SIEMENS

# Introduction to the Basic Principles of Semiconductors

pi

HEYDEN

# Introduction to the Basic Principles of Semiconductors

Hansjochen Benda

SIEMENS AKTIENGESELLSCHAFT
HEYDEN & SON

Heyden & Son Ltd., Spectrum House, Hillview Gardens, London NW4 2JQ, UK.
Heyden & Son Inc., 247 South 41st Street, Philadelphia, Pennsylvannia 19104, USA.
Heyden & Son GmbH, Münsterstrasse 22, 4440, Rheine, West Germany.

Title of German original edition:
Einführung in die Grundlagen der Halbleitertechnik (PU 01)
Von Hansjochen Benda
Siemens Aktiengesellschaft 1973
ISBN 3-8009-4001-9

ISBN 3-8009-4701-3 Siemens AG, Berlin and München
ISBN 0-85501-501-2 Heyden & Son Ltd., London



Typeset in Great Britain by The Universities Press, Belfast

Printed in Great Britain by Henry Ling Limited, The Dorset Press, Dorchester

# Introduction

This programmed instruction (PI) book describes in a straight forward and logical manner the physical properties that give rise to electrical conduction in semiconductors. It is intended principally for use at technical college level as an introduction to the subject of semiconductor devices. It is also suitable for secondary school use, as a refresher for students of advanced technology and also for adult education.

When you have successfully worked through the course you should be able to describe:

How metals and semiconductors differ in their electrical properties;
How charge carriers can be produced in semiconductors;
Which charge carriers occur in semiconductors;
What types of electric current are to be found in semiconductors;
How conduction in semiconductor devices can be influenced by the presence of impurities.

The programmed instruction method means that the material is divided into small steps and by answering the questions asked after each step you can easily check your progress. You can work at your own speed and if you do not understand a step you should repeat it until it is clear.

You should use the book in the following manner:

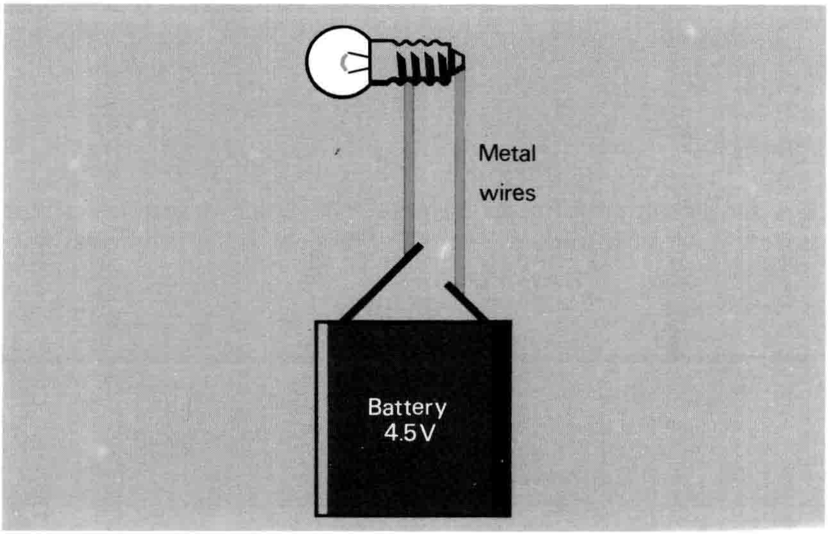
1. Work thoroughly through each Lesson.
2. Answer the Question at the end of each lesson.
3. Check that your Answer agrees with that given on the next page. If it does not agree, work through the lesson again and find out where you made a mistake.
4. Answer the questions in the Intermediate Tests and Final Test.
5. Check your answers with those provided and repeat any lessons that you did not fully understand.

Some of the technical terms used in this book are explained briefly in the Appendix (p. 63).

London, February 1978 THE PUBLISHERS

If you connect the two terminals of a torch battery to the contacts of a small bulb of the correct rating using metal wires, an electric current flows through the wires and the bulb. This is clear because the bulb lights.

Metals are *electrical conductors.* When a potential difference is applied across a piece of metal, an electric current flows in it.




QUESTION 1

What special property does an electrical conductor have?

Think about it! If you know the answer write in your exercise book (not in this instruction book) Answer and the lesson number shown at the top of this page, followed by the answer you have found, thus:

Answer 1

Compare your answer with the solution on the other side of this page only after having answered the question.

The answer in your exercise book should read:

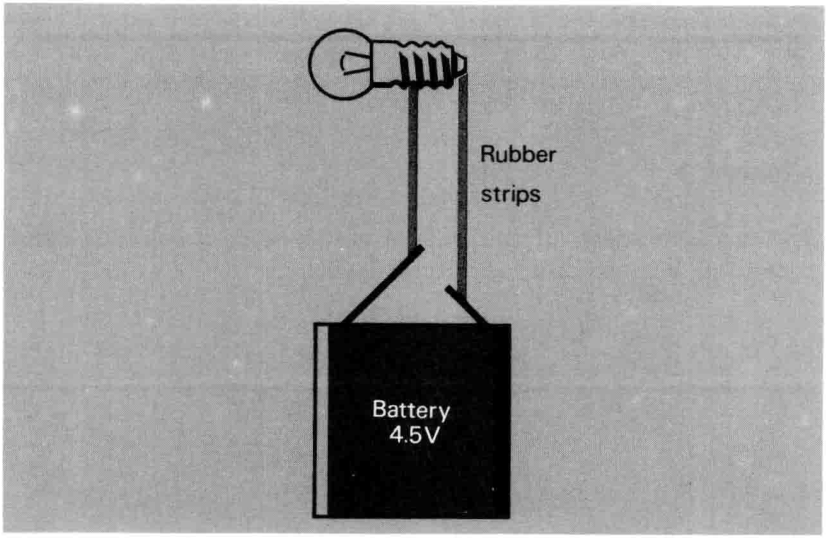
## Answer 1

The special property of an electrical conductor is that an electric current flows in it when a potential difference is applied across it.

No doubt your answer was correct and so your exercise book now contains the first correct entry. Enter subsequent answers in it, in a similar way, one beneath the other.

If we replace the two metal wires of the experiment in Lesson 1 with two rubber strips no current will flow. This will be apparent because the bulb will not light.

Rubber is an *insulator*. Other examples are wood, glass and many plastics. Insulator is the name for materials that do not conduct.




QUESTION 2

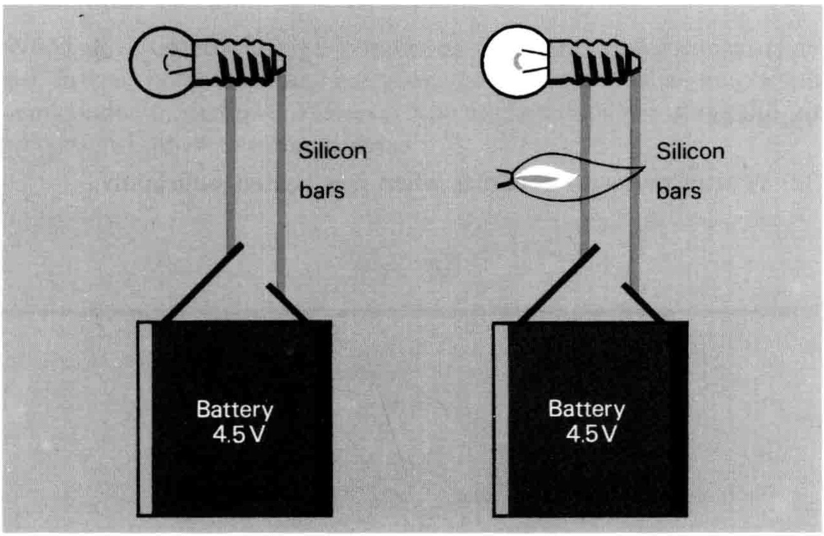
What special property does an insulator have?

## Answer 2

The special property of an insulator is that when a potential difference is applied across it, no current flows.

There are materials which cannot be categorized as conductors or as insulators.

Let us replace the metal wires of the experiment of Lesson 1 with two bars of extremely pure *silicon.* The bulb will not light, which means that the silicon is acting as an insulator (left illustration). However, if we warm the bars with a gas flame, the bulb will light; the silicon then conducts (right illustration). Silicon is a typical *semiconductor* material.




QUESTION 3

What special property is shown by a semiconductor?

(a) That it insulates.

(b) That it conducts.

(c) That it conducts when it is heated sufficiently.

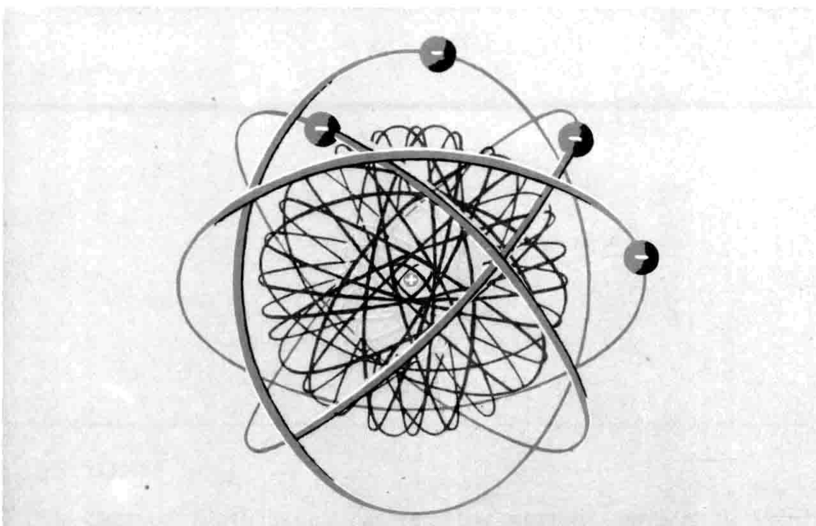
**Answer 3**

(c) A semiconductor conducts when it is heated sufficiently.

An electric current is in fact the movement of minute electrically charged particles. There are positively-charged and negatively-charged particles. Assemblies of positively-charged and negatively-charged particles make up atoms, which in turn are the minute building blocks for all matter.

Each atom consists of a (positive) atomic nucleus and a number of (negative) electrons which orbit the nucleus. The figure illustrates a *germanium atom* as an example. The outer electrons—in the case of germanium (chemical symbol Ge) there are four—can act as bonds to other atoms. They are described as *valence electrons.* We shall refer to the other electrons as *inner electrons.*

We shall repeatedly use germanium as an example of a semiconductor in this book because, early on, germanium was an important semiconductor material. However, the explanations are also valid for silicon and other semiconductors.



QUESTION 4

What is the structure of a germanium atom?

**Answer 4**

A germanium atom consists of a positive nucleus with a number of electrons orbiting it. The four outer electrons are called valence electrons.

We shall now consider those particles in an atom which can produce electric current. We shall limit ourselves to solid materials. In other words we shall not consider liquids or gases. Within the atom there is no possibility of the nucleus, which is positively-charged, being a current carrier. This is because the atoms in a solid material are fixed in position. However, in addition to the nucleus, there are the negatively charged electrons. Most of them are, in a solid material, firmly bound to their nucleus. However, some of the electrons in solids can leave their orbits, which means they are potential current carriers. Such electrons are described as movable. The valence electrons you learnt about in Lesson 4 can be movable electrons; in this case, they are not only responsible for the bonding of atoms, but also under certain circumstances for the conduction of current.

The conditions under which valence electrons become movable, depends upon the way in which the atoms of the material being considered are organized.

QUESTION 5

Which charged particles can be electric current carriers in solid materials?

(a) Those valence electrons which are movable.

(b) All the electrons which are present.

(c) The atomic nucleus.

**Answer 5**

(a) Those valence electrons which are movable.

## Intermediate Test 1

The questions in this test deal with the subject matter of the preceding lessons. If you are unable to answer all the questions you are advised to work through the lessons again.

**1** Under what conditions can an electric current flow in a material?

(a) There must be charged particles available.

(b) There must be movable particles available.

(c) There must be particles available which are both charged and movable.

**2** For what reason can metals always conduct electric current?

**3** Which particles can not be current carriers?

(a) Those in the atomic nucleus

(b) Valence electrons

(c) Inner electrons

## Answers to Intermediate Test 1

**1** (c) Particles must be available which are both charged and movable. (Lessons 4, 5).

**2** The reason is that in metals there are particles which are both charged and movable (see Lesson 7 later).

**3** (a) and (c) Those in the atomic nucleus and inner electrons (Lessons 4, 5).