# Solved Examples

## Example 1 of N-type Semiconductor:

**Silicon (Si) doped with Phosphorus (P)** is a common example of an n-type semiconductor.

- **Silicon (Si)** has four valence electrons.
- **Phosphorus (P)** has five valence electrons. When phosphorus atoms are introduced into the silicon lattice, each phosphorus atom forms covalent bonds with four silicon atoms. However, the fifth electron (the extra electron) is not needed for bonding and becomes a free electron that can move through the material.

These free electrons act as the majority charge carriers, and they significantly increase the conductivity of the material.

**Summary:**

- **Material**: Silicon (Si)
- **Dopant**: Phosphorus (P)
- **Majority charge carriers**: Electrons (negative charge carriers)
- **Minority charge carriers**: Holes (positive charge carriers)
- **Type**: N-type (Negative type)

## Example 2 of P-type Semiconductor:

**Silicon (Si) doped with Boron (B)** is a common example of a p-type semiconductor.

- **Silicon (Si)** has four valence electrons.
- **Boron (B)** has three valence electrons, which is less than silicon's four. When boron is introduced into silicon, it creates a situation where there is a missing electron (a hole) in the structure. This hole can move through the lattice, effectively carrying a positive charge.

**Summary:**

- **Material**: Silicon (Si)
- **Dopant**: Boron (B)
- **Majority charge carriers**: Holes (positive charge carriers)
- **Minority charge carriers**: Electrons (negative charge carriers)
- **Type**: P-type (Positive type)

**Example 3: Determine the position of Fermi level for n-type Si, if $Nd = 10^{15}\ cm^{-3}$, $ni = 10^{10}\ cm^{-3}$**

$n = Nd$

**Solution:**

To determine the position of the **Fermi level** for an **n-type silicon** (Si) semiconductor, we need to consider the following parameters:

- $N_d$ = Donor concentration (in $\mathrm{cm}^{-3}$) = $10^{15}\,\mathrm{cm}^{-3}$
- $n_i$ = Intrinsic carrier concentration (in $\mathrm{cm}^{-3}$) = $10^{10}\,\mathrm{cm}^{-3}$
- $n$ = Electron concentration in the conduction band (in $\mathrm{cm}^{-3}$) = $N_d$ for n-type semiconductors, so $n = 10^{15}\,\mathrm{cm}^{-3}$

In an **n-type** semiconductor, the electron concentration $n$ is approximately equal to the donor concentration $N_d$. The Fermi level $E_F$ is related to the carrier concentration using the following equation:

$$n = n_i \exp\left(\frac{E_F - E_i}{kT}\right)$$

Where:

- $n$ = Electron concentration in the conduction band (in $\mathrm{cm}^{-3}$)
- $n_i$ = Intrinsic carrier concentration (in $\mathrm{cm}^{-3}$)
- $E_F$ = Fermi level (in eV)
- $E_i$ = Intrinsic Fermi level (midgap, approximately 0.56 eV for silicon at room temperature)
- $k$ = Boltzmann constant $(8.617 \times 10^{-5}\,\mathrm{eV/K})$
- $T$ = Temperature in Kelvin (assume room temperature, $T = 300\,\mathrm{K}$)

### Steps to find $E_F$:

1. **Solve for $E_F$ from the equation:**

$$n = n_i \exp\left(\frac{E_F - E_i}{kT}\right)$$

Taking the natural logarithm of both sides:

$$\ln\left(\frac{n}{n_i}\right) = \frac{E_F - E_i}{kT}$$

2. **Substitute the values:**

We know that:

- $n = N_d = 10^{15}\,\text{cm}^{-3}$
- $n_i = 10^{10}\,\text{cm}^{-3}$
- $E_i \approx 0.56\,\text{eV}$
- $k = 8.617 \times 10^{-5}\,\text{eV/K}$
- $T = 300\,\text{K}$

Email ( haider.jabber@uomus.edu.iq)

So:

$$\ln\left(\frac{10^{15}}{10^{10}}\right) = \frac{E_F - 0.56}{(8.617 \times 10^{-5})(300)}$$

$$\ln\left(10^{5}\right) = \frac{E_F - 0.56}{(8.617 \times 10^{-5})(300)}$$

$$\ln(10^5) = 5 \quad (\text{since } \ln(10^5) = 5)$$

$$5 = \frac{E_F - 0.56}{(8.617 \times 10^{-5})(300)}$$

3. **Solve for $E_F$:**

Now, simplify the denominator:

$$(8.617 \times 10^{-5})(300) = 0.02585\,\text{eV}$$

Thus:

$$5 = \frac{E_F - 0.56}{0.02585}$$

Multiply both sides by 0.02585:

$$5 \times 0.02585 = E_F - 0.56$$

$$0.12925 = E_F - 0.56$$

Now, solve for $E_F$:

$$E_F = 0.12925 + 0.56$$

$$E_F = 0.68925\,\text{eV}$$

### Final Answer:

The Fermi level $E_F$ for the given n-type silicon is approximately **0.689 eV** above the intrinsic F level $E_i$.

Email ( haider.jabber@uomus.edu.iq)

## 2. P-Type Semiconductor Example

Given:

- Acceptor concentration $N_a = 10^{15}\,\text{cm}^{-3}$
- Intrinsic carrier concentration $n_i = 10^{10}\,\text{cm}^{-3}$
- Temperature $T = 300\,\text{K}$
- Intrinsic Fermi level $E_i \approx 0.56\,\text{eV}$

For **p-type**, the hole concentration $p \approx N_a$.

We can use the following relation to find the **Fermi level** $E_F$:

$$p = n_i \exp\left(\frac{E_i - E_F}{kT}\right)$$

Where:

- $p$ is the hole concentration (approximated by $N_a$ for p-type semiconductors).
- $k = 8.617 \times 10^{-5}\,\text{eV/K}$ (Boltzmann constant)
- $T = 300\,\text{K}$

Step-by-Step Solution:

1. **Rearranging the equation:**

$$\ln\left(\frac{p}{n_i}\right) = \frac{E_i - E_F}{kT}$$

2. **Substitute values:**

$$\ln\left(\frac{10^{15}}{10^{10}}\right) = \frac{0.56 - E_F}{(8.617 \times 10^{-5})(300)}$$

$$\ln(10^5) = \frac{0.56 - E_F}{0.02585}$$

$$5 = \frac{0.56 - E_F}{0.02585}$$

3. **Solve for $E_F$:**

$$0.56 - E_F = 5 \times 0.02585$$

$$0.56 - E_F = 0.12925$$

$$E_F = 0.56 - 0.12925$$

$$E_F = 0.43075\,\text{eV}$$

**Final Answer:**

For this **p-type silicon**, the **Fermi level** is approximately **0.431 eV** below the intrinsic Fermi level.

---

## Summary of Results:

- For the **n-type** semiconductor, the **Fermi level** is **0.689 eV** above the intrinsic Fermi level.
- For the **p-type** semiconductor, the **Fermi level** is **0.431 eV** below the intrinsic Fermi level.

### Example 1: N-Type Semiconductor (Different Parameters)

Given:

- Donor concentration $N_d = 10^{18}\ \text{cm}^{-3}$
- Intrinsic carrier concentration $n_i = 1.5 \times 10^{10}\ \text{cm}^{-3}$
- Temperature $T = 300\ \text{K}$
- Intrinsic Fermi level $E_i \approx 0.56\ \text{eV}$ (for silicon)

For n-type semiconductors, the electron concentration $n \approx N_d$.

We can use the equation for the Fermi level:

$$n = n_i \exp\left(\frac{E_F - E_i}{kT}\right)$$

Step-by-Step Solution:

1. Rearrange the equation:

$$\ln\left(\frac{n}{n_i}\right) = \frac{E_F - E_i}{kT}$$

2. Substitute values:

$$\ln\left(\frac{10^{18}}{1.5 \times 10^{10}}\right) = \frac{E_F - 0.56}{(8.617 \times 10^{-5})(300)}$$

$$\ln\left(6.67 \times 10^{7}\right) = \frac{E_F - 0.56}{0.02585}$$

$$\ln\left(6.67 \times 10^{7}\right) \approx 18.7$$

$$18.7 = \frac{E_F - 0.56}{0.02585}$$

3. Solve for $E_F$:

$$E_F - 0.56 = 18.7 \times 0.02585$$

$$E_F - 0.56 = 0.483$$

$$E_F = 0.56 + 0.483$$

$$E_F = 1.043\ \text{eV}$$

Final Answer:

For this n-type silicon, the Fermi level is 1.043 eV above the intrinsic Fermi level.

### Example 2: P-Type Semiconductor (Different Parameters)

Given:

- Acceptor concentration $N_a = 10^{16}\,\mathrm{cm}^{-3}$
- Intrinsic carrier concentration $n_i = 1.5 \times 10^{10}\,\mathrm{cm}^{-3}$
- Temperature $T = 300\,\mathrm{K}$
- Intrinsic Fermi level $E_i \approx 0.56\,\mathrm{eV}$

For p-type semiconductors, the hole concentration $p \approx N_a$.

We can use the equation for the Fermi level:

$$p = n_i \exp\left(\frac{E_i - E_F}{kT}\right)$$

Step-by-Step Solution:

1. Rearrange the equation:

$$\ln\left(\frac{p}{n_i}\right) = \frac{E_i - E_F}{kT}$$

2. Substitute values:

$$\ln\left(\frac{10^{16}}{1.5 \times 10^{10}}\right) = \frac{0.56 - E_F}{(8.617 \times 10^{-5})(300)}$$

$$\ln\left(6.67 \times 10^{5}\right) = \frac{0.56 - E_F}{0.02585}$$

$$\ln\left(6.67 \times 10^{5}\right) \approx 13.4$$

$$13.4 = \frac{0.56 - E_F}{0.02585}$$

3. Solve for $E_F$:

$$0.56 - E_F = 13.4 \times 0.02585$$

$$0.56 - E_F = 0.345$$

$$E_F = 0.56 - 0.345$$

$$E_F = 0.215\,\mathrm{eV}$$

Final Answer:

For this p-type silicon, the Fermi level is 0.215 eV below the intrinsic Fermi level.

Email ( haider.jabber@uomus.edu.iq)

---

### Example 3: P-Type Semiconductor (Higher Acceptor Concentration)

Given:

- Acceptor concentration $N_a = 10^{18}\,\text{cm}^{-3}$
- Intrinsic carrier concentration $n_i = 1.5 \times 10^{10}\,\text{cm}^{-3}$
- Temperature $T = 300\,\text{K}$
- Intrinsic Fermi level $E_i \approx 0.56\,\text{eV}$

For p-type semiconductors, the hole concentration $p \approx N_a$.

We can use the equation for the Fermi level:

$$p = n_i \exp\left(\frac{E_i - E_F}{kT}\right)$$

Step-by-Step Solution:

1. Rearrange the equation:

$$\ln\left(\frac{p}{n_i}\right) = \frac{E_i - E_F}{kT}$$

2. Substitute values:

$$\ln\left(\frac{10^{18}}{1.5 \times 10^{10}}\right) = \frac{0.56 - E_F}{(8.617 \times 10^{-5})(300)}$$

$$\ln\left(6.67 \times 10^{7}\right) = \frac{0.56 - E_F}{0.02585}$$

$$\ln\left(6.67 \times 10^{7}\right) \approx 18.7$$

$$18.7 = \frac{0.56 - E_F}{0.02585}$$

3. Solve for $E_F$:

$$0.56 - E_F = 18.7 \times 0.02585$$

$$0.56 - E_F = 0.483$$

$$E_F = 0.56 - 0.483$$

$$E_F = 0.077\,\text{eV}$$

Email ( haider.jabber@uomus.edu.iq)