Semiconductors – Lesson Outline

Syllabus References

9.4.3.2.2 – describe the difference between conductors, insulators and semiconductors in terms of band structures and relative electrical resistance

9.4.3.2.6 - describe how ‘doping’ a semiconductor can change its electrical properties

9.4.3.2.7 - identify differences in p and n-type semiconductors in terms of the relative number of negative charge carriers and positive holes

Resources

Video: Effect of Temperature on Conductivity

Video: P-type and N-type Semiconductors
http://www.hscphysics.edu.au/resource/t7v6ivgeg3pyjev3

Pre-video Activities

Students contribute key physics words pertaining to the miniaturisation of electric circuits. Teacher records words on the board.

Organise students into groups of three, hand out paper and a marker. Students list modern devices and appliances which have evolved from the miniaturisation of electrical components, such as integrated circuits and transistors.

Students draw a timeline to show the evolution and development of technologies during the past century, from light bulbs to MP3 players.

1910

-----------------------------------------------

2010

Students list social and environmental impacts of these changes, both global and local.

Representatives present the group’s responses to the rest of the class. Encourage class discussion and questioning.
Students match key terms to definition by matching the numbers 1-6 to the corresponding letters in the right-hand column:

<table>
<thead>
<tr>
<th>Key terms</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.  conductor</td>
<td>A. A measure of the degree to which an object opposes an electric current passing through it.</td>
</tr>
<tr>
<td>2.  insulator</td>
<td>B. Fundamental subatomic particles that carry a negative electric charge.</td>
</tr>
<tr>
<td>3.  semiconductor</td>
<td>C. A material that readily allows the flow of an electric current</td>
</tr>
<tr>
<td>4.  silicon</td>
<td>D. In a solid lattice, this band is the highest range of energies where electrons can exist and still be held by their 'local' atom</td>
</tr>
<tr>
<td>5.  conduction band</td>
<td>E. A material that resists the flow of electric current</td>
</tr>
<tr>
<td>6.  electrical resistance</td>
<td>F. A metalloid from group IV of the periodic table. After oxygen, it is the second most abundant element in the Earth's crust. It is the principal component of most semiconductor devices.</td>
</tr>
<tr>
<td>7.  electrons</td>
<td>G. A solid that has electrical conductivity in between that of a conductor and that of an insulator,</td>
</tr>
<tr>
<td>8.  valence band</td>
<td>H. The flow of electric charge per unit time through a material.</td>
</tr>
<tr>
<td>9.  electric current</td>
<td>I. The energy band higher than the valence band, where electrons are free to accelerate under the influence of an applied electric field</td>
</tr>
</tbody>
</table>

**View Video**

Video: Effect of Temperature on Conductivity

**Activities**

Student Investigation during the video: Refer to video which demonstrates how the resistance changes when we heat a conductor, semiconductor and insulator. For each of these investigations students should use a predict-observe-explain format. That is, they make a prediction before viewing then record observations and generate plausible explanations.

Format of tables:

**Situation 1: the metal (tungsten filament) is heated**

<table>
<thead>
<tr>
<th>Prediction</th>
<th>Observation</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

**Situation 2: the semiconductor (germanium rod) is heated**

<table>
<thead>
<tr>
<th>Prediction</th>
<th>Observation</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

**Situation 3: the insulator (rubber tubing) is heated**

<table>
<thead>
<tr>
<th>Prediction</th>
<th>Observation</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tbody>
</table>
Back in groups, students graphically illustrate the relationship for resistance versus temperature for conductors and semiconductors.

Student groups write a conclusion for this investigation. Again, one representative presents the group’s work to the rest of the class. Teacher ensures that different group members are presenting findings to class. Note: this experiment can easily be replicated in the school laboratory.

**Advanced Activity**

Advanced Activity: Discussion of different explanations. Advanced students read through the discussion paper in groups of three and discuss models to explain conductors, insulators, and semiconductors.

**View Video**

Video: P-type and N-type Semiconductors
http://www.hscphysics.edu.au/resource/t7v6ivgeg3pyjey3

**Activities**

Students make labelled diagrams to compare an n-type and p-type silicon lattice, modelling the behaviour of semiconductors.

Students (in groups) create a model using bodies and chairs to demonstrate the movement of positive and negative charges in p-type and n-type semiconductors.

Example: Line up 10 chairs and have the 9 people sit in a row leaving the chair on the right vacant; Explain that the external current terminals are positive to the right and negative to the left; The switch is turned on; The excited electrons (people) move (one chair at a time) through the crystal toward the positive terminal on the right; This shows the electrons from a bonded site move toward the positive terminal into an adjacent hole causing the hole to migrate toward the negative terminal (to the left). The hole can also be considered to be a charge carrier.

Students organised into groups of three. Groups each create a concept map to show the connectedness of the following key terms:

Integrated circuits  Transistors  Solid state electronics  Mobile phones  Semiconductors
Doping  Extrinsic  Intrinsic  Valence band  Conduction band  Energy gap  Ipods

**Post-video Activities**

Activity: Semiconductors concept quiz and cloze passage. Students complete the activities individually.
Semiconductors – Concepts

Q1. The conduction of current within a p-type semiconductor is a result of:

A. an excess electron
B. a missing electron
C. the substituted arsenic atoms
D. the silicon atoms

Q2. Why does the conductivity of silicon increase if it is doped with a group III element?

A. The number of free electrons increases
B. The number of positive holes increases
C. The impurity decreases the energy band gap
D. Additional electrons are added to the crystal lattice structure

Q3. Which statement below best explains why metals have low resistance at room temperature?

A. The conduction band has much greater energy than the valence band
B. The valence band has much greater energy than the conduction band
C. There are many electrons available for conduction
D. There are few electrons available for conduction

Q4. A semiconductor is doped with a small amount of boron. This means that:

A. It is negatively charged, and so will conduct electricity more easily
B. It is positively charged, and so will conduct electricity more easily
C. It is neutral, but has more electrons available for conduction
D. It is neutral, but has more holes available for conduction

Q5. Which one of the following statements is NOT true in regards to a hole in semiconductor theory?

A. Holes act as a positive charge
B. Holes can be bound to an atomic nucleus
C. Holes are repelled by electrons
D. Holes have a drift velocity

Q6. Which of the following would best describe the material composing a p-type semiconductor?

A. Extremely pure silicon with some of the silicon electrons removed leaving holes in the resulting crystal lattice
B. Extremely pure silicon with a certain number of extra electrons added leaving some free electrons in the crystal lattice
C. Pure silicon that has small amounts of an element that has one less valence electron
D. Pure silicon that has small amounts of an element that has one more valence electron
Extended Answer

Q7. As temperature decreases, how does the resistance to the flow of electrons in good conductors compare with the resistance to the flow of electrons in semiconductors? Use diagrams where appropriate.

Q8. In terms of semiconductors, explain the concept of electrons and holes.
Q9. In terms of band structures and relative electrical resistance, describe the differences between a conductor, an insulator, and a semiconductor. Use diagrams where appropriate.

Q10. List 5 examples of how semiconductors have been applied in technology.
Semiconductors – Cloze passage

The concepts of semiconductors are a fundamentally important aspect of physics. In the last __________ years, semiconductors have revolutionised our lives, from the size of personal computers to the introduction use of plasma and __________ screen TVs.

To understand semiconductors, we first have to consider a single __________. In a single atom, the energies of electrons are __________. This means they exist at specific energy levels. No electron may remain between these energy levels, and these energy values are called forbidden energy gaps. If there is no disturbance, such as an electric field, the __________ will fill all the energy levels from the ground up.

When two __________ atoms are brought into close proximity, their energy levels shift with respect to one and other. In a solid vast numbers of atoms are closely packed together. The interaction of the atoms causes splitting and merging of energy levels into __________. Each band is composed of an enormous - but __________ - number of energy levels. These bands are separated by __________.

If every __________ within an energy band is filled, then the band is filled. If all the energy bands are either completely filled or completely empty then no electrons can __________ in an electric field. If an energy band is partially filled, then it is __________ active.

All __________ in insulators are either completely filled or completely empty. Conductors always have one __________ energy band. __________ have partially filled energy bands when they are heated.

Imagine heating up a Tungsten filament, which is a conductor. Initially the resistance is quite low but as we heat it up the resistance __________. This is due to increased thermal energy and __________ between the electrons and the metal ions within the lattice.

For the semiconductor, imagine heating up a Germainium rod. Initially, the resistance is quite __________ but as we heat it up the resistance __________. This is because we are supplying the electrons with enough energy to cross the energy gap from the valence band into the conduction band.

For the __________, imaging heating a piece of rubber tubing. The resistance is so __________ that a multimeter cannot display the result. This is because the energy gap between the valence band and conduction band is just so large in __________.

We can change the number of valance electrons around each atom by replacing one of the semiconductor atoms with a different atom. This process is called __________. Materials that become semiconductors through __________ are called extrinsic semiconductors.

Semiconductors are doped with either an atom from group III or group V, depending on the properties required. Doping with a __________ atom results in a missing electron in the lattice because group III atoms have one less __________ than group IV atoms. This missing electron is considered to be a region of missing negative charge in the valance band, and is called a hole. This type of doping is called positive-type, or __________ doping.

Doping with a __________ atom results in an extra electron being inserted into the lattice. This is because group V atoms have one more electron in their valance band than group IV atoms. The presence of this extra electron means there is excess __________ carriers around the lattice. Therefore, this type of semiconductor being called a negative-type, or __________ semiconductor.
Word List:

Atom
High
Group V
P-type
Energy bands
Valence electron
Identical
LCD
Finite
Semiconductors
Fifty
Decreases
Electrically
Doping
Collisions
Insulators
Move
Quantised
N-type
Doping
Partially filled
Forbidden gaps
Increases
Electrons
Group III
Insulator
Energy bands
Negative charge
Energy level
High
Semiconductors –
A discussion of different explanations

In senior textbooks there are two common models for conduction. The biggest difference between the two models is whether they can explain the change in resistance with temperature. This resource looks at the physical reason for energy bands and then discusses two models. It is intended for teachers or advanced students.

What is an energy band?

In a single atom, the energies of electrons are quantised. This means they exist at specific energy levels. Between these energy levels are forbidden energy gaps in which no electron may remain. If there is no disturbance, such as an electric field, the electrons will fill all the energy levels from the ground up.

When two identical atoms are brought into close proximity, their energy levels shift with respect to one and other. For a solid, vast numbers of atoms are packed closely together. The interaction of all the atoms causes splitting and merging of energy levels into energy bands. Each energy band is composed of an enormous - but finite - number of energy levels. If every energy level within an energy band is filled then no additional electrons can take on those energy values. These bands are separated by band gaps, or forbidden energy levels.

Model I

This is a model of conduction commonly found in textbooks:

In insulators the valence band is always full, while the conduction band is always empty. The energy gap between the valence band and the conduction band is too large to be overcome by thermally exciting the electrons.

For conductors, such as metals, the conduction and valence bands overlap. Thus valence electrons easily gain enough energy to become available for conduction.

In semiconductors the energy gap between the conduction band and the valence band is very small – usually less than 1 eV. Electrons can gain sufficient energy when heated or exposed to light to be promoted to the conduction band. Silicon and germanium are two common semiconductors. When temperatures are low, the electrons do not have enough energy to be in the conduction band, so the material acts as an insulator. At higher temperatures, the valence band is nearly full and the conduction band is slightly full.

This explanation often has a diagram similar the following:
Problems with model I

This model correctly explains semiconductors and insulators. However, it does not explain the temperature dependence of resistance in conductors.

As temperature decreases electrons lose energy. In this model, the electron would thus drop from the conduction band into the valence band. This would decrease conduction. This is not what happens in practice. In practice, conduction increases as temperature decreases. This is because at lower temperatures there is less electron scattering from the lattices.

Model II

In solids where all the energy bands are either completely filled or completely empty then no electrons can move in an electric field. Insulators have completely filled or empty energy bands at all temperatures. Semiconductors have completely filled or empty energy bands at low temperatures.

If an energy band is partially filled, then it is electrically active. Semiconductors have partially filled energy bands when they are heated.

Conductors always have a partially filled energy band, between 10 and 90 percent – depending on the material. When electrons gain kinetic energy, through increased temperature or the presence of an electric field, the electron occupies a higher allowed energy within the same band.

This is shown in the following diagram. This representation remains the same for conductors and insulators at all temperatures.