

# Physics Factsheet



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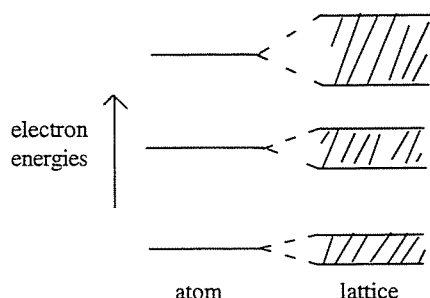
## The Physics of Semiconductor Diodes

Electricity used to be simple. Some materials conducted electricity, and others were insulators. Unfortunately someone then discovered another type of material – the semiconductor.

These materials sometimes act as insulators, and sometimes as conductors. And we have learned to alter and combine them to form a large number of devices that can control electrical circuits in many ways. So perhaps the discovery of semiconductors wasn't all bad.

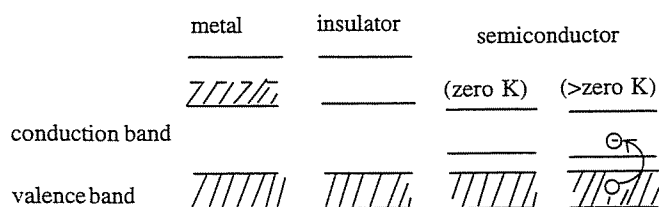
### Intrinsic Semiconductors:

For an atom, we talk about allowed energy levels for the electrons. However, for a solid, these energy levels broaden out into bands:



Conductors have their outer band (the conduction band) partially occupied. These electrons are available to carry current. With an insulator, the conduction band is empty.

A semiconductor (at absolute zero of temperature) is similar to an insulator. However the gap between the two bands is quite small. As the temperature rises, more and more electrons gain enough thermal energy to jump the gap into the conduction band, and the semiconductor can carry a small amount of current.



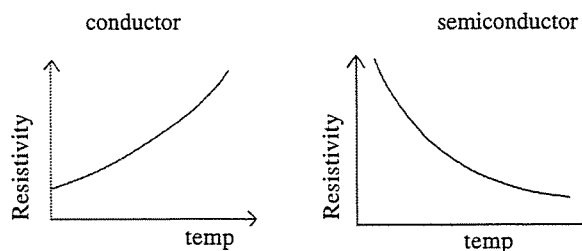
Each **electron** in the conduction band is matched by a **hole** in the valence band. This **hole** acts as a mobile positive charge, adding to the conductivity of the material.

### Example

*As the temperature rises in the semiconductor, why don't all the electrons gain a tiny bit of energy – not enough to jump the gap?*

**Answer:** Things don't work that way. Random collisions, etc, cause a spread of energies. The most energetic electrons will jump into the conduction band.

This thermal effect leads to very different resistance effects in conductors and semiconductors as the temperature rises.



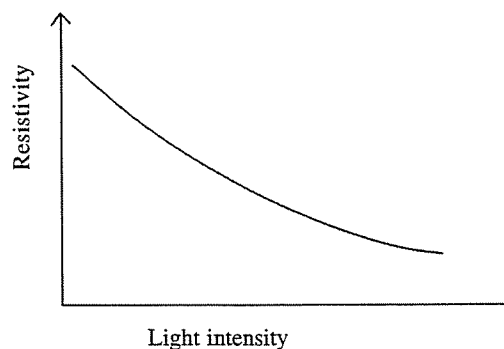
### Example

*In one sentence each, explain the trends noticed in these two graphs.*

### Answer

*With a metal, increased lattice vibration makes it more difficult for the conduction electrons to move through the lattice. With a semiconductor, a rise in temperature enables more and more electrons to jump into the conduction band, and the resistivity falls.*

With some semiconductors, shining visible light onto the material gives some electrons enough energy to jump into the conduction band. The more light, the more electron-hole pairs are formed. This causes an effect on resistivity similar to that of rising temperature.



### Example

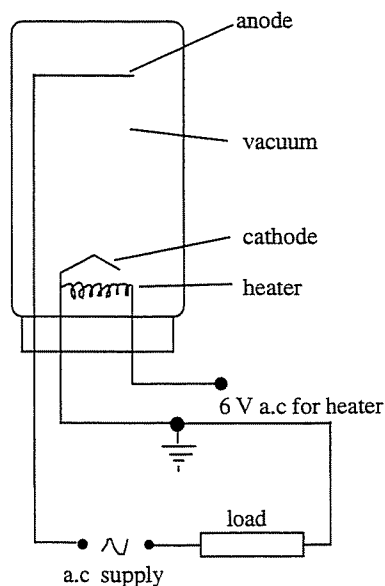
*Name the two semiconductor devices that make use of these effects of temperature and light on resistivity.*

**Answers:** Thermistor and light dependent resistor (LDR).

**Exam Hint:** Be prepared to draw graphs for **resistance v temperature** (as above) and **current v voltage** for a thermistor. Remember that increased voltage causes increased current, which leads to a heating effect. Be prepared to draw relevant graphs for an LDR as well.

### Diode Valves

A diode is a device that only allows a current to flow through it in one direction. We had diodes long before semiconductors were developed;



In this diode valve, a 6V supply causes the heater to glow and make the metal cathode hot. Electrons are freed from the heated cathode and attracted through the vacuum to the positive anode, completing the circuit.

However, when the anode goes negative, it repels the electrons freed from the heated cathode. There is no current flow around the circuit.

This device worked well, but there were many weaknesses compared to the semiconductor diode. Think of some - there is a question about this at the end of the Factsheet.

### Semiconductor (p-n) diode:

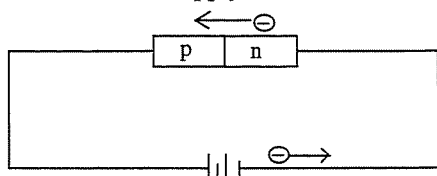
**Intrinsic** semiconductors can be **doped** with impurity atoms which give them either many extra **conduction electrons** (n-type) or **holes** (p-type). They are now called **extrinsic** semiconductors, and can carry far more current.

**Example :** What do the n and the p stand for?

**Answer:** Negative and positive obviously. A totally unnecessary question.

However the real magic happens when the two types of semiconductors are bonded together. At the junction, electrons from the n-type cross over to fill holes in the p-type. A potential difference is formed across this **depletion layer**, stopping any further flow of charge.

The only way that a continuous current can flow through this device is if it is connected across a supply as shown:



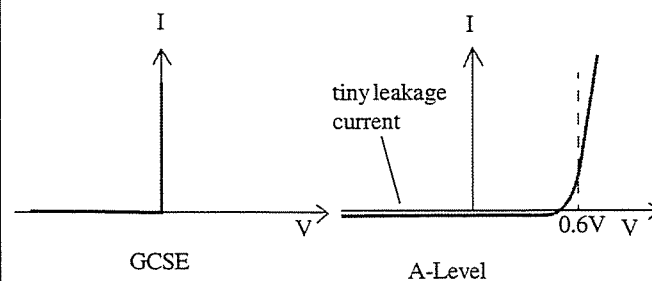
The applied p.d. can force electrons across the depletion layer. The p.d. that must be overcome to enable a current flow is about 0.6 volts for silicon semiconductors.

If the supply is reversed, only a tiny leakage current flows. This leakage current is caused by continuous production of electron-hole pairs from ambient thermal energy. We call the two set-ups **forward biased** and **reverse-biased**.

**Example:** What necessary component has been left out of this circuit?

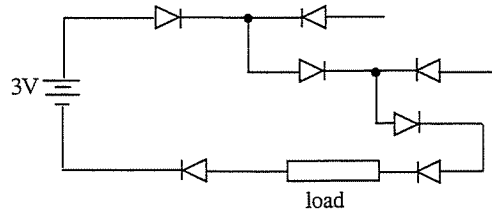
**Answer:** A series resistor to protect the diode. If the applied p.d. is above 0.6 volts, the diode basically acts as a short circuit.

**Key:** Notice from the diagram below the difference between the simplistic understanding of the junction diode from GCSE Physics, and the required understanding at A-level.



### Example

Antonio and Esmerelda design a circuit using diodes to direct the current along a certain path to flow through the load:



What is the difficulty here?

**Answer:** They have forgotten that there is a drop of 0.6 volts across each diode. The supply won't be able to drive any current through the load.

### Specially designed diodes

In addition to the standard junction diode, other diodes have been designed for specific purposes.

#### Light emitting diode

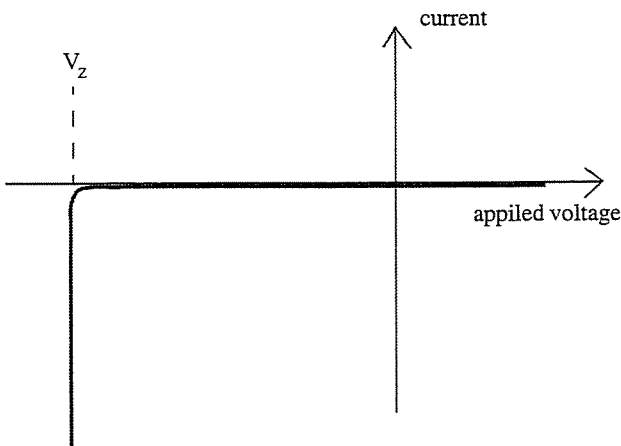
LED's are composed of selected semiconductor materials where the energy released when electrons and holes combine at the junction is given off as visible light. The colour of the light emitted depends on the semiconductor material chosen.

#### Photodiode

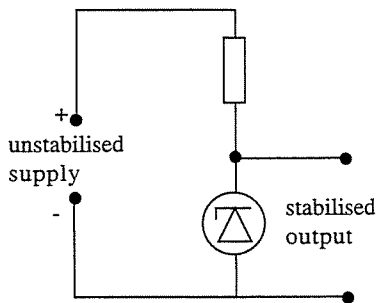
We have mentioned that thermal energy causes a tiny current when the diode is reverse-biased. If light of the right frequency is directed onto the depletion layer, it can also produce extra electron-hole pairs. So the current through a **reverse-biased** photodiode will depend on the amount of light shining onto it (assuming the light is of the correct frequency).

**Zener diode**

Only the tiny leakage current should flow through a reverse-biased diode. But at a certain critical voltage ( $V_z$ ), the diode breaks down:



This voltage is sometimes called the Zener voltage, and diodes can be manufactured to have different values for this. A reverse-biased Zener diode provides a stabilised output voltage from a supply which may not be quite so stable.



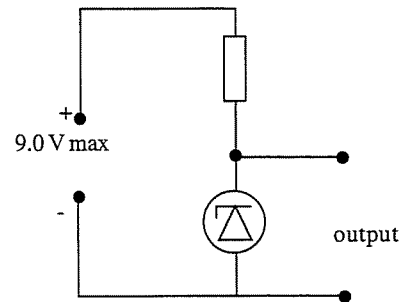
**Practice Questions**

1. Complete this table for a metal and a semiconductor as the temperature rises:

	Metal	Semiconductor
Number of conduction electrons		Increases
Amplitude of lattice vibrations	Increases	
Overall effect on resistance		Decreases

2. Name several advantages of semiconductor diodes over diode valves.

- An LED is used in a circuit as a warning light. the circuit has a 12 volt supply and the LED requires 8mA to operate at its intended brightness.
  - What p.d. is dropped across the LED itself (assume the same properties as a silicon junction diode)?
  - What voltage must be dropped across the series protective resistor?
  - What is the value of this resistor?
- A reverse-biased Zener diode provides a stable voltage of 2.7 volts. The unstabilised power supply across it has a maximum p.d. of 9.0 volts.



- Find the value of the protective resistor, R, if the Zener diode cannot safely dissipate a power of more than 0.10 watts.
- Find the current through a 500 ohm load attached across the output.

**Answers**

1.

	Metal	Semiconductor
Number of conduction electrons	Fixed	Increases
Amplitude of lattice vibrations	Increases	Increases (but this effect is outweighed by a massive increase in conduction electrons and holes)
Overall effect on resistance	Increases	Decreases

- Use less power, portable devices, physically smaller, less fragile, longer lasting, cheaper to make and use, faster response time (higher frequencies), etc.
- 0.6 volts
  - 11.4 volts
  - $R = V/I = 11.4 / 0.008 = 1400$  ohms.
- Diode:  $P = 2.7 \times I$ ,  $I = 0.10 / 2.7 = 0.037A$   
Resistor:  $V_{max} = 9.0 - 2.7 = 6.3$  volts  
 $R = V/I = 6.3 / 0.037 = 170$  ohms
  - $I = V/R = 2.7 / 500 = 0.0054A$  (this will reduce the current through the Zener diode, but won't affect the output voltage)

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