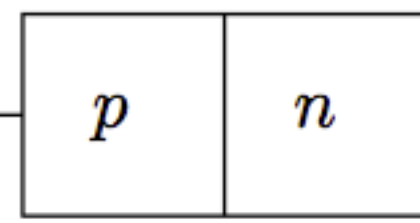
What will happen when I put an n-type semiconductor next to a p-type semiconductor?

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

A potential difference will appear across the junction

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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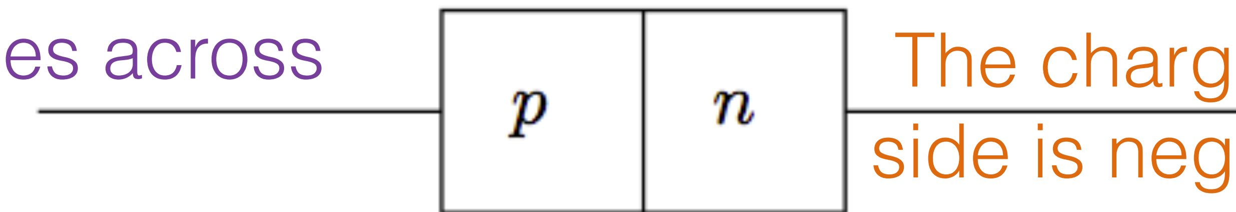

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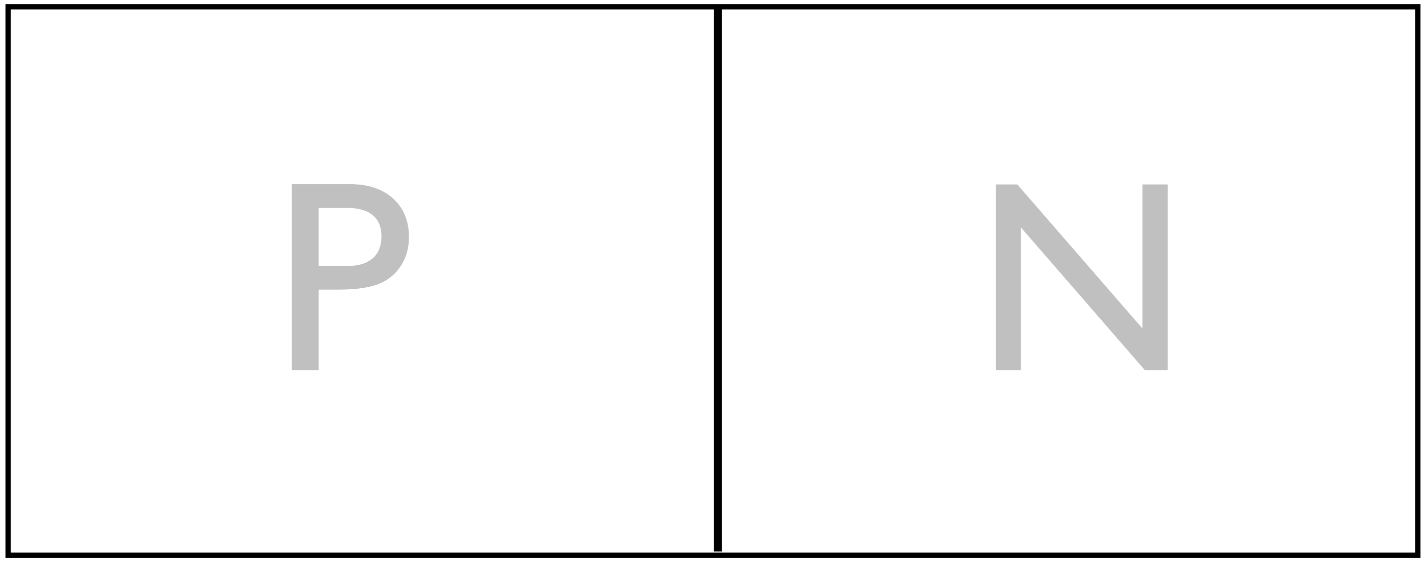
p-n junction, diffusion



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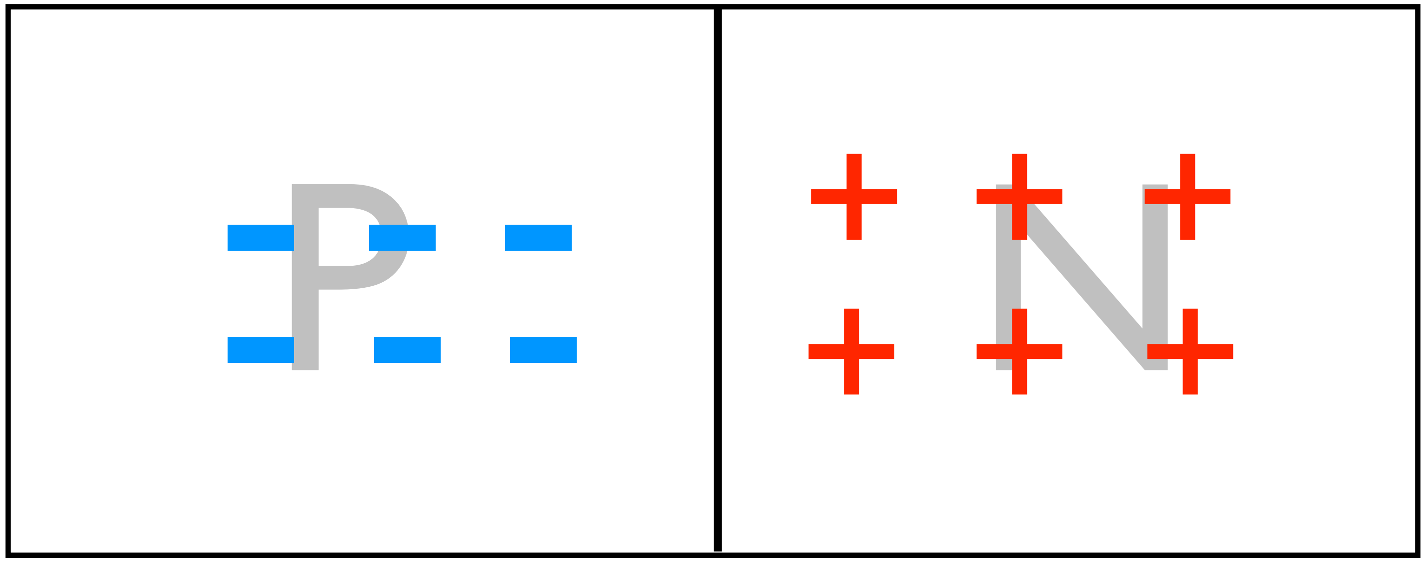

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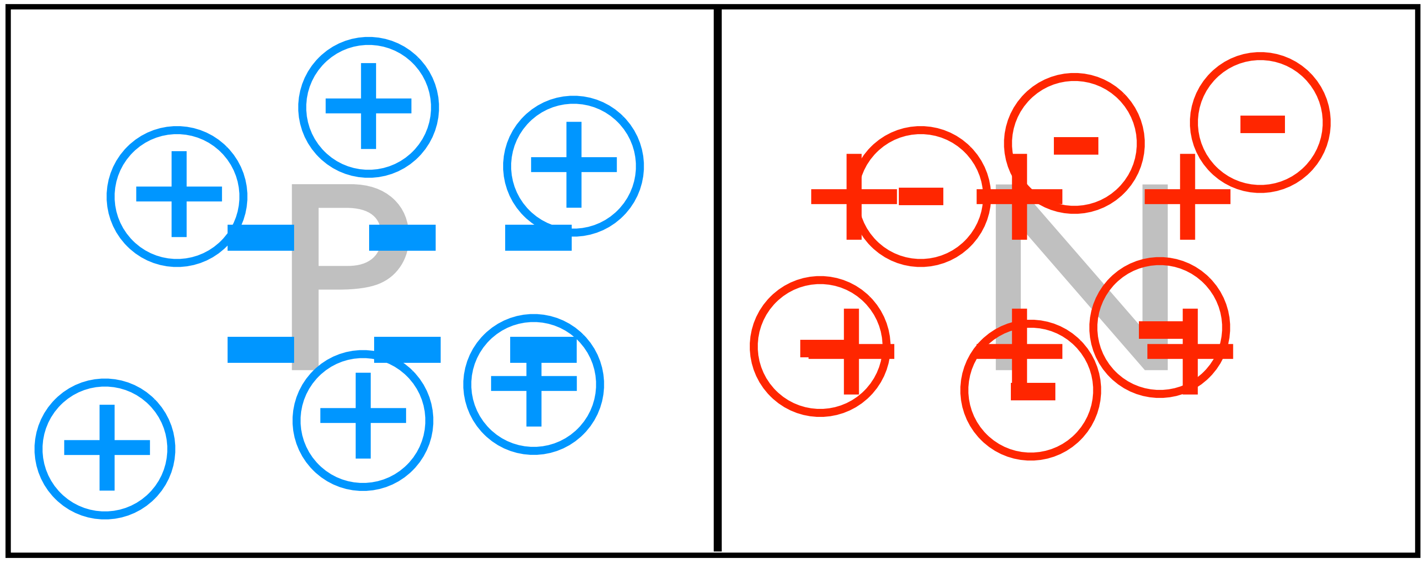

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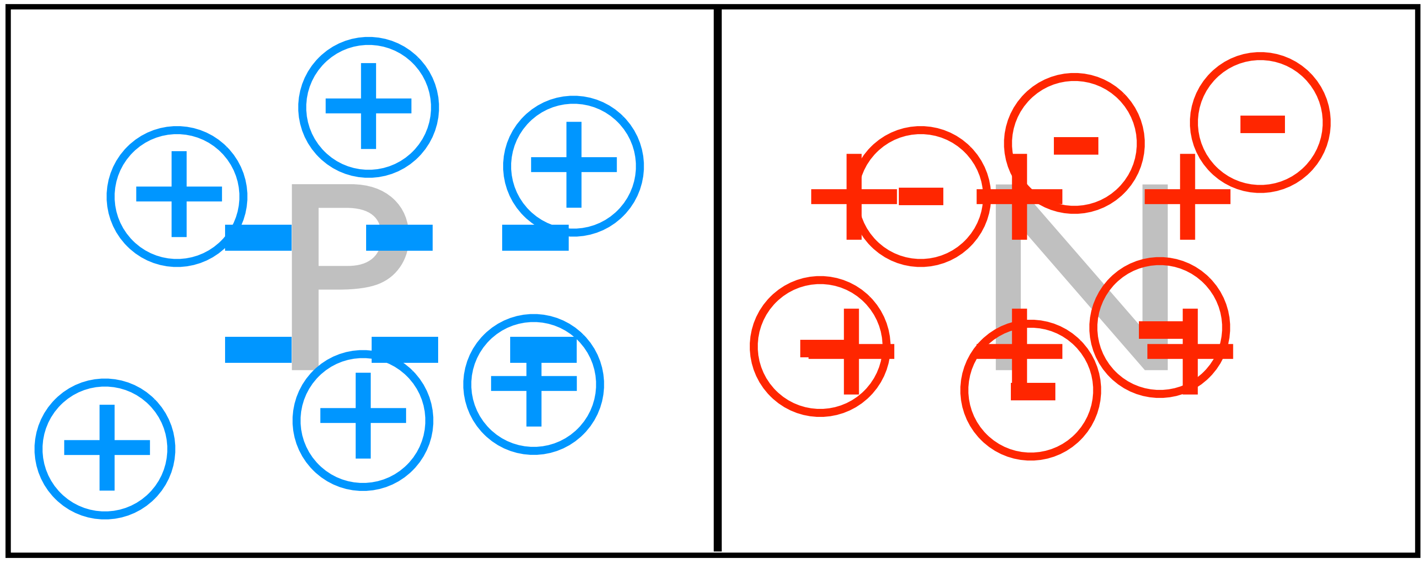
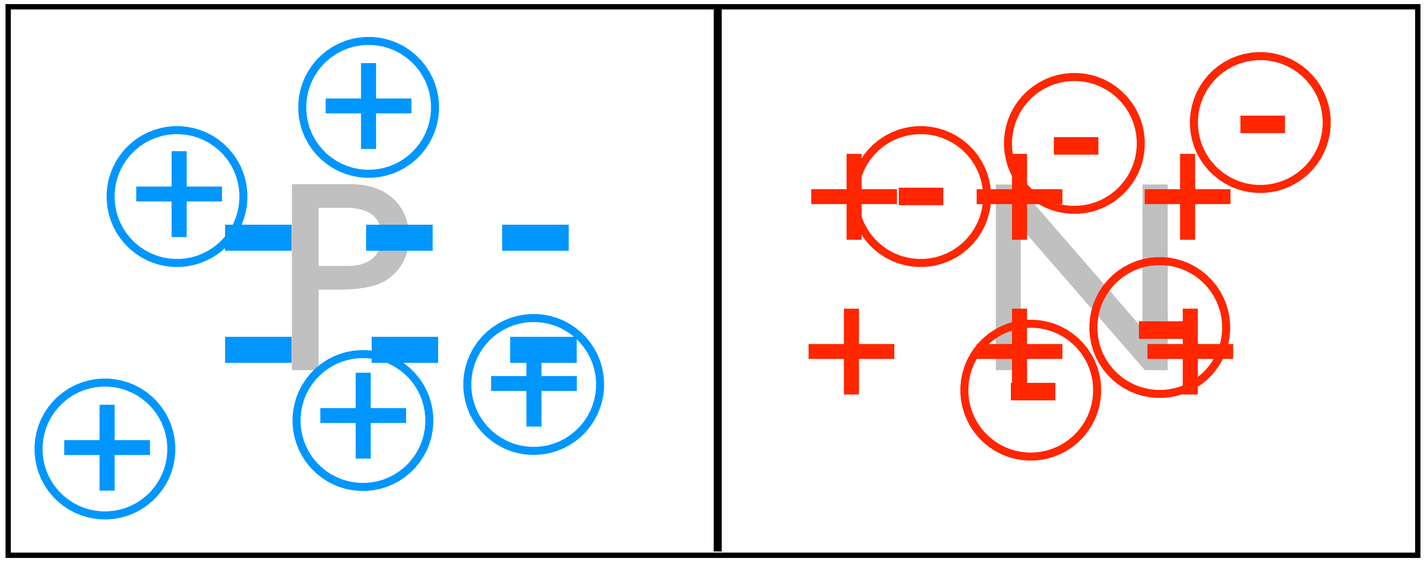
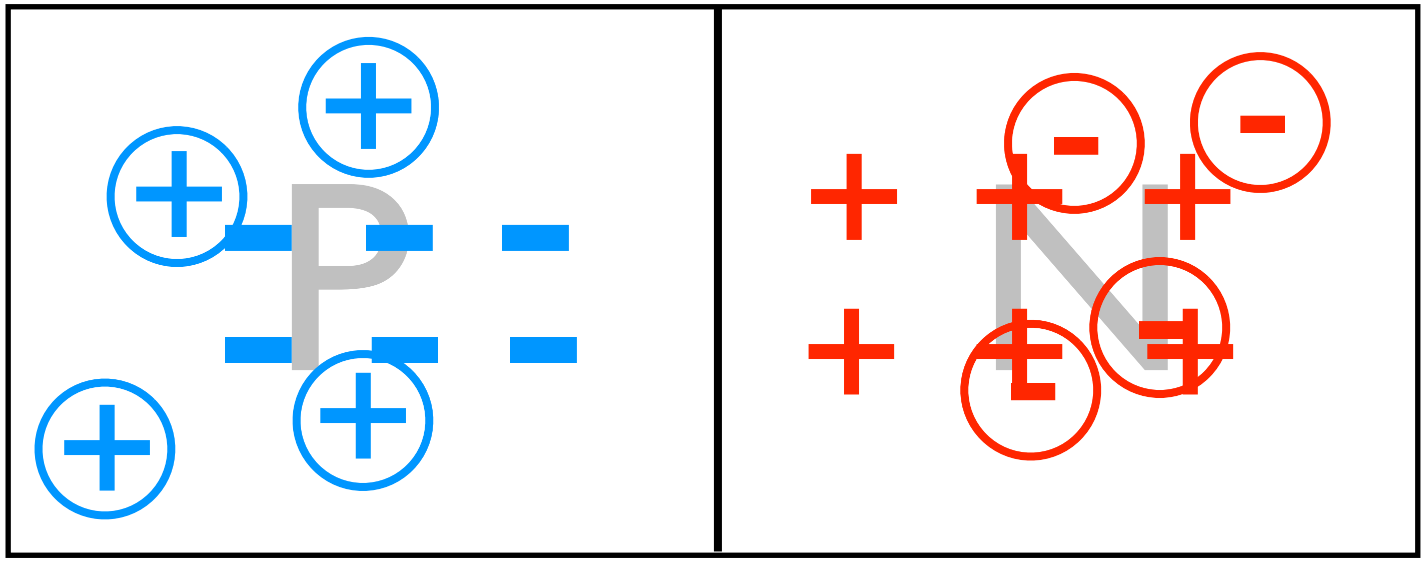


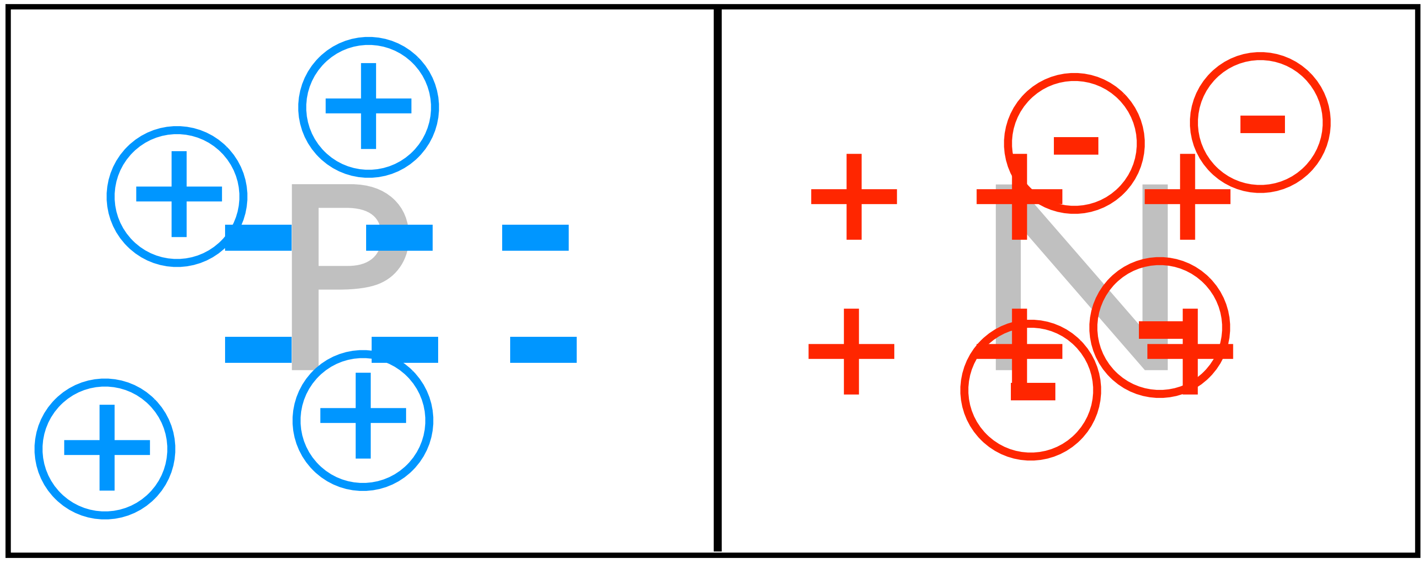
p-n junction, diffusion



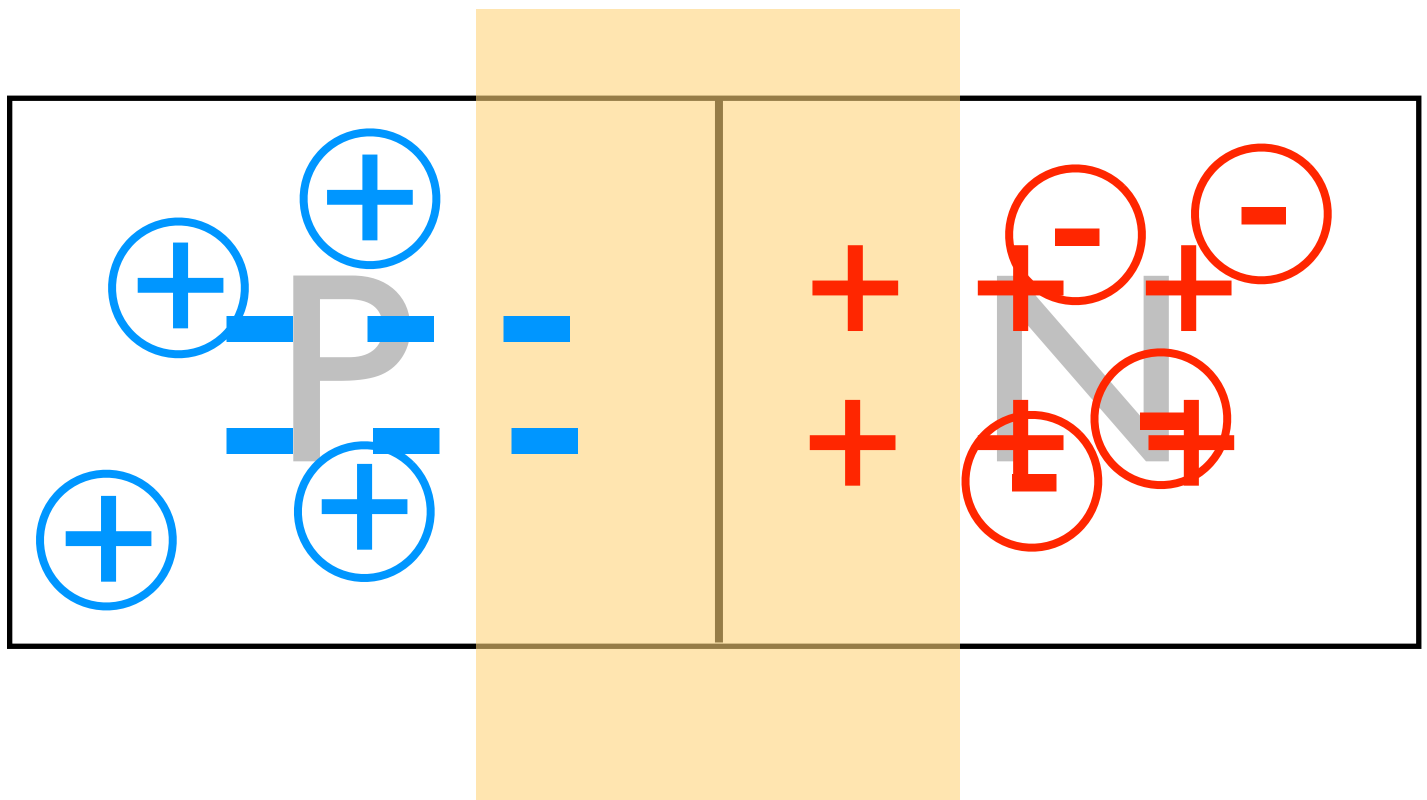
p-n junction, diffusion



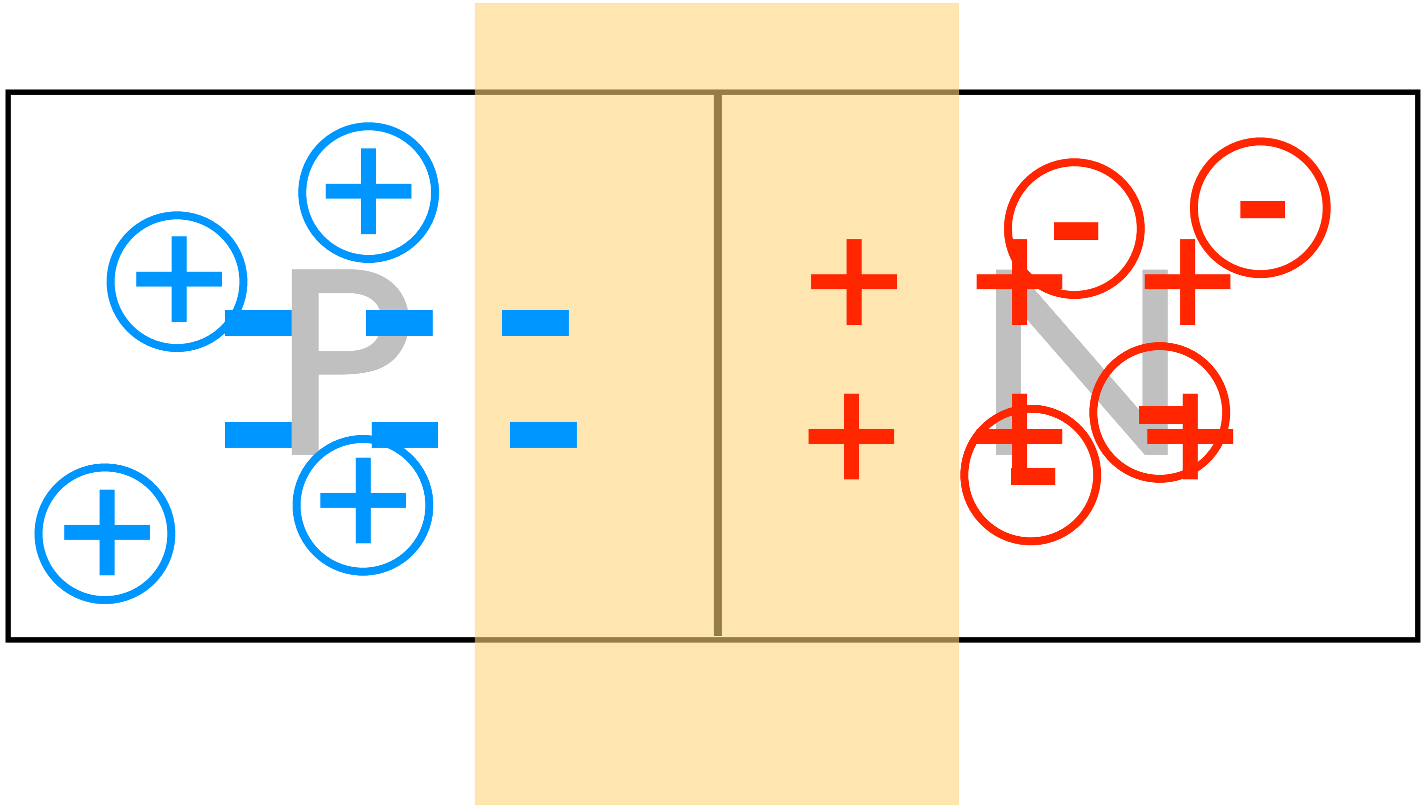
p-n junction, diffusion



p-n junction, diffusion



p-n junction, diffusion



Depletion region
(no carriers)

Question #22

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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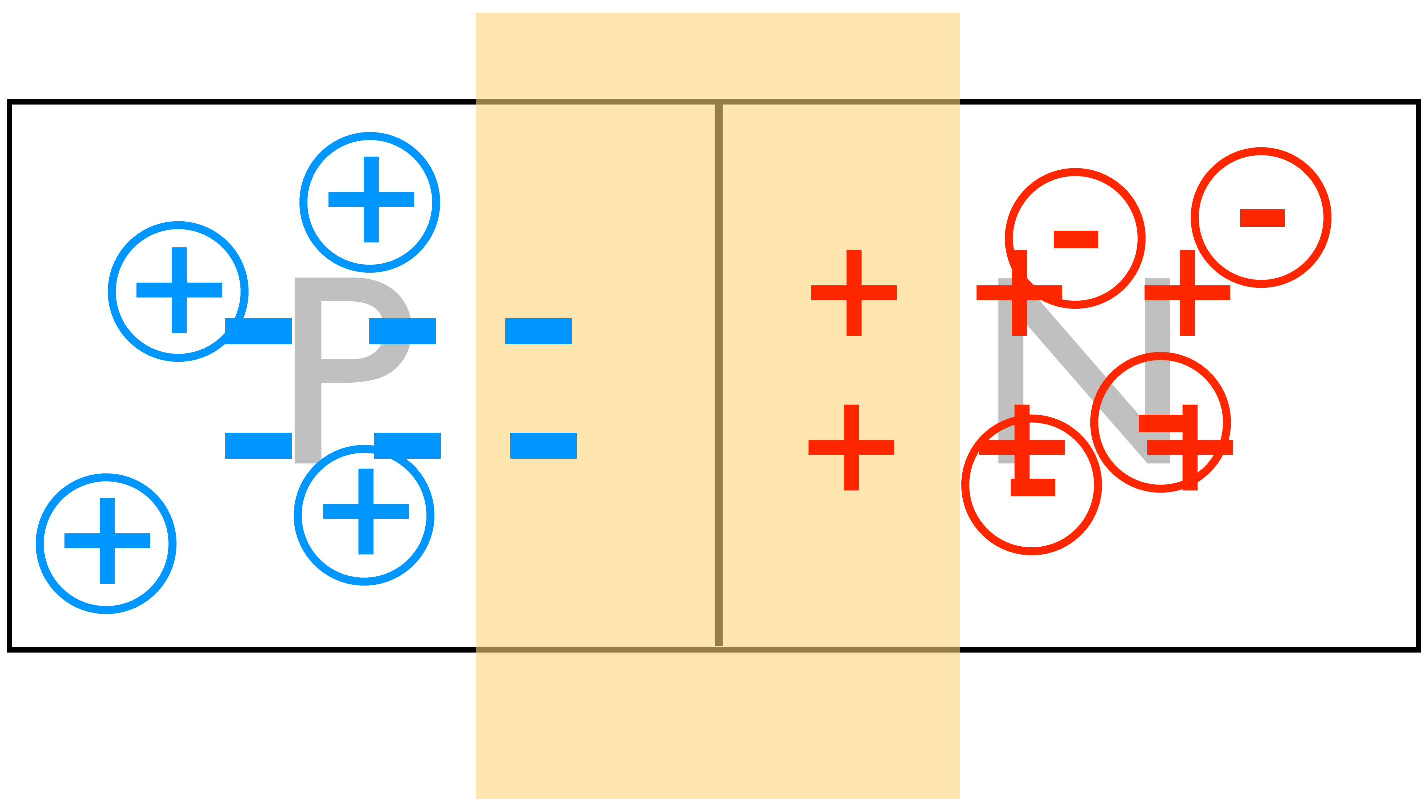


Depletion region

Question #23

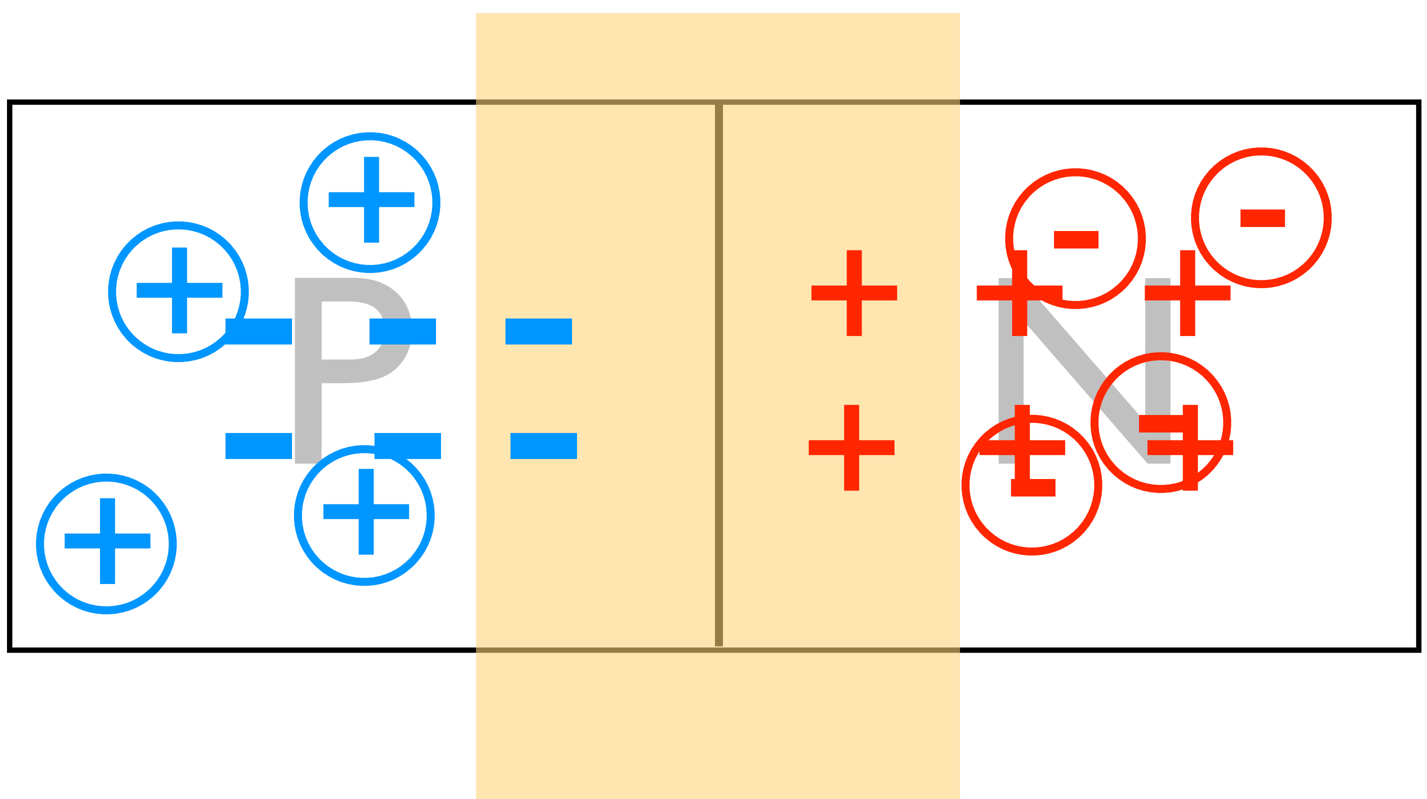
Electric field?

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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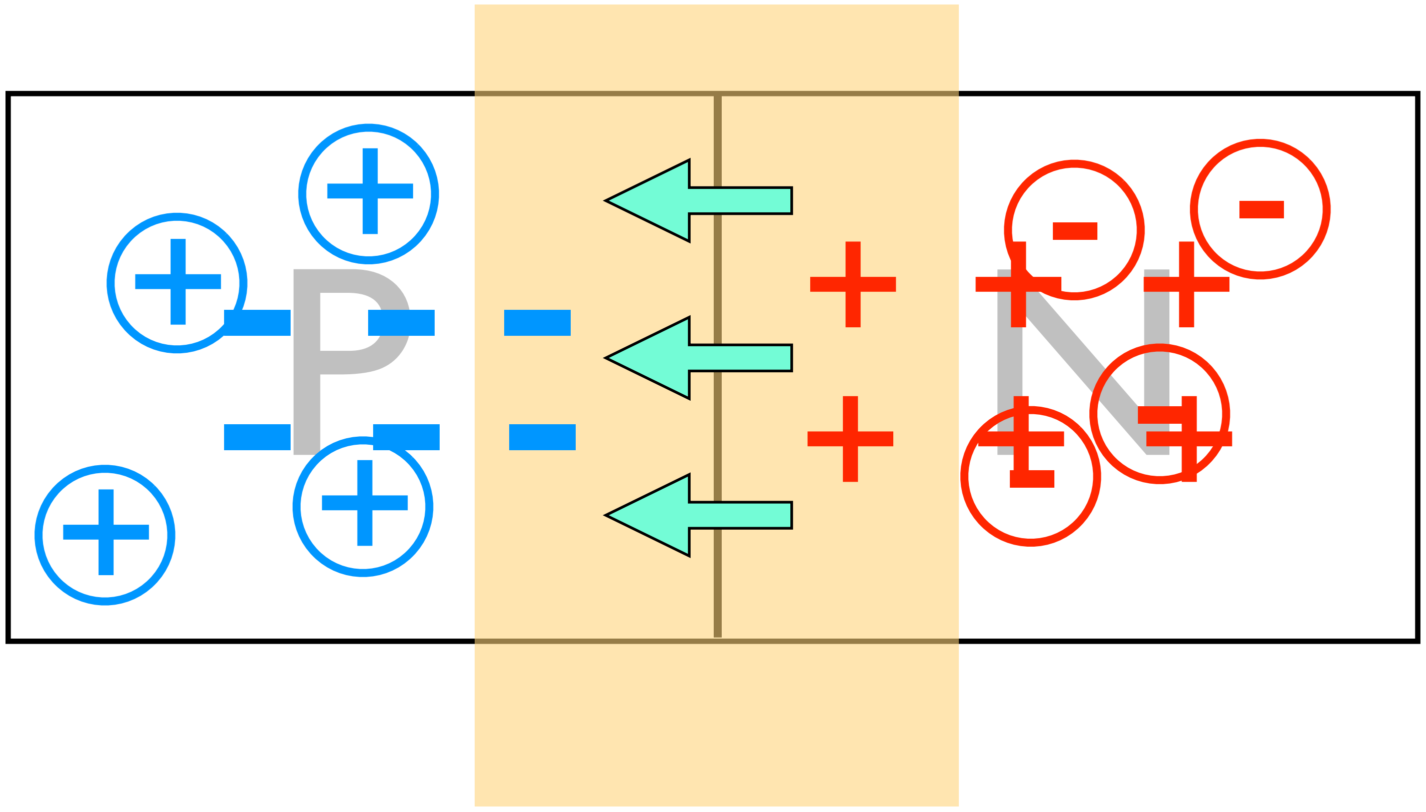
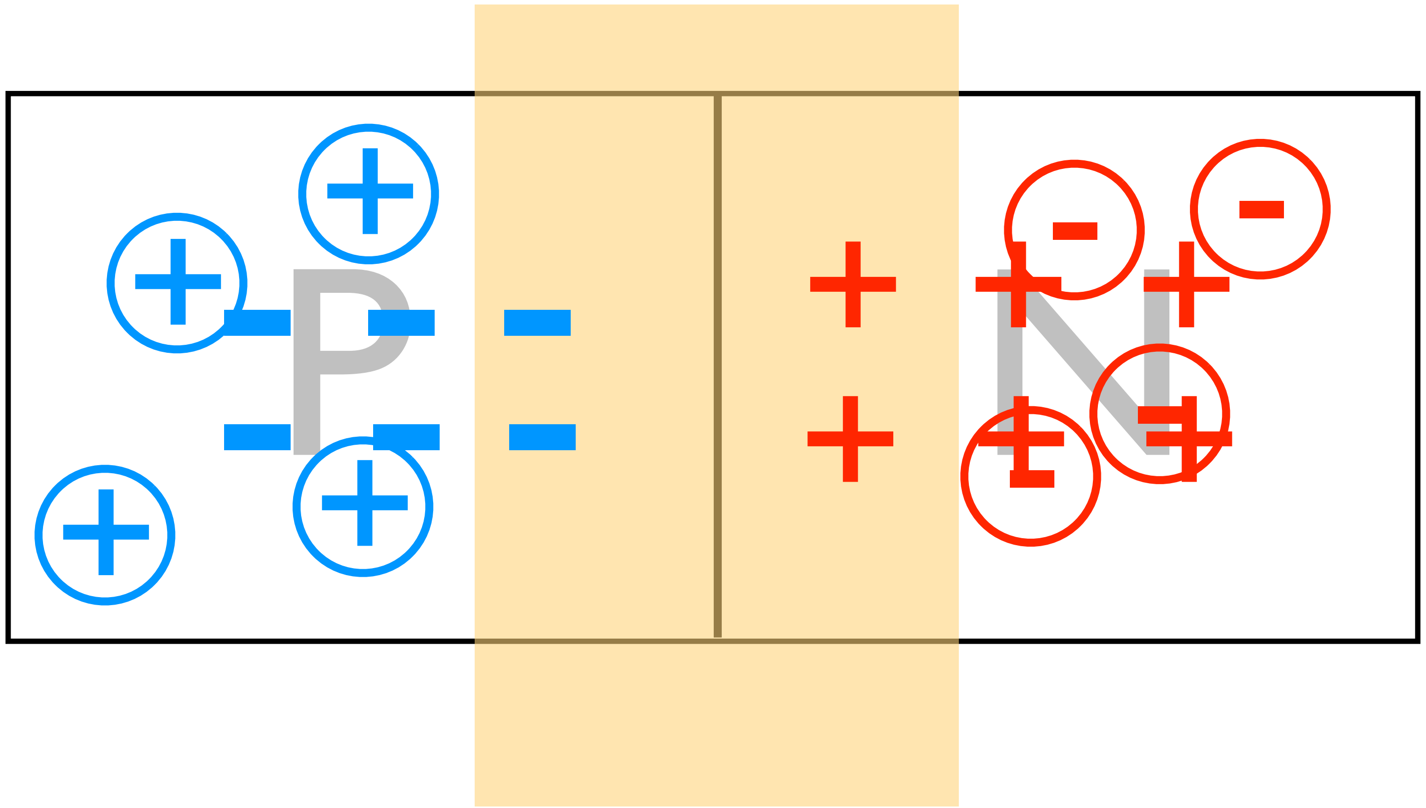


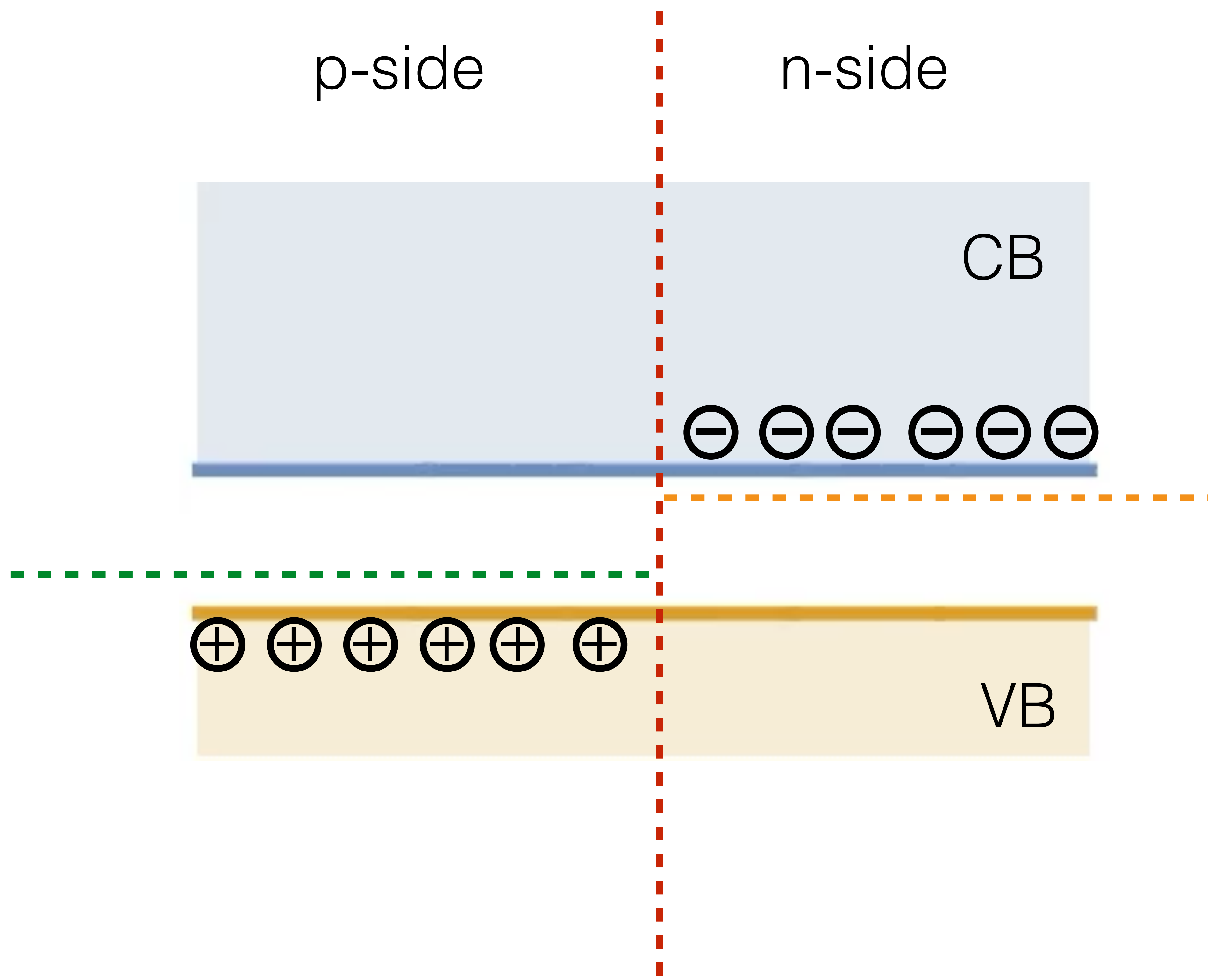
Depletion region

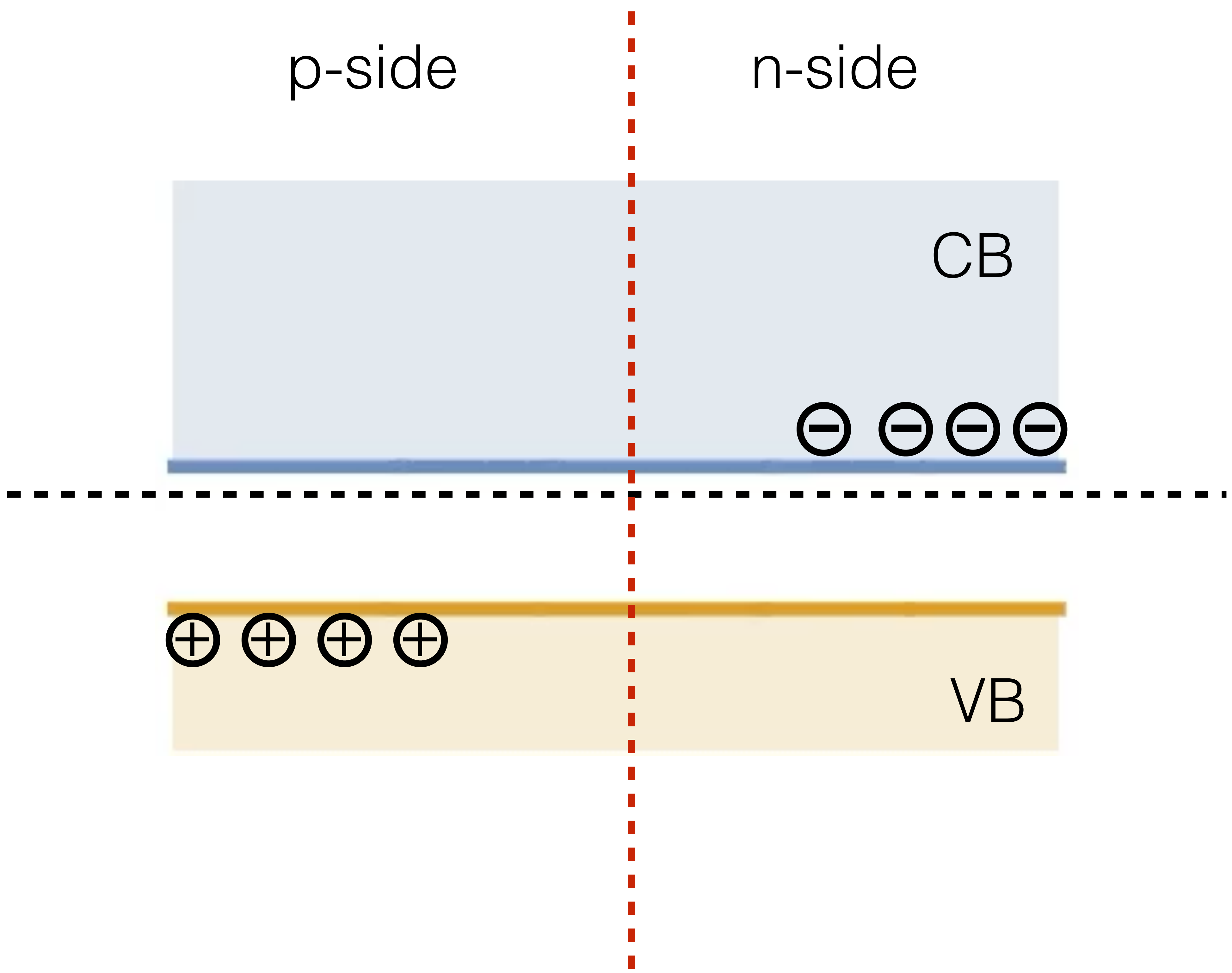
Electric field

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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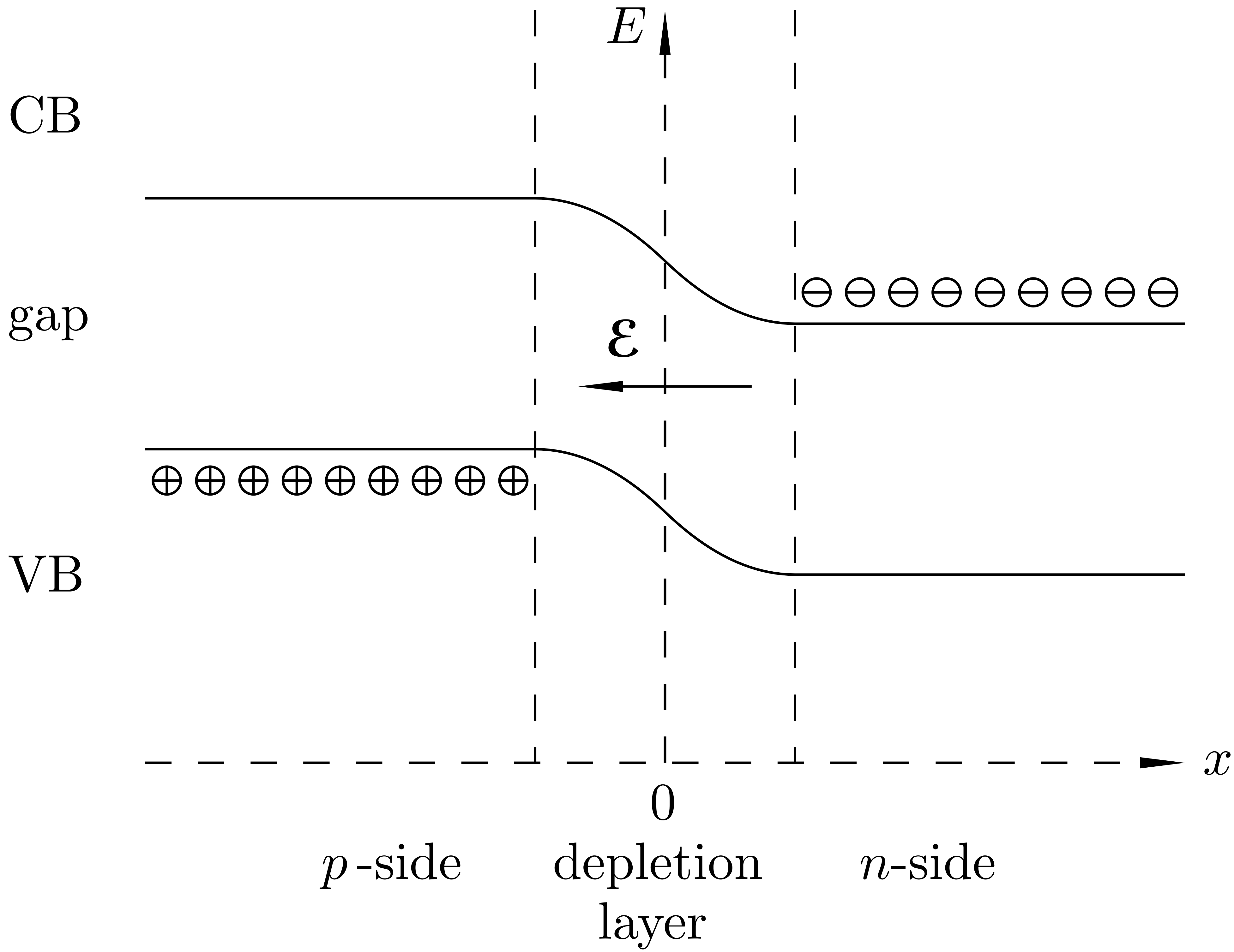

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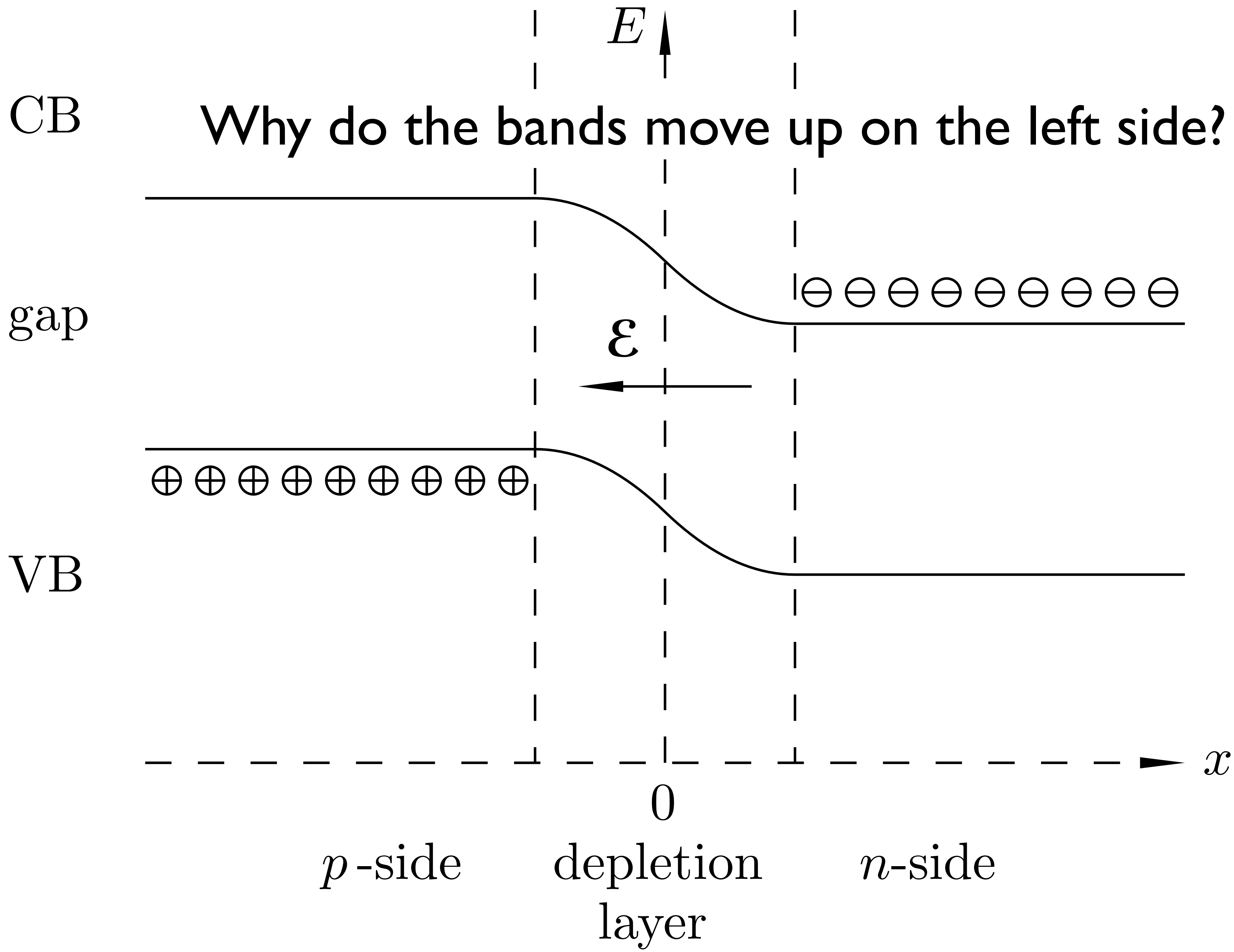
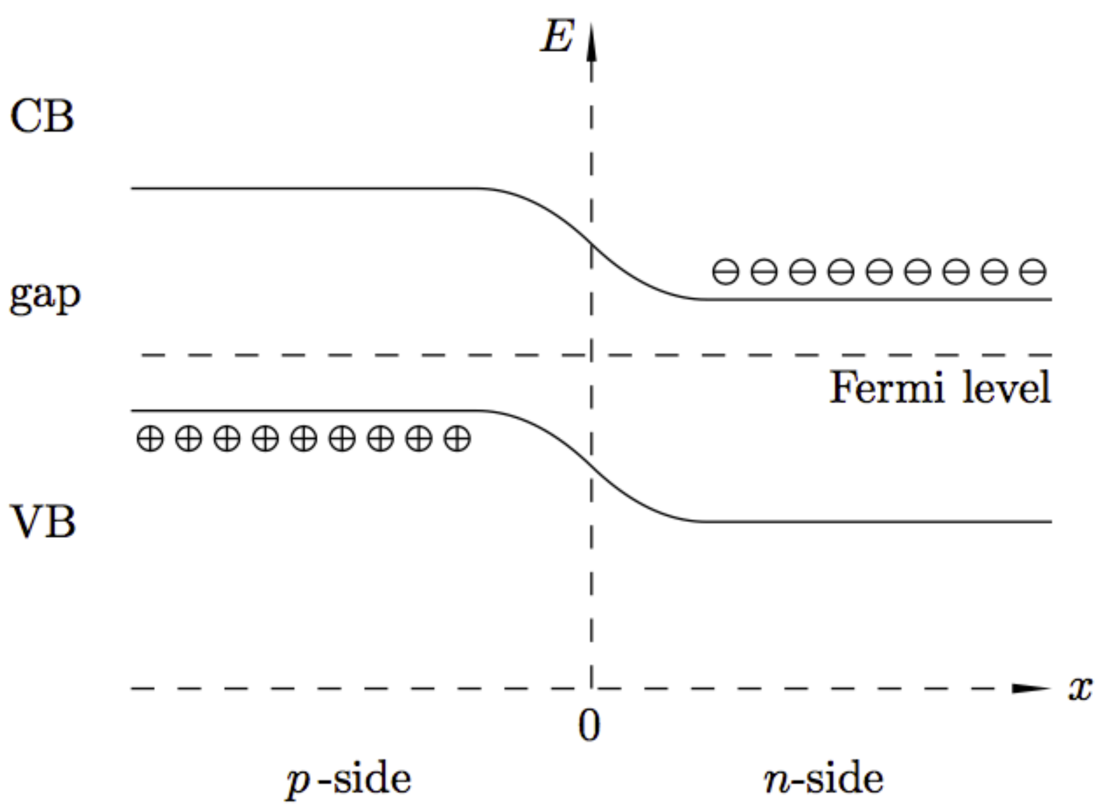


$$n = N_c e^{-\frac{E_c - E_F}{k_B T}}$$

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



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

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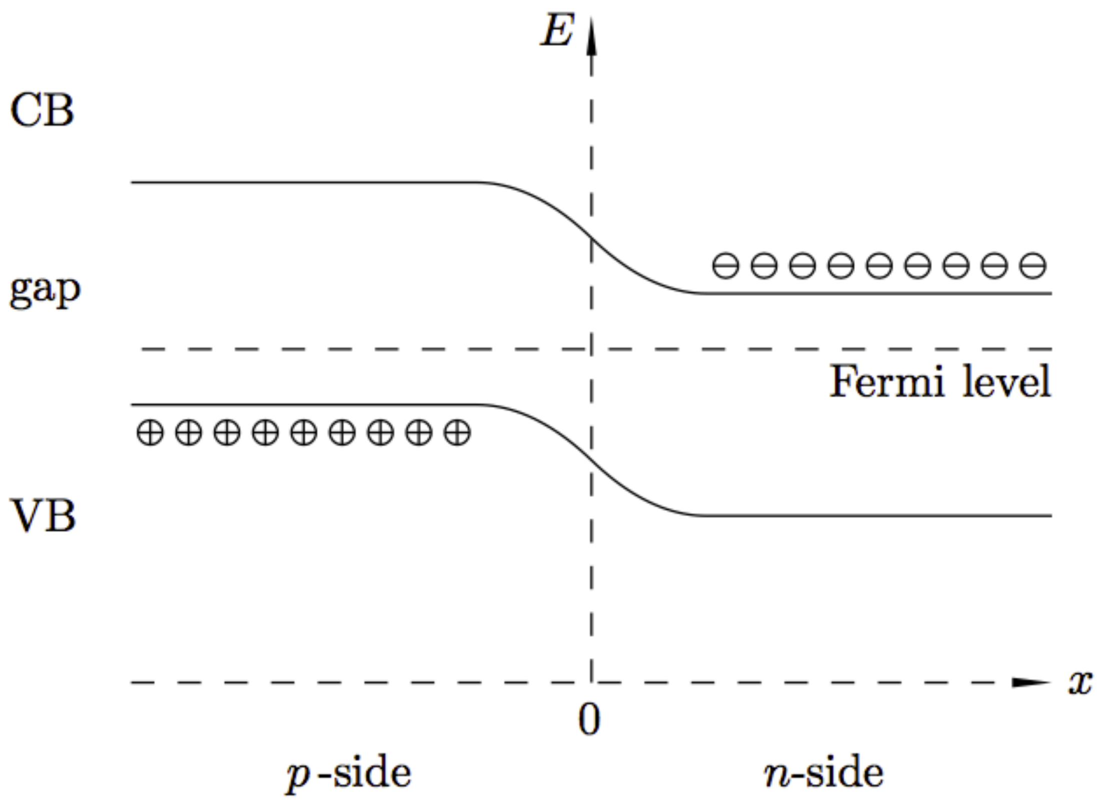


Use the above equations to find the fermi energy on the n-side. (problem 11-1)

Your expression must have n_i in it.

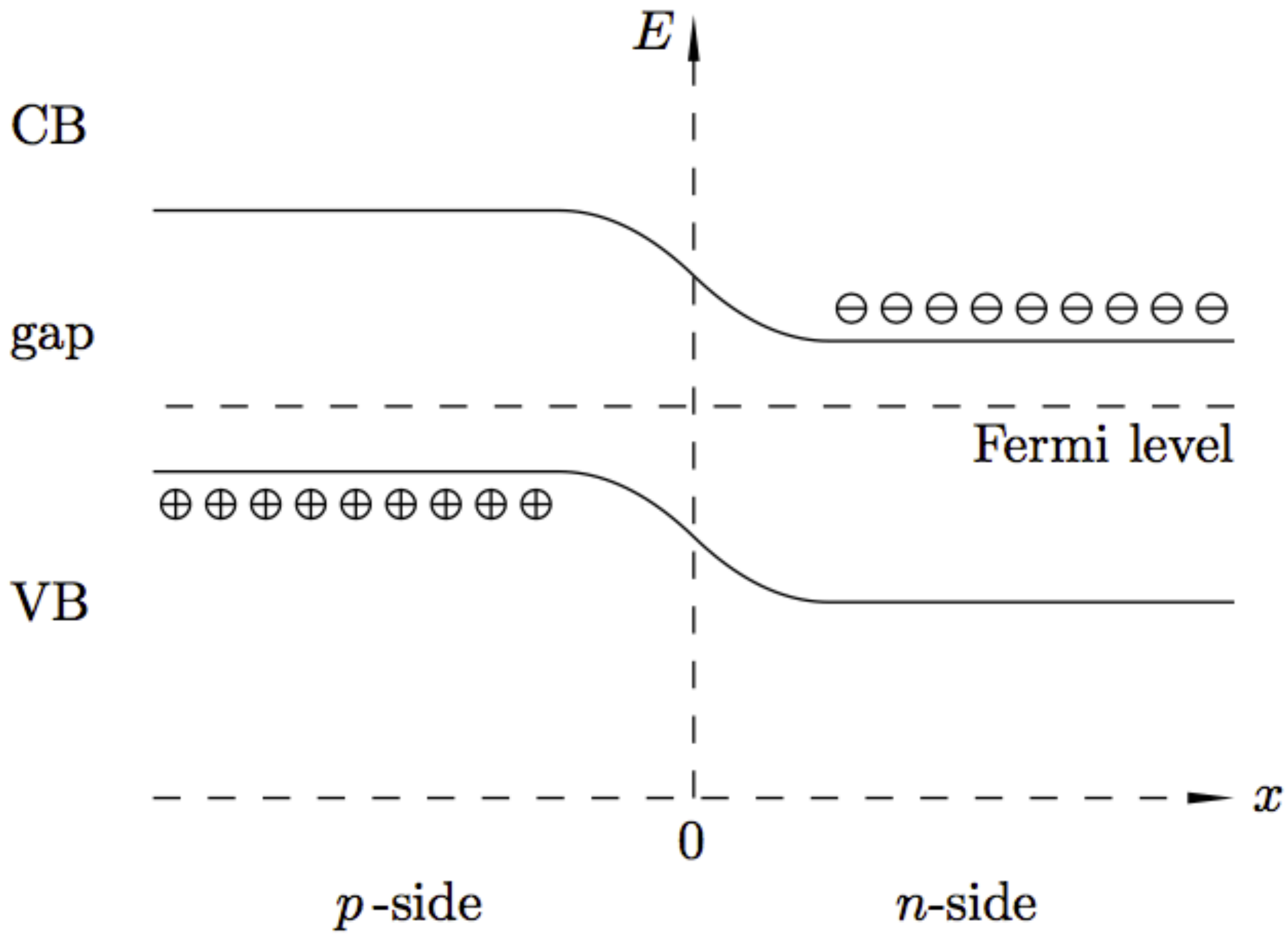
Hint #1: for x >> 0, n = N_D

Hint #2: Start by dividing the equations

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

Question #13

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



B - Decrease

C - Increase

D - Stay the same

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

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

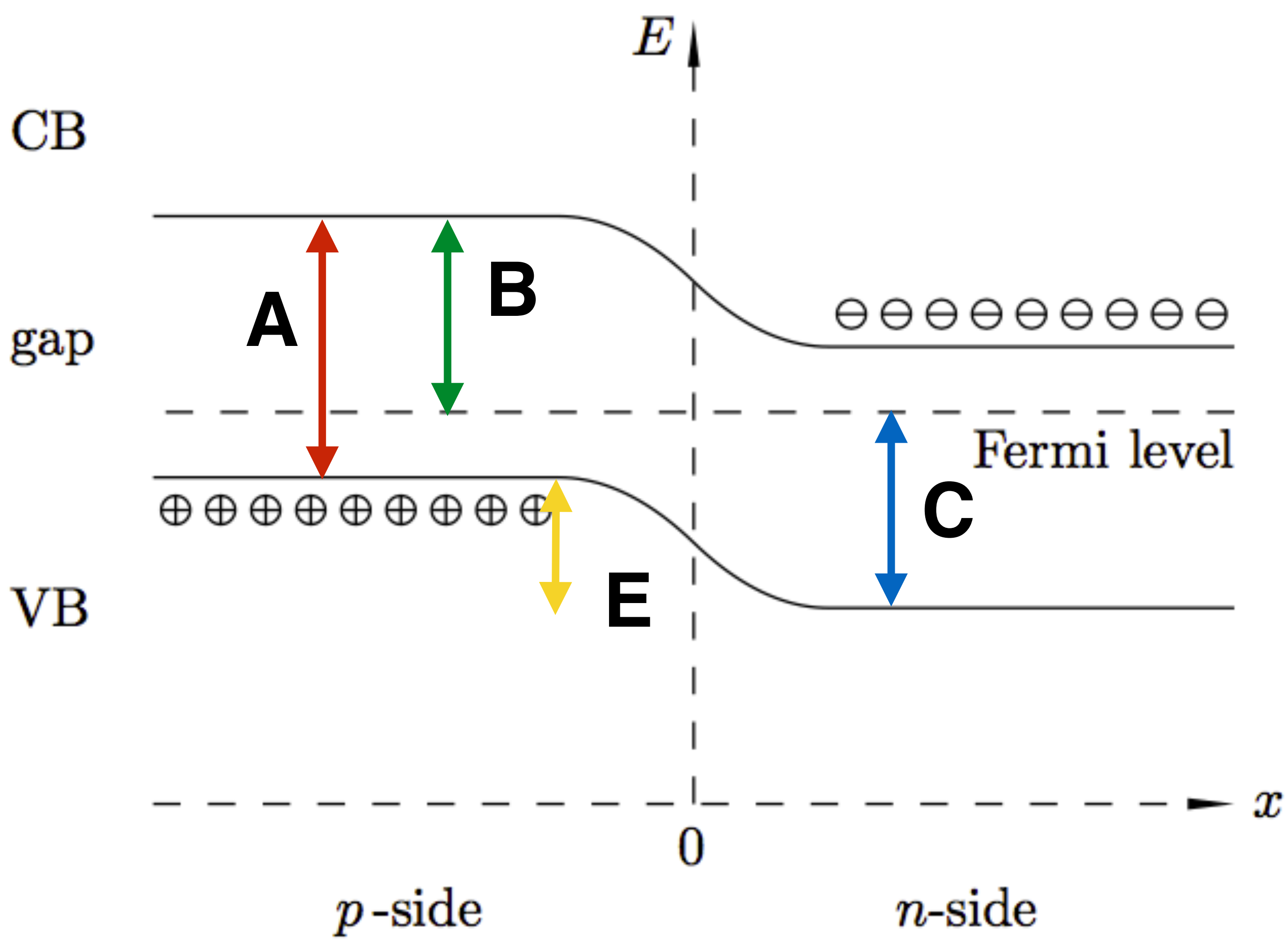
Force the fermi Energies to be equal and solve for:

Problem 11-3

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

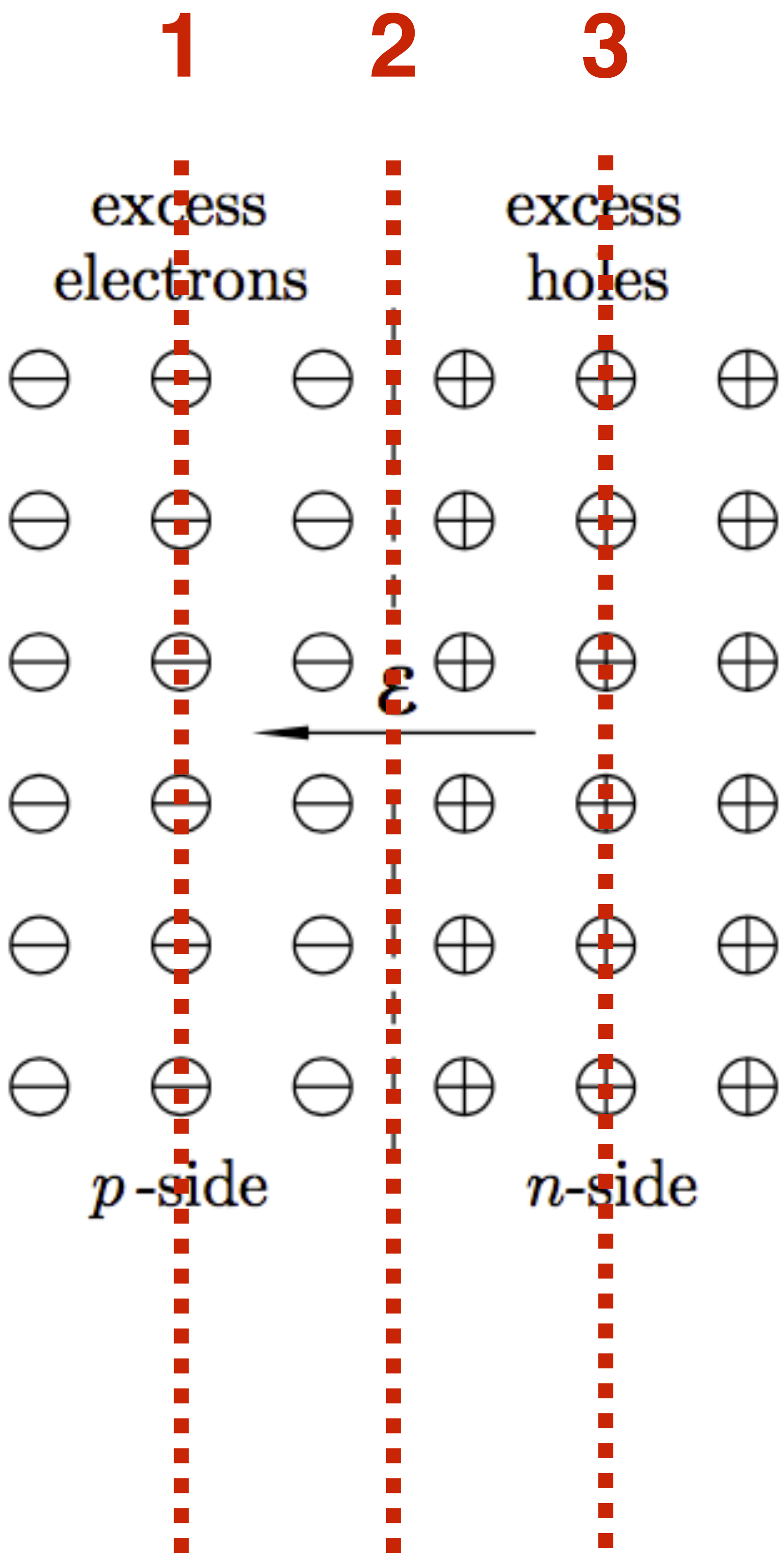
Question #14

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



Identify this energy difference on the diagram.

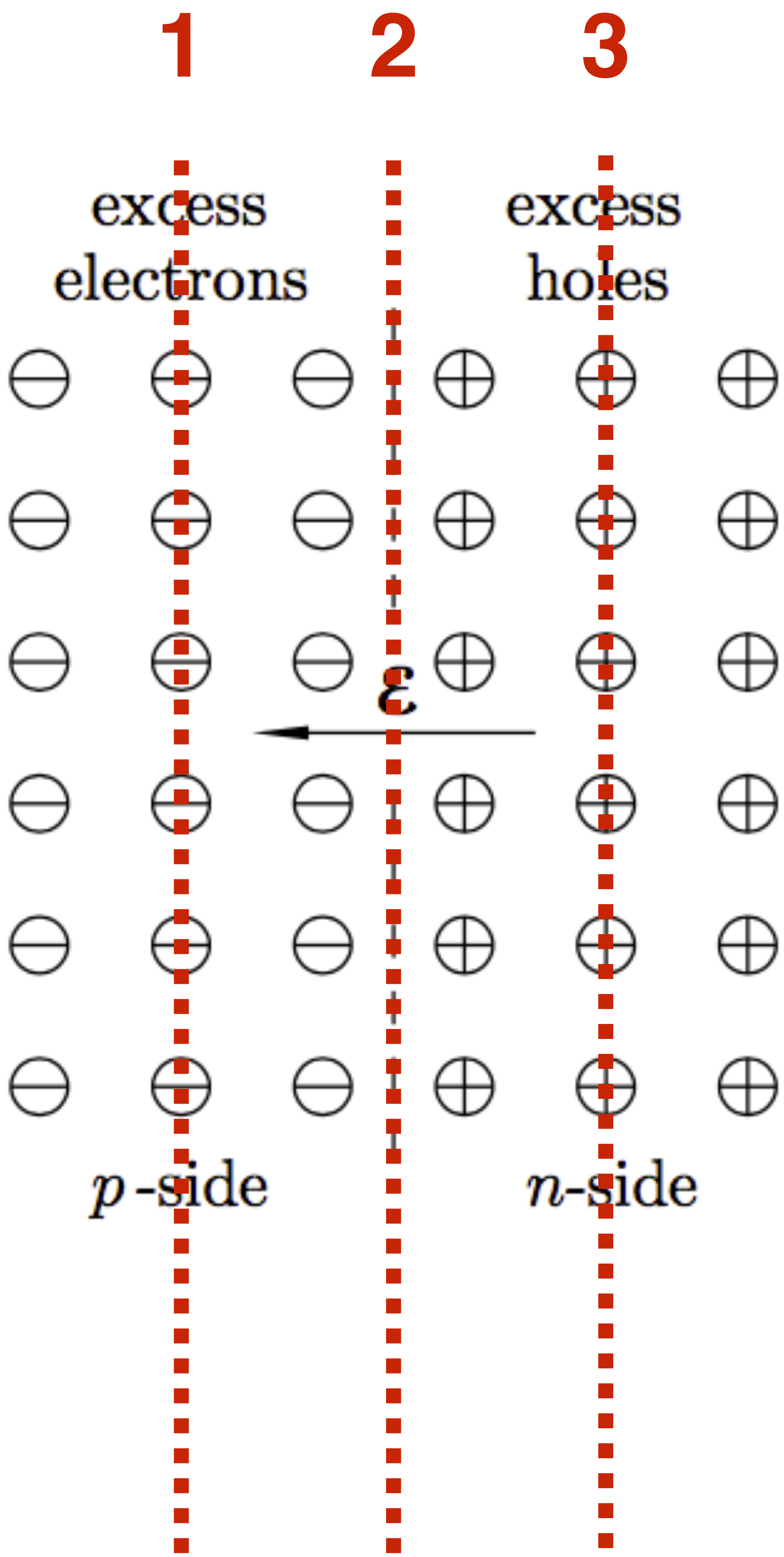
Question #15



Where is the magnitude of the electric field the largest?

C - 1
D - 2
E - 3

Question #15



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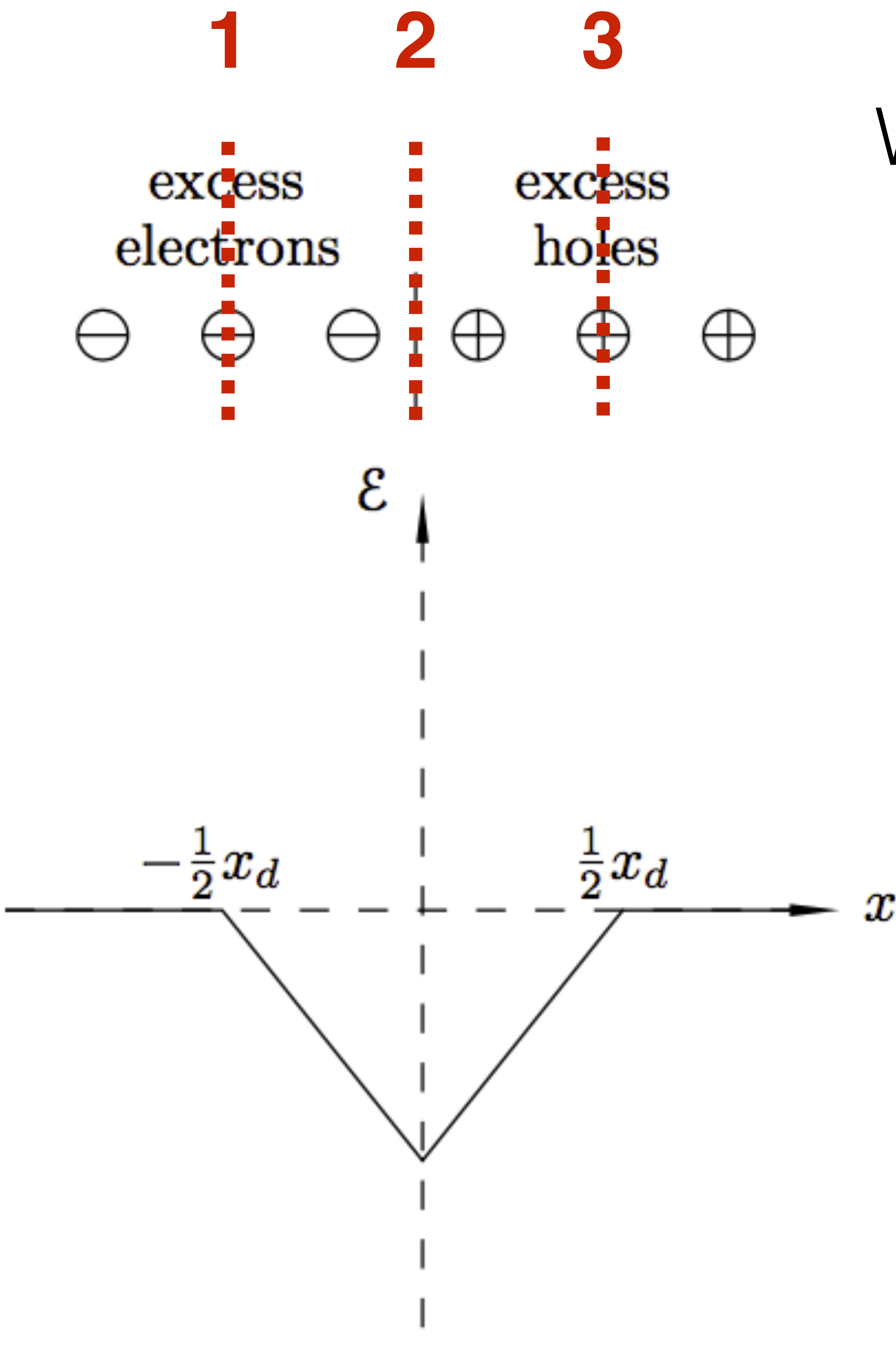
Question #16

At which point(s) does the electric field point to the left?

a) all three
b) 1
c) 2
d) 3



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A little review.

$$\oint \mathcal{E} \cdot d\mathbf{S} = \frac{Q}{\epsilon}$$ Gauss's Law **1**

$$\int (\nabla \cdot \mathcal{E}) dV = \oint \mathcal{E} \cdot d\mathbf{S}$$ Divergence theorem **2**

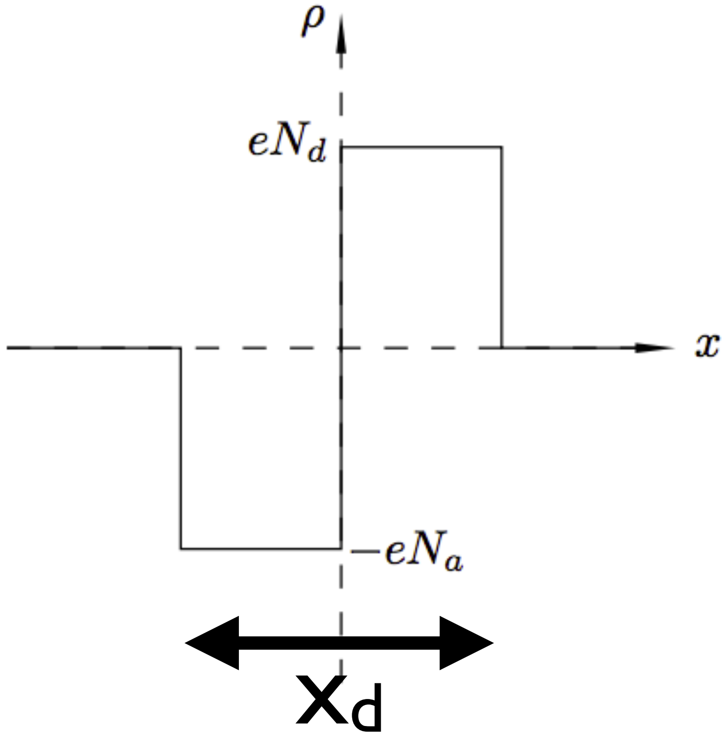
$$\int \boxed{(\nabla \cdot \mathcal{E})} dV = \frac{Q}{\epsilon} \quad = \frac{1}{\epsilon} \int \boxed{\rho} dV$$ **3**

6

$$\mathcal{E} = \frac{1}{\epsilon_0 \epsilon_r} \int_{-\infty}^{x} \rho dx$$

$$\nabla \cdot \mathcal{E} = \frac{\rho}{\epsilon}$$ **4**

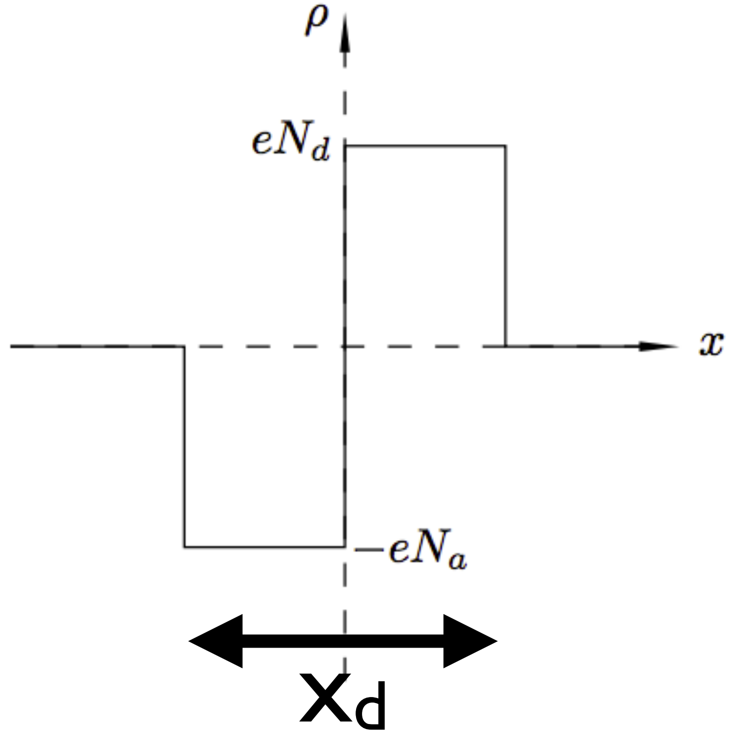
5 $$\frac{d\mathcal{E}}{dx} = \frac{\rho}{\epsilon_0 \epsilon_r}$$ Alternate form of Gauss's law.



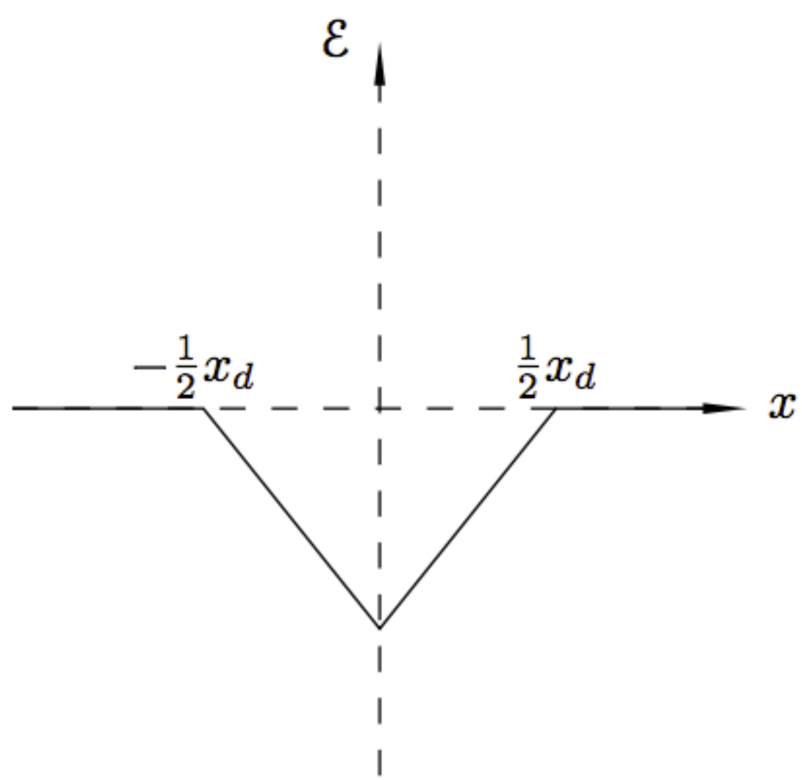
$$\mathcal{E} = \frac{1}{\epsilon_0 \epsilon_r} \int_{-\infty}^{x} \rho dx$$

Perform the integration to get equation 11-12

$$\mathcal{E}_{\mathrm{max}} = \frac{eN_d x_d}{2\epsilon_r \epsilon_0}$$



$$\mathcal{E} = \frac{1}{\epsilon_0 \epsilon_r} \int_{-\infty}^{x} \rho dx$$



Perform the integration to get equation 11-12

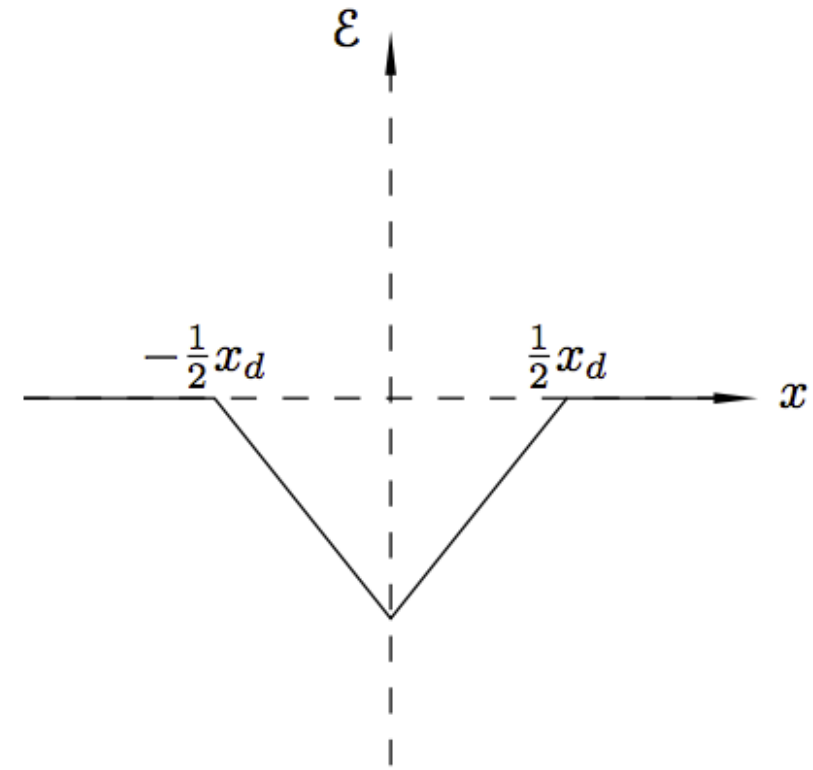
$$\mathcal{E} = -\frac{eN_d}{\epsilon_r \epsilon_0}(\frac{1}{2}x_d + x)$$

$$\mathcal{E}_{\max} = \frac{eN_d x_d}{2\epsilon_r \epsilon_0}$$

$$\mathcal{E} = -\frac{eN_d}{\epsilon_r \epsilon_0}(\frac{1}{2}x_d - x)$$

$$\Delta U = -\int_{-\infty}^{\infty} F dx$$

$$= e\int_{-\infty}^{\infty} \mathcal{E} dx$$



Perform the integration to get to equation 11-16

$$\mathcal{E}_{\max} = \frac{eN_d x_d}{2\epsilon_r \epsilon_0}$$

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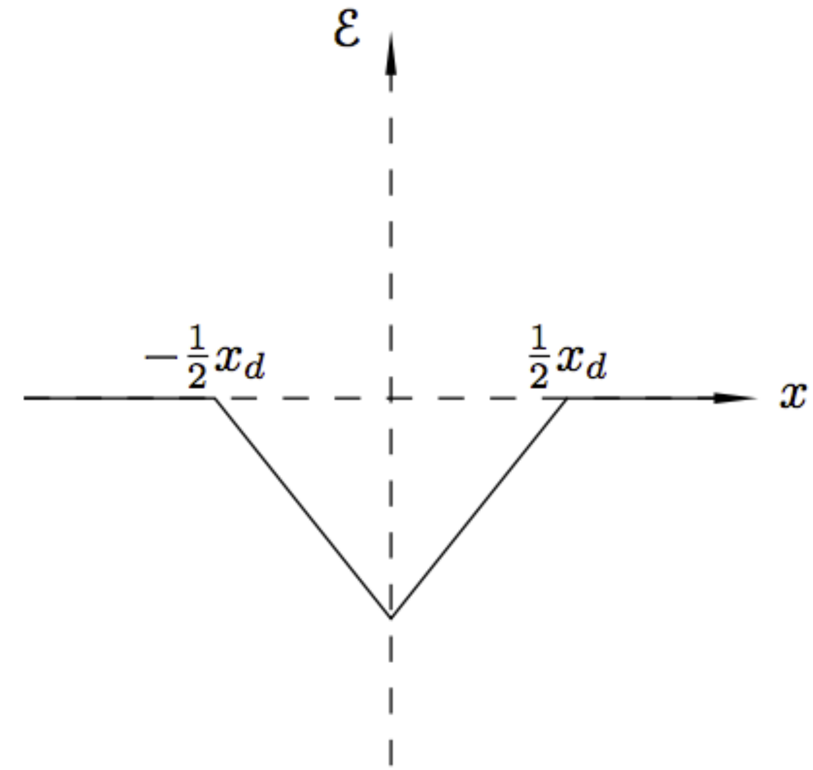

Perform the integration to get to equation 11-16

$$\Delta U = -\frac{e^2 N_d x_d^2}{4\epsilon_r \epsilon_0}$$

$$\mathcal{E}_{\max} = \frac{e N_d x_d}{2\epsilon_r \epsilon_0}$$

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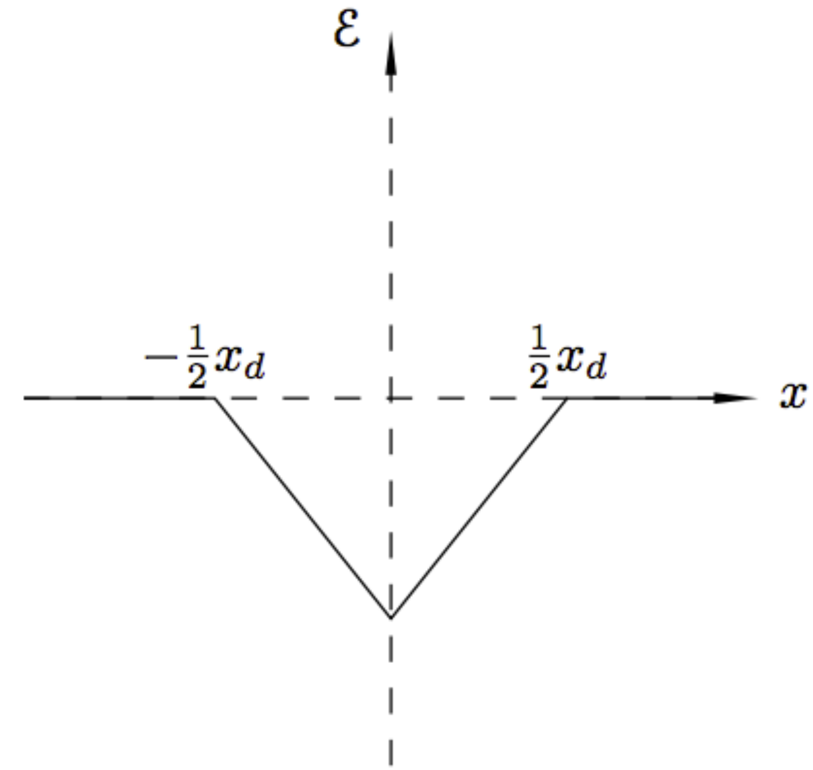

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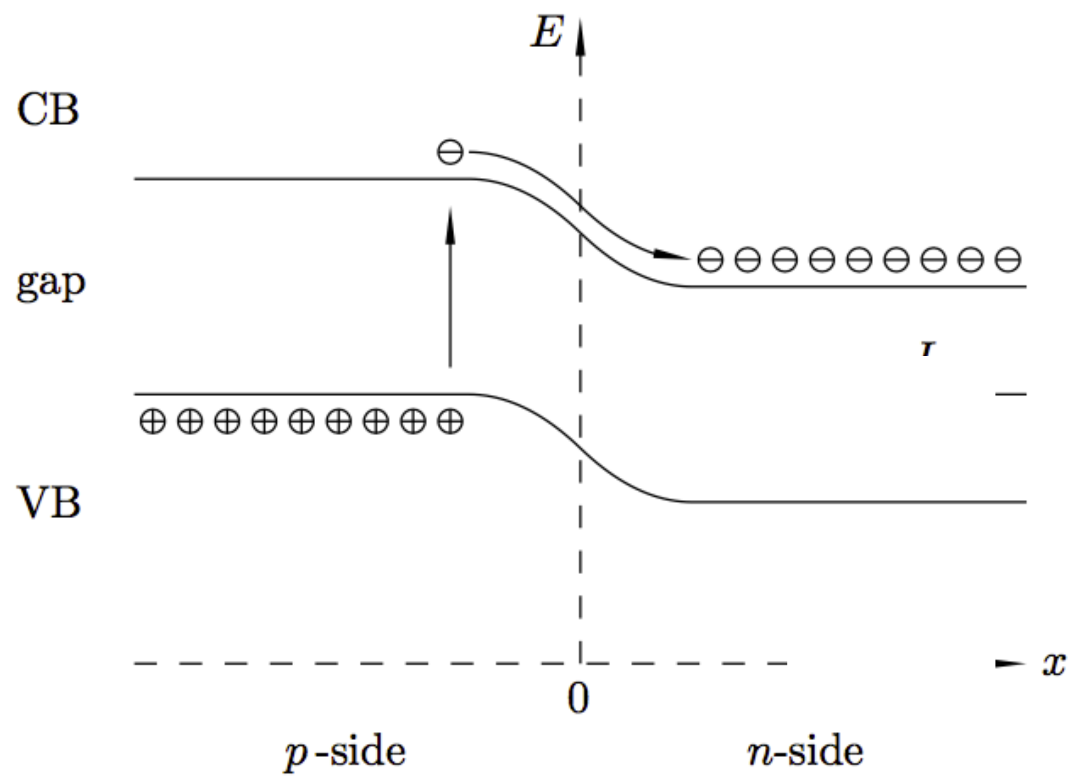
$$x_d = \sqrt{\frac{4\epsilon_r \epsilon_0 \phi}{e N_d}}$$

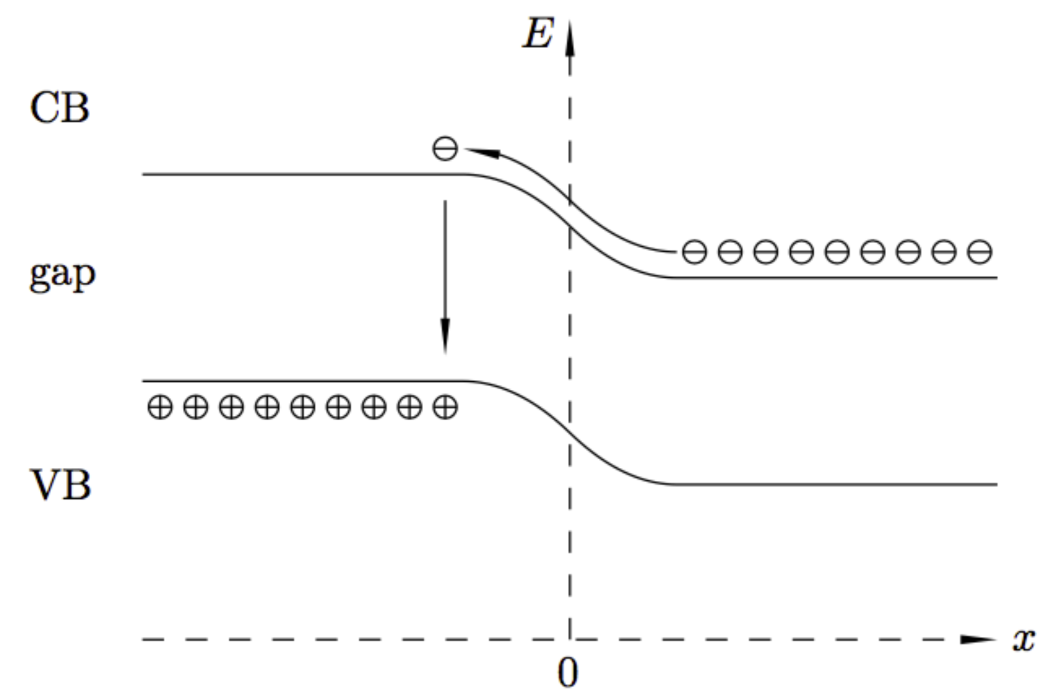
Question #17

Which picture describes recombination current?

a)



b)



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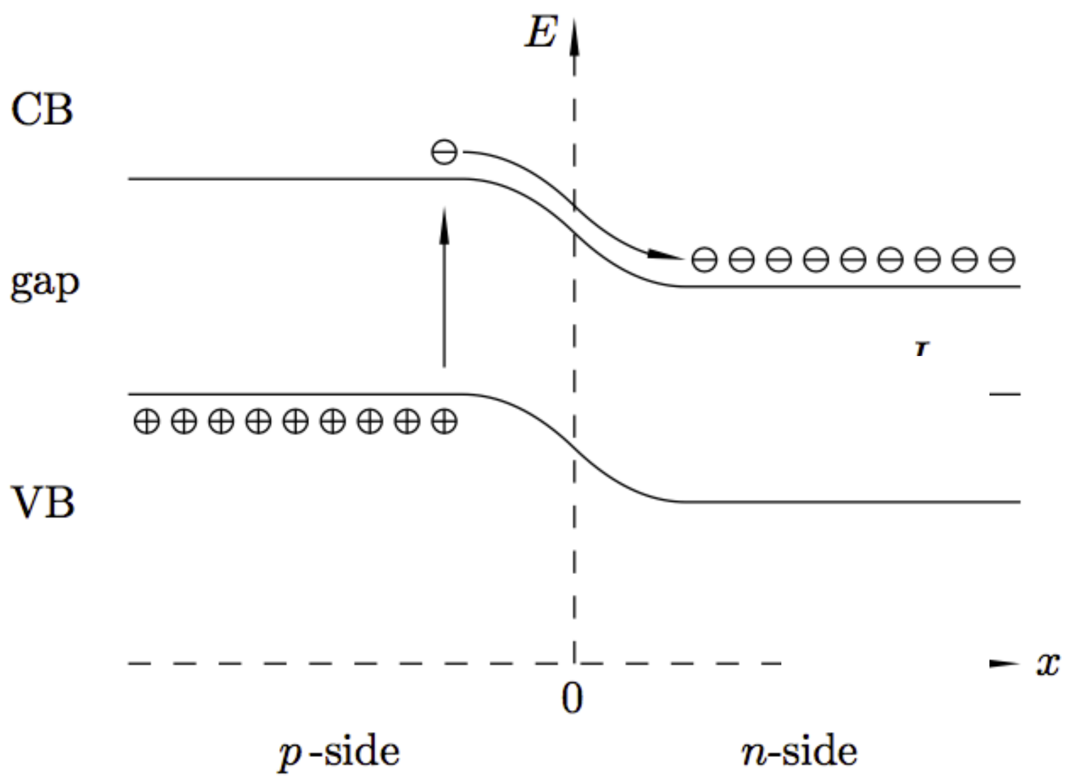
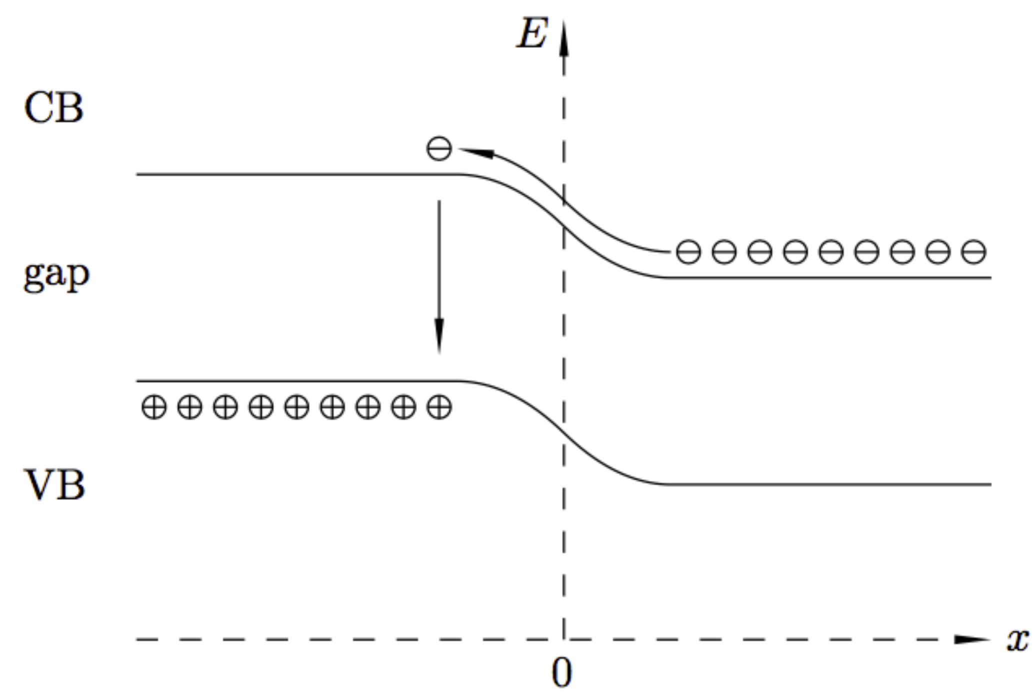


b)



Question #18

What is the direction of the current in (b)?

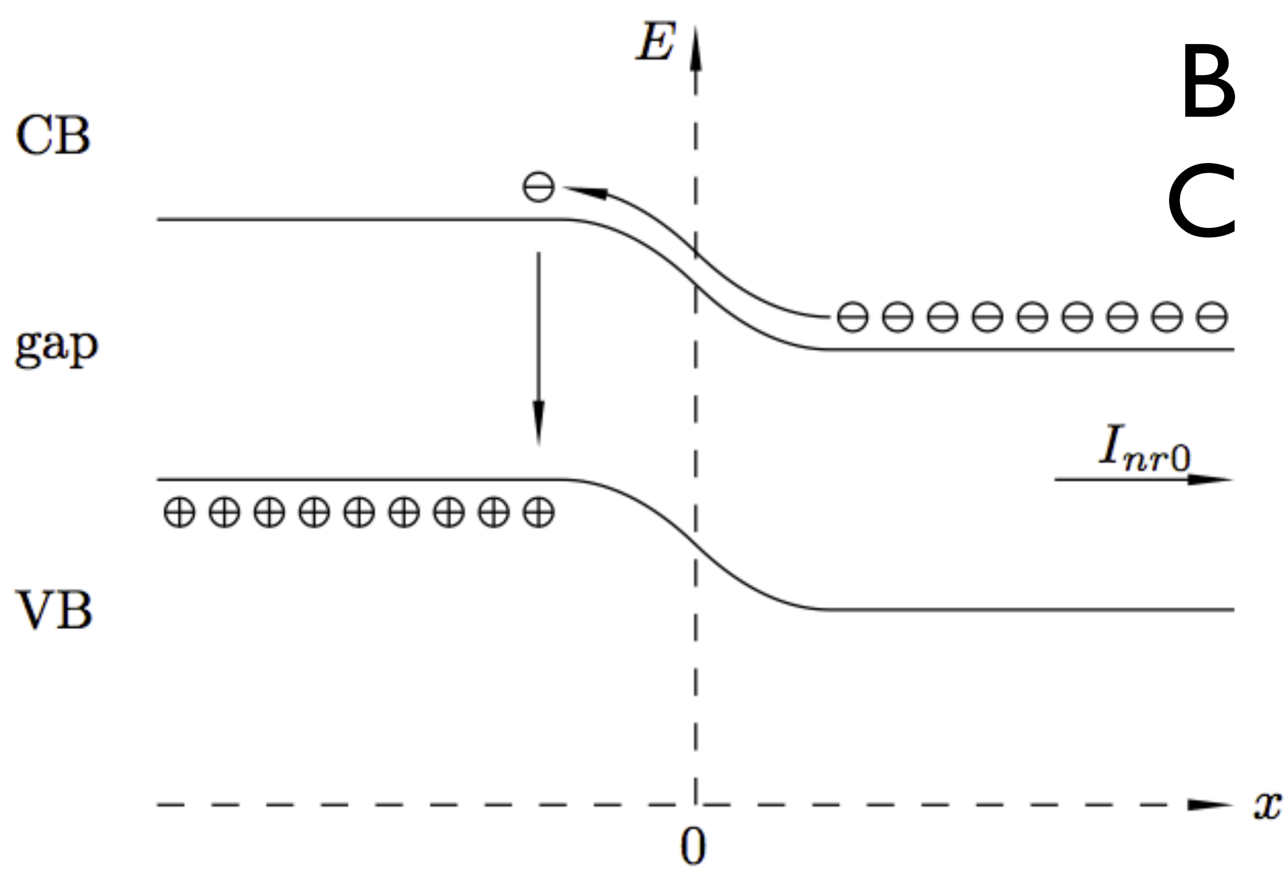
C left

D right

Question #19

If I apply a forward voltage to this junction, how will this affect the recombination current?

Positive terminal of battery connected to the p-side of the junction.



A current decreases
B current increases
C current stays the same.

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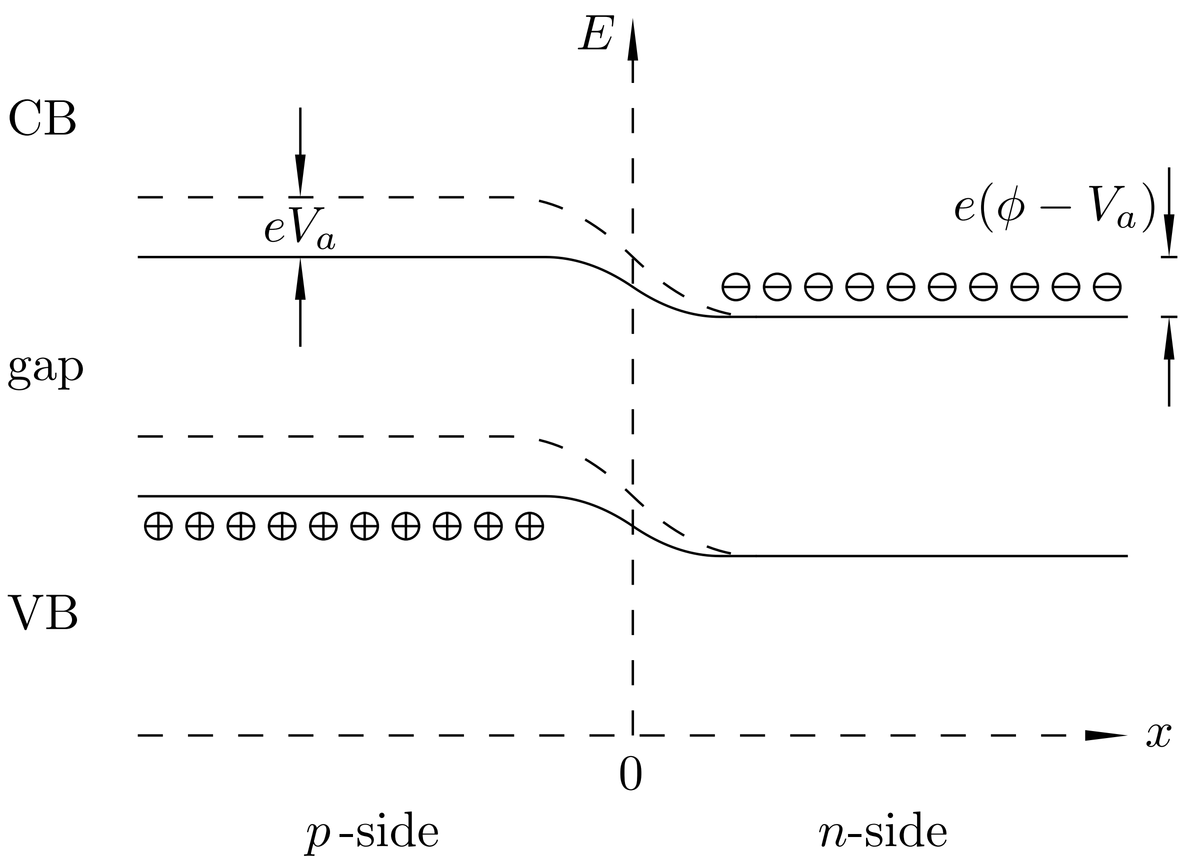
Positive terminal of battery connected to the p-side of the junction.



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Question #20

generation current?

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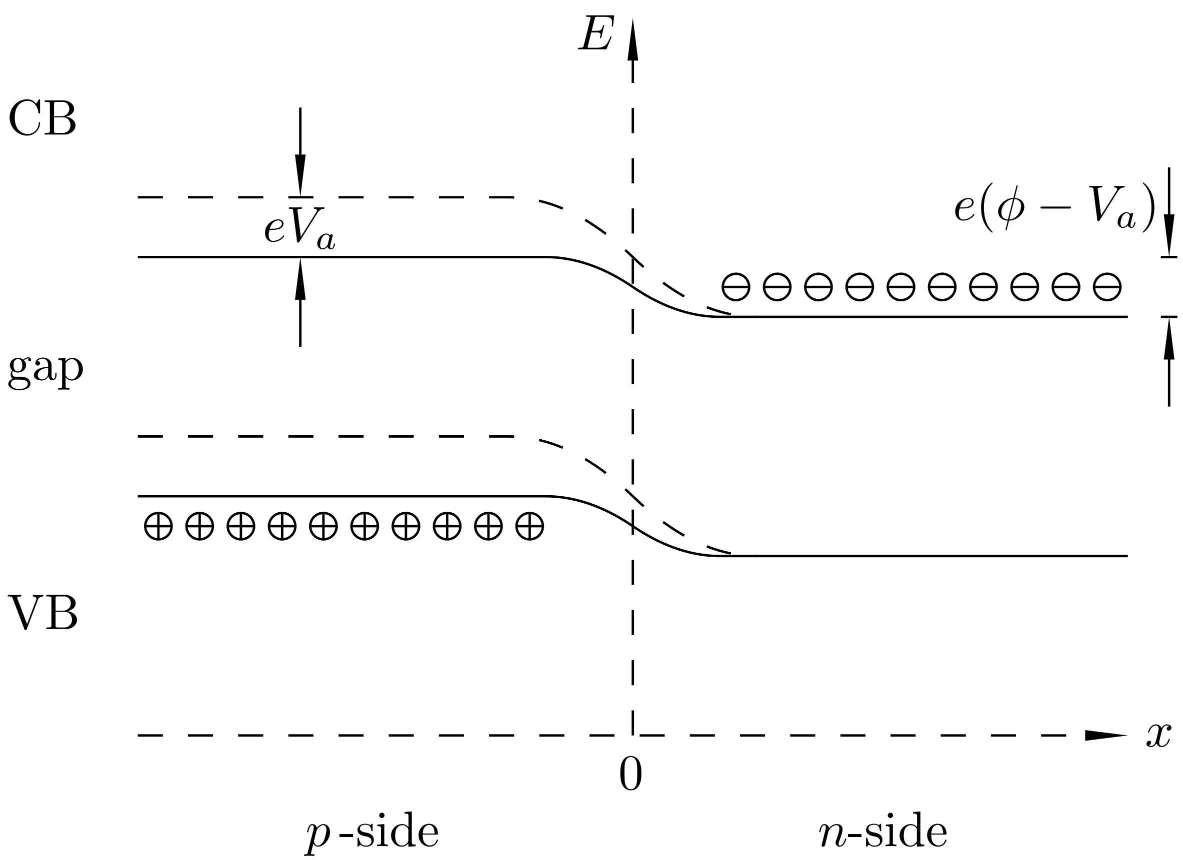
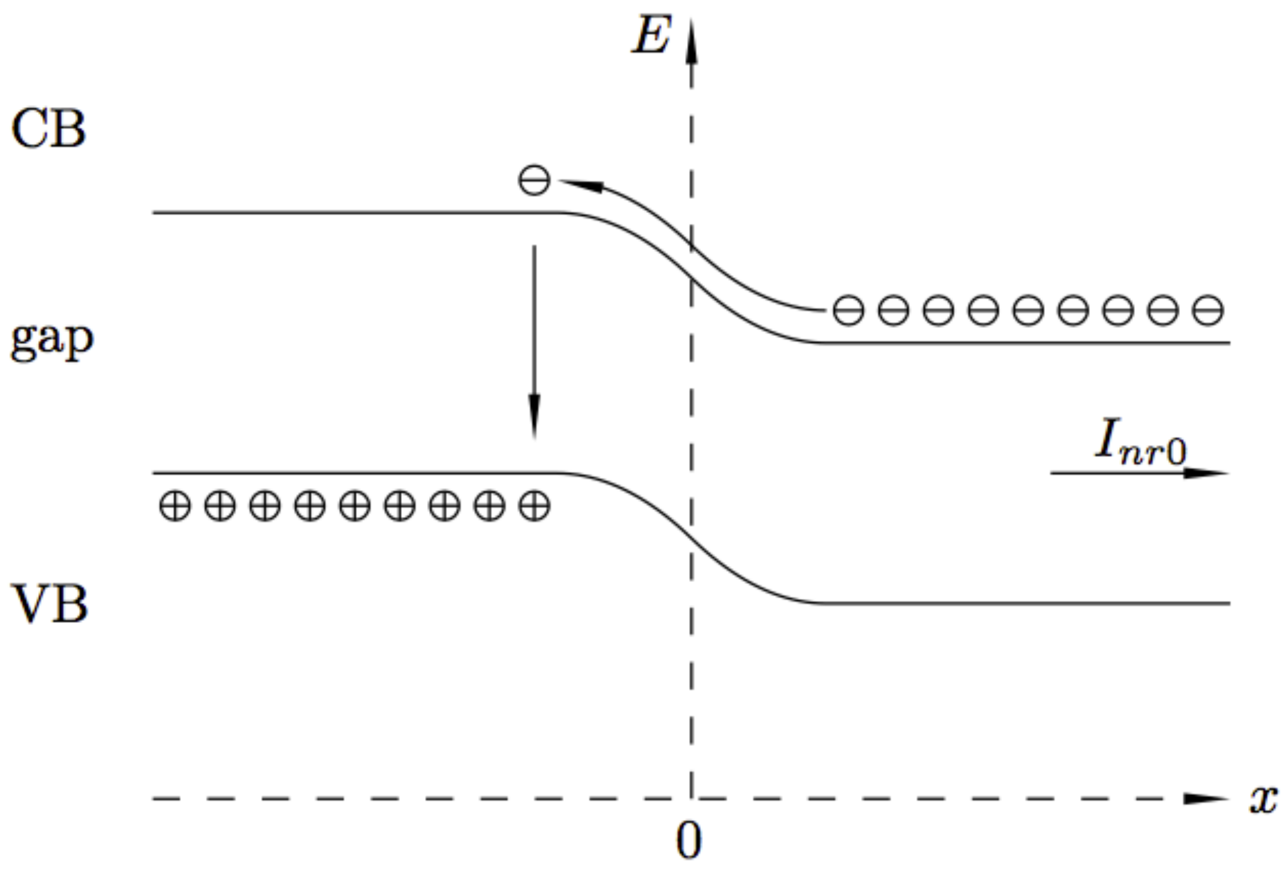


B current decreases
C current increases
D current stays the same.

Question #21

If I apply a backward voltage to this junction, how will this affect the recombination current?

Positive terminal of battery connected to the n-side of the junction.



A current decreases
B current increase
C current stays the same

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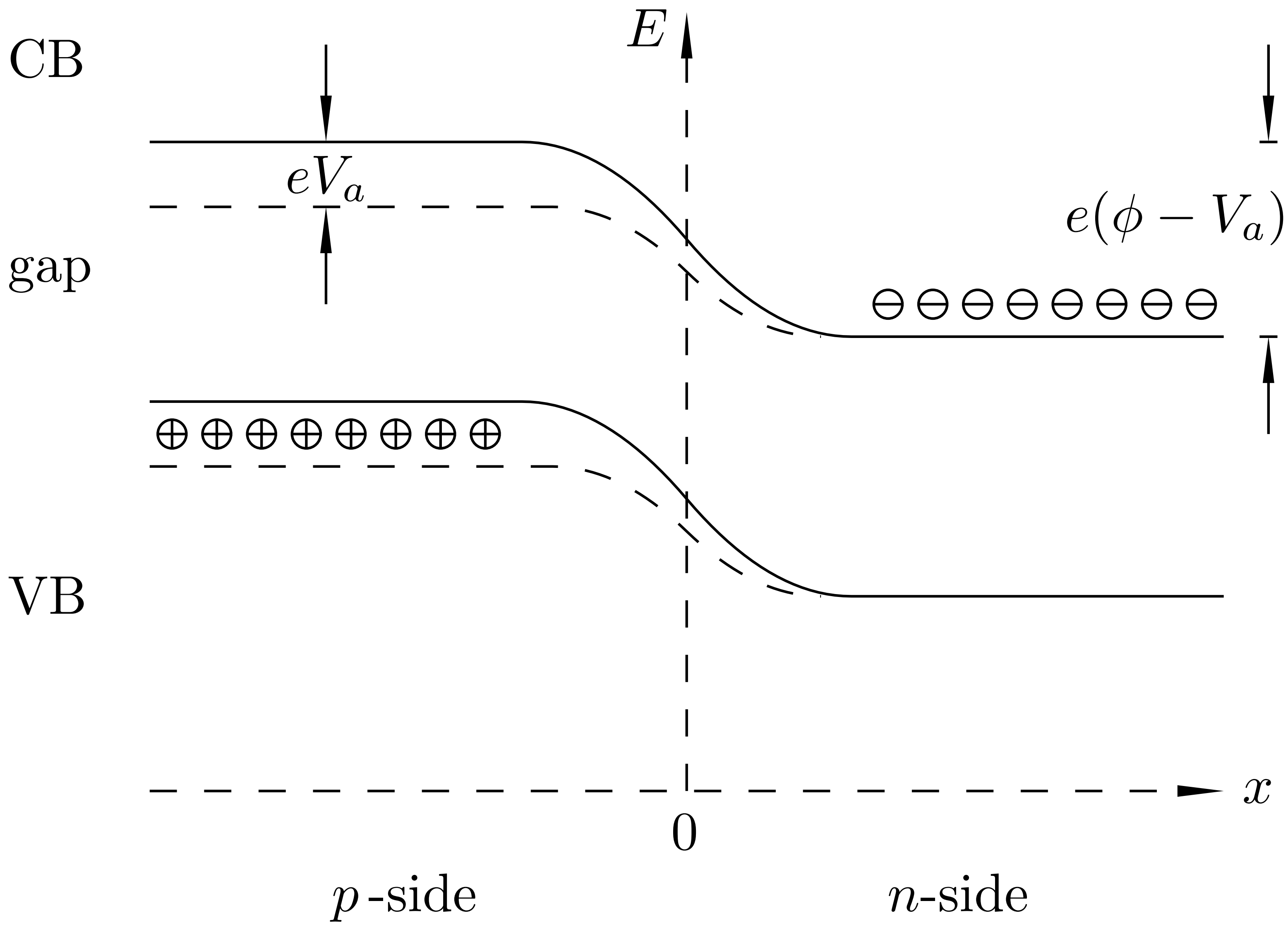
Positive terminal of battery connected to the n-side of the junction.



A current decreases

B current increase

C current stays the same

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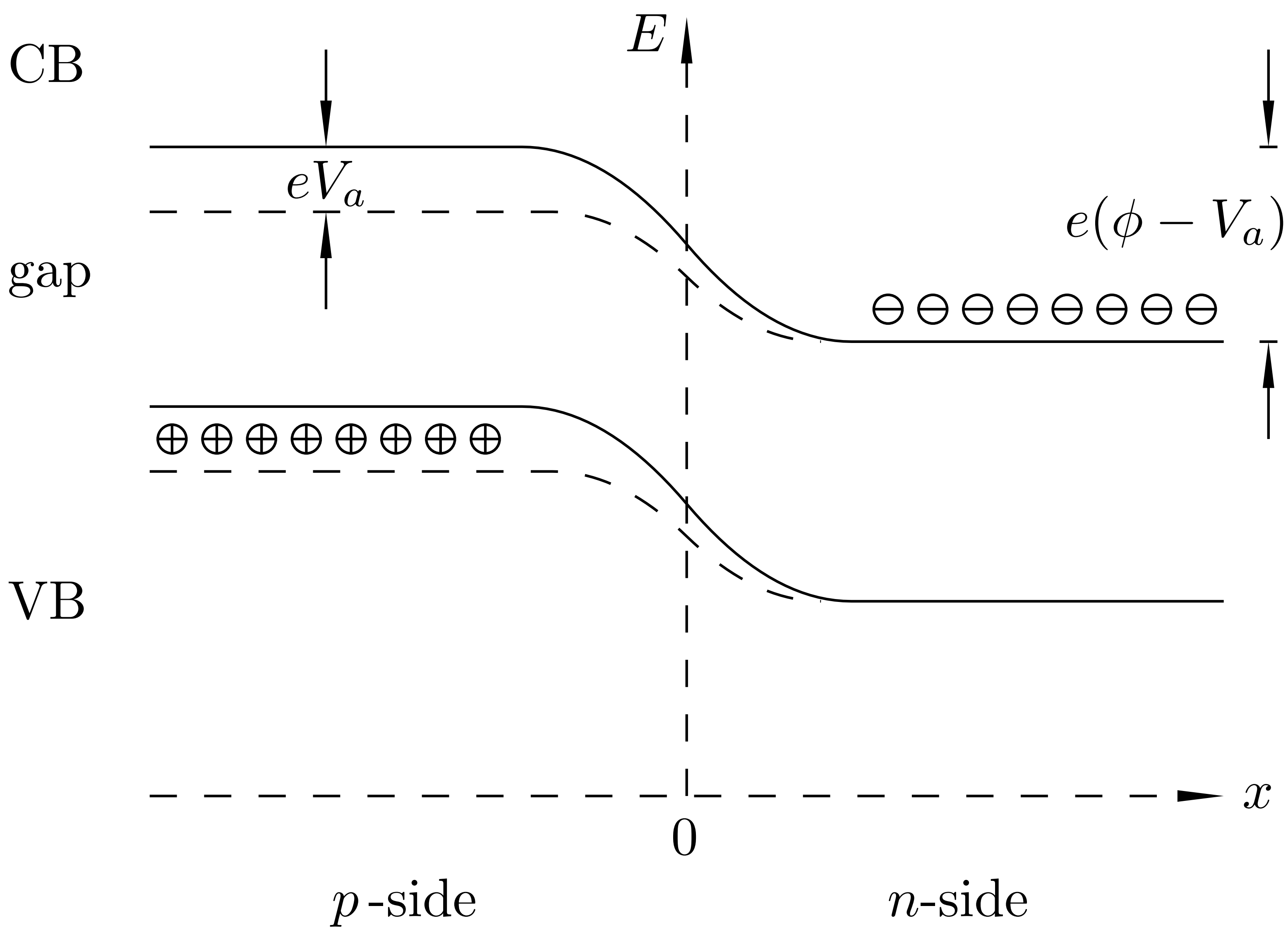


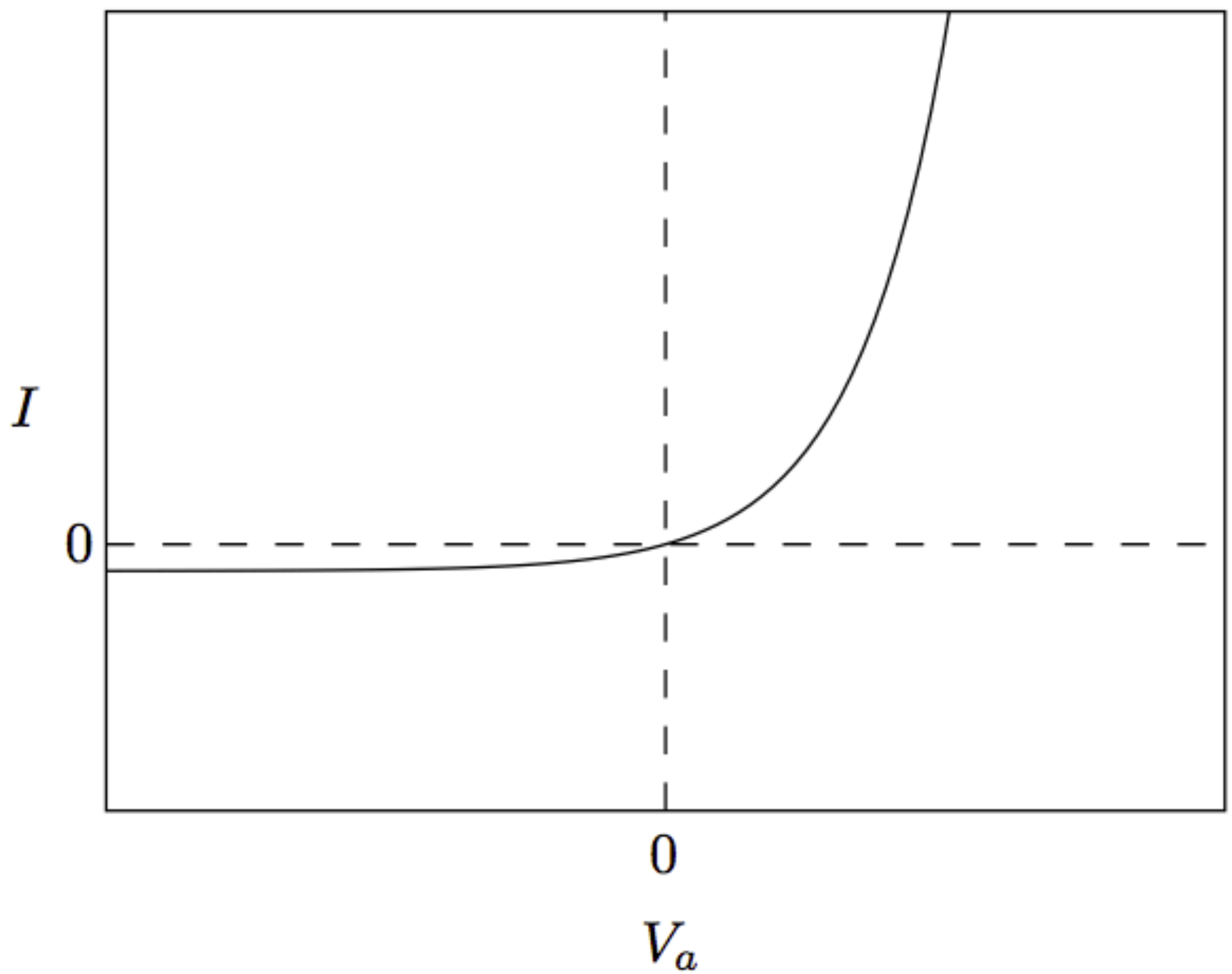
C current decreases

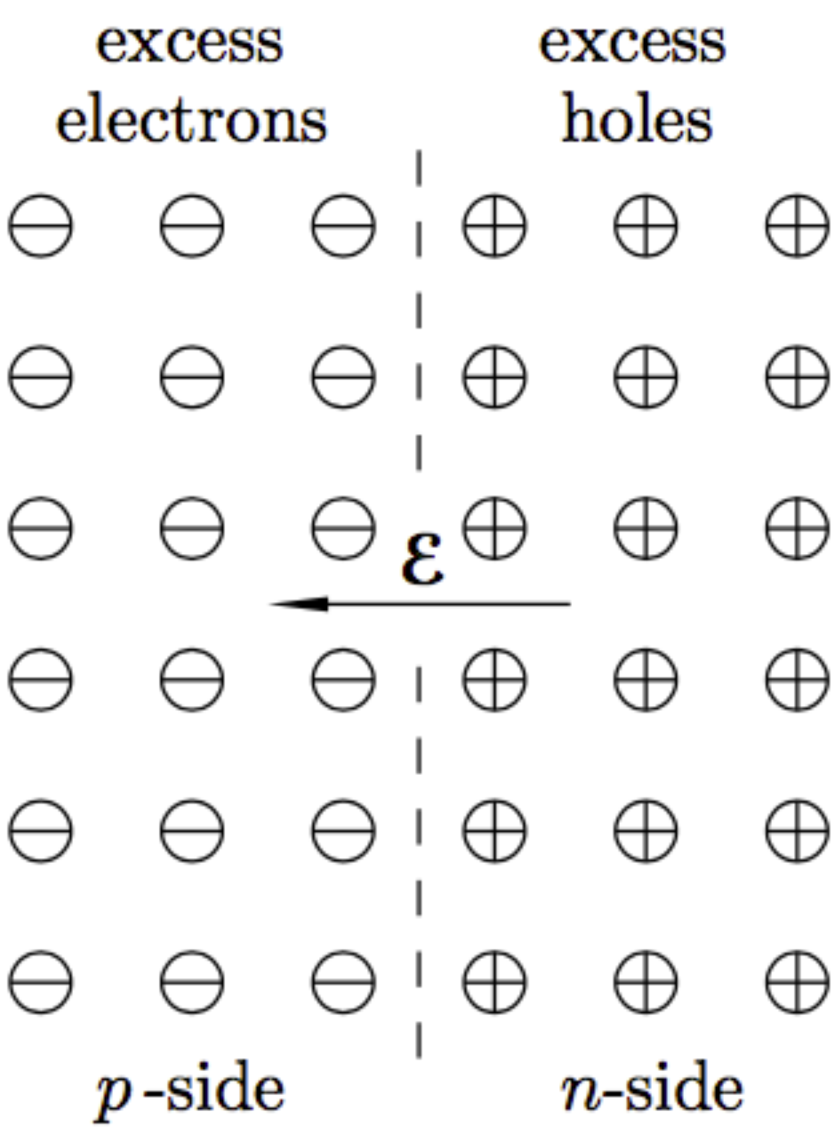
B current increase

A current stays the same

That’s a diode (rectifier)!

$$I = I_0 \left(e^{\frac{eV_a}{k_B T}} + 1 \right)$$

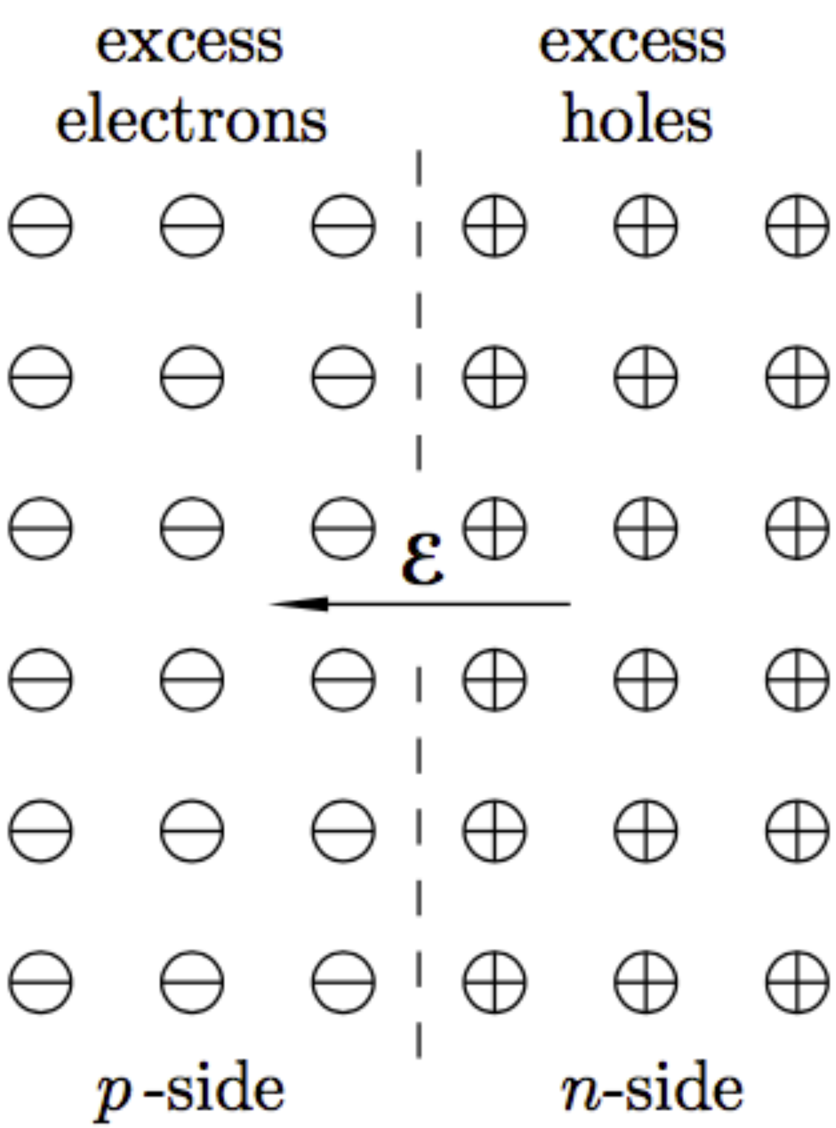




In a **forward-biased** junction, the width of the depletion layer

a) decreases
b) Increases
c) stays the same

Question #23



In a **forward-biased** junction, the width of the depletion layer

a) decreases
b) Increases
c) stays the same

$$x_d = \sqrt{\frac{4\epsilon_r \epsilon_0 \phi}{e N_d}} \qquad \rightarrow \qquad x_d = \sqrt{\frac{4\epsilon_r \epsilon_0 (\phi - V_a)}{e N_d}}$$

Capacitance

$$C = \frac{\epsilon_r \epsilon_0 A}{d}$$ Parallel plate capacitor. (from PH220)

$$x_d = \sqrt{\frac{4\epsilon_r \epsilon_0 (\phi - V_a)}{eN_d}}$$

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$$C = \frac{\epsilon_r \epsilon_0 A}{d}$$ Parallel plate capacitor. (from PH220)

$$x_d = \sqrt{\frac{4\epsilon_r \epsilon_0 (\phi - V_a)}{eN_d}}$$

$$C = A\sqrt{\frac{\epsilon_r \epsilon_0 e N_d}{4(\phi - V_a)}}$$