9.4.3 Semiconductors

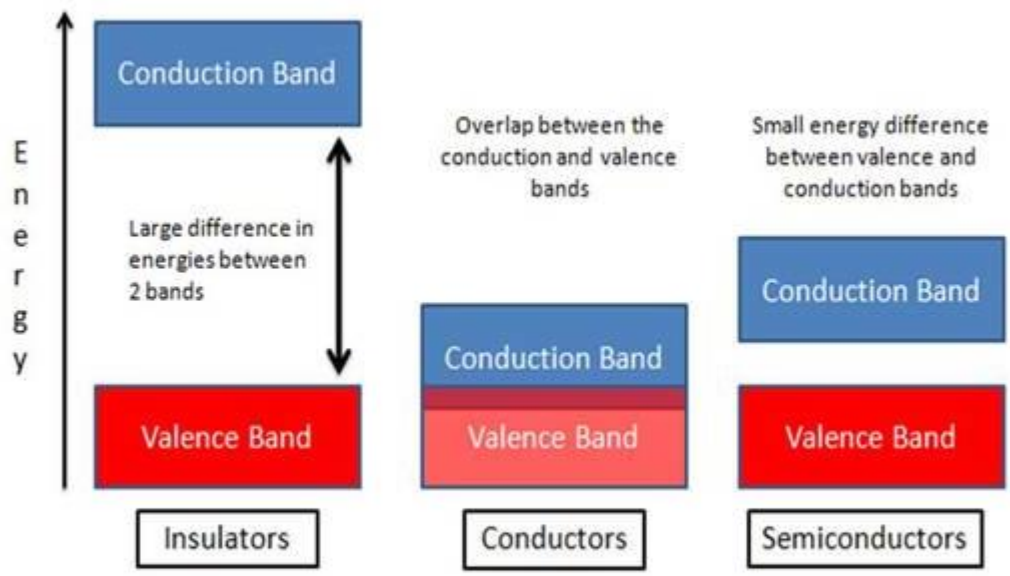
Limitations of past technologies and increased research into the structure of the atom resulted in the invention of transistors

3.1 Identify that some **electrons in solids are shared between atoms** and **move freely**

- '**Sea of electrons**' model of a metal – **positive metal ions** surrounded by **sea of delocalised electrons**
    - Electrons do not stay with metal, they are **free** and shared among other atoms
- Valence shell/valence electrons: electrons on the outermost electron shell, have most energy

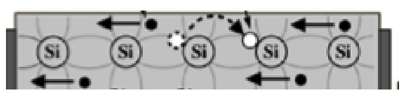
3.2 Describe the **difference between conductors, insulators and semiconductors** in terms of **band structures and relative electrical resistance**

- For an atom, energy is the same for all electrons in the same electron shell
- For many atoms, energy level of electrons 'blur' and electrons can take all values of energy
- <u>**Energy band**</u>: range of energy electrons possess in a lattice
    - <u>**Valence band**</u>: made up of energy levels of the valence electrons – higher energy than energy bands formed by the electrons found in the inner shells
    - <u>**Conduction band**</u>: when valence electrons gain energy, they move to higher energy shells previously empty – these electrons make up the conduction band
    - **Forbidden energy gap:** Energy gap between **valence and conduction bands**
- In a **conductor**, conduction and valence bands overlap – valence electrons easily move to conduction band
- In an **insulator**, large forbidden energy band – valence electrons difficult to move between
- In **semiconductors**, forbidden energy band is too wide, low conductivity



3.3 Identify **absences of electrons** in a nearly full band as **holes**, and recognise that **both electrons and holes help to carry current**

- When a valence electron moves into the conduction band it leaves a **hole** – one less valence electron
    - An electron from nearby can move and **fill in the hole**
    - This creates **another hole** – transfer of electrons



- Equivalent to electric current in a semi-conductor, called **electron-hole pair conduction**

3.4 Compare qualitatively the relative number of **free electrons that can drift from atom to atom** in conductors, semiconductors and insulators

- **Drift velocity**: Electrons moving in a net current and 'drifting'
- In **conductor**, some electrons move easily from atom to atom
- In **semiconductors and insulators**, not many electrons can move to conduction band
- Raising **temperature, lighting conditions, creating potential difference** can induce electrons to move

3.5 Identify that the **use of germanium in early transistors** is related to **lack of ability to produce other materials of suitable purity**

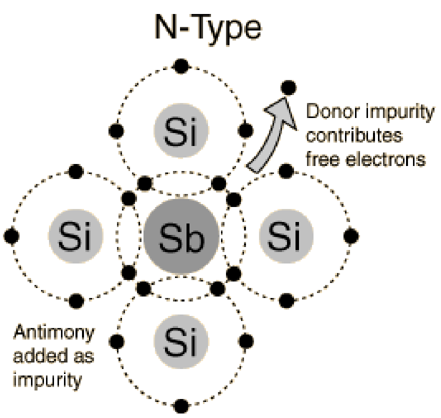
- Semiconductors used to make solid state devices must be **extremely pure**
  - **Only technology** was for germanium
- Now, **silicon** is used as it is:
  - More **economical** (sand)
  - Functions well under **high temperatures**, maintaining semiconductivity (unlike germanium)
  - Ability to form an **oxide layer**, essential for producing microchips

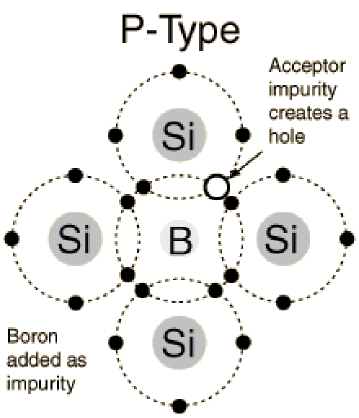
3.6 Describe how '**doping' a semiconductor** can change its **electrical properties**

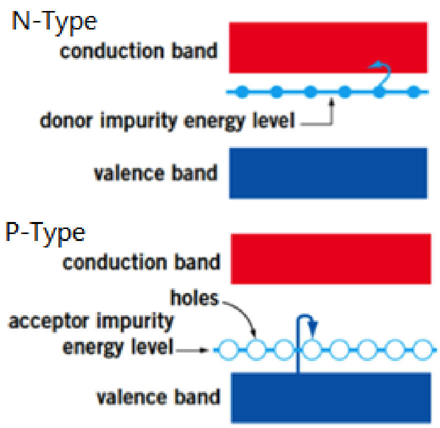
- <u>**Intrinsic**</u> **semiconductors**: pure semiconductors conducting by **electron-hole pair conduction**
- <u>**Extrinsic**</u> **semiconductors**: impurities added in a process called **doping** – increase number of charge carriers
  - Enhances current carrying capacity of semiconductor, doping only 0.001%
- Two types of extrinsic semiconductors – either **one more or one less** valence electron
- Doping elements should **fit well** so structure is not distorted

3.7 Identify **differences in p and n-type semiconductors** in terms of the **relative number of negative charge carriers and positive holes**

- **N-type semiconductors**: doped with **5 valence electron atoms** (Group V in periodic table)
  - This results in **increased number of <u>free electrons</u>** but no increase in negative charge
  - Impurity atoms chosen so valency band is close to **conduction band** of semiconductor
- **P-type semiconductors**: doped with **3 valence electron atoms** (Group III)
  - Results in **increased number of <u>holes</u>** again no net positive charge
  - Impurity atoms chosen so valency band close to **valency band** of semiconductor







- <u>**Diode**</u>: joining of N and P semiconductors – **only allows current to flow in one direction**
  - Electrons fill up holes in P layer – creates a potential difference between N and P

3.8 Discuss **differences between solid state and thermionic devices** and discuss why **solid state devices replaced thermionic devices**

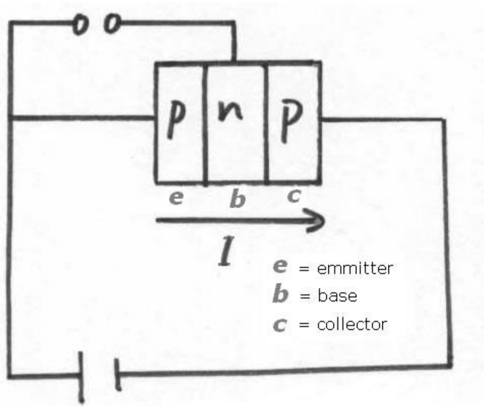
- **Thermionic devices**: vacuum tube – filament for (thermionic) cathode, vacuum and anode
    - When turned on, **filament heats up** and electron burned off filament (**thermionic emission**)
    - Does not work the other way as there is no filament and no electron flow
- Solid state devices (e.g. diode) use **semiconductors** to generate flow of current
    - Does not require heating circuit
    - Work immediately, require less power, produce less heat, smaller, simpler
    - Does not require a vacuum/glass tube – packaged in thermosetting plastic, normal atm
    - Much smaller than thermionic devices

3.P1 Perform an investigation to model the **behaviour of semiconductors** including the **creation of a hole or positive charge** on the atom that has lost the electron and the **movement of electrons and holes** in opposite directions when an electric field is applied across the semiconductor

- An A3 sheet of 5cm grid paper placed on the table
- Red counters used as electrons, blue counters used as holes
- Rearrange counters to simulate behaviour of semiconductors

3.P2 Gather, process and present secondary information to **discuss how shortcomings in available communication technology** lead to an **increased knowledge of the properties of materials** with particular reference to the **invention of the transistor**

- **Thermionic devices** were required for **communications**, developing technologies such as **radar (WWII)**
    - Communication between pilots, control towers, field commands
    - Portability was required for light transceivers powered by atteries
    - Transistor invented by **John Bardeen and William Shockley** in 1947 after war ended
- **<u>Solid state devices</u>** are electronic devices made from **semiconductors**
- **<u>Diode</u>**: an n type with a p type – only allows electric current to flow in one direction
    - From n to p, if reversed a **depletion zone** will be generated, preventing current flow
- **<u>Transistor</u>**: created either P-N-P or N-P-N (N-P-N more common)
    - Made of **collector, base and emitter**
    - Are **'three legged monsters'** – three leads allow it to be connected across two circuits
        - One with emitter and base, one emitter and collector
    - Small AC current between **emitter and base** produces a large current flow between **emitter and collector**
    - Acts as a **amplifier** as small current makes a larger copy of itself in main current
    - Can also completely stop the current and act as a **switch**



3.P3 Identify data sources, gather, process, analyse information and use available evidence to **assess the impact of the invention of transistors on society** with particular reference to their **use in microchips and microprocessors**

- **<u>Integrated circuit</u>**: assembly of electronic devices and connections **fabricated in a single unit or chip**
    - Uses **semiconducting material** connecting individual parts **normally connected by wires**
- **Two types of transistors in integrated circuits**
    - 'Bipolar transistors' are **current controlled devices** to increase current (e.g. radios)
    - 'MOSFET' is **voltage controlled** and use small current normally to **switch** signals on and off
- **<u>Microprocessor</u>**: type of microchip that can perform **arithmetic, logic and control operations**
    - Example of microprocessor is **CPU** of a computer
    - Many devices integrated into a single chip
        - As more semiconductor devices increases, **placed closer** so **transmission more efficient**
        - **Power dissipation** also reduced – less resistance, less heat loss
- Assessment of impact:
    - Promoted development of **information technology**
    - Application of integrated circuits are found in **many electronic devices**
    - Enables **computers** to be made – used in business, industries
    - Invention of **intelligent robots and terminals** – replace human labour

    - Higher unemployment rates due to loss of human labour
    - Negative **social impacts of computer usage**

Extra: Identify data sources, gather, process and present information to **summarise the effect of light on semiconductors in solar cells**

- Solar cells can **convert sunlight energy into electricity**
    - Light frees electrons from semiconductor at the junction because of **photoelectric effect**
- Electrons gain enough energy and move to conduction band
- Accelerate towards **n type silicon** (against electric field dirn)
    - Electrons collected from **front** metal grid to generate electricity and go back to **bottom metal grid**