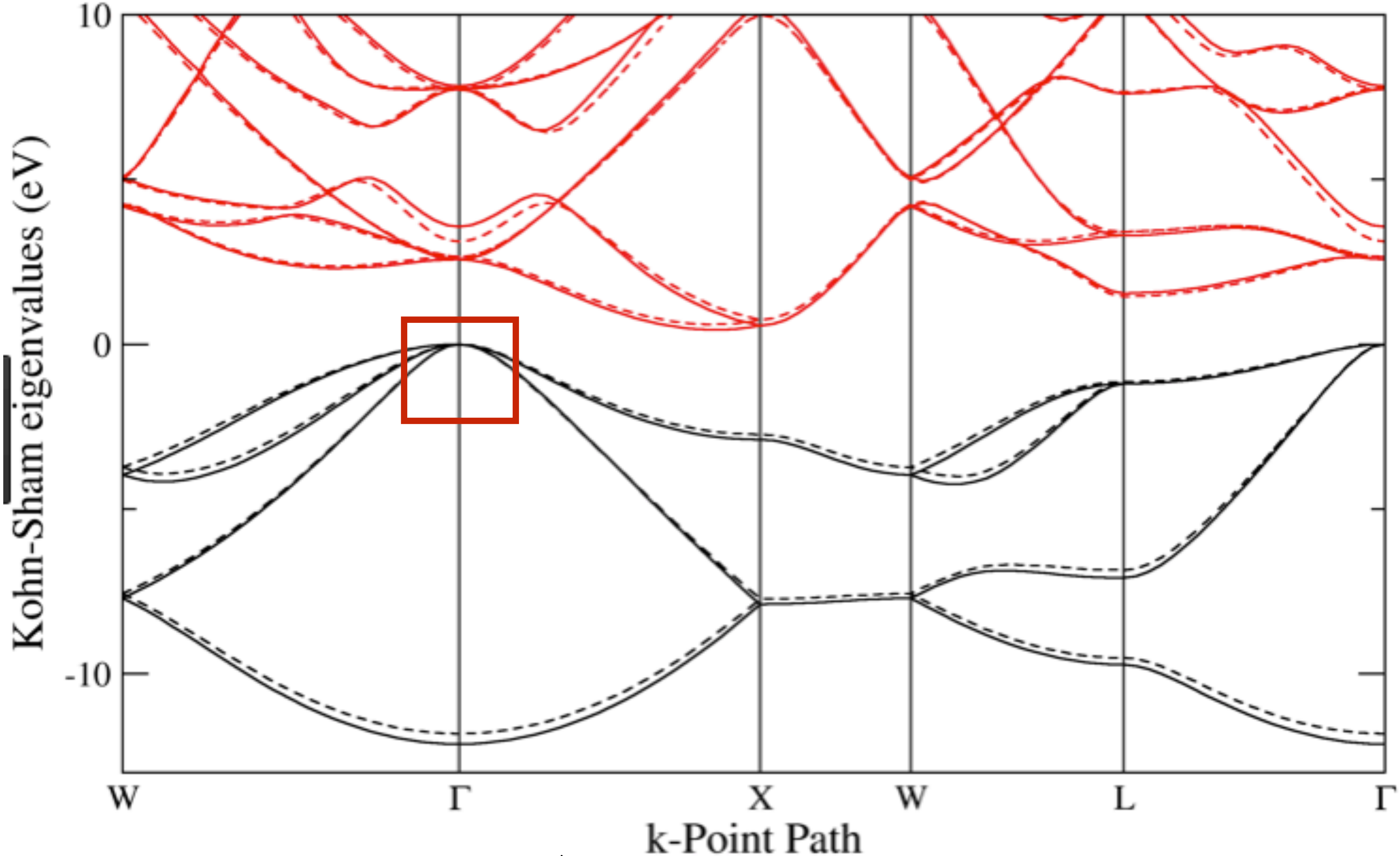
$$g(E) = \frac{V}{2\pi^2}\left(\frac{2m_p^*}{\hbar^2}\right)^{3/2}\sqrt{E_v - E}$$

What does the "new" effective mass have to be so that you can combine these two terms into one.

A $\quad m_p^* = \left[(m_h^*)^{3/2} + (m_l^*)^{3/2}\right]^{2/3}$

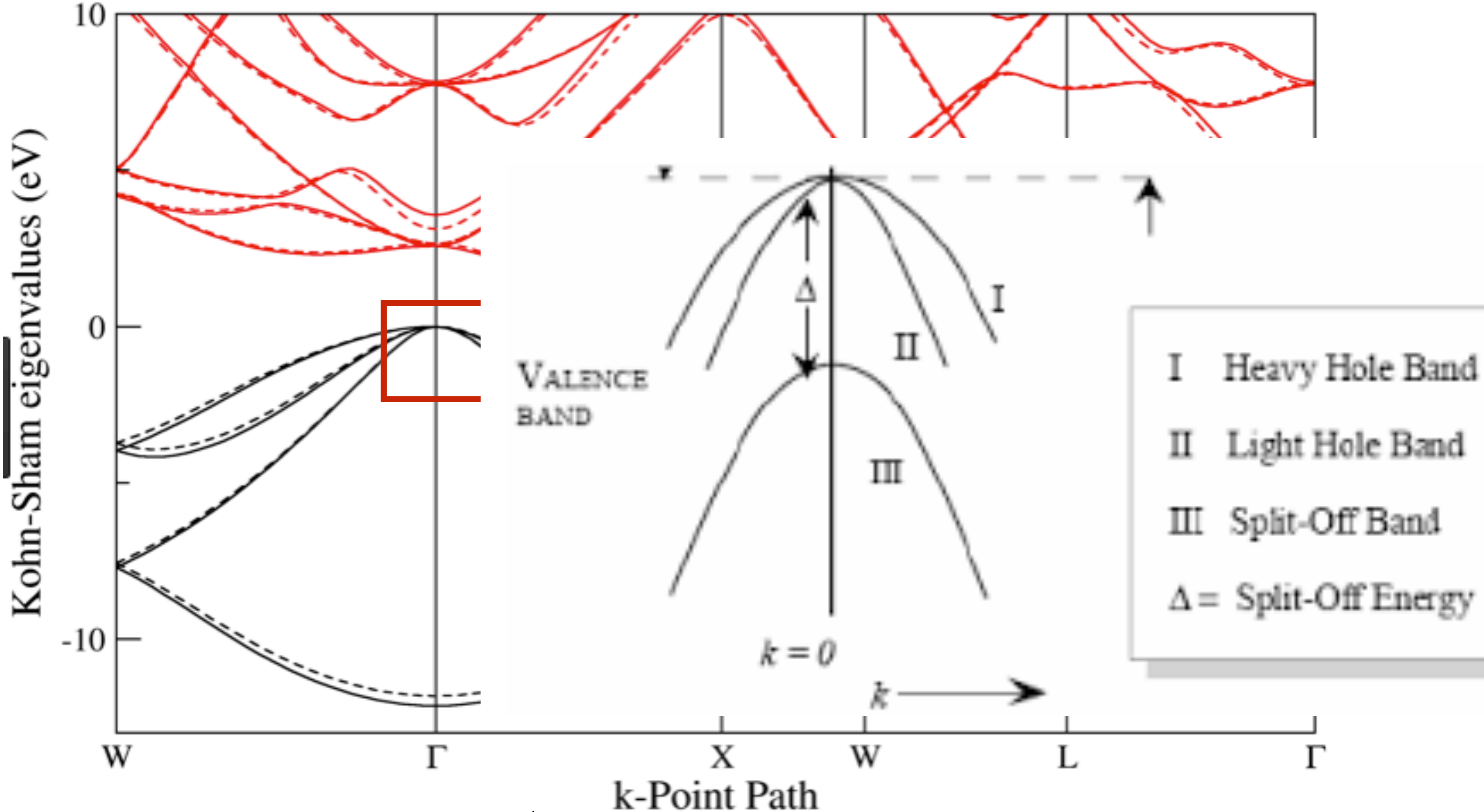
B $\quad m_p^* = \left[(m_h^*)^{3/2} + (m_l^*)^{3/2}\right]^{3/2}$

C $\quad m_p^* = \left[(m_h^*)^{3/2} + (m_l^*)^{3/2}\right]$



$$g(E) = \frac{V}{2\pi^2} \left(\frac{2m^*_{so}}{\hbar^2} \right)^{3/2} \sqrt{E_v - E - \Delta_{so}}$$

$$p_{so} = 2 \left(\frac{m^*_{so} k_B T}{2\pi\hbar^2} \right)^{3/2} e^{-\frac{E_F - E_v - \Delta_{so}}{k_B T}}$$



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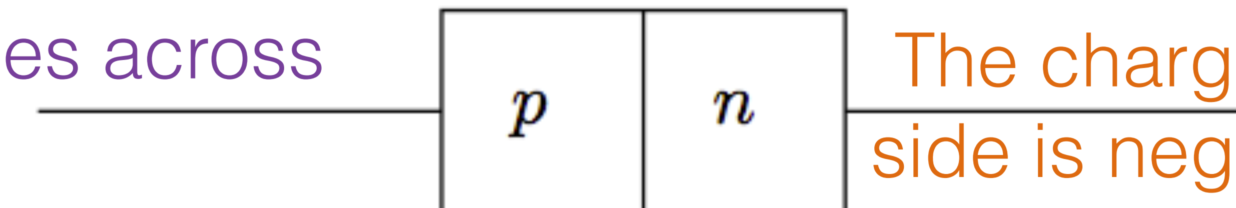
What will happen when I put an n-type semiconductor next to a p-type semiconductor?

A potential difference will appear across the junction

The charge of the junction's p-side is negative and the charge of the junctions n-side is positive.

The Fermi energy varies across the junction



The charge of the junction's n-side is negative and the charge of the junctions p-side is positive.

electrons from n-side diffuse to the p-side.

The junction is neutrally charged

electrons from p-side diffuse to the n-side.

The Fermi energy is constant across the junction.

holes from p-side diffuse to the n-side.

electrons and holes recombine at the junction.

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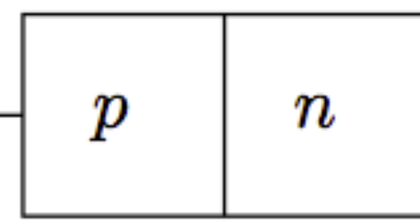

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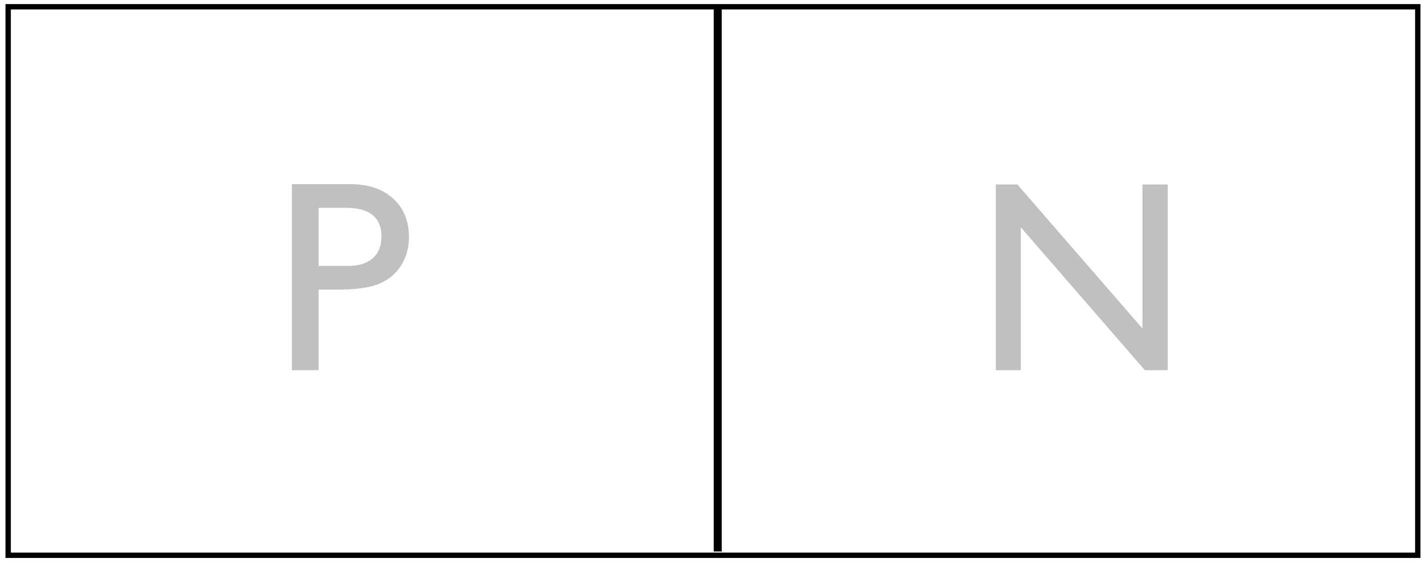
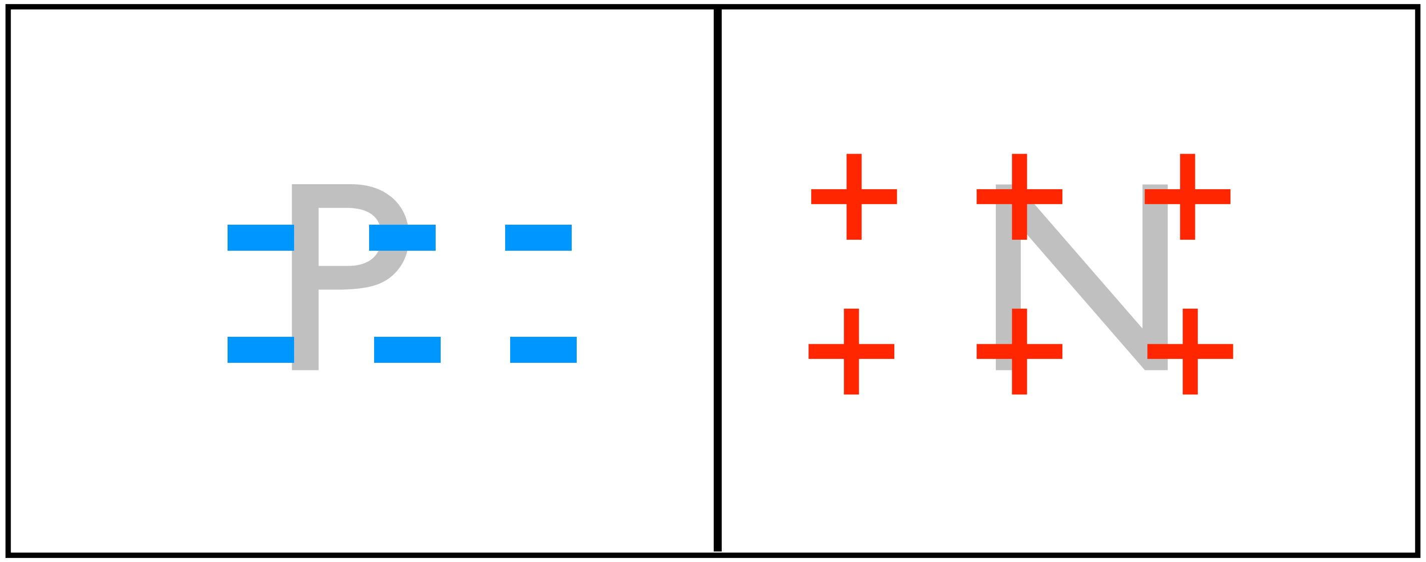
p-n junction, diffusion



p-n junction, diffusion



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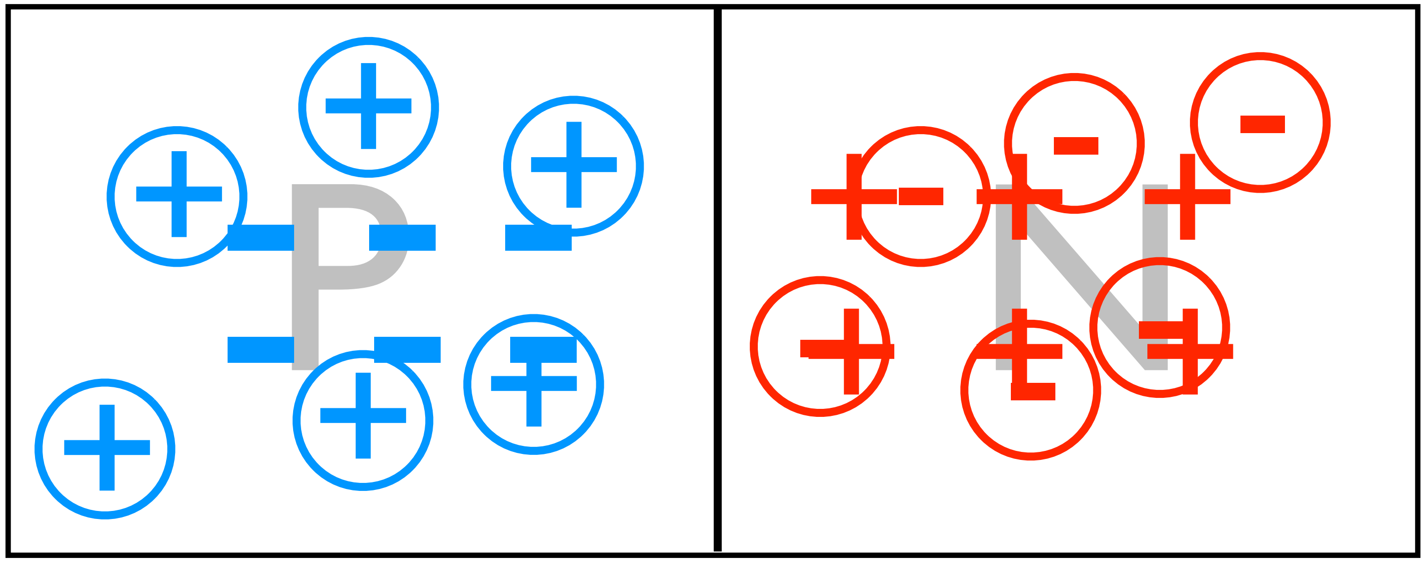

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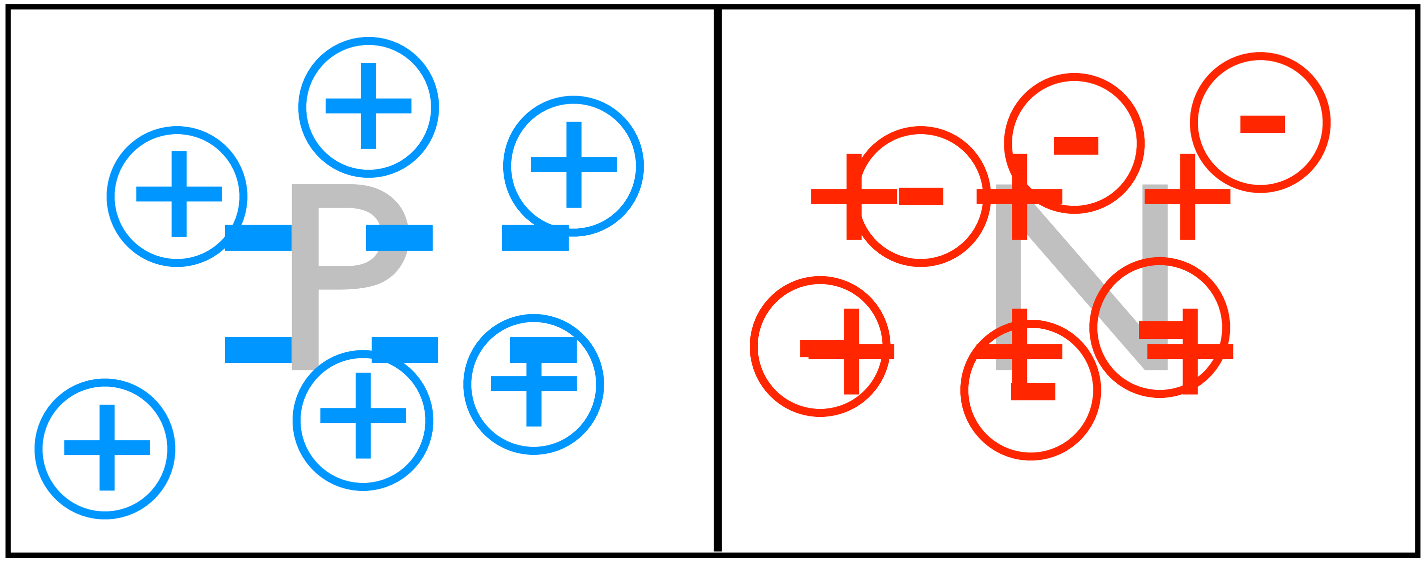
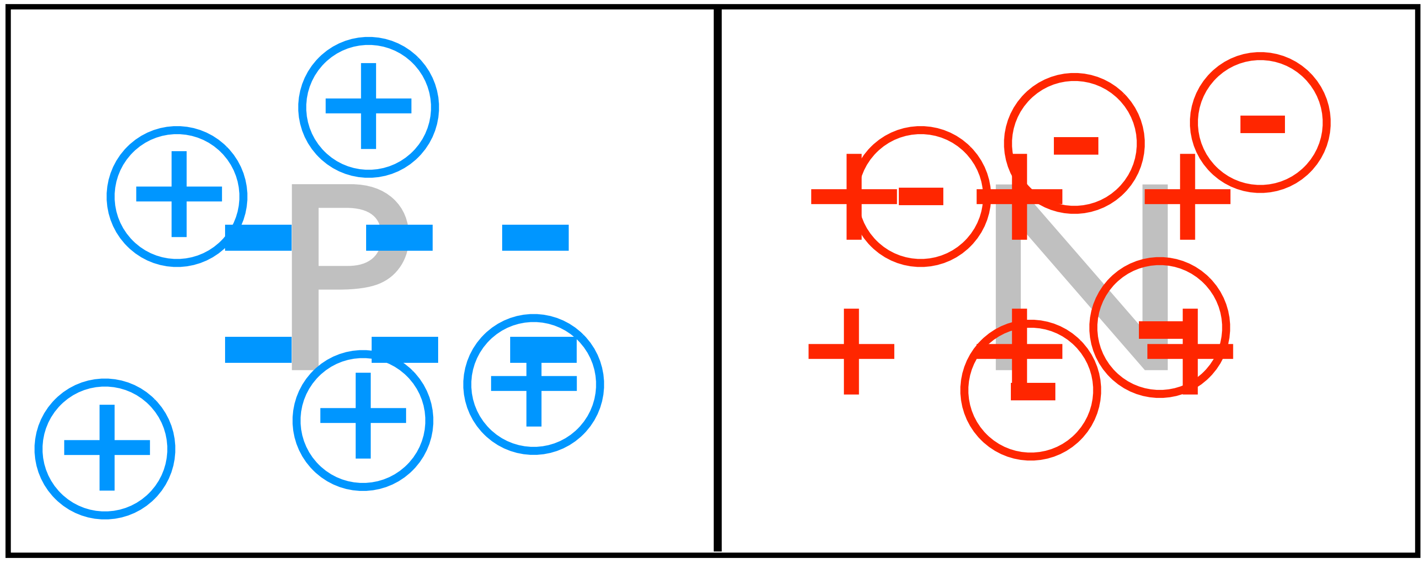
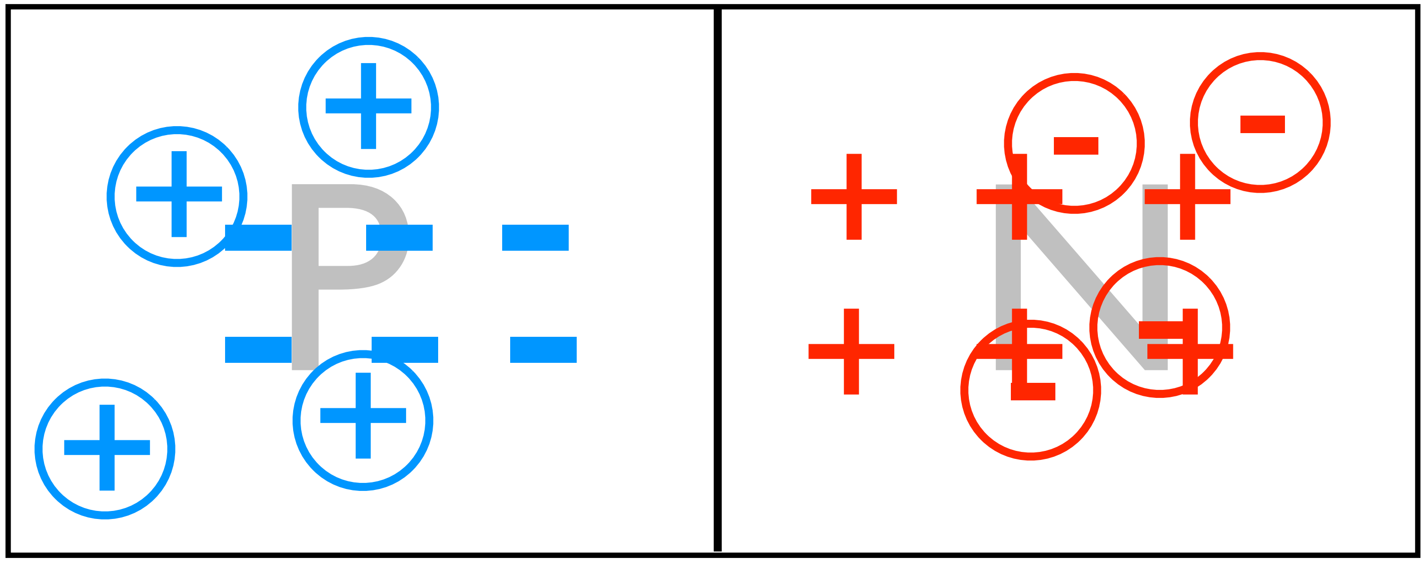


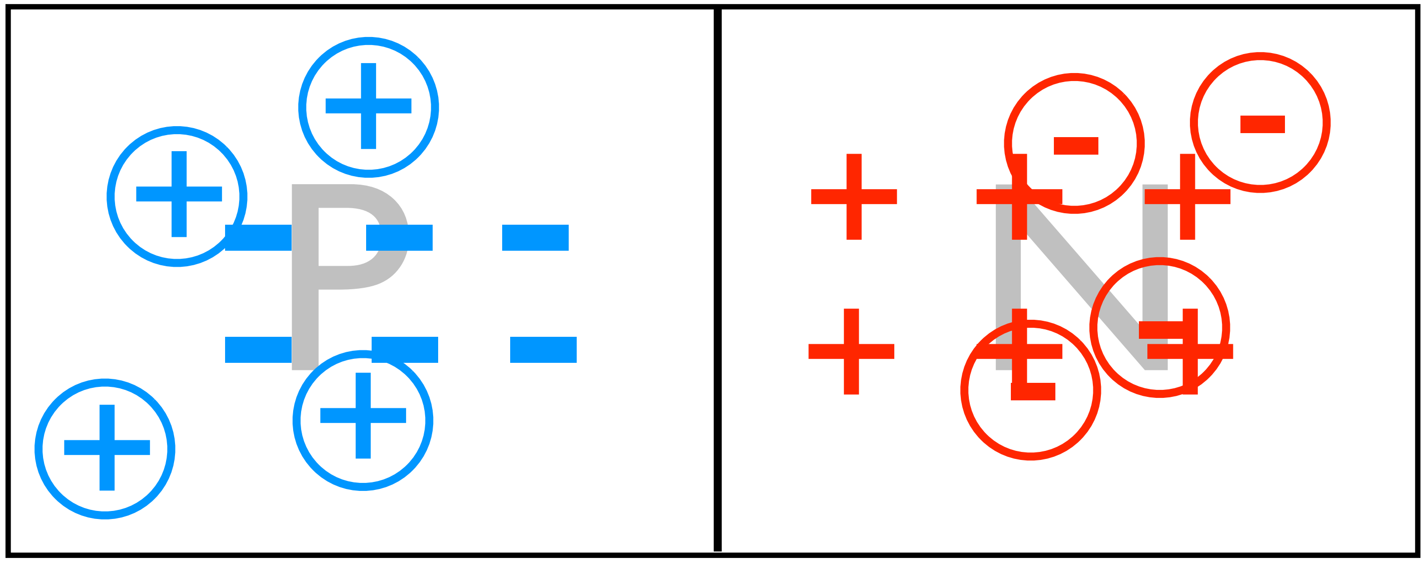
p-n junction, diffusion



p-n junction, diffusion



p-n junction, diffusion



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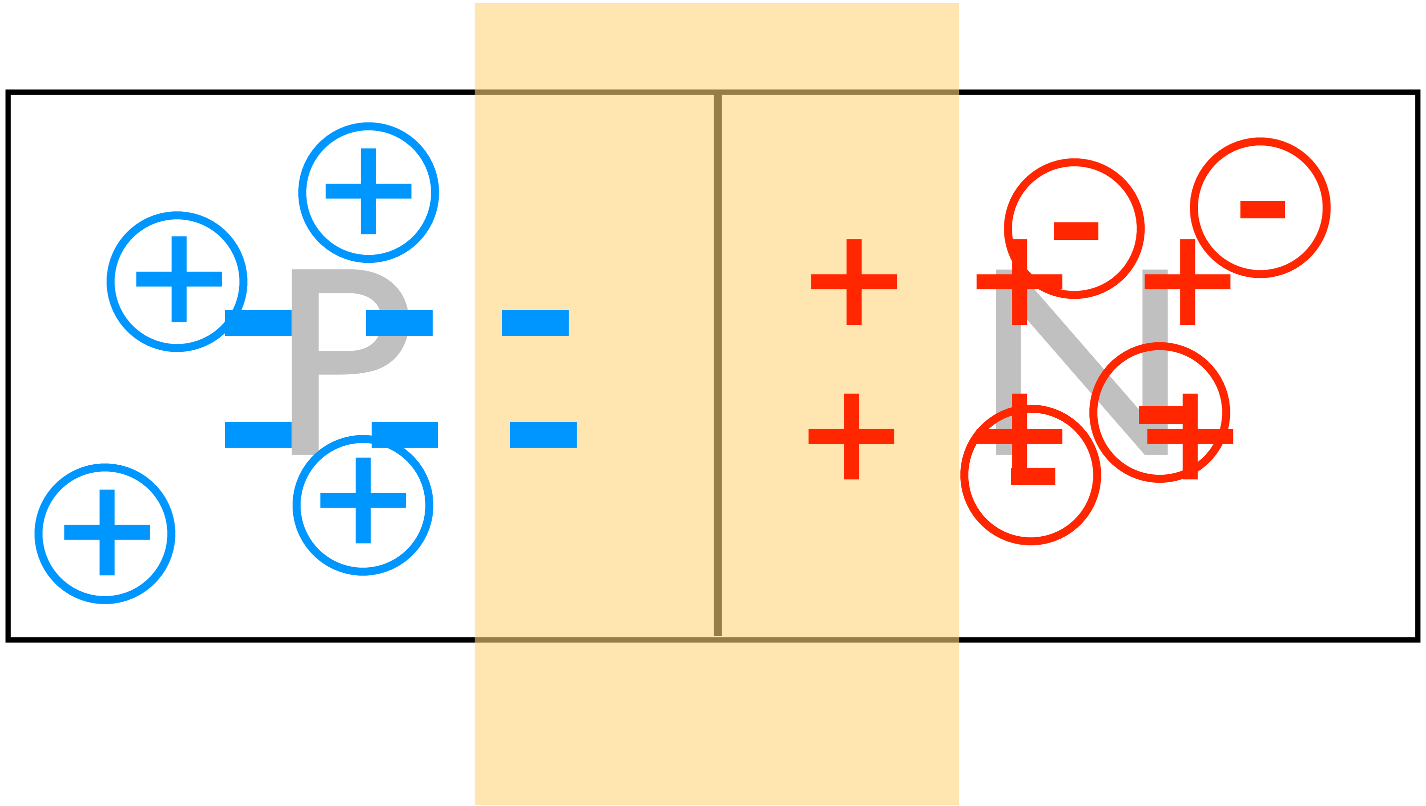
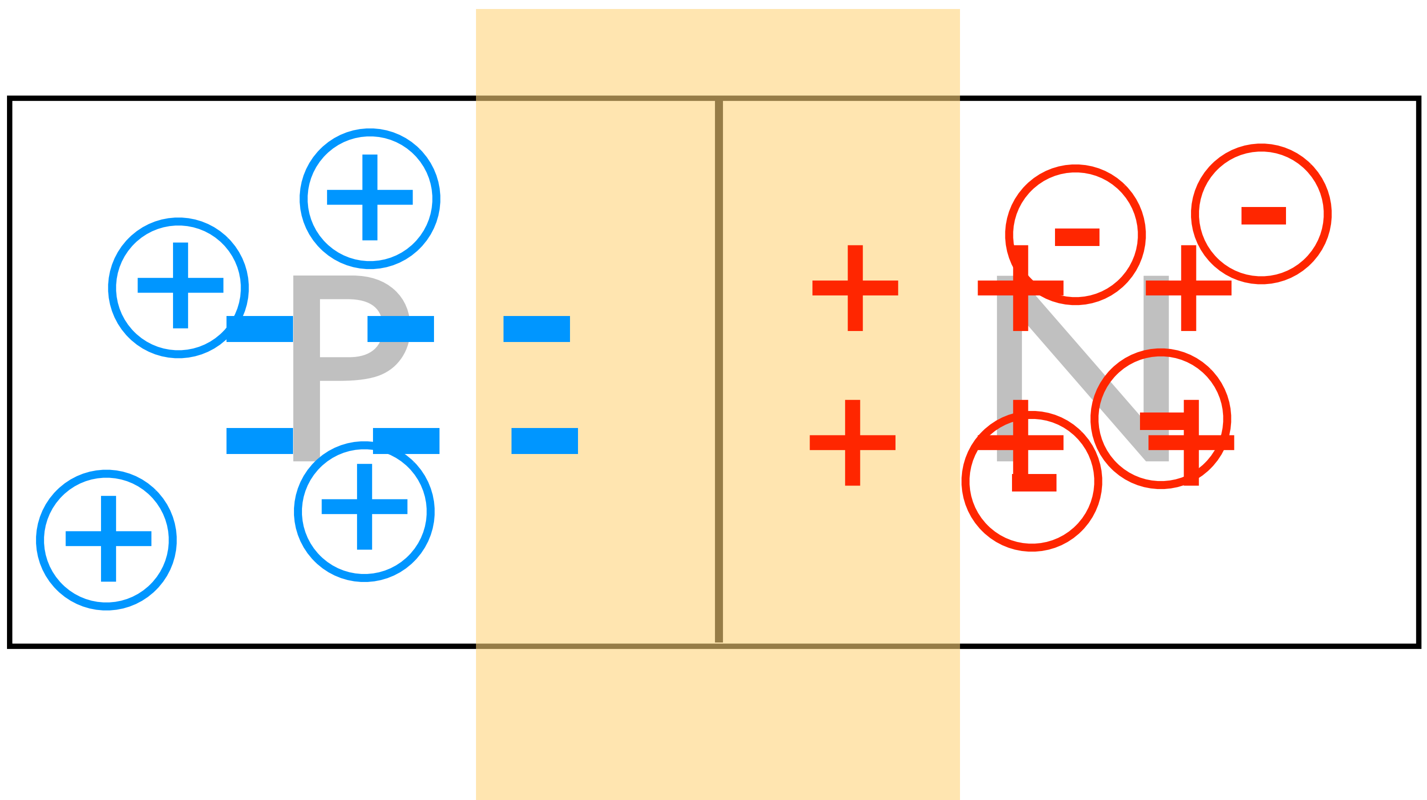


p-n junction, diffusion



Depletion region
(no carriers)

p-n junction, diffusion

The net charge density in the depletion region on the p side of a p-n junction is
(A) positive.
(B) zero.
(C) negative.

Question #22

p-n junction, diffusion

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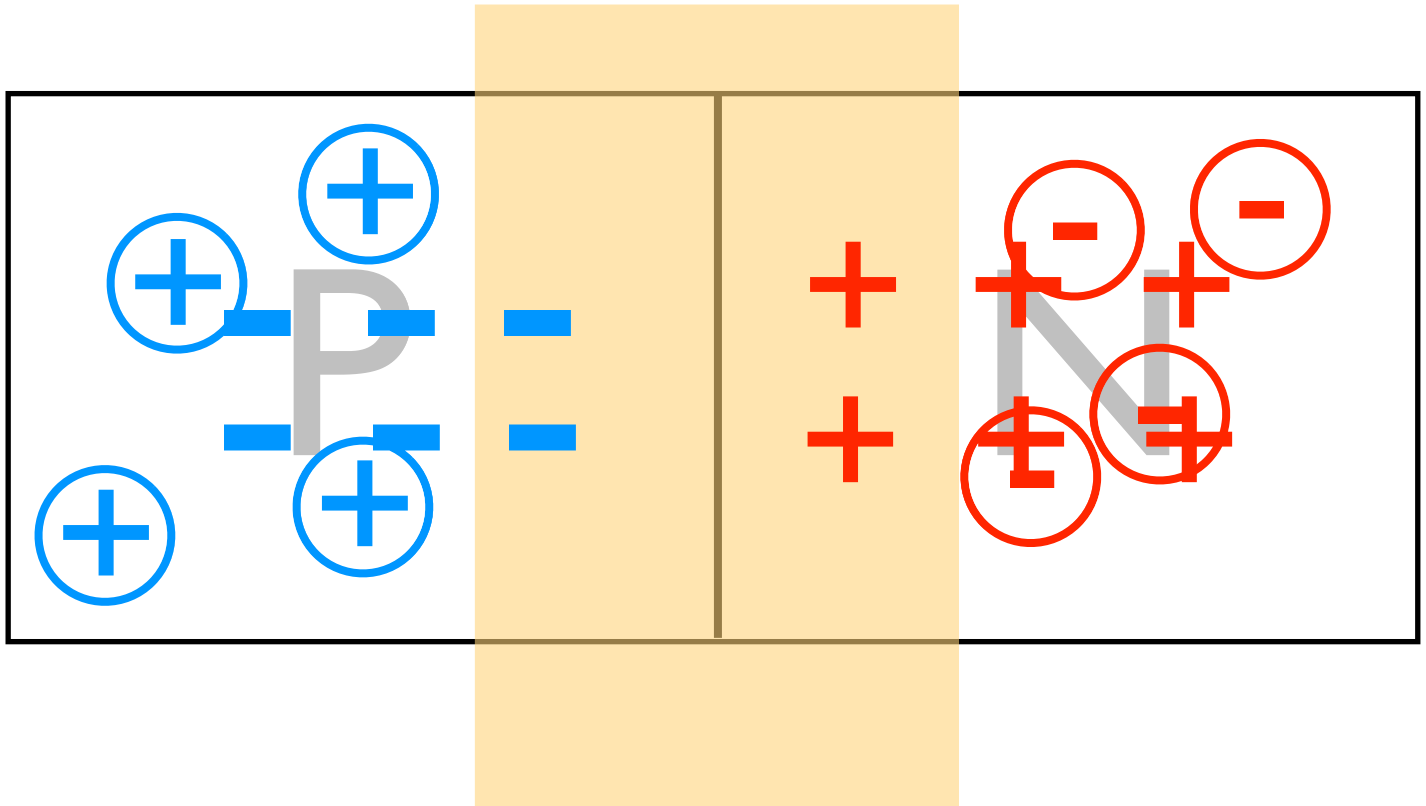
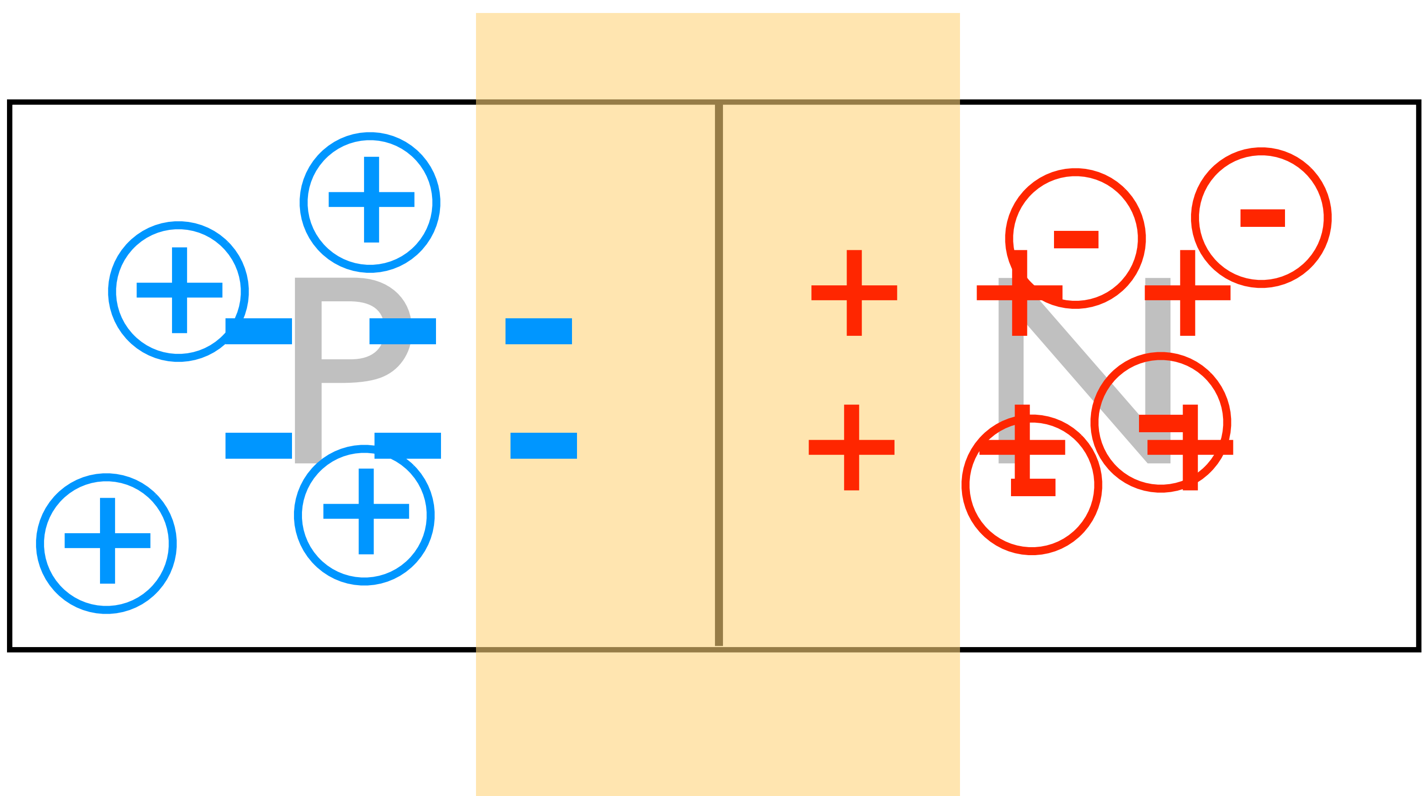


Depletion region

Electric field?

In the depletion region
(C)there is no electric field—no net charge.
(D) there is an electric field pointing right.
(E) there is an electric field pointing left.



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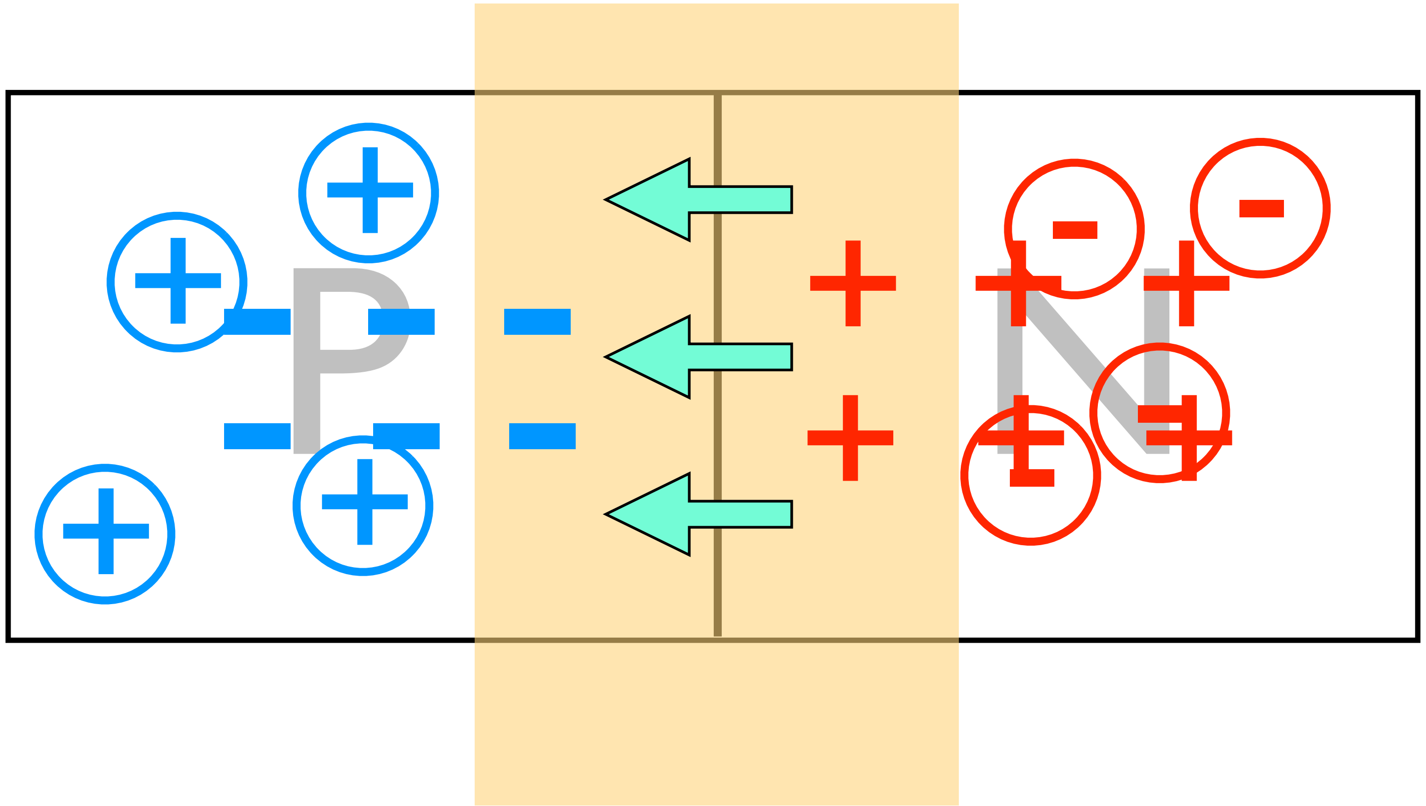
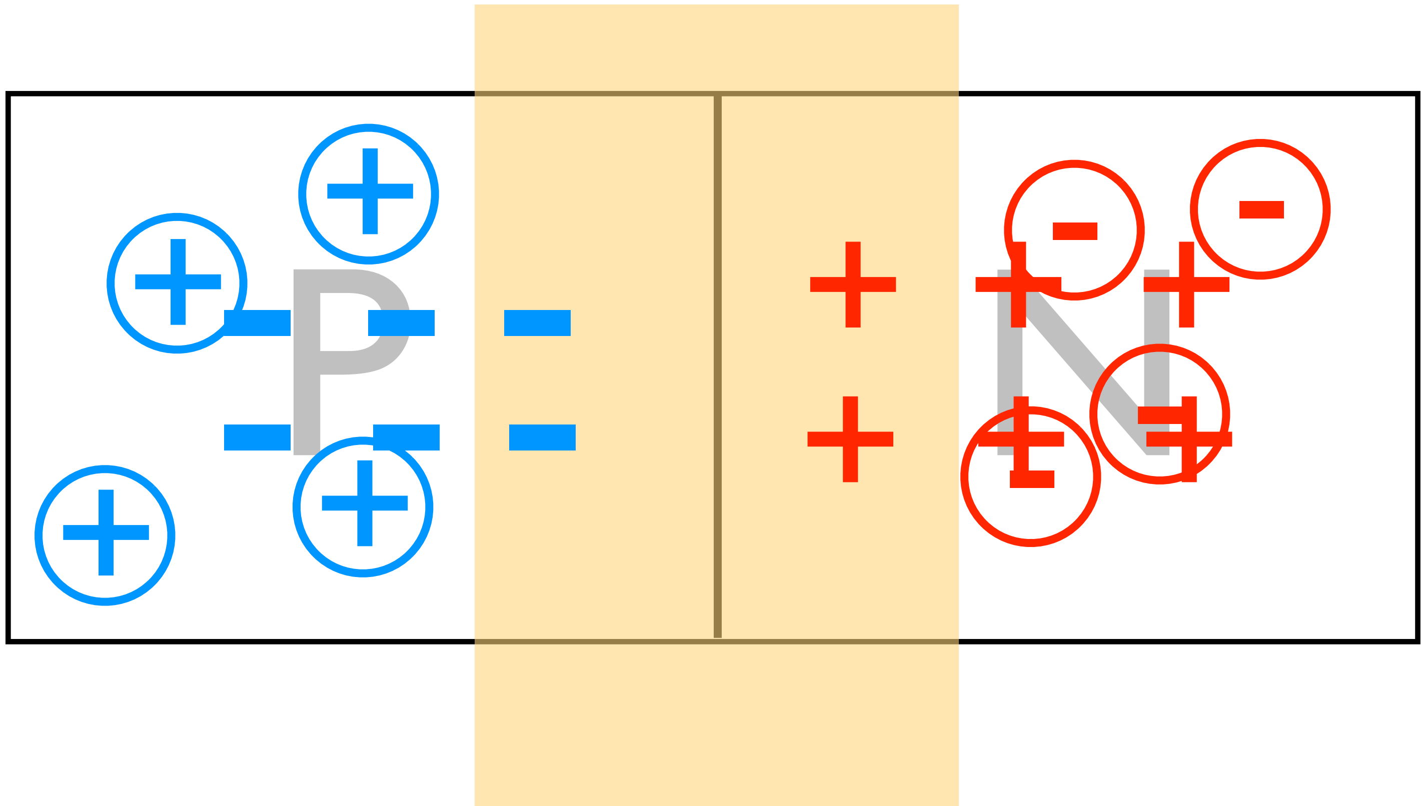


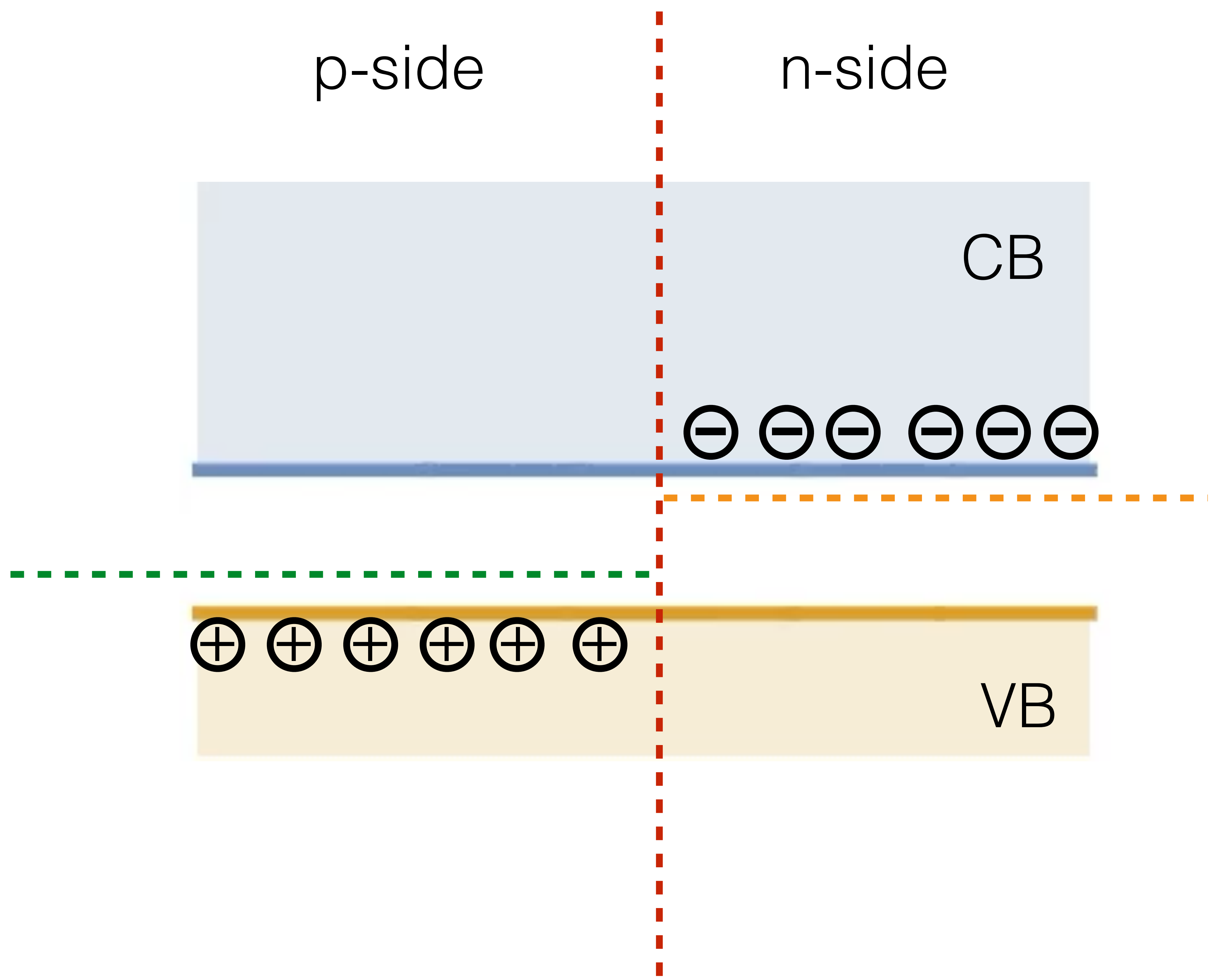
Depletion region

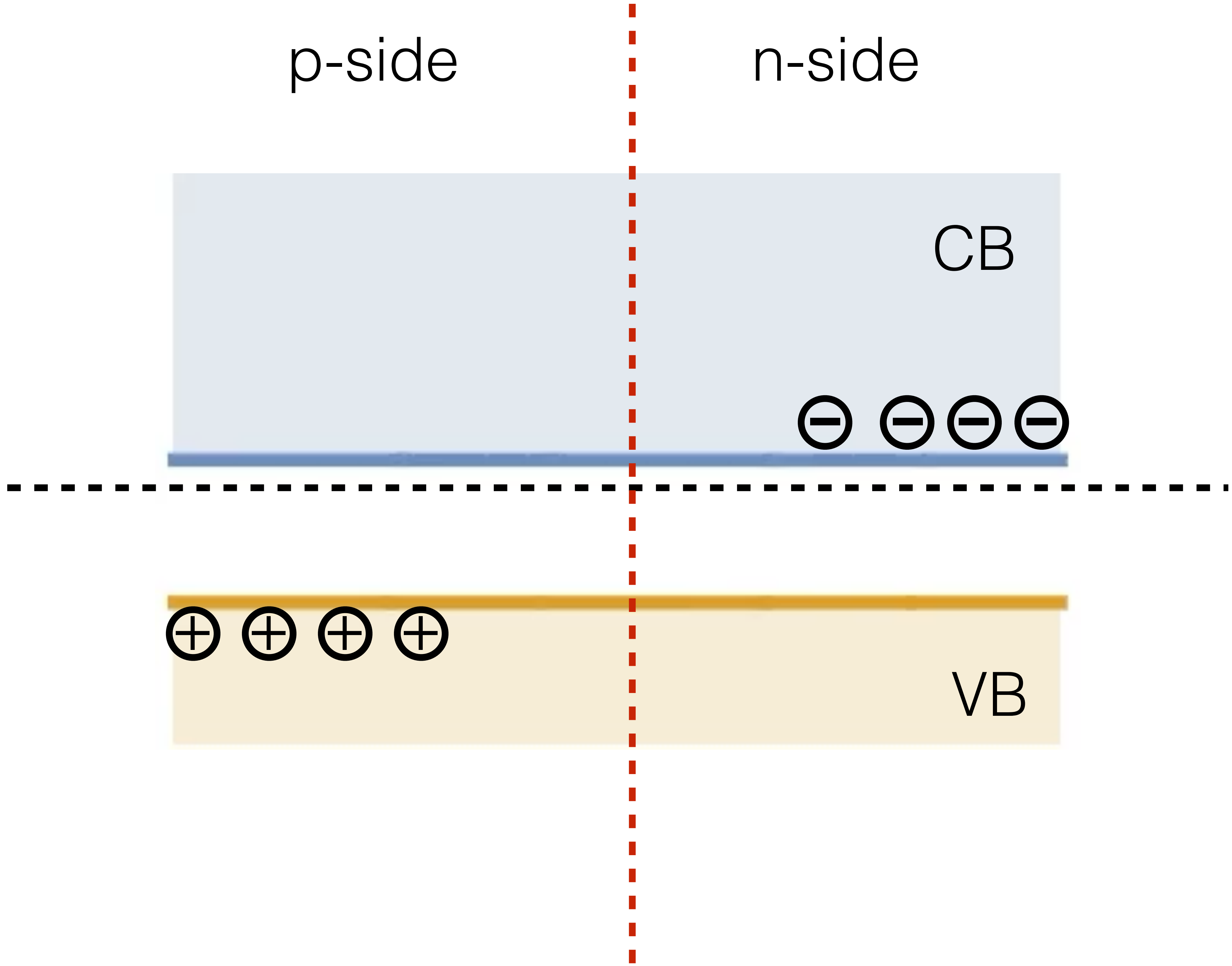
Electric field

What is the effect of the field on the bands?



Depletion region


p-side
n-side
CB
VB


p-side
n-side
CB
VB

What happens to the bands when depletion region forms?

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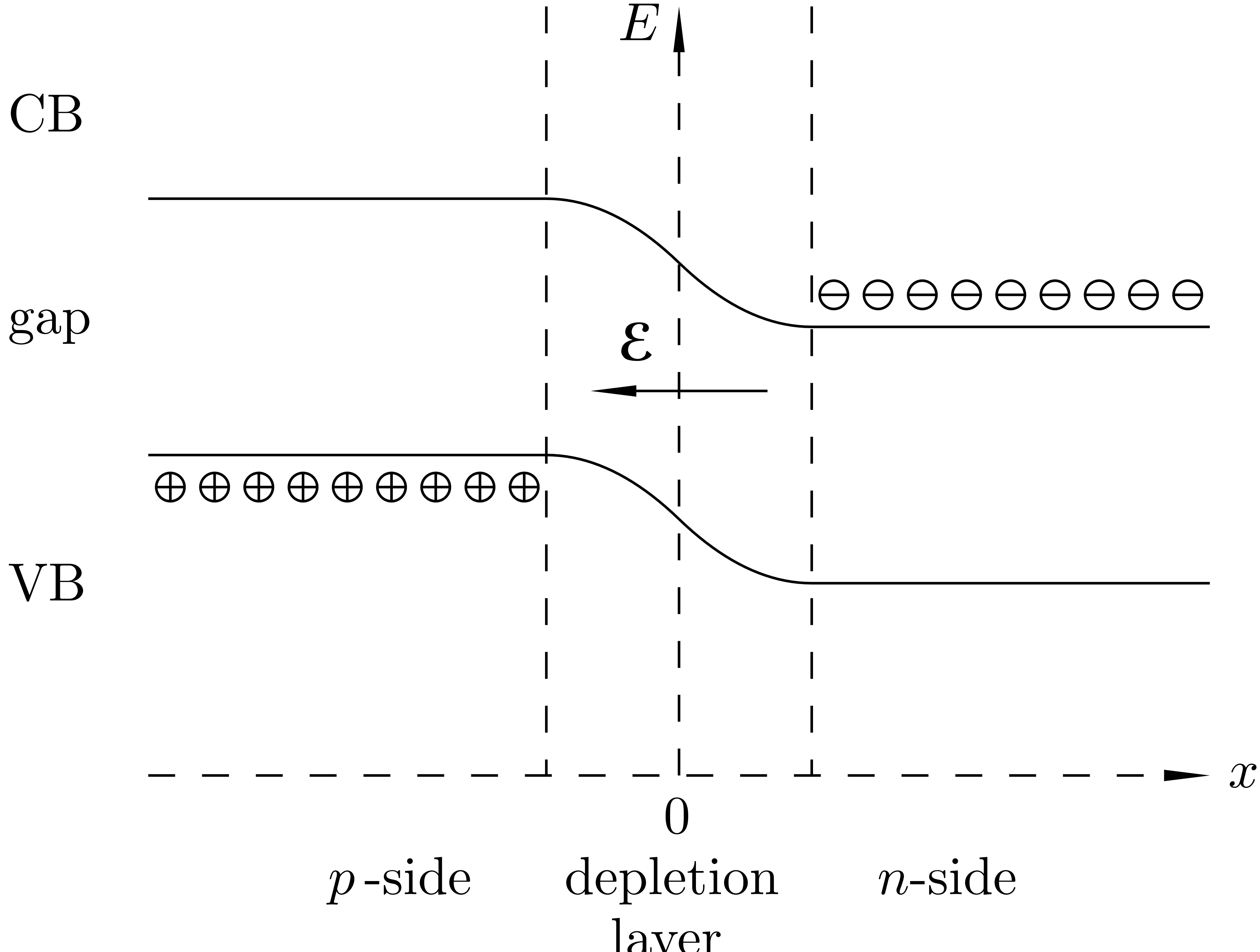

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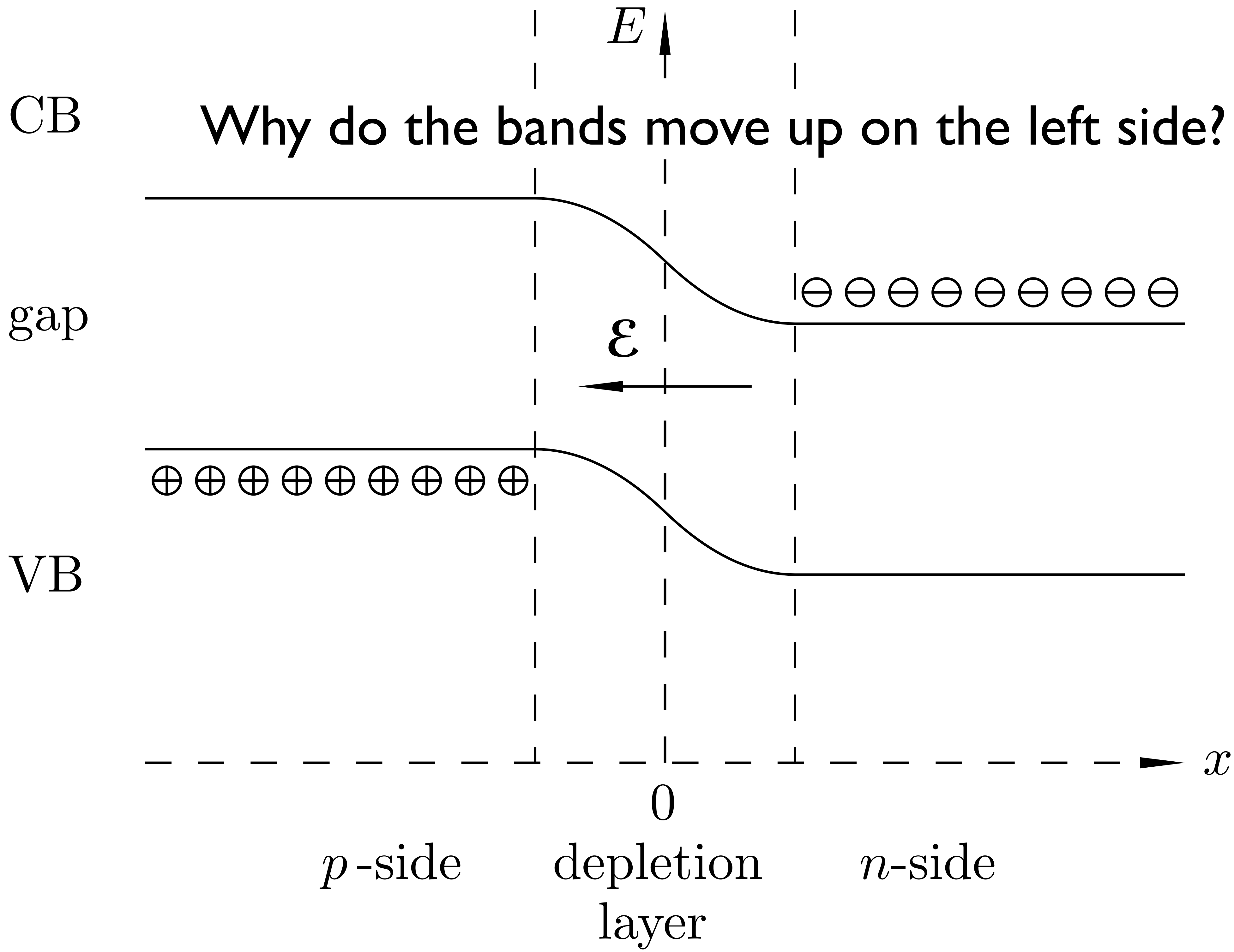
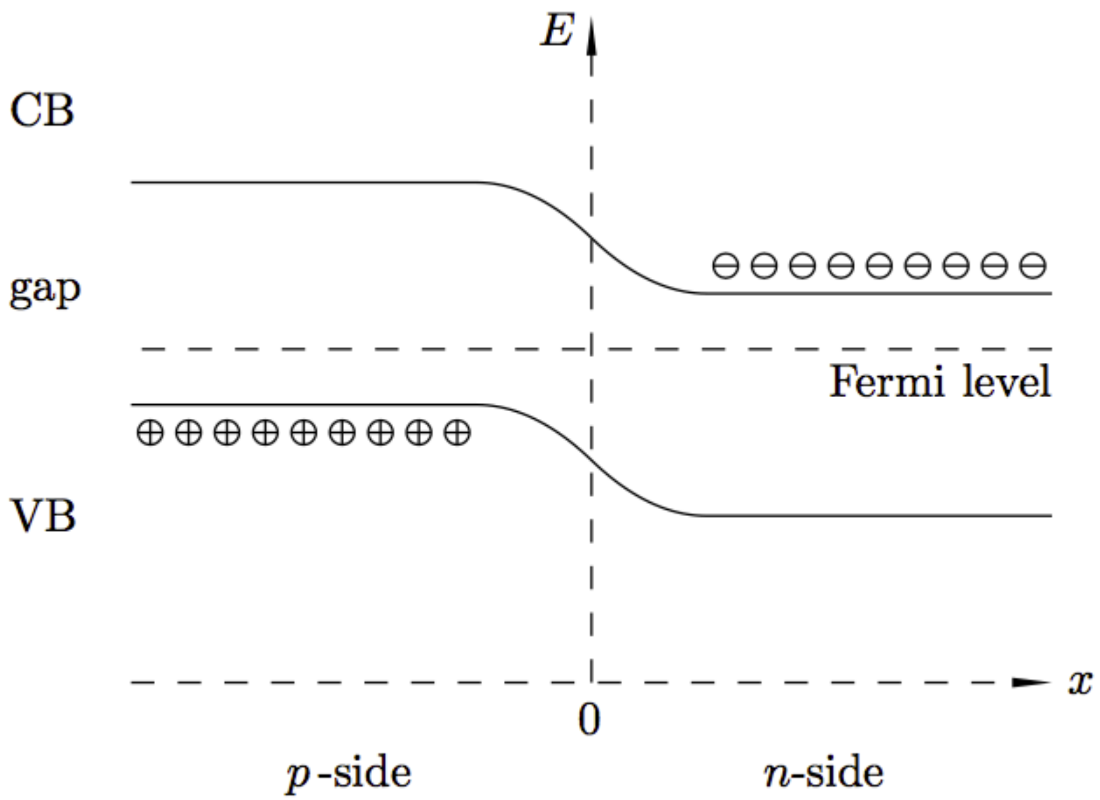


$$n = N_c e^{-\frac{E_c - E_F}{k_B T}}$$

$$n_i = \sqrt{N_c N_v} e^{-\frac{E_g}{2 k_B T}}$$



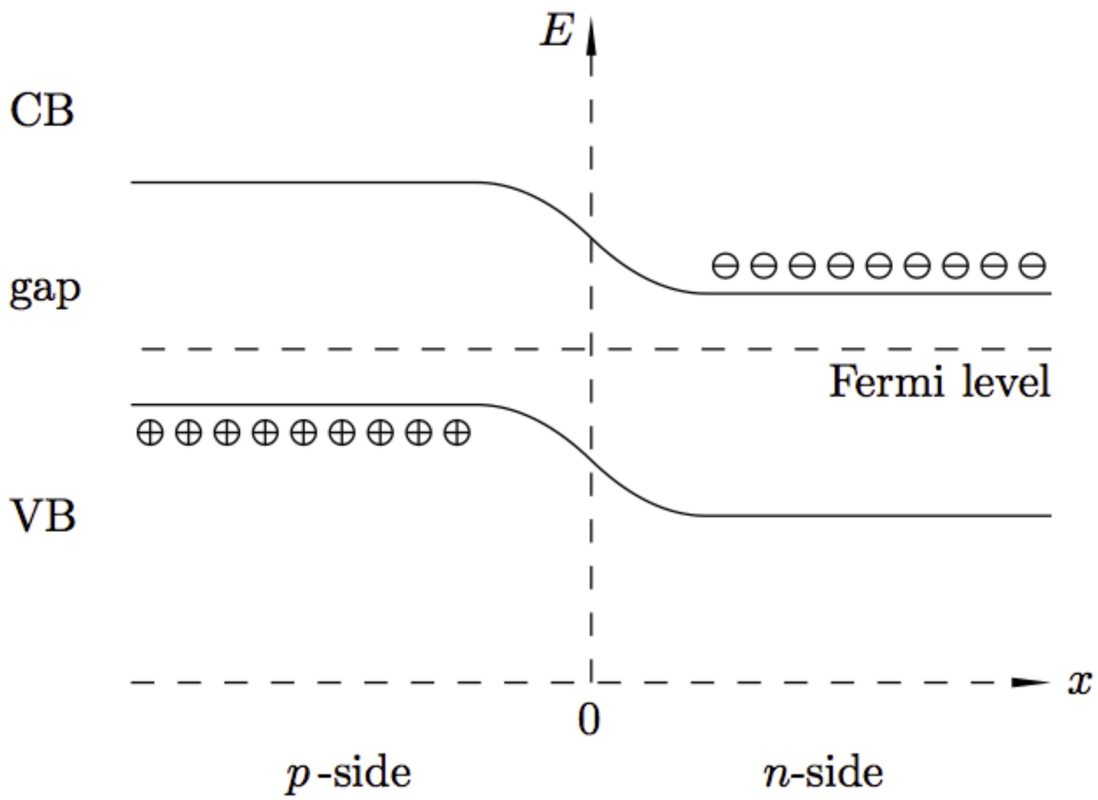
Use the above equations to find the fermi energy on the n-side. (problem 11-1)

Your expression must have n_i in it.

Hint #1: for $x \gg 0$, $n = N_D$

Hint #2: Start by dividing the equations

$$n = N_c e^{-\frac{E_c - E_F}{k_B T}} \qquad n_i = \sqrt{N_c N_v} e^{-\frac{E_g}{2k_B T}}$$



Use the above equations to find the fermi energy on the n-side. (problem 11-1)

Your expression must have n_i in it.

Hint #1: for x >> 0, n = N_D

Hint #2: Start by dividing the equations

$$E_F = \frac{1}{2}(E_c + E_v) + k_B T \ln\left(\sqrt{\frac{N_v}{N_c}} \frac{N_d}{n_i}\right)$$

$$E_F = \frac{1}{2}(E_c + E_v) + k_B T \ln\left(\sqrt{\frac{N_v}{N_c}}\frac{N_d}{n_i}\right)$$

rename…

$$E_F = \frac{1}{2}\left(E_{cn} + E_{vn}\right) + k_B T \ln\left(\sqrt{\frac{N_c}{N_v}}\frac{N_d}{n_i}\right)$$ n-side

$$E_F = \frac{1}{2}\left(E_{cp} + E_{vp}\right) - k_B T \ln\left(\sqrt{\frac{N_v}{N_c}}\frac{N_a}{n_i}\right)$$ p-side

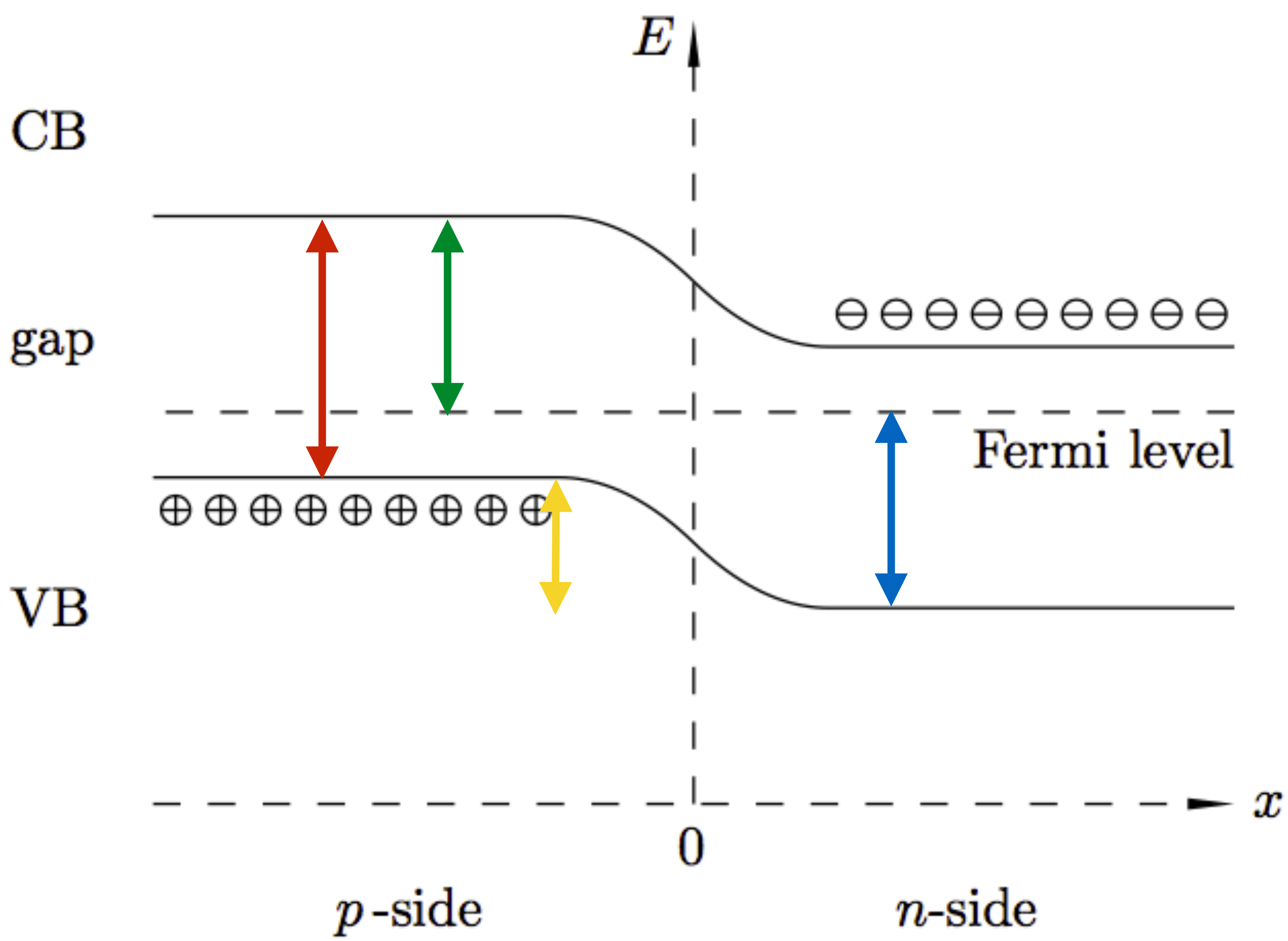
Force the fermi Energies to be equal and solve for:

$$E_{vp} - E_{vn}$$

Problem 11-3

Question #24

$$E_{vp} - E_{vn} = k_B T \ln\left(\frac{N_a N_d}{n_i^2}\right)$$



Question #24

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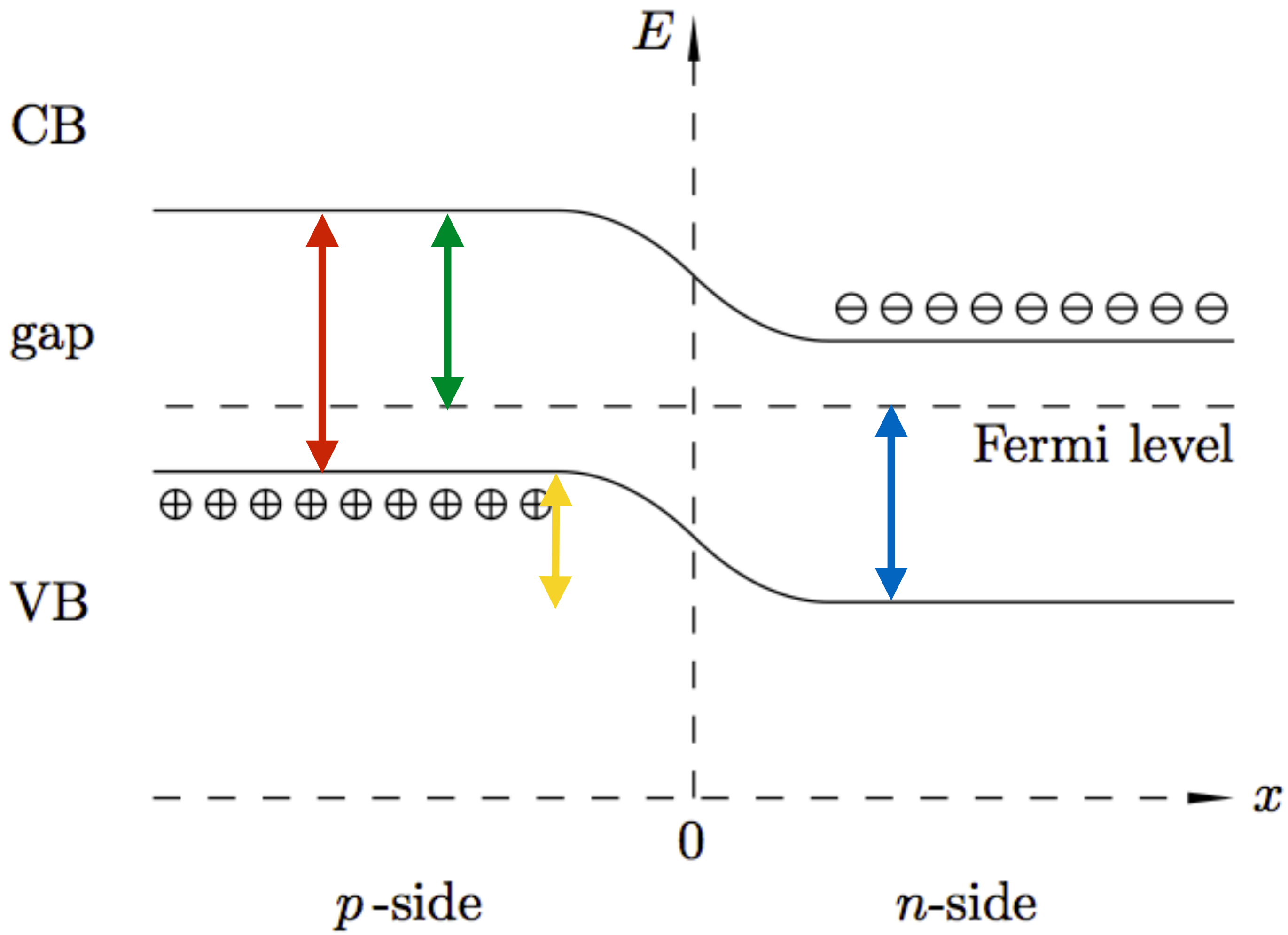

Identify this energy difference on the diagram.

Question #24

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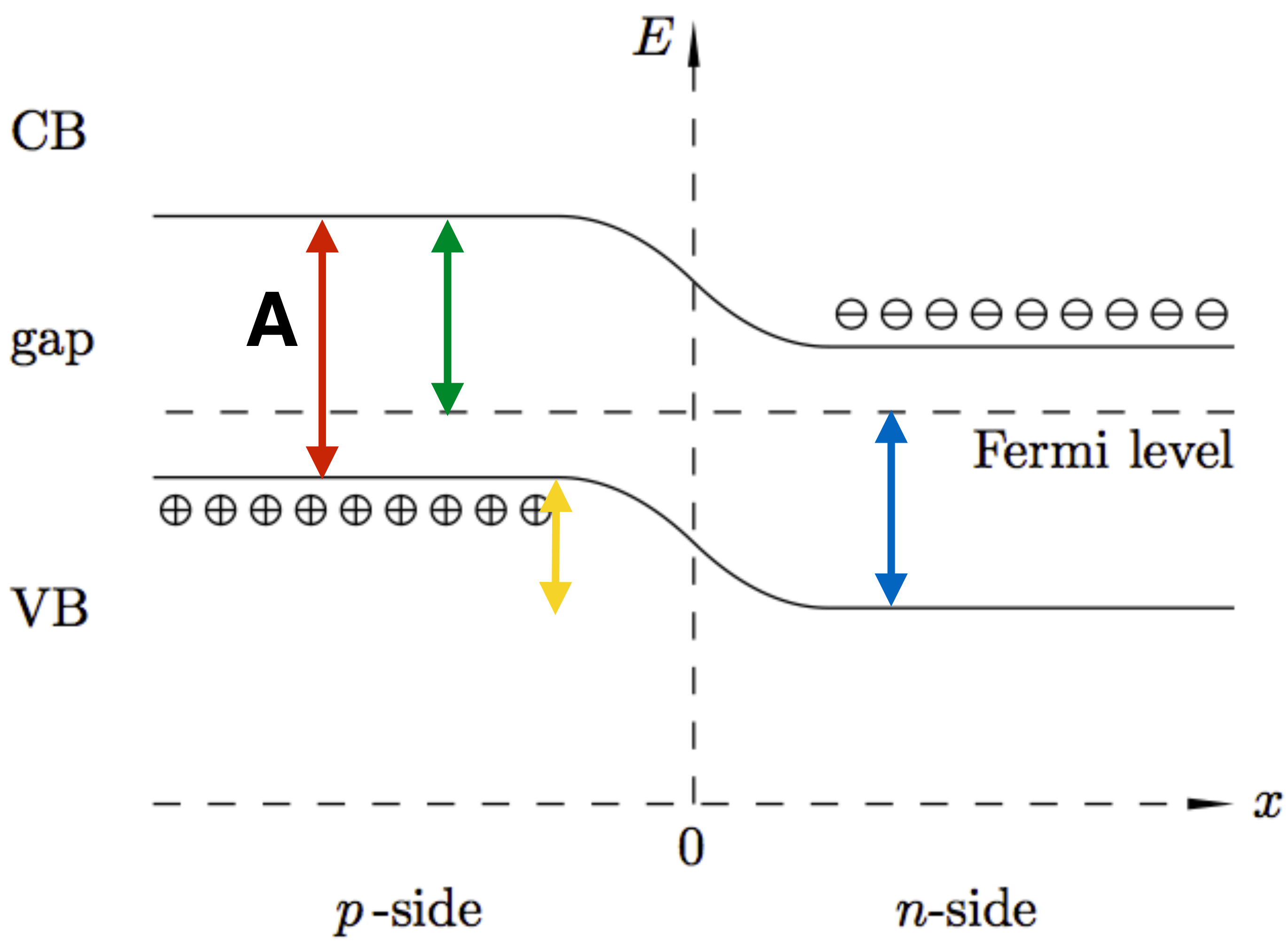

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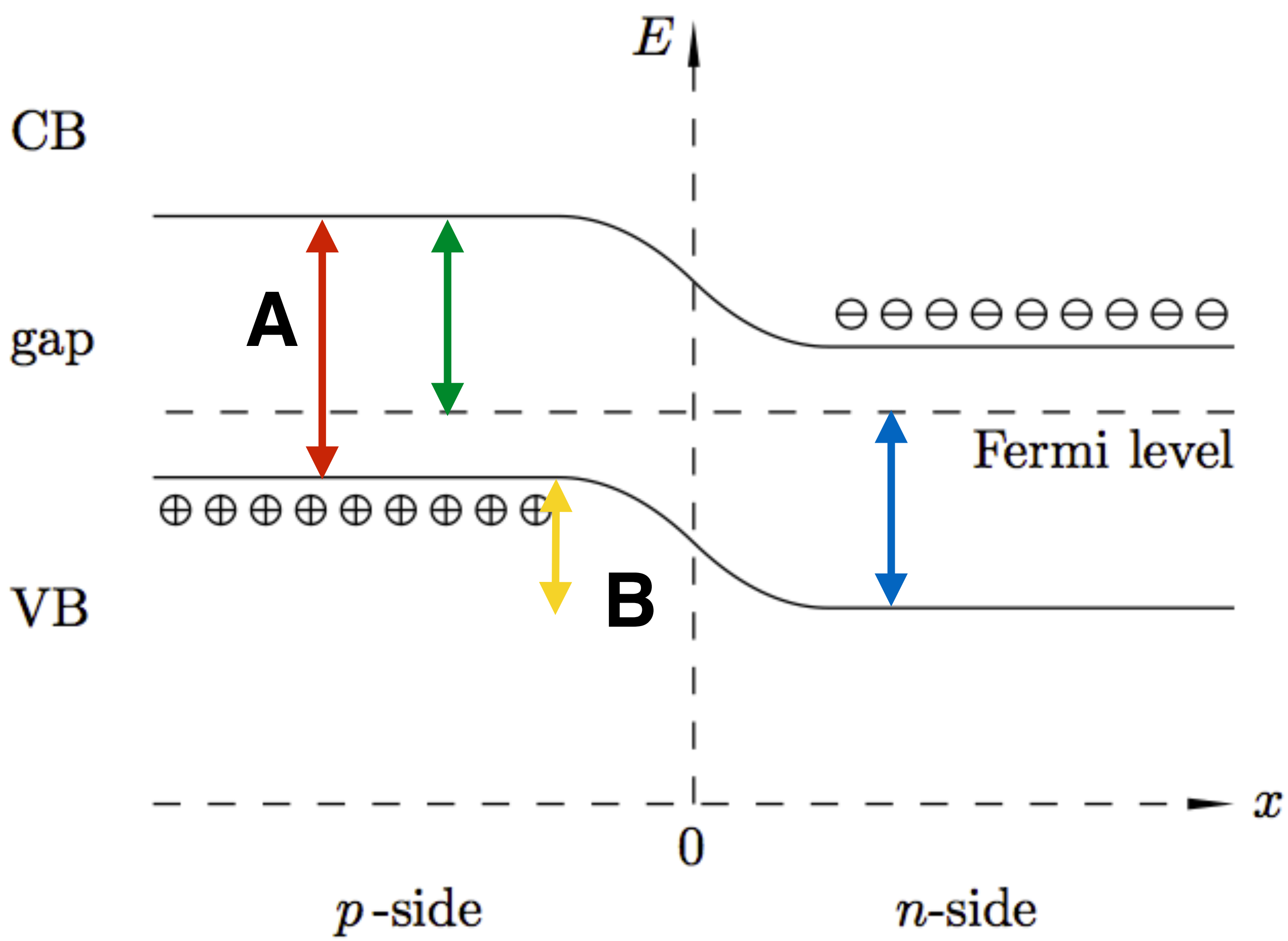

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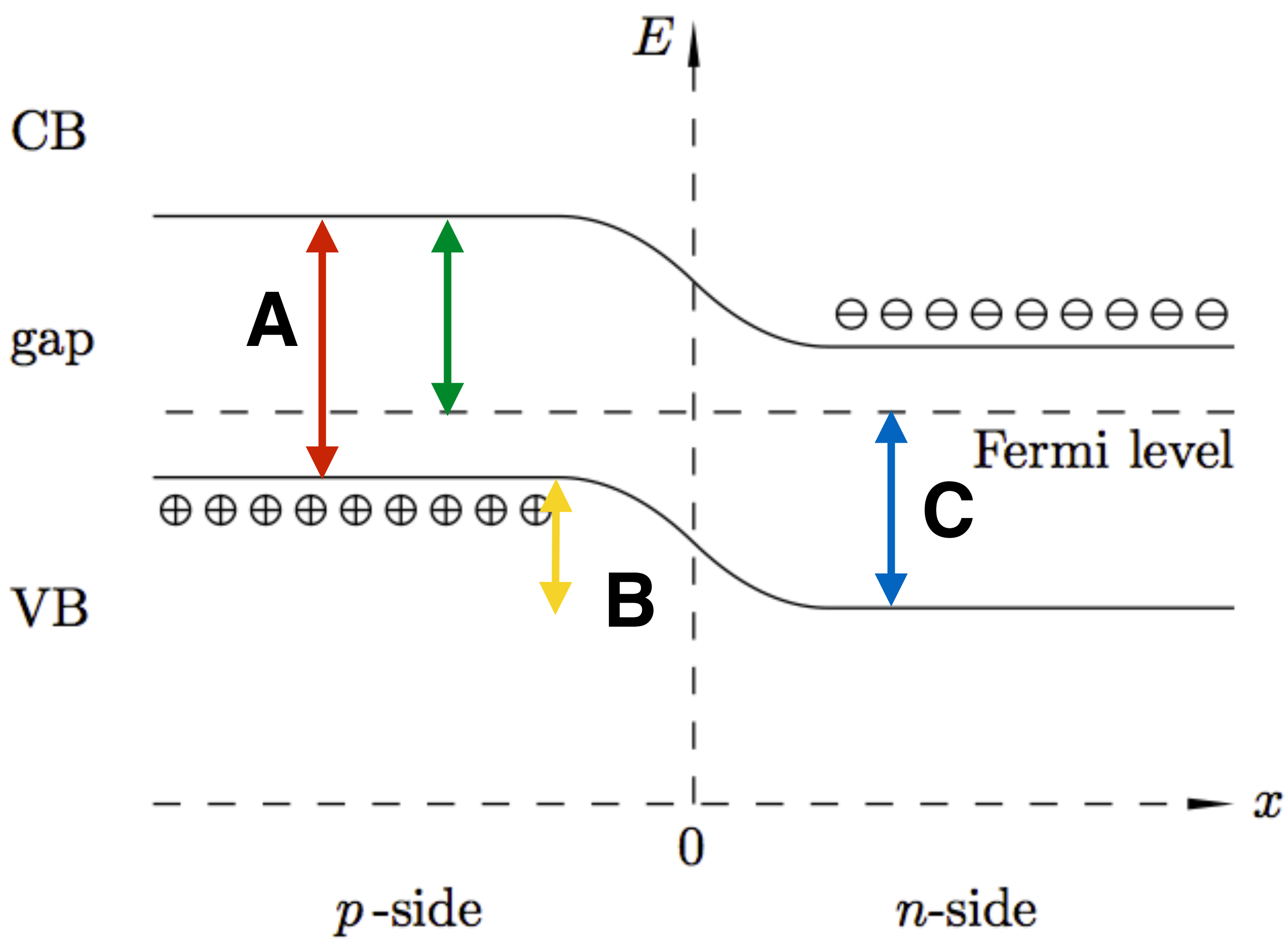
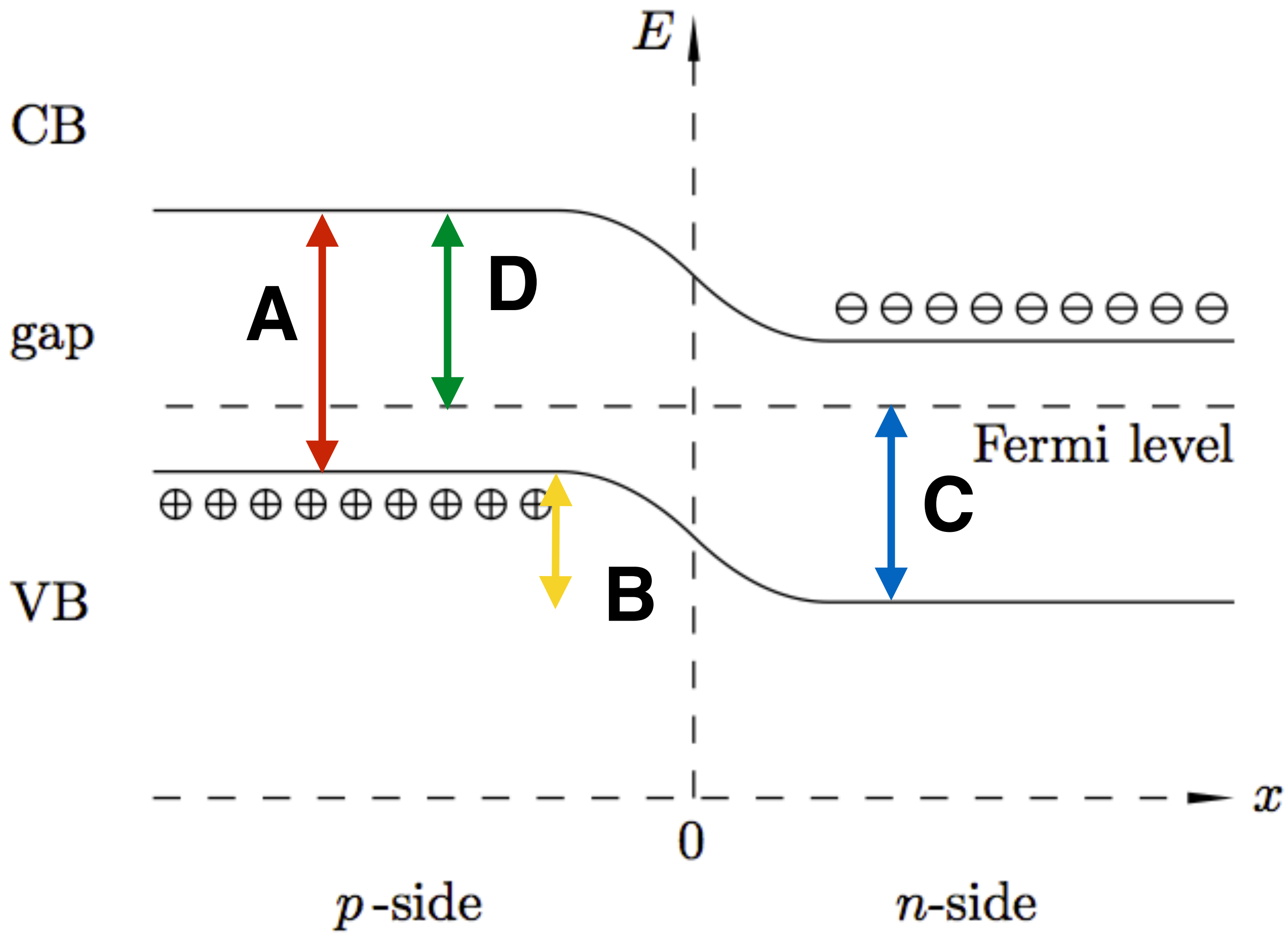


Identify this energy difference on the diagram.

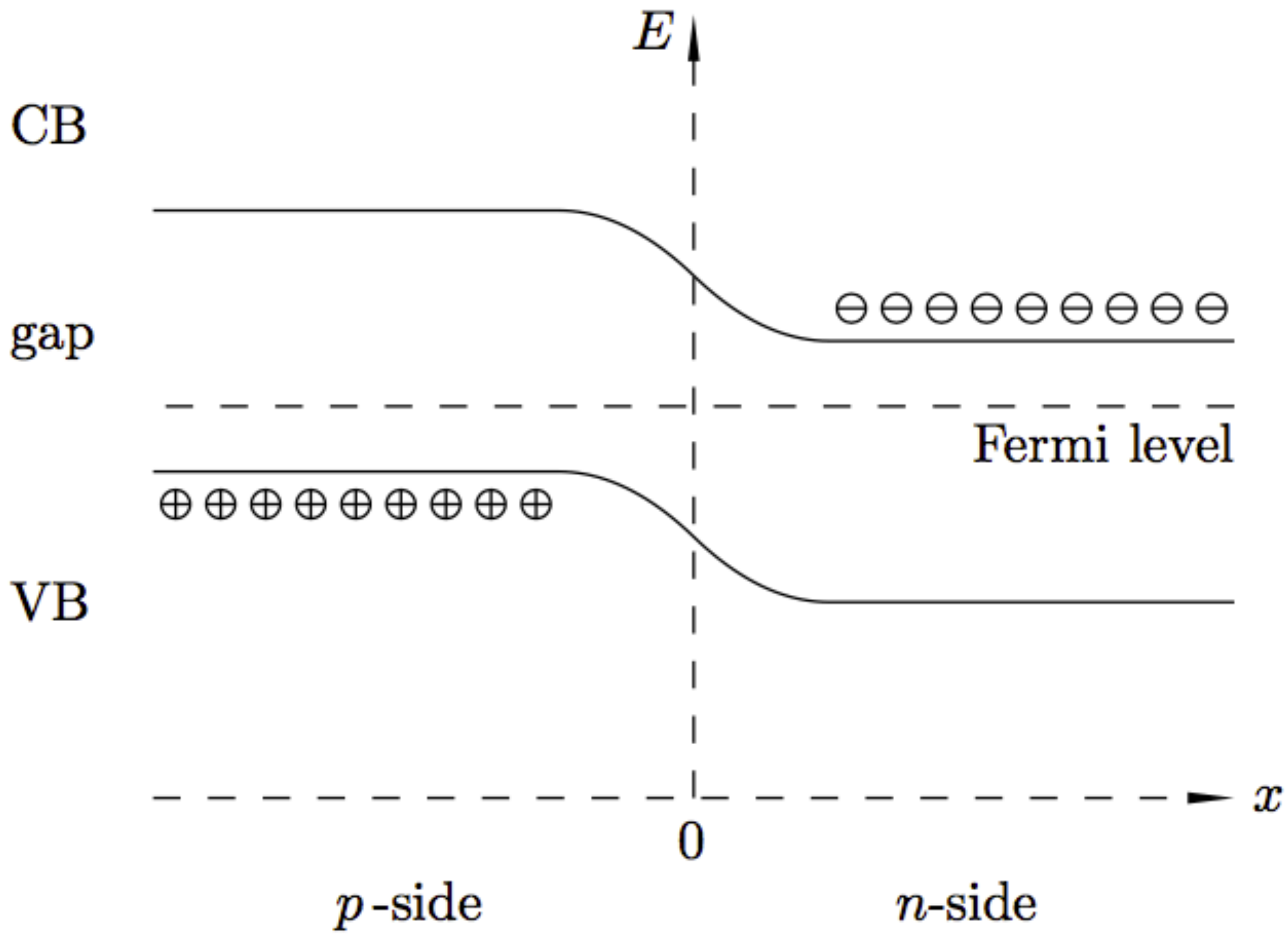
Question #24

$$E_{vp} - E_{vn} = k_B T \ln\left(\frac{N_a N_d}{n_i^2}\right)$$



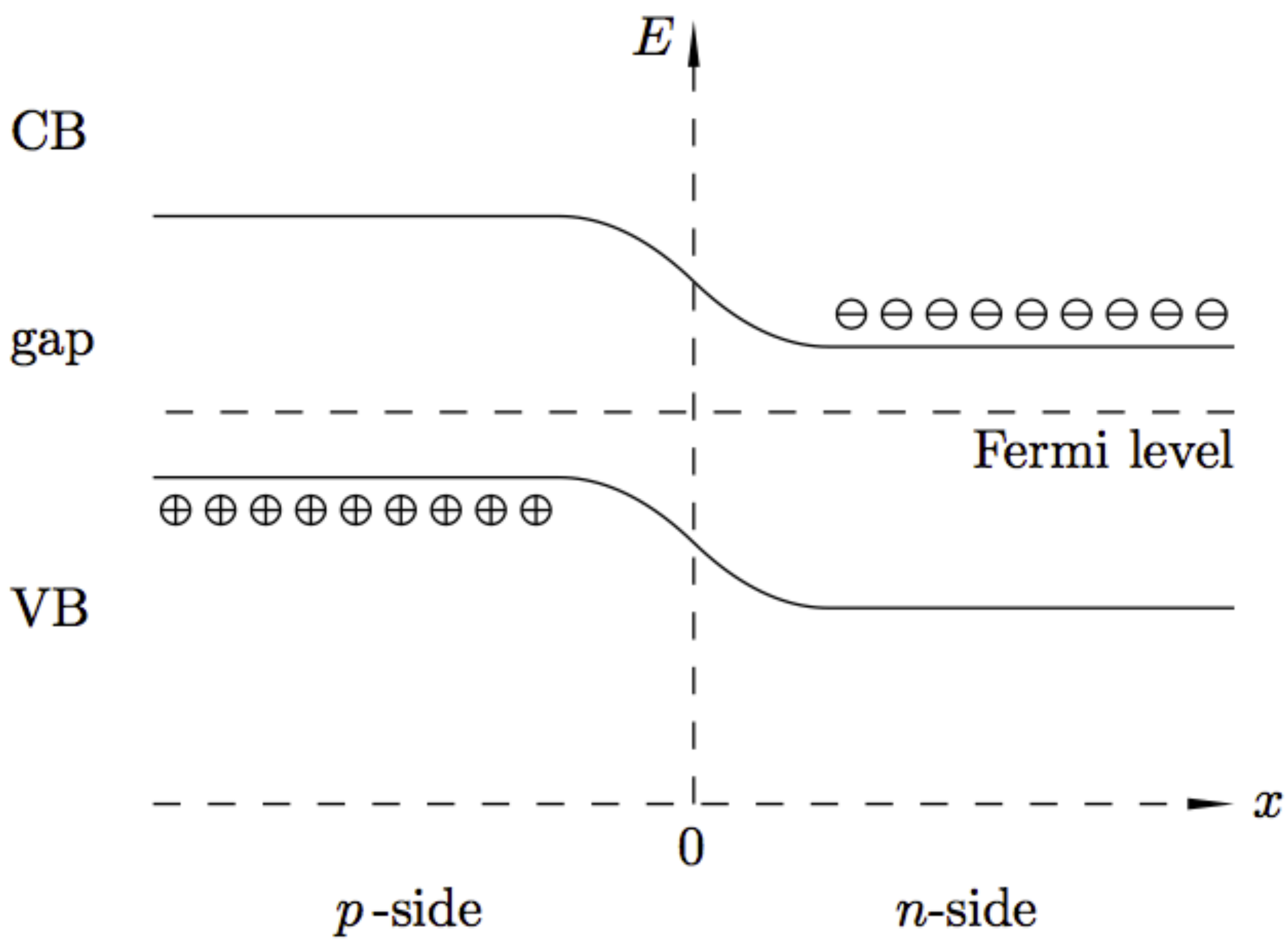
Identify this energy difference on the diagram.

Question #25



Question #25

If I increase the temperature, will the contact potential increase, decrease or stay the same?



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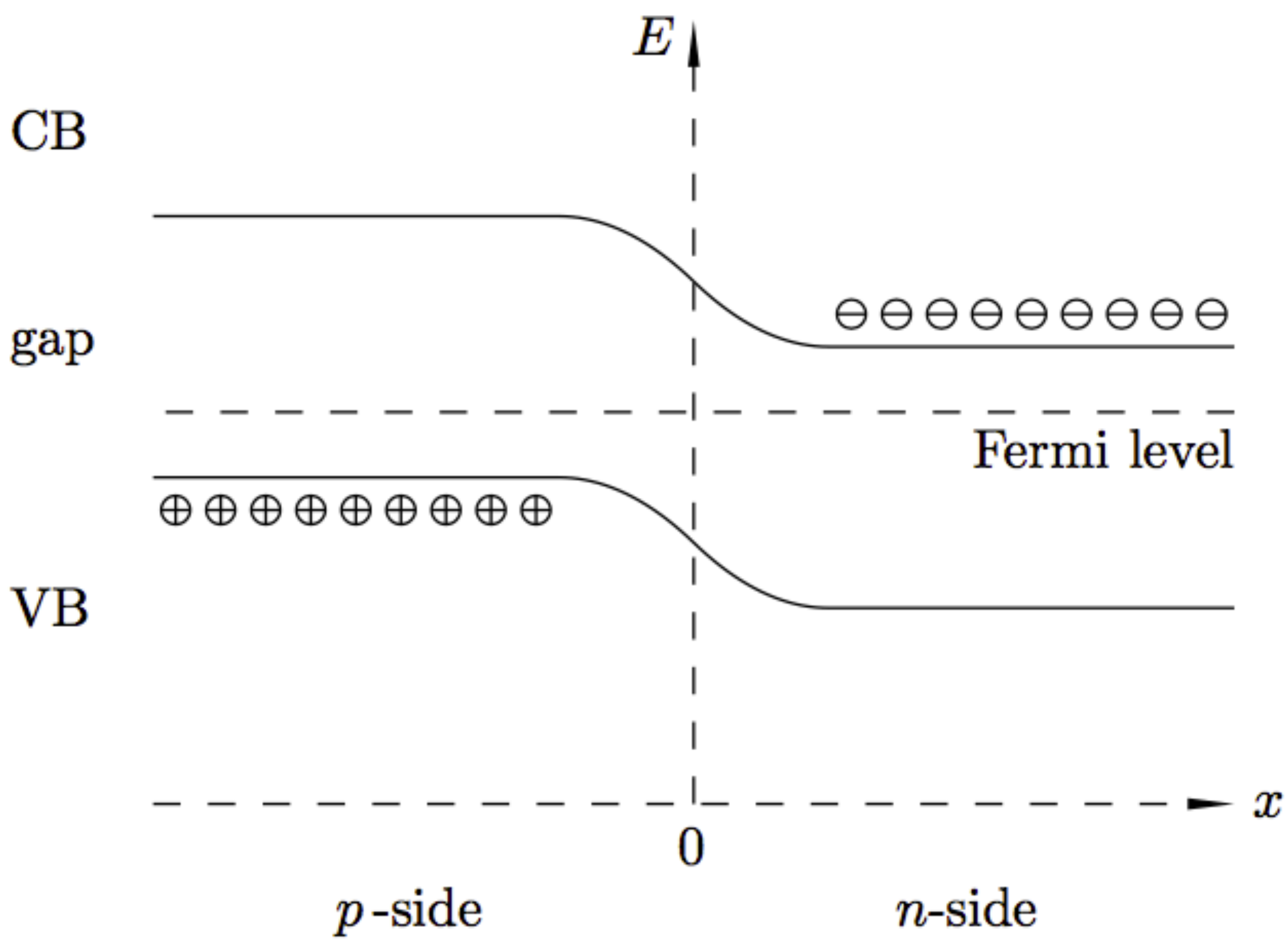

Why must the Fermi energy be close to the CB on the n-side and close to the VB on the p-side?

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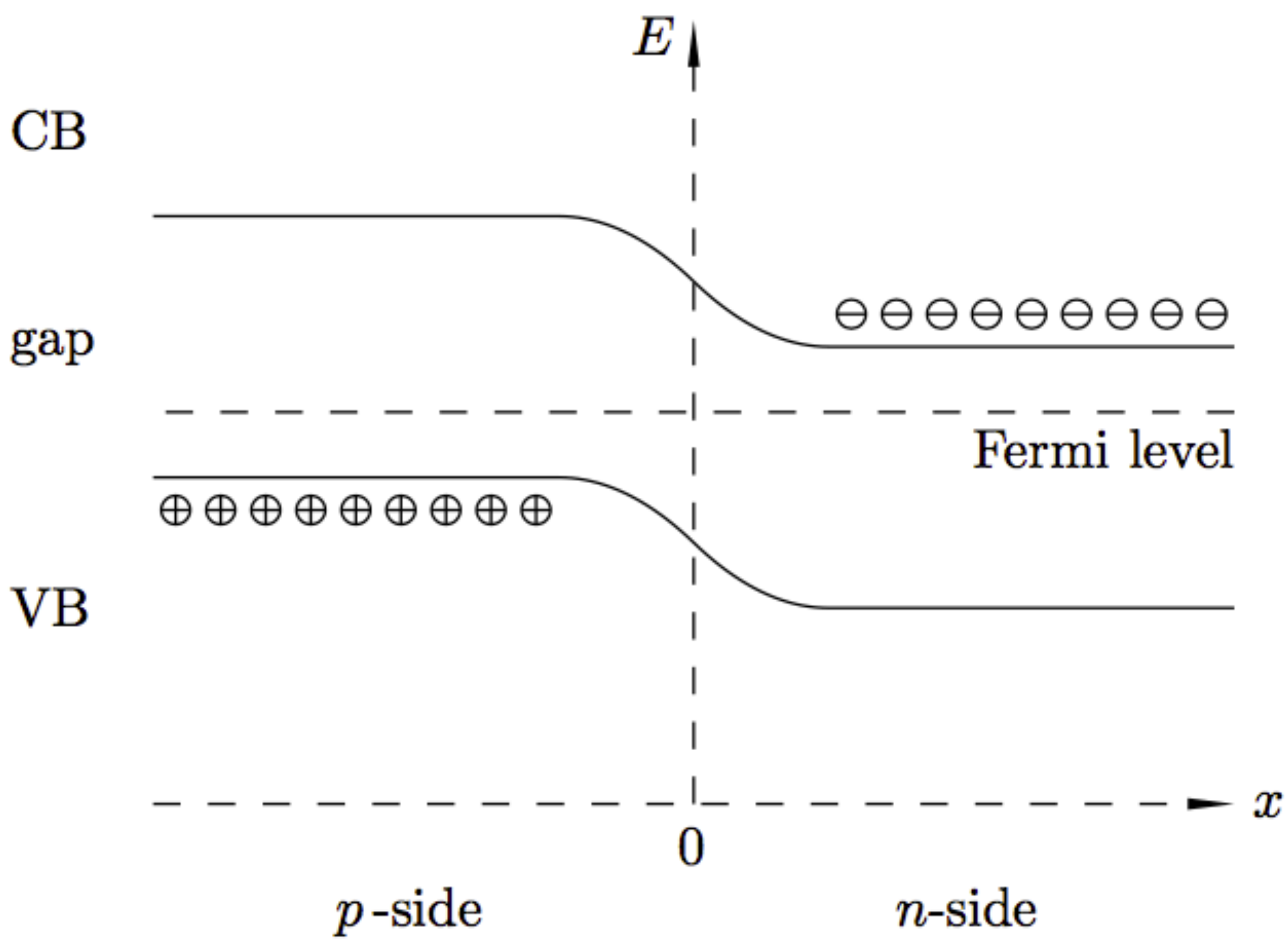

a) Increase
b) Decrease
c) Stay the same

Why must the Fermi energy be close to the CB on the n-side and close to the VB on the p-side?