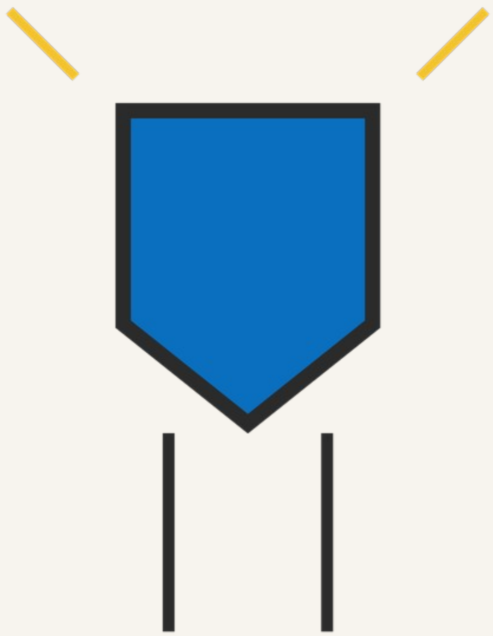
ELECTRICITY 5 · SEMICONDUCTORS

Semiconductors & p-n Junctions

Why some solids conduct, some don't, and some can be talked into it.

Higher Physics



Starter

2009 Higher Physics

Scan the code and answer these:

Q8 **Q11**

Section A · charged particles, capacitors

Show your working, not just the letter.

Scan for the paper

Marking scheme

PART 1

Energy bands

Every solid has its own band structure — and that structure is what decides whether it conducts.

By the end of this part...

1. I can describe how energy bands form from the energy levels of single atoms.
2. I can name and describe the conduction band and the valence band.
3. I can use band structure to explain why a solid conducts or does not.

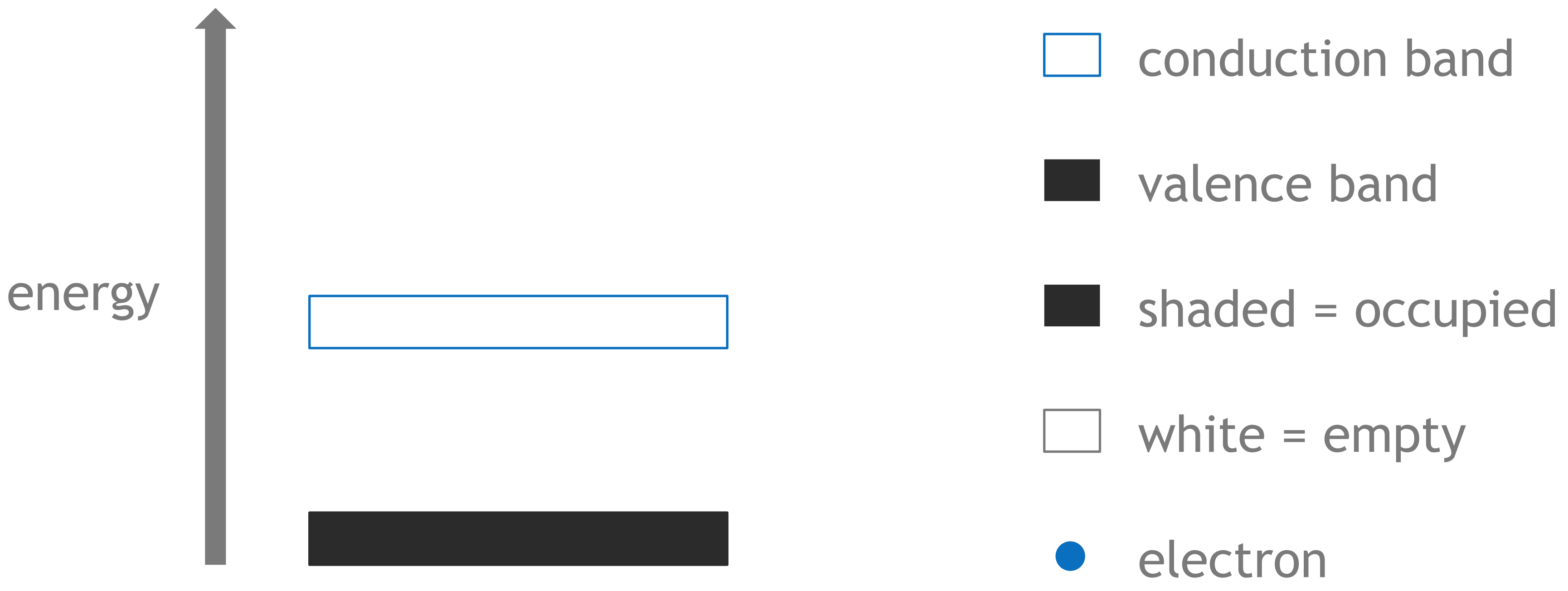
From energy levels to energy bands

- In a single atom, electrons sit in separate, fixed energy levels.
- Bring millions of atoms together into a solid and those levels merge into wide bands.
- Between the bands are gaps — energies no electron in the solid is allowed to have.

The two bands that matter

JOTTER NOTES

Every solid has both. What changes is the gap between them.



JOTTER NOTES

The conduction band and the valence band

The valence band holds the electrons that bond the solid together.

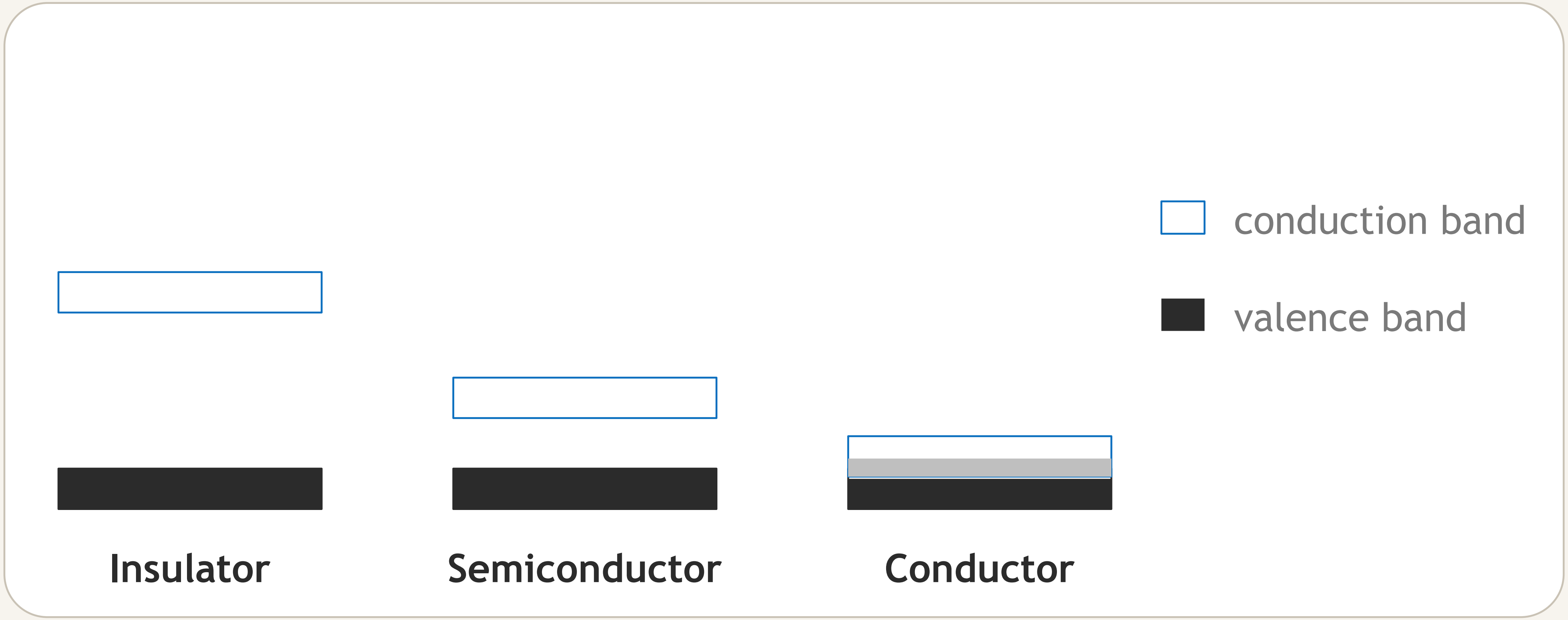
The conduction band is the band an electron has to reach before it can move freely and carry a current.

Between them is a gap — a range of energies no electron is allowed to have.

Three kinds of solid

JOTTER NOTES

Same two bands every time. Only the gap changes.



JOTTER NOTES

Conductors

In a conductor the conduction band and the valence band overlap.

There are electrons free to move AND empty states for them to move into.

There is no gap to cross, so a conductor conducts very well.

JOTTER NOTES

Insulators

In an insulator the valence band is full and the gap above it is very large.

At room temperature no electron has enough energy to cross that gap.

The conduction band stays empty, so no current flows.

JOTTER NOTES

Semiconductors

In a semiconductor the valence band is full, but the gap above it is small.

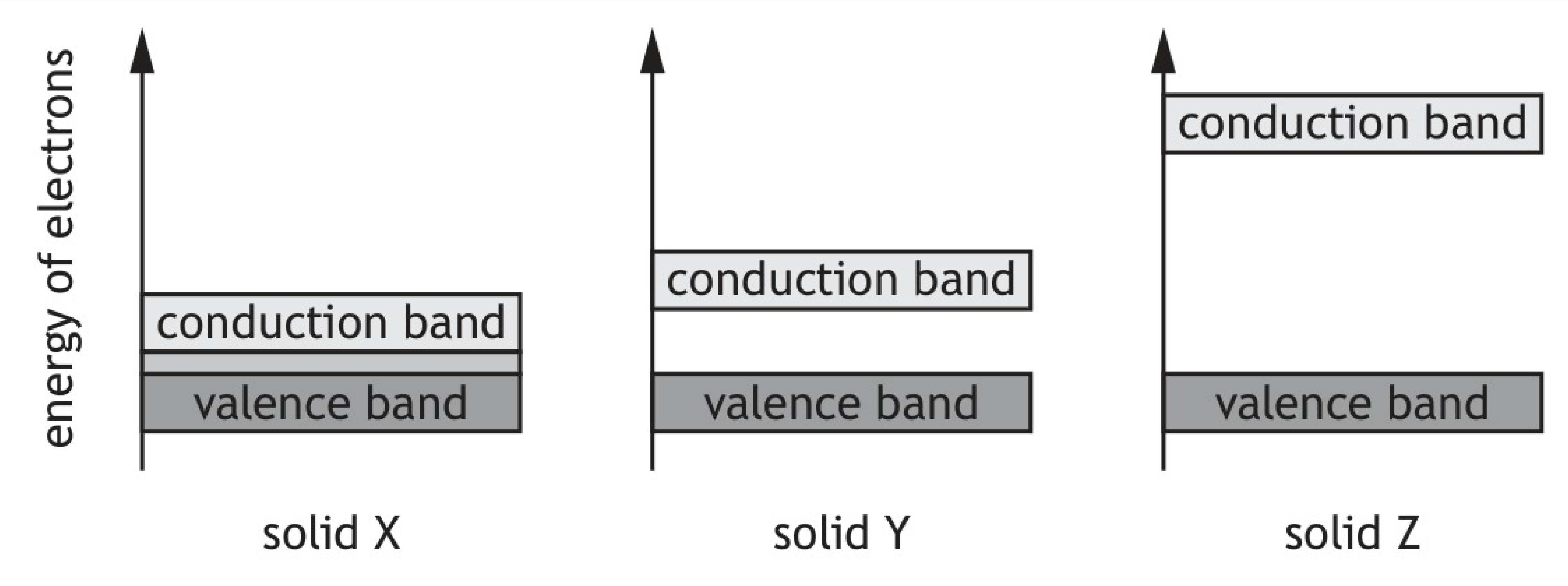
At room temperature a few electrons have enough energy to cross it.

That gives a little conduction — more than an insulator, far less than a metal.

Warm it up and more electrons cross the gap, so a semiconductor conducts better when it is hotter.

The same diagram in an exam

No colour, and the bands are named rather than shaded.



Watch Out — conducting needs two things

THE MISTAKE

- Saying a solid conducts just because it has free electrons
- The conduction band is the highest occupied band in an insulator

THE CORRECT ANSWER

- It needs free electrons AND empty states to move into.
- There are no electronics in the conduction band therefore the valance band is the hights occupied band

Show Me: classify the solid

SHOW ME BOARDS

1. State which band an electron must reach before it can carry a current.
2. A solid has a full valence band and a very large gap. State what kind of solid it is, and why it does not conduct.
3. State the two things a solid needs before it can conduct.
4. Explain why a semiconductor conducts better when it is warmed up.
5. State and justify what happens to the conductivity of a metal when it is warmed up.

Task

Work through the band structure questions. On every explanation, name the bands and say how big the gap is.

Past papers: 2018 Q11, 2022 Q11

Past Paper Finder

Starter

2013 Higher Physics

Scan the code and answer these:

Q8 **Q11**

Section A · charged particles, capacitors

Show your working, not just the letter.

Scan for the paper

Marking scheme

PART 2

Doping

Add the right impurity to a semiconductor and a brand new energy level appears inside the gap.

By the end of this part…

1. I can describe what doping is and state why it is done.
2. I can tell p-type and n-type semiconductors apart.
3. I can explain both types using their band structure.

What doping is

- During manufacture, a semiconductor is doped — small amounts of a specific impurity are added.
- This is done to increase its conductivity in a controlled way.
- Doping produces two types of semiconductor: $\mathrm{n\text{-}type}$ and $\mathrm{p\text{-}type}$.

JOTTER NOTES

Doping

Doping means adding a small amount of a specific impurity to a semiconductor during manufacture.

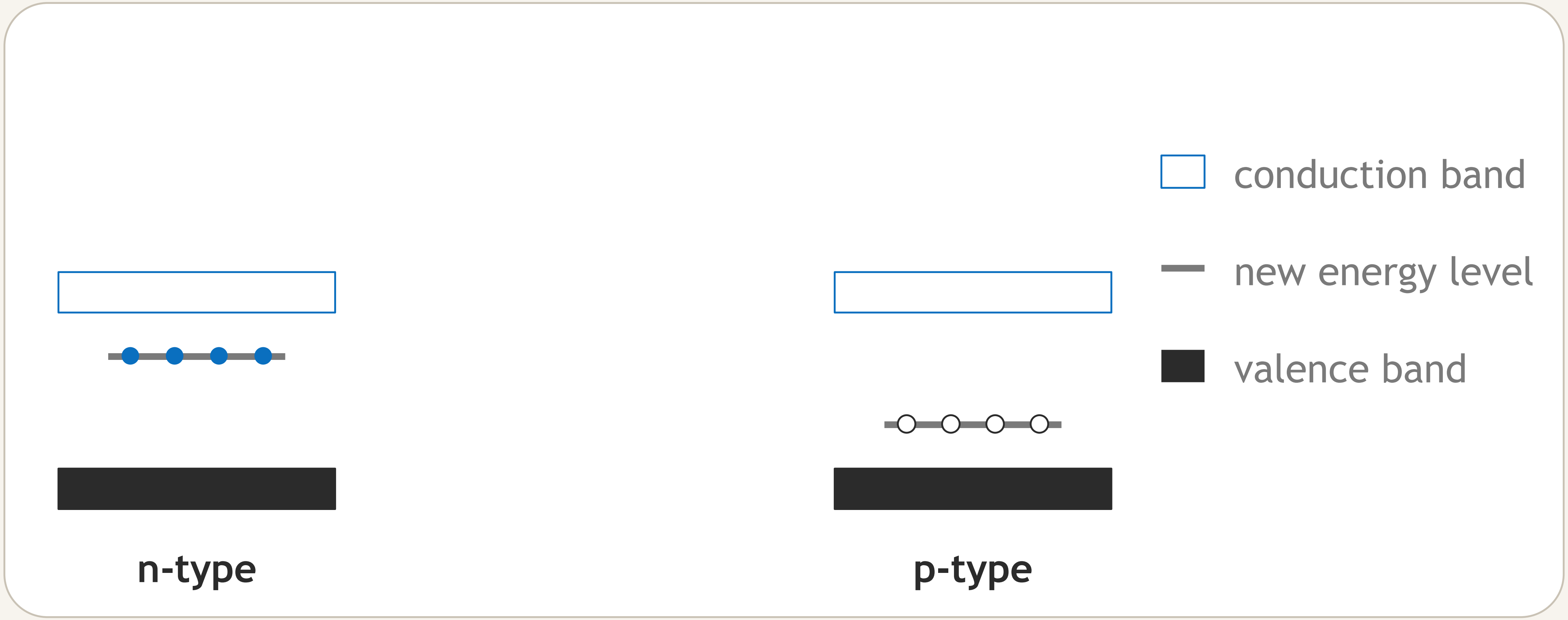
It is done to increase the conductivity in a controlled way.

Doping produces two types of semiconductor: n-type and p-type.

What doping does to the bands

JOTTER NOTES

The impurity adds a new energy level inside the gap.



JOTTER NOTES

n-type semiconductors

In an n-type semiconductor the new level sits just below the conduction band.

Electrons on that level need only a little energy to reach the conduction band.

So conduction happens by electrons in the conduction band, and the charge carriers are negative.

JOTTER NOTES

p-type semiconductors

In a p-type semiconductor the new level sits just above the valence band, and it is empty.

Electrons in the valence band move up into those empty spaces, leaving spaces behind them.

So conduction happens in the valence band, and the charge carriers behave as if, they are positive.

Watch Out — say what doping is FOR

THE MISTAKE

- Saying that doping decreases resistance
- Calling n-type material negatively charged

THE CORRECT ANSWER

- Say it increases conductivity.
- Both types are neutral overall — the CARRIERS differ.

Show Me: doping

SHOW ME BOARDS

1. State what is meant by doping a semiconductor.
2. State why a semiconductor is doped.
3. A semiconductor's charge carriers are electrons. State whether it is p-type or n-type.
4. State where the new energy level sits in an n-type semiconductor.
5. Explain, in terms of bands, how conduction happens in a p-type semiconductor.

Task

Work through the doping questions.
Every answer names a band and says where the new level sits.

Past papers: 2011 Q18, 2014 Q18

Past Paper Finder

Starter

2015 Revised Higher Physics

Scan the code and answer these:

Q17 **Q19** **Q20**

Section A · a.c., semiconductors

Show your working, not just the letter.

Scan for the paper

Marking scheme

PART 3

The p-n junction

Put the two doped layers next to each other and the bands take a step at the boundary.

By the end of this part...

1. I can describe how a p-n junction is formed and what it contains.
2. I can state what forward bias and reverse bias mean.
3. I can state the effect of each on the electric field in the junction.

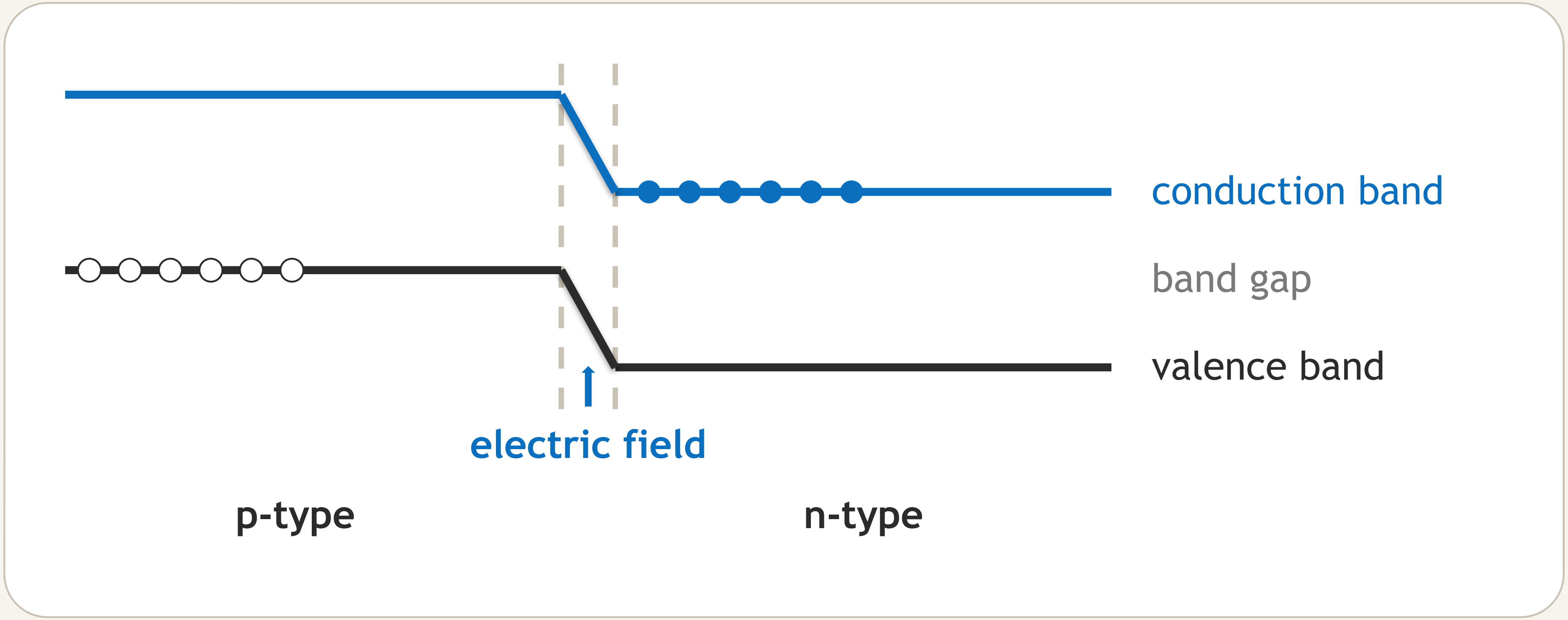
How the junction forms

- One piece of semiconductor is doped p-type at one end and n-type at the other.
- Where the two layers meet, a p-n junction is formed.
- There is an electric field in the p-n junction, and every device in this topic depends on it.

The p-n junction

JOTTER NOTES

Both bands take a step down as you cross from p-type to n-type.



JOTTER NOTES

The p-n junction

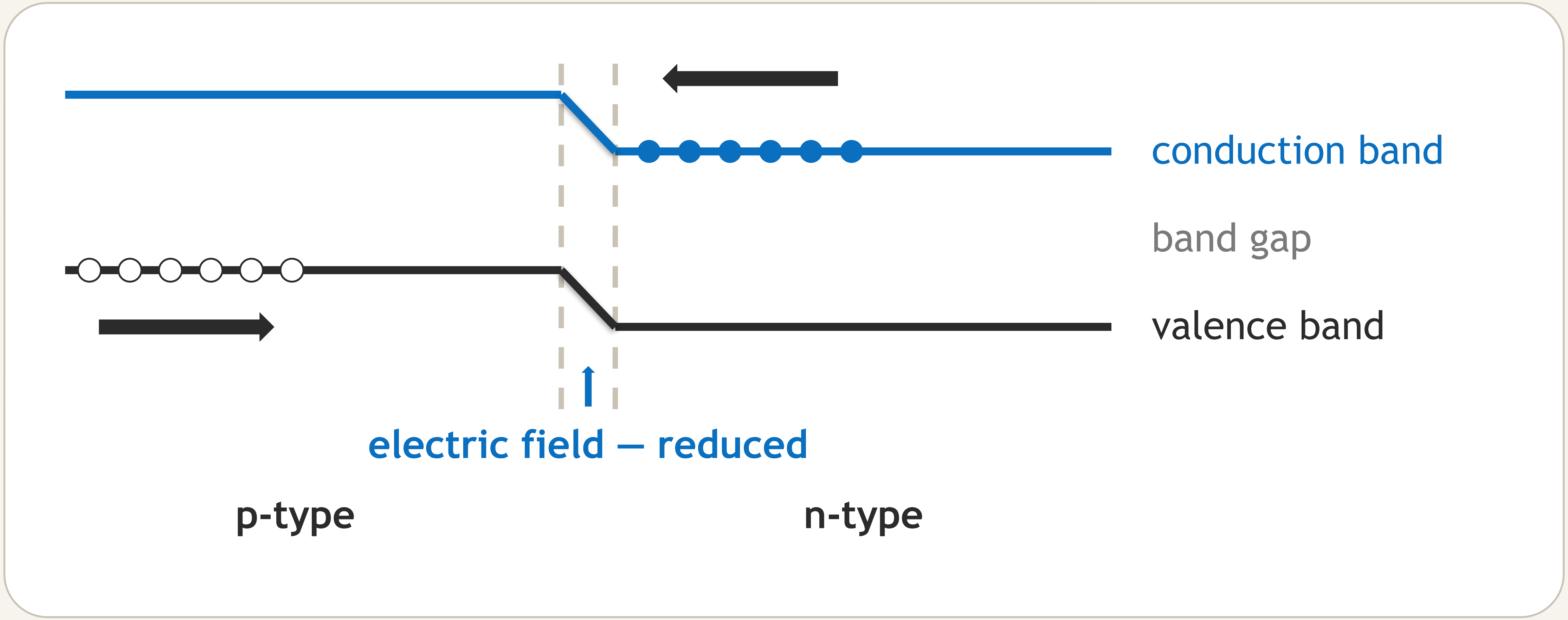
A p-n junction is formed where a p-type layer and an n-type layer sit next to each other.

There is an electric field in the p-n junction.

On a band diagram that field shows up as a step: both bands drop as you cross from the p-type side to the n-type side.

Forward bias

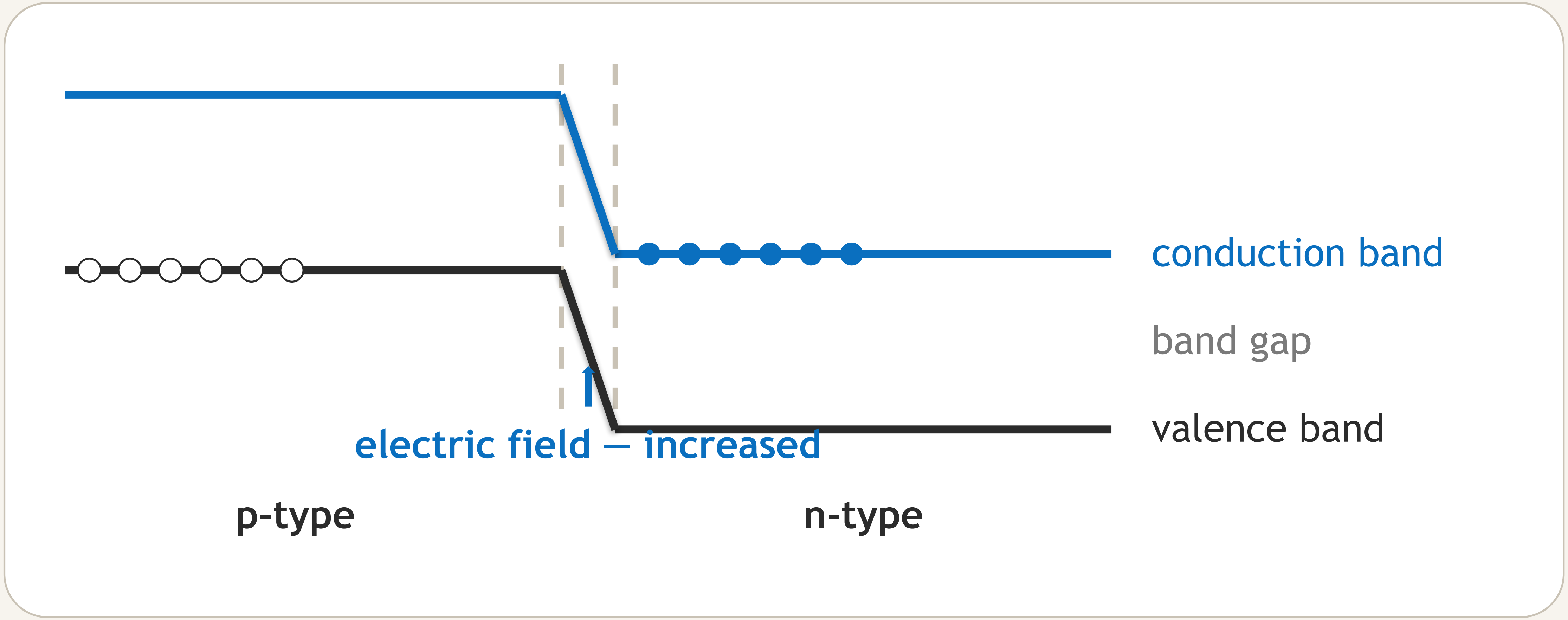
The step gets smaller, so the carriers can cross.



Reverse bias

JOTTER NOTES

The step gets bigger, so the carriers cannot cross.



JOTTER NOTES

Forward and reverse bias

Forward bias connects the supply so that the electric field in the junction is reduced.

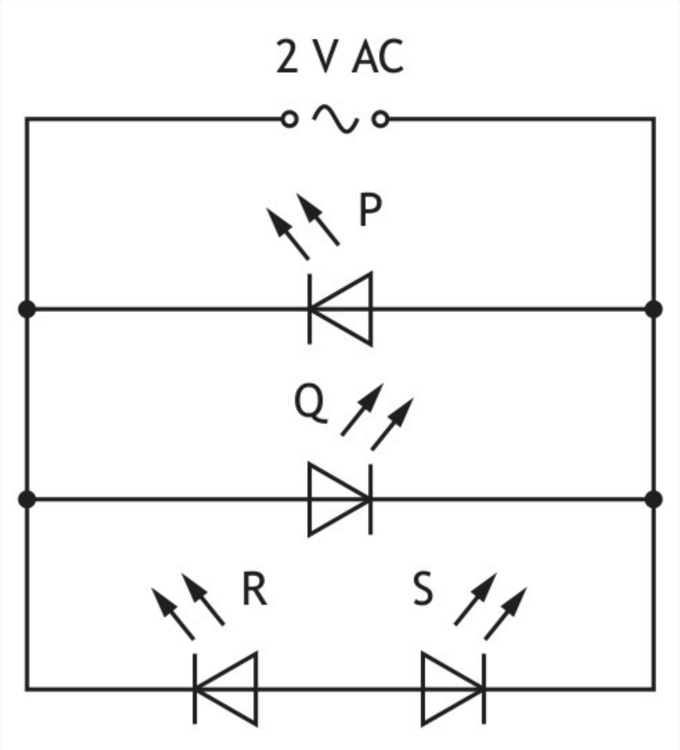
On the diagram the step gets smaller, so electrons and spaces can cross the junction and a current flows.

Reverse bias connects it the other way, so the field is increased.

The step gets bigger, nothing can cross, and no current flows.

Bias in a real exam question

Four LEDs on one supply. Which ones are forward biased?



JOTTER NOTES

Spotting the bias in a circuit

The triangle in the diode symbol points the way the current is allowed to flow.

If the triangle points from the positive side towards the negative side, the diode is forward biased and it conducts.

Pointing the other way, it is reverse biased and nothing flows.

Show Me: junctions and bias

SHOW ME BOARDS

1. State what is produced when p-type and n-type layers sit next to each other.
2. State what a p-n junction contains.
3. State the effect of forward bias on the electric field in a junction.
4. State the effect of reverse bias on the electric field in a junction.
5. A diode is connected so that no current flows. State how it is biased, and what has happened to the field.

Task

Work through the p-n junction questions. Sketch the band diagram for each bias from memory, then check it.

Past papers: 2016 Q12(b), 2008 Q21(c)

Past Paper Finder

Starter

2014 Higher Physics

Scan the code and answer these:

Q10 **Q11**

Section A · a.c., capacitors

Show your working, not just the letter.

Scan for the paper

Marking scheme

PART 4

Light-emitting diodes

An LED is a forward-biased p-n junction doing one very specific job: turning electrons into photons.

By the end of this part…

1. I can describe an LED as a forward-biased p-n junction diode.
2. I can describe, in terms of bands, how an LED emits a photon.
3. I can explain why different LEDs emit different colours.

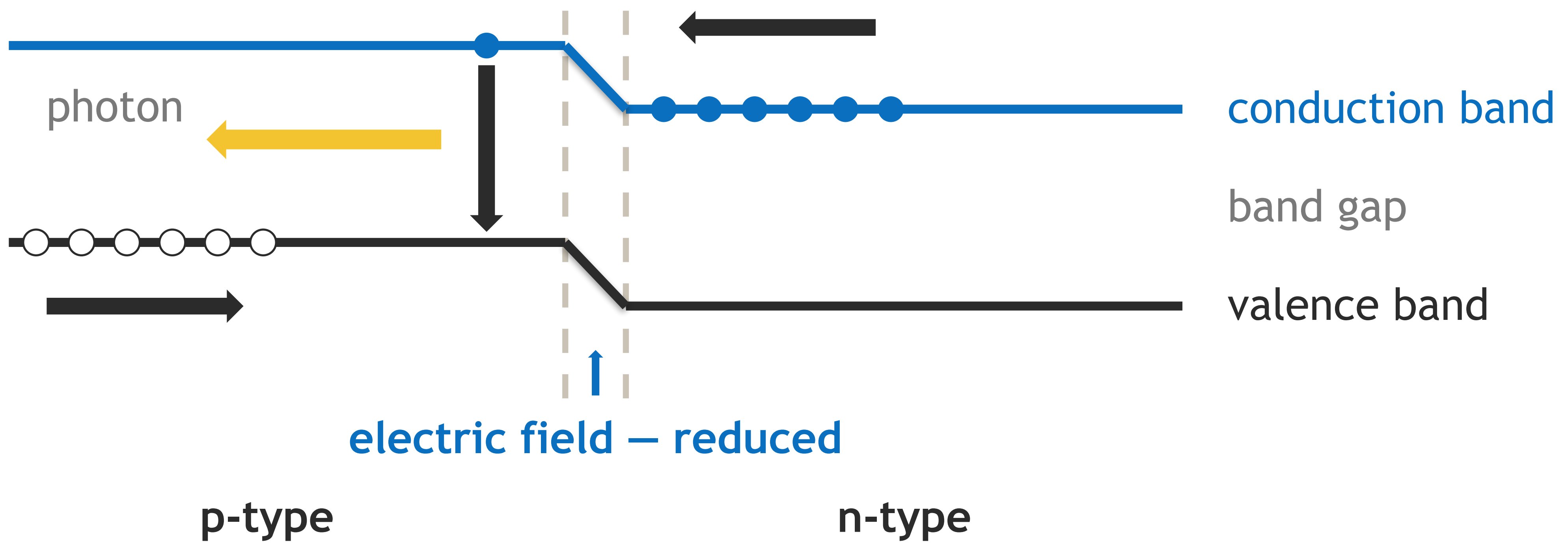
What an LED is

- An LED is a forward-biased p-n junction diode that emits photons.
- The forward bias moves electrons from the conduction band of the n-type side towards the conduction band of the p-type side.
- Photons are emitted when those electrons fall from the conduction band into the valence band.

How an LED emits light

JOTTER NOTES

An electron falls across the gap, and a photon leaves.



JOTTER NOTES

Light-emitting diodes

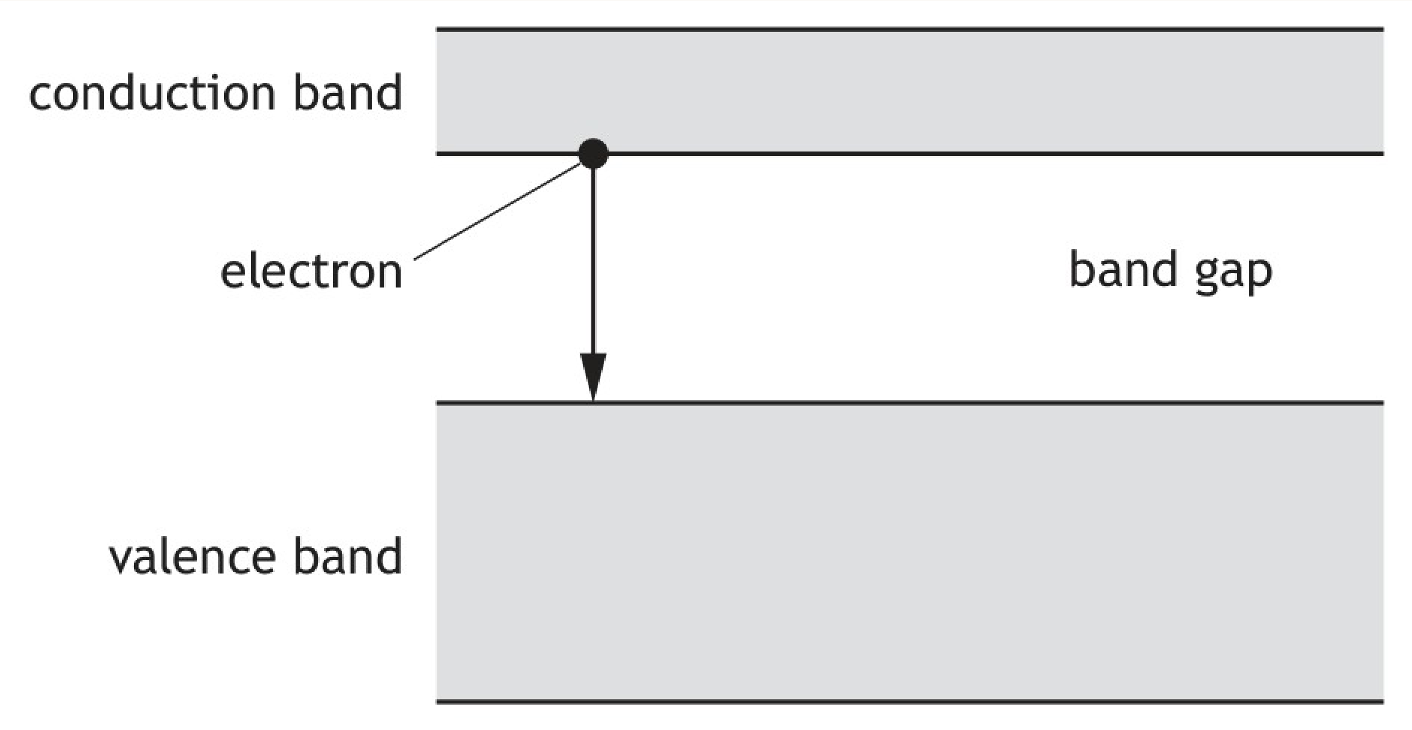
An LED is a forward-biased p-n junction diode that emits photons.

The forward bias moves electrons from the conduction band on the n-type side towards the conduction band on the p-type side.

A photon is emitted when an electron falls from the conduction band into the valence band, either side of the junction.

The same idea in an exam question

One electron, one drop across the gap, one photon.



JOTTER NOTES

Band gap and colour

The electron loses exactly the energy of the gap as it falls.

All of that energy leaves as one photon, so the photon's energy is equal to the band gap.

A bigger gap gives a higher-energy photon, which is bluer light.

A smaller gap gives a lower-energy photon, which is redder light.

Watch Out — always mention the band gap

THE MISTAKE

- Explaining LED colour without mentioning the band gap
- Treating every LED's photon energy as the same

THE CORRECT ANSWER

- Photon energy equals the band gap. Say so.
- A different colour means a different gap.

Show Me: LEDs

SHOW ME BOARDS

1. State what an LED is, in terms of a p-n junction.
2. State how an LED must be biased before it will emit light.
3. Describe, in terms of bands, how an LED emits a photon.
4. Two LEDs emit red and blue light. State and justify which has the larger band gap.
5. Explain why one LED emits a single colour rather than a range of colours.

Task

Work through the LED questions.
Every band-theory answer names both bands and the gap.

Past papers: 2018 Q11(c), 2025 Q23

Past Paper Finder

Starter

2014 Revised Higher Physics

Scan the code and answer these:

Q8 **Q16** **Q18**

Section A · particles, semiconductors

Show your working, not just the letter.

Scan for the paper

Marking scheme

PART 5

Solar cells

Run the LED backwards — light goes in instead of coming out — and you have a solar cell.

By the end of this part…

1. I can describe a solar cell as a p-n junction and name the photovoltaic effect.
2. I can describe, in terms of bands, how a solar cell produces a p.d.
3. I can state the difference between a solar cell and an LED.

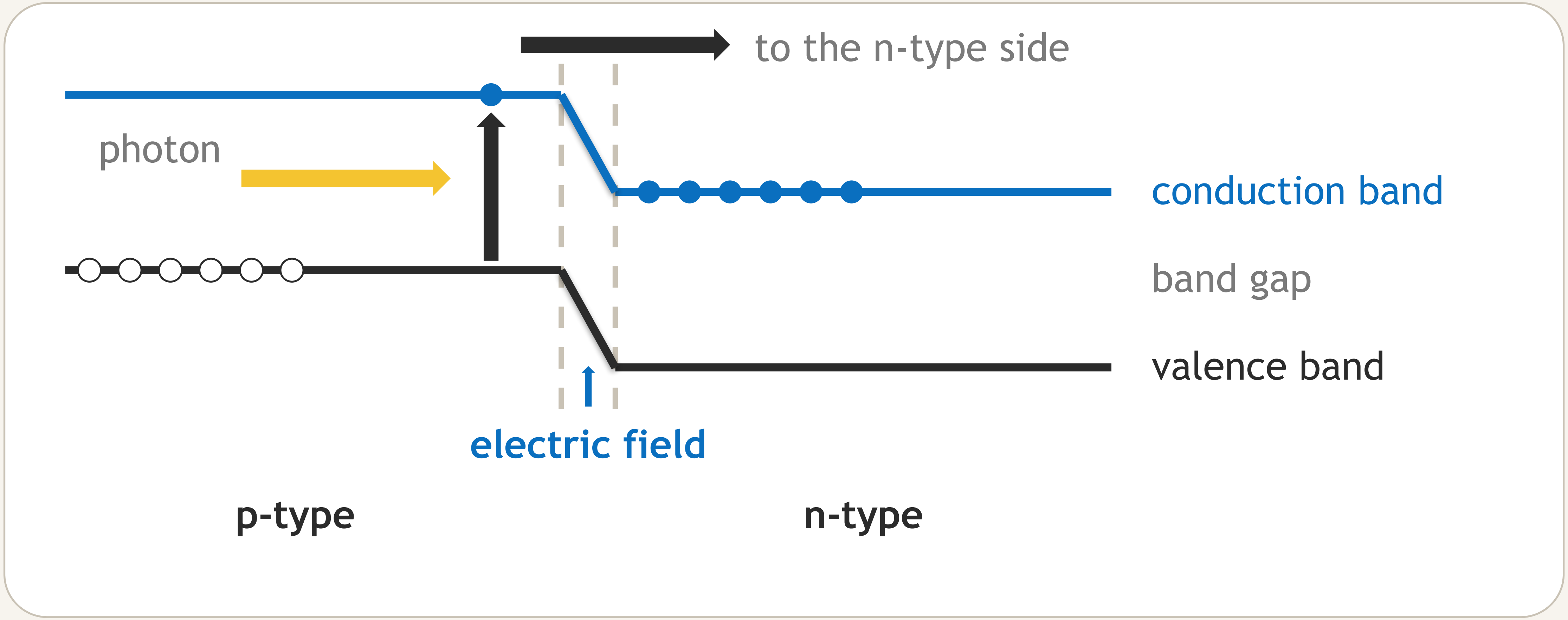
The photovoltaic effect

- A solar cell is a p-n junction designed so that a p.d. is produced when photons are absorbed.
- That is the photovoltaic effect.
- Absorbing a photon gives an electron enough energy to be raised from the valence band to the conduction band.

How a solar cell works

JOTTER NOTES

A photon arrives, and an electron is raised across the gap.



JOTTER NOTES

Solar cells

A solar cell is a p-n junction designed to produce a potential difference when photons are absorbed.

This is called the photovoltaic effect.

Absorbing a photon gives an electron enough energy to be raised from the valence band to the conduction band.

JOTTER NOTES

How the potential difference appears

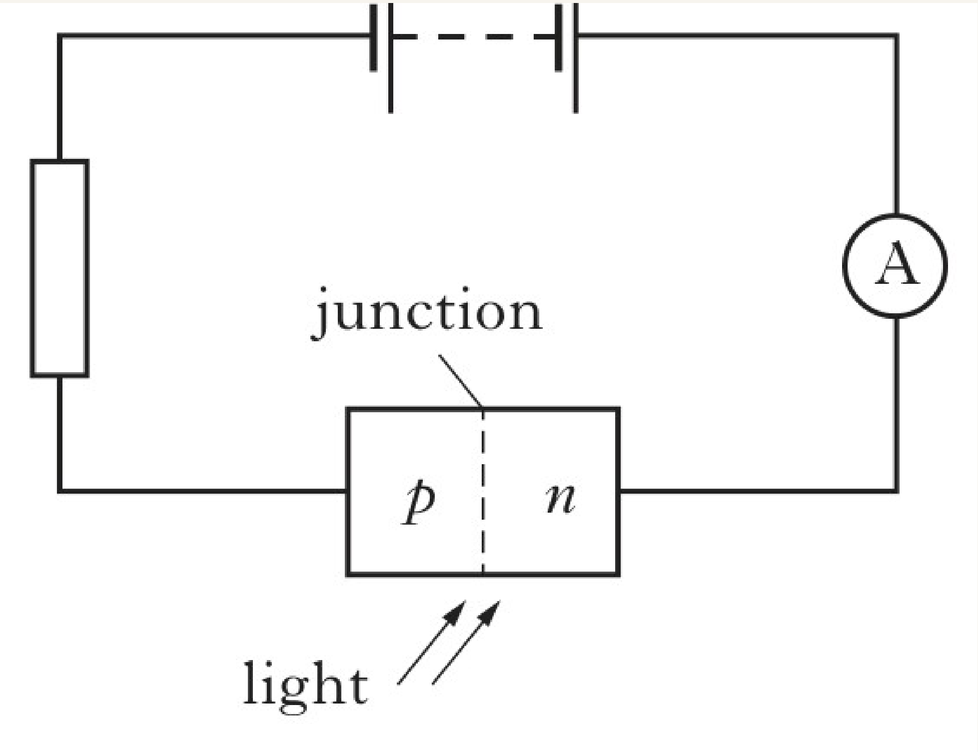
Once the electron is in the conduction band, the junction's electric field moves it towards the n-type side.

Electrons gathering on one side and not the other is what produces a potential difference.

That potential difference appears across the whole solar cell.

A p-n junction with light on it

The same junction, drawn as a component in a circuit.



JOTTER NOTES

Reading the circuit version

The box marked p and n is the junction itself, with the dashed line showing where the two layers meet.

The arrows show light falling on the junction.

Light in gives a potential difference out, which is what the meter in the circuit reads.

Show Me: solar cells

SHOW ME BOARDS

1. Name the effect by which a solar cell produces a potential difference.
2. State what happens to an electron when a solar cell absorbs a photon.
3. Describe, in terms of bands and the junction's field, how a solar cell produces a p.d.
4. A solar cell and an LED are both p-n junctions. State the key difference in what each one does.
5. Explain why a solar cell produces no potential difference in the dark.

Task

Work through the solar cell questions. Read the question twice — solar cells and LEDs are easy to swap by mistake.

Past papers: 2017 Q14(b), 2024 Q15(b)

Past Paper Finder

Checkpoint

1. State the difference between the valence band and the conduction band.
2. A solid conducts well and barely changes with temperature. State what it is, and why.
3. Explain, in terms of band structure, why a semiconductor conducts better when it is warmer.
4. State what doping is, and where it puts a new energy level.
5. Describe, in terms of bands, how an LED emits a photon.

Exam Practice

2024 Q15(b) — band theory for a solar cell, not an LED.
2018 Q11(c) — comparing a red LED and a blue LED.
2016 Q12(b) — doping and the p-n junction.

Past papers, Section A

LOOKING AHEAD

Next: Motion, Graphs & Projectiles

Scalars, vectors, and the equations that connect them — the largest topic of the course.

Plenary

SHOW ME BOARDS

1. Name the two bands, and say what the gap between them means.
2. Explain, using band structure, why an insulator does not conduct.
3. State what doping is, and why a semiconductor is doped.
4. State the effect of forward bias on the field in a p-n junction.
5. An LED emits light and a solar cell absorbs it. Explain the difference in terms of the electron's journey between the bands.

Extension

SHOW ME BOARDS

1. A pure semiconductor is doped n-type. Sketch its band diagram before and after, and explain what changed.
2. Solar panels lose efficiency as they get hot, even though semiconductor conductivity rises with temperature. Suggest why.
3. Explain, using band diagrams, why a p-n junction passes current one way but not the other.