SEMICONDUCTOR DIODES AND TRANSISTORS

PROGRAMED INSTRUCTION

MANUFACTURERS OF CATHODE-RAY OSCILLOSCOPES

VOLUME 1
BASIC SEMICONDUCTORS AND DIODES

TEKTRONIX PUBLICATION 062-053

SEMICONDUCTOR DIODES AND TRANSISTORS

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BASIC SEMICONDUCTORS AND DIODES

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SEMICONDUCTOR DIODES AND TRANSISTORS

VOLUME 1

BASIC SEMICONDUCTORS AND DIODES

This volume is about the basic concepts of semiconductor devices. It discusses the physics and characteristics of the materials used in making semiconductor devices and the effects of these materials when used to form semiconductor diodes. It further discusses the effects of external forces such as temperature and applied voltage on the materials in a semiconductor diode.

PREREQUISITES:

This volume assumes the learners comprehension of the following concepts. If he does not, some outside study is indicated before starting this volume.

1. Basic electrical current, voltage, resistance and power.
2. Ohms Law: $E = IR$ (voltage = current x resistance).
3. Power (Watts) = I^2R (current^2 x resistance) = IE (current x voltage).
4. Kirchhoff's voltage and current laws.
5. Thevinen's, Norton's and Millman's theorems.
6. Basic alternating current theory including capacitance, inductance and reactance.
7. Algebra to the level of linear equations.
8. Centigrade and Kelvin Temperature scales.
9. Basic physics including the atomic structure of matter.
10. Definitions of the words and prefixes:
    - a. Diode
    - b. Transistor
    - c. Semiconductor
    - d. Semiconductor Device
    - e. Ions
    - f. Molecules
    - g. Proton
    - h. Electron
    - i. Nucleus
    - j. Kinetic Energy
    - k. Milli (m)
    - l. Micro (μ)
    - m. Nano (n)
    - n. Pico (p)
    - o. Kilo (K)
    - p. Mega (M)

BROAD OBJECTIVES:

When the learner has successfully completed this volume, he will have gained knowledge of basic semiconductors and diodes and prepared himself by meeting the prerequisites for Volume 2 of this semiconductor programed instruction series (Diode Devices).

SPECIFIC OBJECTIVES:

When the reader has successfully completed this volume, he will be able to do the following:

1. Recall that electrons exist in energy levels about the nucleus of an atom and that the amount of energy the electron possesses governs its placement in orbit about the nucleus.
2. Recall that electrons exist in energy bands separated by band gaps when atoms form molecules in structures and that the bonding together of atoms takes place in the valence band. Moving electrons out of their normal bands is termed exciting the atom.
3. Recall that electrons move from a lower energy band to a higher energy band when an atom is excited.
4. Recall that the number of valence electrons, the complexity of the atoms, and the type of bonding determines the electrical characteristics of a structure and be able to explain with energy band diagrams.
5. Recall that atoms bond together in a covalent bond to form semiconductor structures, and that this effects their electrical characteristics.
6. Recall that changes in temperature varies the electrical characteristics of the pure semiconductor structure due to forming "hole electron pairs".
7. Recall that adding inpurities to intrinsic semiconductor is termed doping, and doping forms N and P type semiconductors.
8. Recall that holes moving in the valence band serve as majority current carriers in P type semiconductors and electrons moving in the conduction band serve as majority current carriers in N type semiconductors.
9. Recall that electrons moving between bands result in the electrons taking on or giving up energy.
10. Recall that the immobility of the nucleus of the dopent atoms results in the formation of positive ions in the N material and negative ions in the P material during recombination, and this prevents the loss of N and P properties in doped semiconductor diodes.

11. Recall that an increase in temperature increases the availability of carriers of current in semiconductors.
12. Recall that the fermi level is the 50% electron probability level and that doping changes the placement of the fermi level.
13. Recall that recombination of holes and electrons takes place until a state of equilibrium is reached at the junction when a PN junction is formed and be able to recognize an energy band diagram of a junction at equilibrium.
14. Recall that forward bias moves majority carriers across the junction where they become minority carriers until they recombine. Reverse bias opposes majority carrier movement across the junction but enhances the movement of minority carriers across the junction.
15. Recall that forward current through a junction diode occurs as a result of recombination of holes and electrons after they have crossed the junction.
16. Recall that hole-electron pairs provide current carriers when the junction is reverse biased and an increase in temperature increases the number of hole electron pairs.
17. Recall that sufficient reverse voltage can cause either avalanche or zener breakdown depending on the doping levels and both the amount of doping and the temperature effect the breakdown voltage point.
18. Recognize the PN junction diode characteristic curve and recall that it represents the voltage versus current characteristics of the diode.
19. Recall that power handling capabilities are limited by the maximum junction operating temperature <u>before</u> the diode is damaged.
20. Recall that thermal resistance is the opposition offered in the path of heat transfer and that thermal resistance effects the power handling capabilities of the PN junction.
21. Recognize the symbols for thermal resistance and be able to solve a problem dealing with thermal resistance and power handling capabilities.
22. Recall that minority carriers make up a stored charge about a forward biased PN junction and this stored charge must be established for the diode to be turned on and removed for the diode to be turned off.
23. Recognize a carrier distribution chart for a PN junction with zero, forward and reverse bias and that the forward bias chart represents the stored charge about the junction.

The learner will know when he has met these objectives by correctly answering 90% of the questions in the self test in the back of this volume.

INSTRUCTIONS:

The material in this volume is presented in a series of numbered statements. Each numbered statement is termed a "frame" and each group of frames bearing the same first number (3, 3.1, 3.2, etc.) is termed a "set". The answer to each frame is in a small box in the lower left hand corner of the following frame.

The material is presented in three types of frames within a set; the "gating frame", the "teaching frame", and the "criterion frame".

The first frame in each set is the gating frame. Cover the following frame which contains the answers with the mask provided. Read the frame carefully, studying any diagrams that are provided and fill in the blanks. Do not look at the answer until you fill in the blanks.

You must know something about the material to fill in the blanks in the gating frames as there is no clue given to the answer. If you can answer the gating frame and you are sure of the material, skip to the next gating frame and continue. The gating frames are designed to give the student that is familiar with the subject an indication of the information contained in the set and allow him to skip the set if he feels he knows the information covered.

If you cannot answer the gating frame, continue with the teaching frames in that set, covering the answers and filling in the blanks. You will find clues to the answers in the teaching frames or their diagrams.

The last frame in each set will have 2 (**) asterisks following the number. This is the criterion frame and once again, no clue is given to the answers. The preceeding teaching frames should have provided the information needed to work the criterion frame. If your answer is wrong, go back and review the material in the teaching frames.

You may progress through the program at any speed you select. Don't miss an opportunity to review the material in a set if you can answer the gating frame but are a little hazy on the subject.

This is not a test. You are not being graded and you are not expected to be able to answer the gating frames unless you have the knowledge to let you skip a set. If you answer the teaching frames or the criterion frames incorrectly, do not be concerned, but go back and review the previous frame or frames as needed. Answer from the information presented and if you answer does not match, review the material before going on.

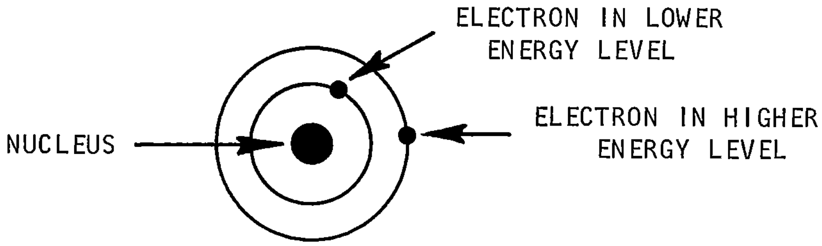
If you would like to measure your progress, go to the back of the volume and do the self test without grading it before proceeding with the programed material. After completing the programed material, do the self test again and grade both attempts. This will give you an indication of the gain that you have made with this volume.

Do each set of the programed material in sequence, starting with Set 1.

If you are ready to proceed with the programed material, turn to the first gating frame - - - - -

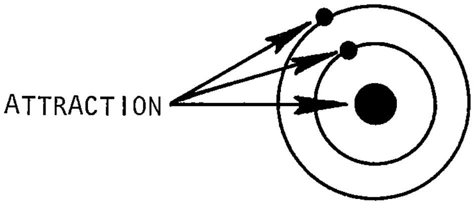
1 Electrons orbit around the nucleus of an atom in ___________ levels. An electron moves to an orbit further from the nucleus as its ____________ increases.

1.1 Electrons orbiting around the nucleus of an atom, orbit at given distances from the nucleus. Each electron has a kinetic energy which determines its distance from the ____________.



energy
energy

1.2 Electrons orbit the nucleus in energy levels. There is an attraction between the nucleus and the electrons. In order to maintain their orbits, the electrons must possess ______________.



nucleus

1.3 The amount of energy an ______________ possesses determines the energy level in which it orbits. The orbit of the ______________ about the nucleus is determined by the energy it possesses.

---

energy

1.4** The more energy the electron in orbit possesses, the ______________ (greater, less) the distance from the ____________.

---

electron
electron

1.5 END OF SET

---

greater
nucleus

---

2 When atoms bond together to form molecules, their energy levels merge into ____________ ____________. The bonding together of atoms takes place in the ____________ band of structures. Applying external energy to the atom and moving the electrons out of their normal bands is termed ________________ the atom.

2.1 When atoms link together or interconnect in some fashion to form molecules of matter, the linkage or interconnection is called bonding. Atoms ___________ together to form molecules.

---

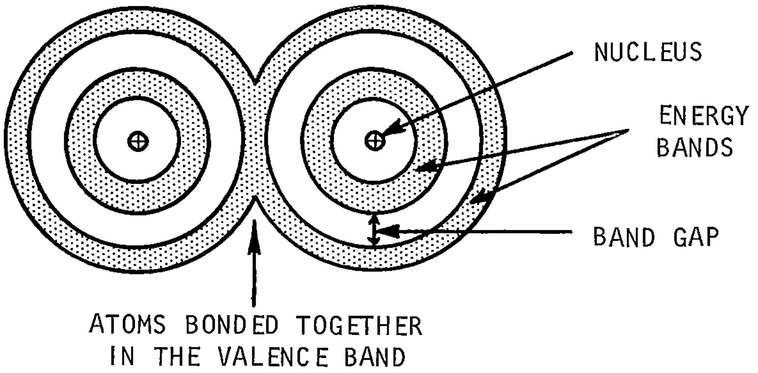
energy bands
valence
exciting

2.2 The bonding together of atoms to form molecules tends to merge the individual energy levels together in groups separated by areas where no electrons can exist. The groups of energy levels are referred to as energy bands. There are separate energy levels within the energy ___________.

---

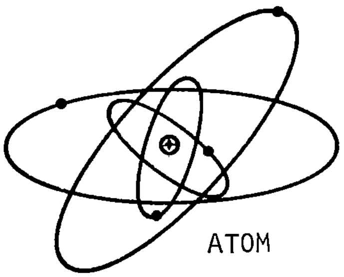
bond

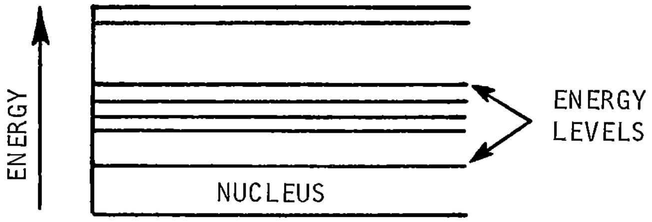
2.3 The areas between the energy bands are referred to as forbidden regions or band gaps. The forbidden regions can contain no ____________________.



bands

2.4 For the single atom shown, a diagram can be constructed showing the energy the electron possesses to maintain its orbit as an energy level a certain number of energy units from the ______________.

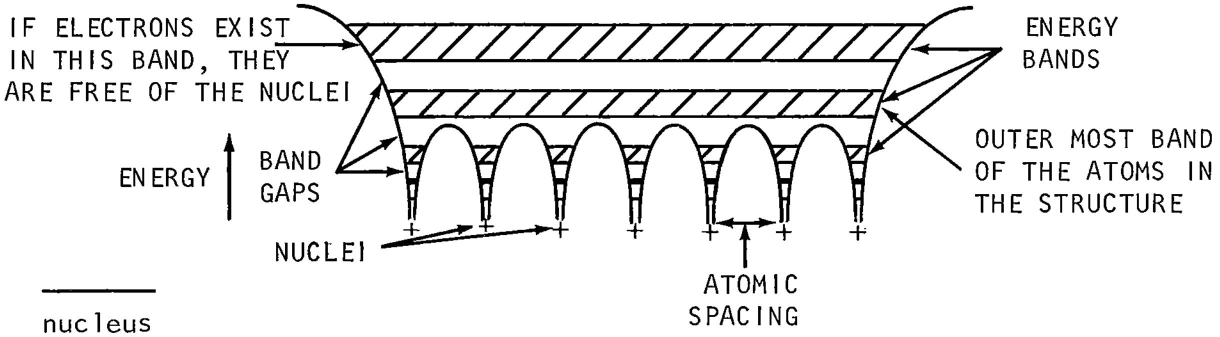




ENERGY LEVEL DIAGRAM OF THE ATOM

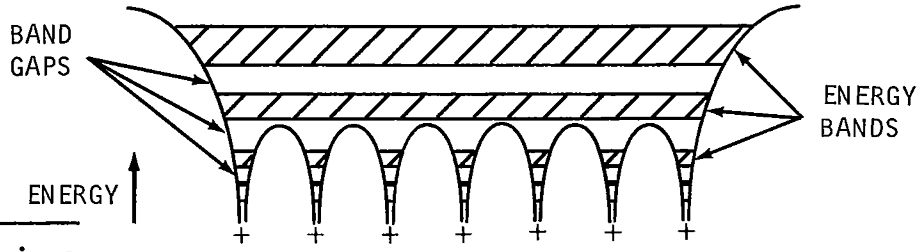
electrons

2.5 A two dimensional diagram of a small section of a structure is shown. The energy the electrons in the bands possess is plotted with respect to the nuclei. The energy bands are separated by forbidden regions or band gaps. Electrons cannot exist in the ______________ ______________.



nucleus

2.6 Energy band diagrams for atoms in molecules do not show the individual energy levels but show the energy bands in which these levels exist. It should be remembered that the energy ____________ in these diagrams contain separate _______________ levels.



forbidden regions
or
band gaps

2.7 The complexity of the atom effects its electrical characteristics. The more complex the atom (number of protons in the nucleus and orbital electrons it contains), the farther the outside electrons will exist from the _________.

bands
energy

2.8 When dealing with structures or solids containing molecules, energy band diagrams are used. When molecules are formed due to bonding together of the atoms, the energy ________ merge and form energy bands.

nucleus

2.9 The more complex the atoms in the structure, the more energy bands will be filled. Those bands ________________ (closest, farthest) from/to the nucleus will be filled first as long as no external energy is applied to move the electrons out of their normal bands.

levels

2.10 Applying external energy to atoms in a structure can move electrons out of their normal bands. This is termed "exciting" the atom. When the electrons are displaced from their normal bands, the atom is termed "________________".

closest

2.11 The outermost band of the unexcited atom (in a structure) that contains electrons is termed the valence band. The more complex the atom, the ________________ (farther, nearer) the valence band will be from/to the nucleus.

excited

2.12 Energy bands existing above the valence band will contain electrons only when that atom is excited. Electrons existing above the valence band indicate that the atom has been ________________.

farther

2.13 The more complex the atom, the more energy the valence electrons possess. The more energy the ____________ electrons possess, the farther the valence ____________ from the nucleus.

excited

2.14 Atoms bond together by interaction in the valence band. ______________ band electrons take part in the bonding together of _____________ in structures.

valence
band (electrons)

2.15** The atoms in <u>molecules</u> have electrons existing in energy ______________. Bonding together of atoms is accomplished in the ____________ band. The application of external energy to the atom and moving the electrons out of their normal bands is termed _______________ the atom.

Valence
atoms

2.16 END OF SET

bands
valence
exciting

3 Structures or materials used to make diodes and transistors are made up of atoms linked together by ________________ bonding. When bonding takes place, the valence band is considered filled when it contains __________ electrons per atom.

3.1 When atoms bond together to form molecules of matter, they try to have eight electrons in the valence band of the individual atoms. An octet structure indicates that the individual atoms have ________(#) electrons in their valence bands.

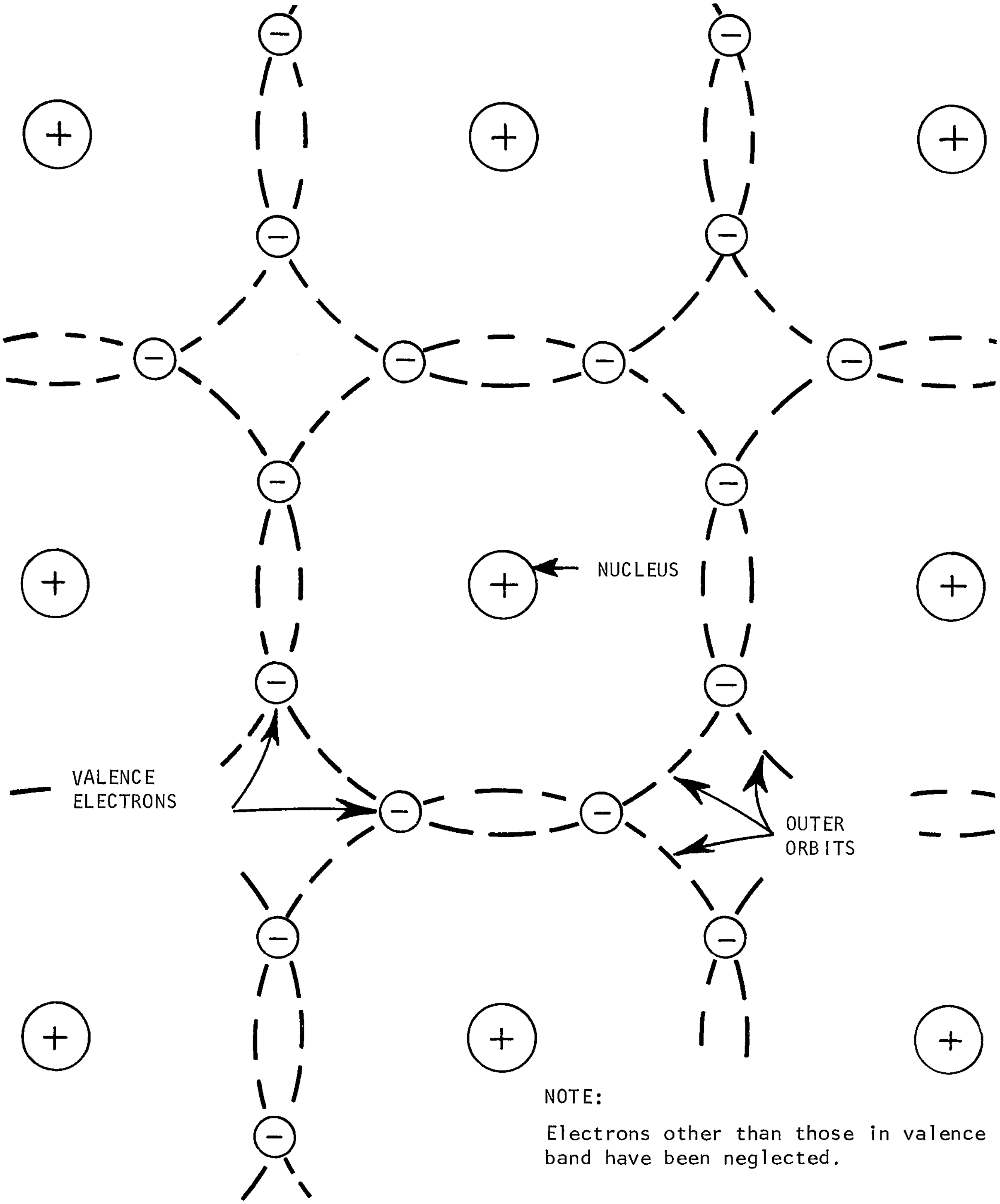
covalent
8

3.2 In an octet structure, the valence band is considered to be "filled" when each atom has eight electrons in the valence band. The valence band is ________________ when it contains __________(#) electrons per atom.

8

3.3 Atoms bond together in the valence band to form molecules of matter. The bonding together in the ______________ band tries to fill each individual atoms portion of the ____________ band with the eight electrons.

filled
8



NOTE:

Electrons other than those in valence band have been neglected.

Each atom shares its valence electrons with four other atoms.

FIGURE 3

3.4 Crystal structures are formed when atoms bond together in a covalent bond. Covalent bonding refers to the type of interconnection or bonding between atoms when molecules of ________________ structures are formed.

valence
valence

3.5 Atoms in crystals arrange themselves to share each others valence electrons. The sharing of valence electrons is referred to as ____________ bonding.

crystal

3.6 When atoms share valence electrons in a covalent bond, the atoms are tightly bonded together. In crystal structures, the atoms are
_______________ bonded together.
(tightly, loosely)

covalent

3.7 Figure 3 shows the covalent bond that exists in intrinsic (no impurities) or pure germanium. Each atom shares valence electrons with four neighboring atoms and each germanium atom will appear to have a valence of _____(#).

tightly

3.8 The orbits of the valence electrons of adjacent atoms of germanium take a path that carries them through the adjacent atoms valence band. This gives the structure an effective valence of 8.

8

3.9 Germanium atoms have four valence electrons but when in a covalent bond to form a crystal structure, appear to have an effective valence of ______(#).

no answer needed

3.10 The interlacing or "lattice" work due to covalent bonding extends through the entire germanium crystal, each atom sharing valence electrons with ________(#) adjacent atoms.

8

3.11** Structures such as germanium are made up of atoms in a _____________ bond. This type of bonding has the atoms sharing ______________ ______________. The valence band is considered filled when it contains ______(#) electrons per ___________________.

4

3.12 END OF SET

---

covalent
valence electrons
8
atom

---

4 When an atom in a molecule is excited, electrons move from the ___________ band to the _______________ band. Electrons in the _______________ band and below are bound to the atom while electrons in the __________________ band are free to become current carriers.

4.1 The energy band above (at a higher energy point) the valence band that can contain electrons when the atom is excited, is termed the conduction band. Electrons in the conduction band possess more ________________ than electrons in the ___________ band.

---

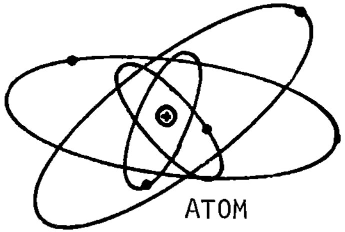
valence
conduction
valence
conduction

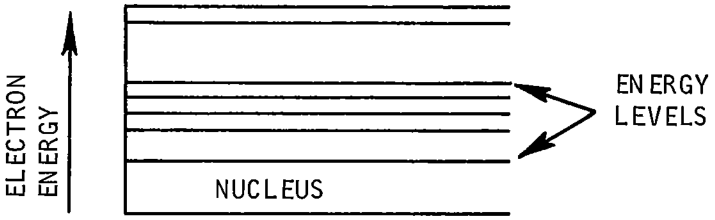
4.2 Electrons do not normally exist in the conduction band. The electrons that move to the conduction band are those electrons from the ___________ band that have gained enough energy to move there.

---

energy
valence

4.3 Considering the individual atom, a one dimensional diagram can be constructed showing the energy the electrons possess vertically as shown in the diagram. The more energy the electron possesses with respect to the nucleus, the ______________ it will appear in the diagram.
(lower, higher)

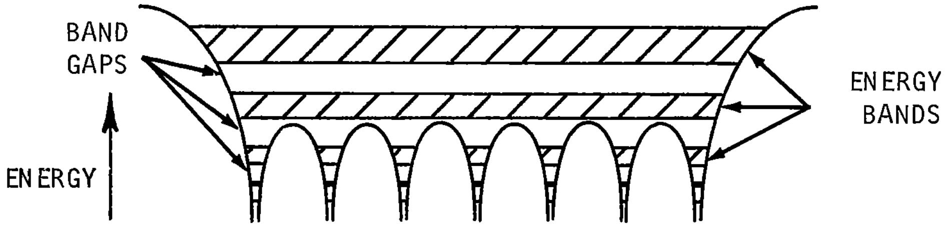




ENERGY LEVEL DIAGRAM OF THE ATOM

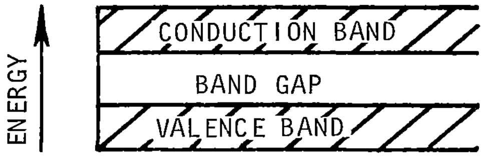
valence

4.4 Energy band diagrams for atoms in molecules do not show the individual energy levels but show the energy bands in which these levels exist. It should be remembered that the energy ______________ in these diagrams contain separate ______________ levels.



higher

4.5 The inner bands below the valence band are present but disregarded in most energy band diagrams. Only the ______________ and ______________ bands are normally shown. This energy band diagram is used often to show the action of semiconductors.



bands
energy

4.6 Electrons that are excited (given more energy) to the conduction ________ are free to be moved from the atom by application of some external force (become current carriers).

valence
conduction

4.7 Sufficient energy must be imparted to the valence electrons to move them across the band or energy gap to be free of the atom. Once in the __________ band, the electrons can be moved away from the atom.

band

4.8 The conduction band is an energy band ______________ the valence band
(above, below)
where existing electrons are free to be moved away from the atom.

conduction

4.9 Electrons in the conduction band become current carriers and are free to be moved by external forces. Electrons in the valence band are in an orbital pattern and must _________ energy to move to the conduction band.

above

4.10 The _________ energy band is lower in energy than the conduction energy band.

---

gain/increase/receive/etc.

4.11** To excite an atom sufficiently to provide electrons that may be moved from the atom, valence electrons must be given sufficient energy to cross the ______ ______ to the ______________ energy band.

---

valence

4.12 END OF SET

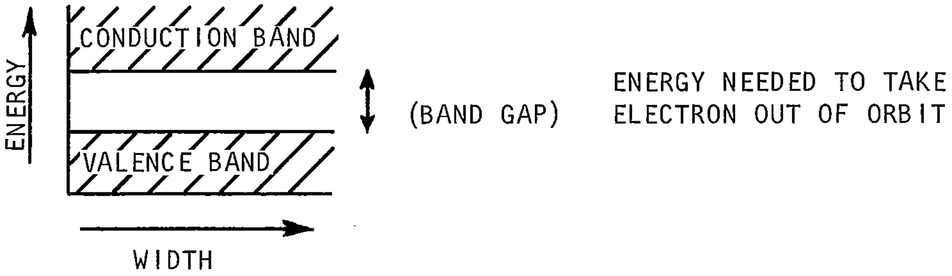
---

forbidden or band gap
conduction

---

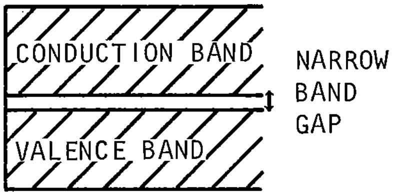
5 Different types of material require different amounts of energy to move an electron into the conduction band. Conductors require __________ energy than insulators. Semiconductors have a __________ (wider, narrower) band gap between the valence and conduction band than insulators.

5.1 Electrons cannot exist between the valence and conduction bands, they must be in one or the other. The area between these bands is called the forbidden energy band, or band gap. An electron in the valence band must take on energy in order to cross the __________ __________ to the conduction band.

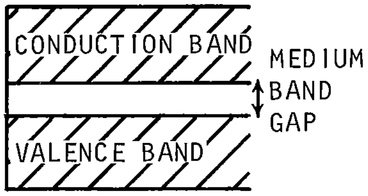


less
narrower

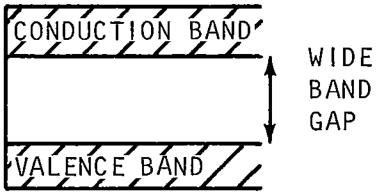
5.2 Electrons must be present in the conduction band to have electron current. A conductor is a material that allows valence electrons to move into the __________ band with little applied energy.



CONDUCTOR



SEMI-CONDUCTOR



INSULATOR

(In some conductors, the conduction and valence bands overlap)

band gap, forbidden band, etc.

5.3 An insulator requires much more energy than a conductor to move __________ into the conduction band.

conduction

5.4 The band gap width of a semiconductor is between that of an insulator and a __________.

electrons

5.5 Semiconductors are not good conductors or ________________.

conductor

5.6** The band gap between the valence band and the conduction band of a semiconductor is _____________ (narrow, wide) compared to the same band gap of a conductor, and _____________ (narrow, wide) compared to the band gap of an insulator.

insulators

5.7 END OF SET

wide
narrow

6 The electrical characteristics of a material are determined by the number of ________ electrons, the ________________ of the atom, and the type of bonding.

6.1 More complex atoms have their valence bands existing farther from the nucleus than simple atoms. Electrons in the valence bands of more complex atoms possess more __________ than the valence electrons of simple atoms. Simple atoms are those with few protons and orbiting __________________.

valence
complexity

6.2 The farther the electron exists from the nucleus, the more ________________ it is bound to the nucleus. This is because it
(tightly, loosely)
possesses more ________________

energy
electrons

6.3 The valence electrons of simple atoms are more tightly bound to the nucleus and possess ___________ energy than the valence electrons of
(more, less)
complex atoms.

loosely
energy

6.4 Atoms with few valence electrons tend to give up their valence electrons more readily than atoms with many valence electrons. Atoms with few valence electrons have them more ____________ bound to the nucleus
(tightly, loosely)
than atoms with many valence electrons.

less

6.5 An atom with one valence electron will give up the valence electron more readily than an atom with five ________ electrons.

loosely

6.6 A complex atom with a valence of one will give up its valence electron easier than a simple atom with a valence of one. Complex atoms have their valence electrons existing farther from the nucleus than __________ atoms.

valence

6.7 Atoms with a large number of valence electrons have a wider band gap between the valence and the conduction band than atoms with few ________ ______________ and the same number of filled energy bands.

simple

6.8 The smaller the number of valence electrons per atom and the more complex the atom, the ____________ (narrower, wider) the band gap between the valence and conduction band.

valence electrons

6.9 Conductors have a narrow band gap between the valence and the conduction band. Insulators have a ____________ (wide, narrow) band gap.

narrower

6.10** The number of ____________ electrons, the complexity of the atoms, and the type of bonding determines the ____________ characteristics of the material. Better conductors are made up of ____________ (complex, simple) atoms with a ____________ (large, small) number of valence electrons per atom.

wide

6.11 END OF SET

valence
electrical
complex
small

7 A material with a valence band containing 5 electrons per atom can be ________________ with a material with a valence band containing _____(#) electrons per atom to complete a covalent bond. A ________________ is a bond of two or more dissimilar atoms.

7.1 Silicon or germanium have a valence of four electrons per atom and when the atoms bond together, they fill each others valence band by sharing valence electrons. This ______________ of valence electrons is termed covalent bonding.

---

compounded
3
compound

7.2 The bonding together of two or more types of basic dissimilar atoms to obtain a material is termed "compounding". A 3-5 compound gives an effective valence of __________(#).

---

sharing

7.3 Gallium arsenide is a compound of gallium with a valence of three and arsenic with a valence of five. Gallium and arsenic form a covalent bond structure with a valence of _______(#).

8

7.4 Gallium arsenide is a covalent bond structure with an effective valence (number of valence electrons per atom) of eight. Gallium arsenide is a compound of ________________ and arsenic.

8

7.5 Semiconductor devices are made from materials with a valence of four, five and three, with the possibility of using materials with a valence of two and six. Bonding together materials with a valence of six and two could give an effective valence of _____(#).

gallium

7.6 Atoms that form a covalent bond structure fill the valence band with eight electrons by sharing electrons in the valence band. The valence band is considered filled when it contains ______(#) valence electrons per atom.

8

7.7 Dissimilar atoms (atoms with a different valence) can be compounded to form molecules of structures. Compounding is the process of bonding ________ (atoms with a different valence) atoms.

8

7.8** A compound is a bond of two or more ________________ atoms. A material with a valence of ______(#) can be compounded with a material with a valence of three to form a covalent bond structure.

---

dissimilar

7.9 END OF SET

---

dissimilar
5

---

8 With no external energy applied (to include heat and light), a covalent bonded semiconductor structure appears as an __________ since the valence band appears to be filled, but at room temperature some ________________ ________________ pairs are formed providing ________________ carriers.

8.1 At 0° Kelvin, the <u>pure</u> semiconductor or covalent structure has the electrons bound tight in the valence band and no ____________ are existing in the conduction band.

insulator
hole-electron
current

8.2 At 0° Kelvin, a pure semiconductor structure acts as an insulator since the valence is effectively ______(#) and no current carriers are available.

electrons

8.3 At room temperature (25°C), enough energy in the form of heat has been imparted to some of the valence electrons to break the covalent bond. The covalent bond is broken at room temperature by ______ energy.

eight

8.4 Heat moves electrons to the conduction band leaving holes in the semiconductor structure, forming hole electron pairs. They are called hole electron pairs since for each electron moved to the conduction band, a ________ is left in the valence band.

heat

8.5 Breaking of some of the bonds due to heat energy moves a few electrons to the conduction band leaving an incomplete covalent bond in the semiconductor structure. The structure is not complete at points due to heat forming ________ electron ________.

hole

8.6 At room temperature, some current carriers are available due to the formation of hole electron pairs as a result of _______ energy.

hole
pairs

8.7 At room temperature, the covalent bonded structure is not a good insulator or conductor, hence it is a ______________________.

heat

8.8 An increase in temperature results in more _______ _______ _______ and more current carriers available.

semiconductor

8.9 Any current carried by the intrinsic semiconductor is temperature dependent because changes in temperature result in a change in the number of current carriers available. This is due to the change in the number of _______ _______ _______ with temperature changes.

hole-electron pairs

8.10 The resistivity of a semiconductor is _______________ dependent.

hole-electron pairs

8.11** Materials made up of atoms in a covalent bond are electrical ___________ at room temperature. Heat forms _______ _______ _______ providing current carriers and the resistivity of semiconductors varies with _______________ changes.

temperature

8.12 END OF SET

semiconductors
hole-electron pairs
temperature

9 Adding impurities to the intrinsic semiconductor is termed ________ and this process results in changing the intrinsic semiconductor to _____ or ______ type semiconductor. Electrons are the majority current carriers in _____ type semiconductors and holes are the majority current carriers in ______ type semiconductors.

9.1 When a small amount of a material such as arsenic with a valence of five electrons per atom is added to pure germanium or silicon having a valence of four electrons per atom, the germanium or silicon is termed "doped". Adding impurity atoms to the pure semiconductor is termed DOPING.

---

doping
N, P
N
P

9.2 Germanium or silicon can also be doped with an impurity such as Indium which has a valence of three electrons per atom. The doping process involves adding impurity atoms with a different _____________ than the basic material used.

---

no answer needed

9.3 Adding arsenic to germanium or silicon results in more valence electrons available than needed to complete the covalent bond. Arsenic has five valence electrons per atom, _____(#) more than germanium or silicon.

---

valence (number of valence electrons per atom)

9.4 Four of the individual arsenic atoms' valence electrons will bond with four adjacent germanium or silicon valence electrons, the fifth arsenic valence electron has no place in the covalent bond and is easily moved into the conduction band.

1

9.5 The extra electron present as a result of doping cannot exist in the valence band or the band gap. At room temperature, there is sufficient heat energy to move it into the ________________ band.

no answer needed

9.6 Silicon or germanium doped with arsenic is called "N" type semiconductor. N type semiconductor has __________ (more, less) electrons than needed to complete the covalent bond.

conduction

9.7 N type semiconductors can have electrons existing in the conduction band <u>without</u> corresponding holes in the valence band. The electrons in the conduction band are a result of ________________ (adding impurities).

more

9.8 "N" type semiconductors can have electrons available as current carriers without holes existing in the valence band. This is a result of doping the intrinsic semiconductor with impurity atoms with more ______________ ______________________ than the material being doped.

doping

9.9 Indium is used to form "P" type semiconductors when added to either germanium or silicon. Indium has three valence electrons. This is one ____________ than germanium or silicon.
(more, less)

valence electrons

9.10 Adding Indium (as a coping impurity) to silicon or germanium results in an insufficient number of valence electrons to complete the covalent bond and results in an unfilled ______________________ band at points in the structure.

less

9.11 Indium doped germanium or silicon will have no _______________ available as current carriers as a result of doping.

valence

9.12 Silicon or germanium doped with a valence of three material will have an incomplete bond at points in the structure. There will be ______ in the structure with this type of doping.

electrons

9.13 Silicon or germanium doped with valence three material is referred to as "P" type semiconductor. "P" type semiconductor has ______ in the structure.

holes

9.14 The holes in the "P" type semiconductor are assigned a net positive charge as they represent a missing electron in the bond. The holes exhibit an attraction for electrons and are assigned a __________________ charge.

holes

9.15 There will be some hole-electron pairs formed in P semiconductor at room temperature as a result of thermal energy. There will be some free

_______________ in P material as well as the holes at room temperature.

positive

9.16 There will be more holes than free electrons in P material at room temperature, therefore the holes are said to be in the majority.

electrons

9.17 Holes serve as current carriers in P type semiconductor and are referred to as ____________________ carriers.
(majority, minority)

no answer needed

9.18 The holes in "P" type semiconductor serve as current carriers and are attracted to a negative charge. __________________ and not ______________ serve as the majority current carriers in P type semiconductors.

majority

9.19 The holes serve as the majority current cariers in "P" semiconductor and there are no _________ available as a result of doping.

holes
electrons

9.20 N type semiconductor will have hole-electron pairs formed as a result of heat energy at room temperature. This means that at room temperature, there will be some ______________ in N type semiconductor along with the free __________________.

electrons

9.21 The holes in N type semiconductor make up less than 50% of the current carriers present, and are therefore termed __________________ carriers.
(minority, majority)

holes
electrons

9.22 Electrons are termed _________________ current carriers in N type semiconductor, while holes are termed _________________ current carriers.

minority

9.23** Adding impurities with a different number of valence electrons per atom than the semiconductor to which they are added is termed ______________ and this forms N and P type semiconductors. Electrons are the majority current carriers in ________ semiconductors and holes are the majority current carriers in ________ semiconductors.

majority
minority

9.24 END OF SET

doping
N
P

10 Doped semiconductors have ________(#) types of current carriers available at room temperature; majority carriers present as a result of ____________ and minority carriers present as a result of ____________ ______________. ________________ as current carriers travel in the conduction band and ________________ as current carriers travel in the valence band. The movement or transport of minority carriers in either N or P material is termed ______________________.

10.1 "N" type semiconductors will have hole-electron pairs formed at room temperature as a result of heat energy. At room temperature, there will be some free ______________ along with the free electrons in "N" semiconductors.

two
doping
heat energy
electrons
holes
diffusion

10.2 The free electrons in N type semiconductors are termed "majority carriers" and the free _________________ in N type semiconductors are termed "minority carriers".

holes

10.3 Carriers are termed either majority or minority carriers. The type of carrier that makes up greater than 50% of the total current carriers present in a material are termed ________________ carriers

holes

10.4 At room temperature, there will be some electrons in the conduction band of P type material due to heat energy forming ____________ ____________ pairs.

majority

10.5 P type semiconductors have holes existing in the valence band which serve as majority current carriers. The holes move as current carriers in the valence band.

hole-electron

10.6 Any electrons in the conduction band of "P" semiconductor are minority carriers. Minority current carriers travel in the ________________ band of "P" type semiconductors.

no answer needed

10.7 Holes are majority current carriers in "P" semiconductor and ________ are minority current carriers. Holes as current carriers travel in the ________________ band and electrons as current carriers travel in the ________________ band.

conduction

10.8 Electrons in the conduction band of N material, carry current in much the same fashion as a conductor. There is a net drift of electrons through the conduction band when external energy is applied.

electrons
valence
conduction

10.9 Free electrons traveling in P semiconductors, take a random, erratic path in the conduction band since there are so few ____________ (minority carriers) present.

no answer needed

10.10 The movement of electrons (minority carriers) in P semiconductor is termed diffusion. Electrons diffusing in P semiconductor take an ________________ path through the conduction band.

electrons

10.11 When external voltage is applied to P semiconductor, there is a net drift of holes (majority carriers) through the valence band that results in electron current in the external circuit.

random or erratic

10.12 Since there are so few holes in the valence band of N material, hole (minority carrier) movement in N semiconductor is by ____________________.

No answer needed

10.13** Doped semiconductors have __________(#) types of current carriers at room temperature; __________________ carriers as a result of doping; ___________ carriers as a result of heat energy. Electrons as current carriers travel in the _____________________ band while holes travel in the _____________ band. Minority carriers move as current carriers by a transport process termed ____________________.

diffusion

10.14 END OF SET

two
majority
minority
conduction
valence
diffusion

11 Doping impurities used to form N type semiconductors are referred to as _______________ impurities, and doping impurities used to form P type semiconductors are referred to as _________________ impurities. The doping process provides ____________________ current carriers.
(majority, minority)

11.1 Donor impurities provide or donate extra electrons to form N semiconductors. Arsenic donates extra electrons when added to silicon or germanium. Arsenic is a donor impurities and forms ___________ type semiconductors.

donor
acceptor
majority

11.2 Silicon, when used as a doping impurity in gallium arsenide, provides more valence electrons than needed to complete the bond. The silicon atoms replace atoms of gallium. Silicon added to gallium arsenide serves as a ____________________ impurity and forms N type gallium arsenide.

N

11.3 Acceptor impurities "accept" electrons from adjacent atoms. Indium, when added to silicon or germanium, accepts an electron from an adjacent atom creating a hole in the valence band of the semiconductor structure. __________________ impurities are used to form P semiconductors.

donor

11.4 Zinc creates holes when used to dope gallium arsenide. Zinc has a valence of two electrons per atom and is used to make __________ type semiconductors when added to GaAs (gallium arsenide).

---

acceptor

11.5 Indium, when used to dope silicon or germanium, creates holes and P type semiconductors. There will also be some electrons lifted to the conduction band of P type at room temperature due to _____________ energy.

P

11.6 When arsenic is used to dope silicon, it forms N type semiconductors. ________________ are the majority current carriers and ________________ are the minority current carriers in N type semiconductors.

---

heat

11.7 There are more holes than electrons in properly doped P semiconductors at room temperature with no external energy other than heat of the surrounding air applied. The electrons are present in P material as a result of ____________ _____________.

---

electrons
holes

11.8** Acceptor impurities are added to make ______ type semiconductors and donor impurities are added to make _____ type semiconductors. Doping provides _________ carriers while ________________ carriers are a result of heat energy when no other source of energy is applied.

heat energy

11.9 END OF SET

P
N
majority
minority

12 Holes as current carriers travel in the ____________ band while electrons as current carriers travel in the ______________ band. Electrons in N material and holes in P material are the ______________ current carriers. __________________ current carriers travel by diffusion. Minority carriers move much ______________ as/than majority carriers.
(slower, faster)

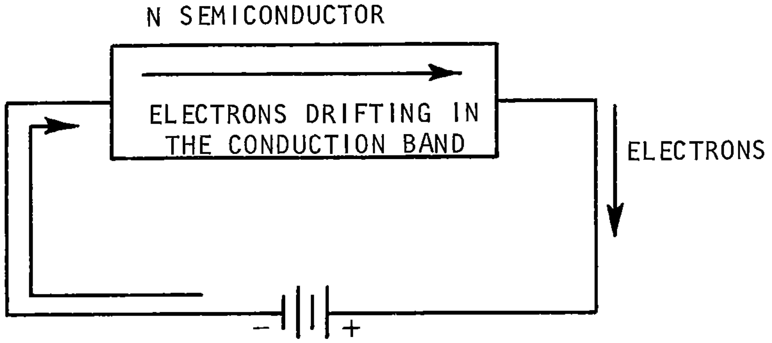
12.1 For electrons to become carriers of current, they must be excited in some way to the __________________ band where they are free of the nucleus and the covalent bond.

valence
conduction
majority
minority
slower

12.2 Once excited to the conduction band, the electron is free to move as a carrier of current. ________________ move as current carriers in the conduction band.

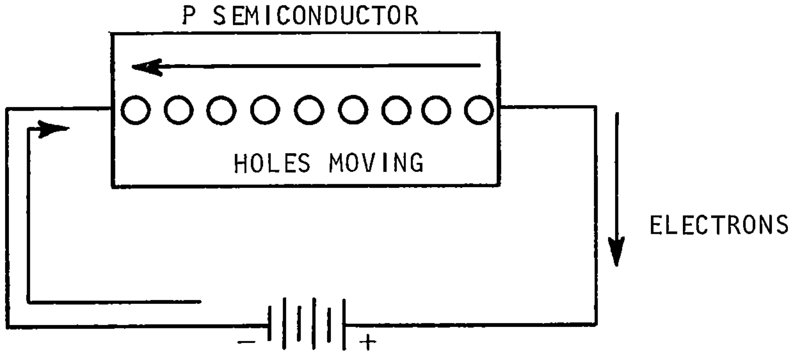
conduction

12.3 N semiconductors have electrons available in the conduction band without ______ having to exist in the valence band at room temperature.



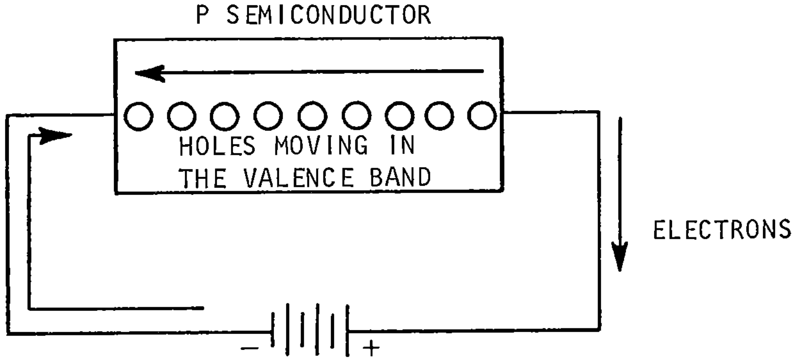
electrons

12.4 The diagram shows a bar of P material. The battery is forcing the holes to move in the ______________ band of the material.



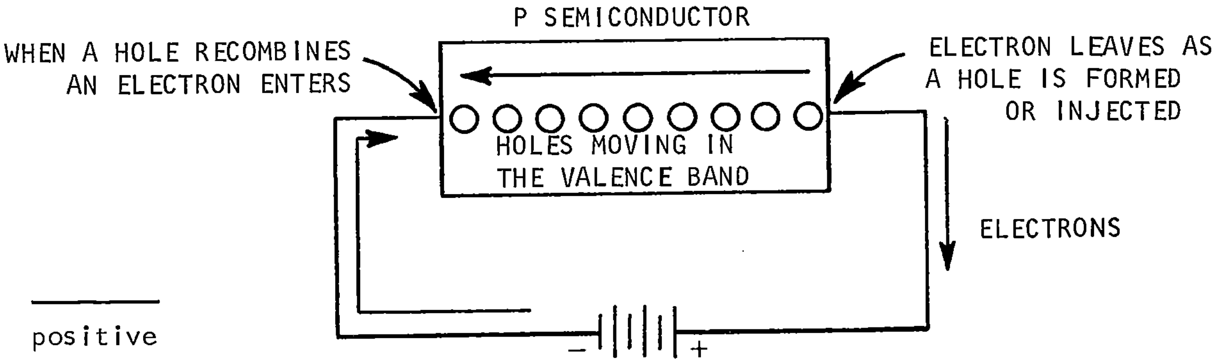
holes

12.5 Holes are a deficiency of an electron in the valence band, hence they have a positive charge. They may be attracted by a negative charge or repelled by a ______________ charge.



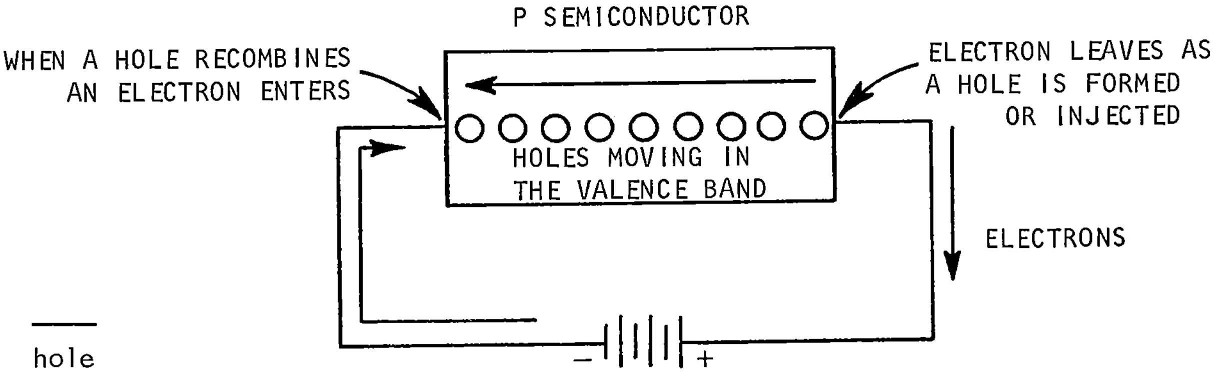
valence

12.6 When a hole recombines with an electron, electrons move in the external circuit. An electron will enter when a ______ recombines with an electron.



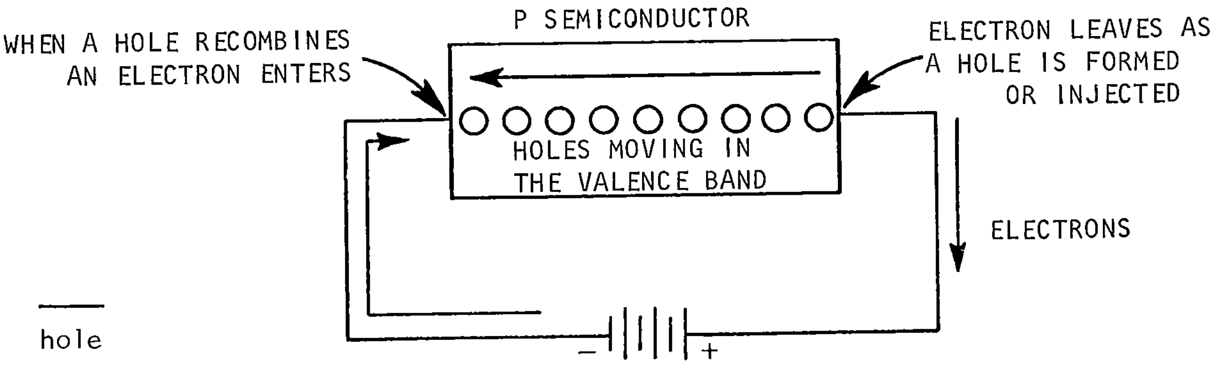
positive

12.7 The drift of holes through the valence band causes an electron to leave the material at the positive polarity of the external energy source. When a ______ is formed or is injected, an electron leaves the P material.



hole

12.8 If holes are forced to move through the valence band of P semiconductor, ______________ will flow in the opposite direction in the external circuit.



hole

12.9 Holes moving in the ______________ band of P material and electrons moving in the ______________ band of N material, serve as a major or majority current carriers in semiconductors.

electrons

12.10 The transport of holes in P semiconductor and electrons in N semiconductor (majority carrier movement) when an external generator is applied, is much faster than the diffusion of minority carriers in the same materials.

valence
conduction

12.11 The movement of electrons in N type semiconductor is typically 40 times faster than the diffusion of electrons in P type germanium (free electrons existing as minority carriers in P type).

no answer needed

12.12 The movement of holes in P type semiconductor is typically 38 times faster than the diffusion of holes in N type germanium (free holes existing as minority carriers in N type).

no answer needed

12.13 Electrons travel typically 40 times faster when moving as ______________ carriers than when moving as ________________ carriers in semiconductors.

no answer needed

12.14 Holes travel typically 38 times faster when moving as ___________ carriers than when moving as ______________ carriers in semiconductors.

majority
minority

12.15 Transport by diffusion is ______________ than the transport of majority carriers.
(slower, faster)

majority
minority

12.16 Unless accelerated in some way, minority carrier transport is ___________ than majority carrier transport.

slower

12.17** __________ as current carriers travel in the conduction band, and when in the majority, travel ________________ than when in the minority. When
(faster, slower)
serving as minority carriers the transport is by __________.

---

slower

12.18 END OF SET

---

electrons
faster
diffusion

---

13 N and P semiconductors keep their properties even though electrons are forced into P material or out of N material because ________ are formed due to the immobility of the nuclei of the dopent atoms.

13.1 Forcing an electron into P material will fill the vacancy in the valence band. The P impurity atom does not have enough protons in the nucleus for the added electron to exist in a normal orbit and therefore, looses its charge neutrality.

ions

13.2 Forcing an electron into P material, causes an impurity atom to take on a negative charge, since there is no proton for the added electron.

no answer needed

13.3 Forcing electrons into P material forms negative ions which start repelling electrons that are trying to enter. The P material takes on a ____________ charge.

no answer needed

13.4 If a path is provided for the added electrons to leave the P material, the impurity atom will return to its original state. Any electrons that have been forced into P material will ______ if a path is provided.

negative

13.5 Forcing electrons out of N material will satisfy the covalent bond, but the impurity atoms are left with more protons in the nucleus than orbital electrons and take on a ________ charge.

leave

13.6 Forcing electrons out of N semiconductor creates positive _______ giving the N material a ____________________ charge.

positive

13.7 If electrons are allowed to return, the N material will return to its original neutral charge state. The N material loses its _______________ charge if the electrons are returned.

ions
positive

13.8** The impurity atoms, being immobile and becoming ______ when electrons are added or removed, prevent the loss of N and P properties in semiconductors.

positive

13.9 END OF SET

ions

14 A change in temperature changes both the amount of ________________ and ________________ carriers present in N and P type semiconductor material. A higher temperature can be tolerated by ______________ than germanium.

14.1 The number of hole-electron pairs in semiconductors varies directly as temperature varies. A decrease in temperature ______________________ (increases, decreases) the amount of hole-electron pairs present.

majority
minority
silicon

14.2 The number of majority carriers is directly affected by temperature. The higher the temperature the more carriers are available due to the formation of more ____________ ________________ pairs

decreases

14.3 Since silicon atoms are less complex than germanium, the band gap between the valence and conduction band in silicon is wider than in germanium. __________________ has a higher resistance than germanium.

hole-electron

14.4 Silicon has a higher resistance than germanium. The band gap is wider and

__________ hole-electron pairs are formed in silicon than germanium at
(more, less)
a given temperature.

silicon

14.5 There will be less majority and minority current carriers available at a given temperature in silicon than in germanium. ________ will require more voltage applied for the same current at a given temperature than germanium.

less

14.6 Temperature is a factor in determining the resistance (or conductance) of semiconductors and resistance will vary ________________ as
(directly, indirectly)
temperature varies.

silicon

14.7** The number of majority and minority carriers in semiconductors varies

________________ as temperature varies. At a given temperature, there
(inversely, directly)
will be less minority carriers in ____________ than ____________
(types of semiconductors).

indirectly

14.8 END OF SET

directly
silicon
germanium

15 The ______________ level exists in the ______________ of the forbidden band between the valence band and the conduction band in the energy band diagram of intrinsic semiconductor material. This level is termed the ________% electron probability level.

Fermi
center
50

15.1 The Fermi level indicates the 50% probability level for the existence electrons in the bands of an energy band diagram. The ________________ level is assigned midway between the 0% and 100% electron probability levels.

Fermi

15.2 Intrinsic semiconductor material with no external energy applied (to include heat) has the valence band filled and no electrons existing in the conduction band. The lowest level in the conduction band is the ______% probability level for the existence of electrons.

0

15.3 Intrinsic (pure) semiconductors with no external energy applied have a 100% probability level for the existence of electrons in the highest level in the valence band. Under these conditions, electrons will ____________ in the highest level in the valence band.

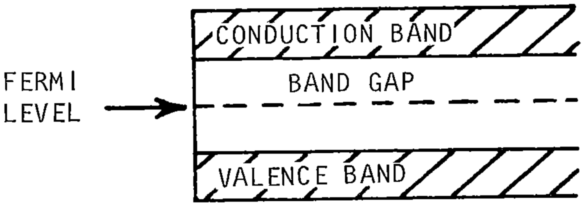
15.4 The Fermi level is assigned at the 50% electron probability level, or ________ between the 0% and 100% probability levels.

exist, be, etc.

15.5 The probability levels are energy levels which have a certain percentage of electron probability. (The probability of electrons existing in that level.)

midway, halfway, etc.

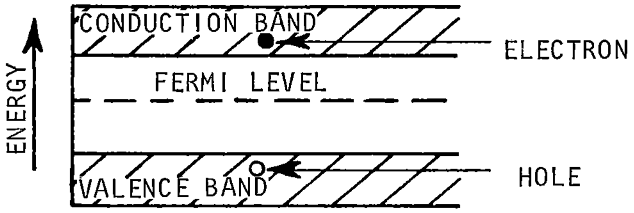
15.6 The Fermi level is midway in the band gap in intrinsic semiconductors. This is the ________% electron probability level.



INTRINSIC GERMANIUM

no answer needed

15.7 Since the Fermi level is the 50% electron probability level, an electron excited to the conduction level will exist a given number of energy units above the Fermi level. This will leave a hole the same number of ________ units below the Fermi level in intrinsic semiconductors.



50

15.8 The Fermi level indicates the energy level, midway between the highest energy level that normally contains electrons and the level to which these electrons must move if excited by external energy.

energy

15.9 The Fermi level is the midpoint between the level of the unexcited electron and the level at which the ______________ exists if excited by external energy.

no answer needed

15.10** The _______ level is an indicator of the probability of the existance of ________ in the bands of an energy band diagram. It indicates the _____% electron probability level. The Fermi level is located in the __________ of the ____________ gap above the valence band in intrinsic semiconductors.

electron

15.11 END OF SET

Fermi
electrons
50
center
band

16 Doping a semiconductor with donor impurities causes the Fermi level to exist closer to the ____________ band. An energy band diagram of N semiconductor will have the Fermi level closer to the ____________ band than the band diagram of intrinsic semiconductor.

16.1 Adding donor impurities to intrinsic semiconductor provides electrons that must exist at higher energy levels than the outer electrons in the intrinsic material. This means the 0% electron probability level moves ____________ in the diagram (when compared to an intrinsic diagram).
(higher, lower)

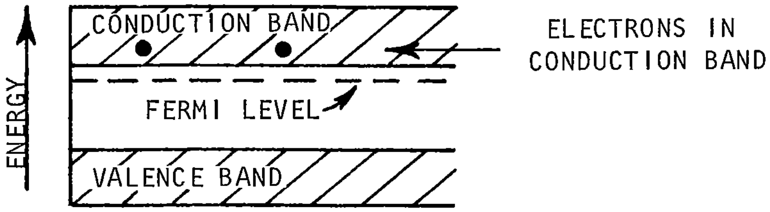
conduction
conduction

16.2 Electrons provided by donor impurities, cause the 0% probability level to exist higher in the energy band diagram. The more donated electrons, the higher the ____% ________________ level will exist in the energy band diagram.

higher

16.3 When electrons are provided by doping with donor impurities, the 0% probability level exists higher in the energy band diagram than for intrinsic semiconductors. This means that the 50% level will exist ____________________ the conduction band in the energy band diagram
(nearer to, farther from)
than for intrinsic semiconductors.

0
probability



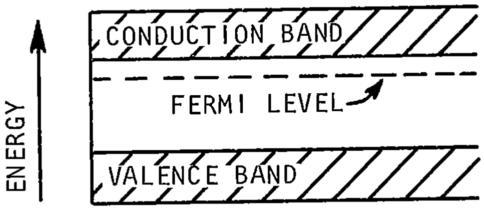
16.4 Doping with donor impurities forms N type semiconductors, providing electrons as majority current carriers. The 50% probability level exists ____________ in the energy band diagram when compared to intrinsic
(higher, lower)
semiconductors.

nearer to

16.5 The more donor impurities added, the higher the donated electrons will exist in the energy band diagram. Increasing the donor impurities moves the Fermi level ______________ in the energy band diagram.

higher

16.6 Doping with __________ type impurities called donors, causes the Fermi level to exist higher in the energy band diagram, indicating a greater probability of electrons existing in the conduction band.



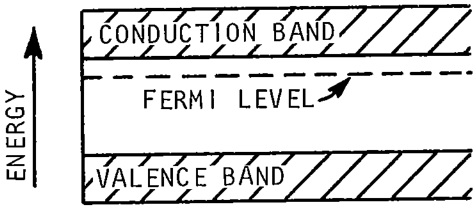
"N" SEMICONDUCTOR

higher, up, etc.

16.7 Donor impurities cause the Fermi level to exist farther from the valence band and nearer the conduction band. This indicates a greater probability of __________________ existing in the ____________________ band.

N

16.8** An energy band diagram showing the Fermi level closer to the conduction band than to the valence band indicates that the diagram represents _______________ type semiconductor.



electrons
conduction

16.9 END OF SET

N

17 Adding acceptor impurities to an intrinsic semiconductor causes the Fermi level to exist closer to the __________ band in the energy band diagram of _______ type semiconductors (when compared to the diagram of the intrinsic material).

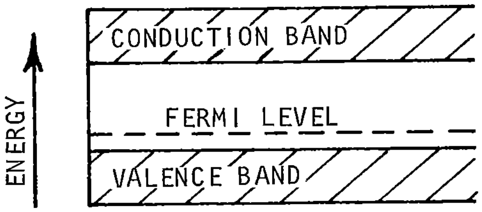
17.1 With an unfilled valence band, the 100% electron probability level exists lower in the energy band diagram than in the diagram of intrinsic semiconductors.

valence
P

17.2 Doping holes into the valence band results in the 100% electron probability level moving _________ (up, down) in the valence band when compared to the diagram of the intrinsic material.

no answer needed

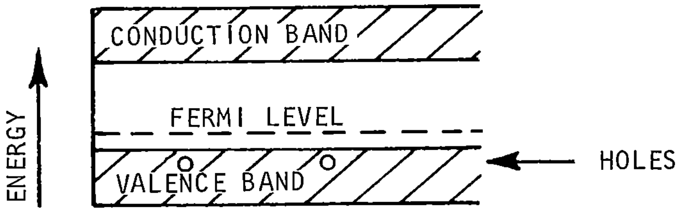
17.3 Acceptor impurities form P type semiconductors which have holes existing in the valence band. Holes in the valence band result in the 100% electron probability level and the Fermi level existing lower in the energy band diagram of P semiconductor.



"P" SEMICONDUCTOR

down

17.4 With holes in the valence band, the lower 100% electron probability level causes the 50% electron probability level to exist ______________ (higher, lower) in the energy band diagram than for intrinsic semiconductor.

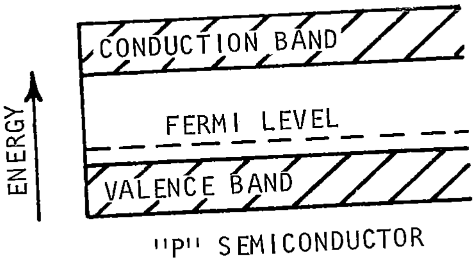


no answer needed

17.5 The addition of acceptor impurities results in the Fermi level existing nearer the valence band than intrinsic semiconductor because ________ are formed in the valence band.

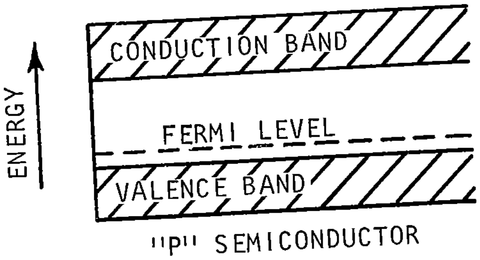
lower

17.6 P type semiconductors have holes in the valence band and a 0% probability of electrons existing in the conduction band (with no external energy applied). This results in the Fermi level being closer to the _______ band in P semiconductor than in intrinsic semiconductor.



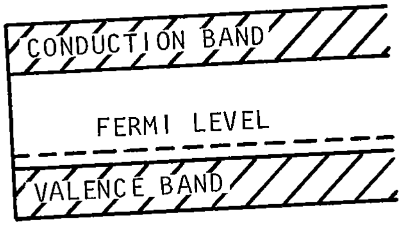
holes

17.7 P semiconductors have the ________ level closer to the valence band than to the conduction band and this level is the ____% electron probability level.



valence

17.8** A semiconductor energy band diagram with the Fermi level existing closer to the valence band than the conduction band, indicates that the diagram represents a ________ type semiconductor.



Fermi
50

17.9 END OF SET

P

18 Adding N impurities to one end of a piece of pure semiconductor material and adding P impurities to the opposite end, forms a PN junction. The ________ levels of the two ends must line up for a state of ________ to exist. The two sides do not lose their N and P properties when they are joined since the dopent atoms are ________ and form ________ as a result of recombination. This process results in a ________ difference across the junction.

Fermi
equilibrium
immobile, fixed, etc.
ions
potential

18.1 Two halves of a single piece of semiconductor are doped oppositely with N and P impurities to form a semiconductor junction diode. The region of change from N to P type semiconductor is called the junction or transition region. The semiconductor is doped differently on opposite sides of the ________.

junction (or transition region)

18.2 Considering the instant the impurities are added to the opposite ends of a semiconductor junction, free electrons exist in the conduction band of the N side, and free ________ exist in the valence band of the P side.

holes

18.3 Recombination is the process of an electron from the conduction band filling a hole in the valence band and neither being available as current carriers. Electrons in the conduction band will cross over the junction from the N side to the P side and try to recombine with holes in the valence band when a junction is formed.

18.4 Holes will cross the junction from the P side to the N side when the diode is formed. The hole will seek a donor impurity and recombine with an electron.

no answer needed

18.5 Holes and electrons are attracted to one another and will cross the junction and recombine if N and P semiconductors are brought together. The word recombine means that an ________ fills a ________ and neither are left as carriers.

no answer needed

18.6 An atom with equal numbers of orbital electrons and protons in the nucleus is electrically neutral. When an atom is electrically ________, it has no charge.

electron
hole

18.7 When an atom has more orbiting electrons than protons in the nucleus, it has a negative ________ and is no longer electrically neutral.

neutral

18.8 When an atom has more protons in the nucleus than orbiting electrons, it has a _______ charge and___________ electrically neutral.
(is, is not)

charge

18.9 When a material or structure contains only neutral atoms, the <u>material</u> can be said to be electrically ___________.

positive
is not

18.10 Separate N and P materials are electrically neutral because a balance exists between orbital electrons and protons in the nucleus of the atoms. Separate N and P material have no charge as the atoms are ______________.

neutral

18.11 The N and P semiconductors by themselves are electrically neutral as they do not exhibit a positive or negative ________ .

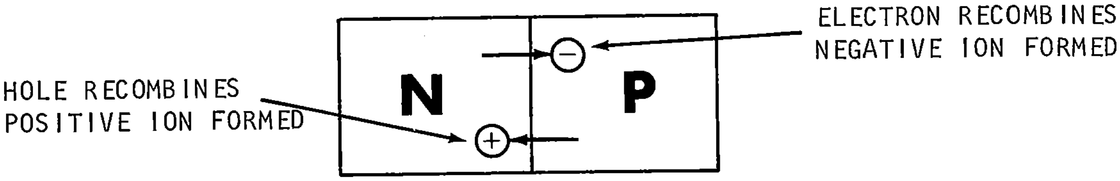
neutral

18.12 On joining N and P semiconductors to form a junction diode, __________ from the N material move into the P side and recombine, and __________ in the P material move into the N side and recombine.

---

charge

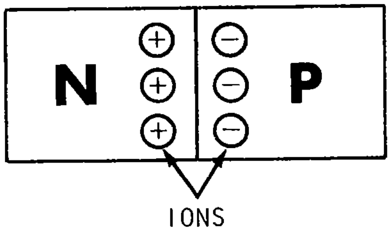
18.13 Once recombination starts, the N and P sides are no longer electrically neutral. Electrons entering the P side and recombining, form ________ ions and holes entering the N side and recombining, form ________ ions.



---

electrons
holes

18.14 When recombination takes place, the N side starts taking on a positive charge and the P side starts taking on a negative charge. This is a result of recombination forming ________ in the two sides.



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negative
positive

18.15 The formation of ions in the N and P sides due to recombination shifts the energy bands of the two sides until recombination ceases. ______________ stops when the fermi levels line up.

ions

18.16 When the Fermi levels of the two sides are not lined up, carriers are setting at a higher energy level on one side of the junction than on the other and an unbalance exists. The carriers will move until there is no ____________________.

recombination

18.17 The Fermi level indicates the 50% electron probability level in both sides. When the ________ levels of the two sides line up, the junction is in a state of ______________________.

unbalance, etc.

18.18 The formation of positive ions in the N side tends to start repelling the ____________ that are migrating from the P side, and the formation of negative ions in the P side starts repelling _____________ that are migrating from the N side.

Fermi
balance, equilibrium, etc.

18.19 When equilibrium is reached, a potential difference exists across the junction due to the formation of ions. The amount of negative charge taken on by the P side with respect to the positive charge taken on by the N side will determine the amount of ________ __________ across the junction.

holes
electrons

18.20 The amount of potential difference varies with the type of semiconductor. For germanium, it is approximately 0.3 volts. For silicon, it is approximately 0.7 volts. The potential difference existing across a _________ PN junction is about 0.7 volts.

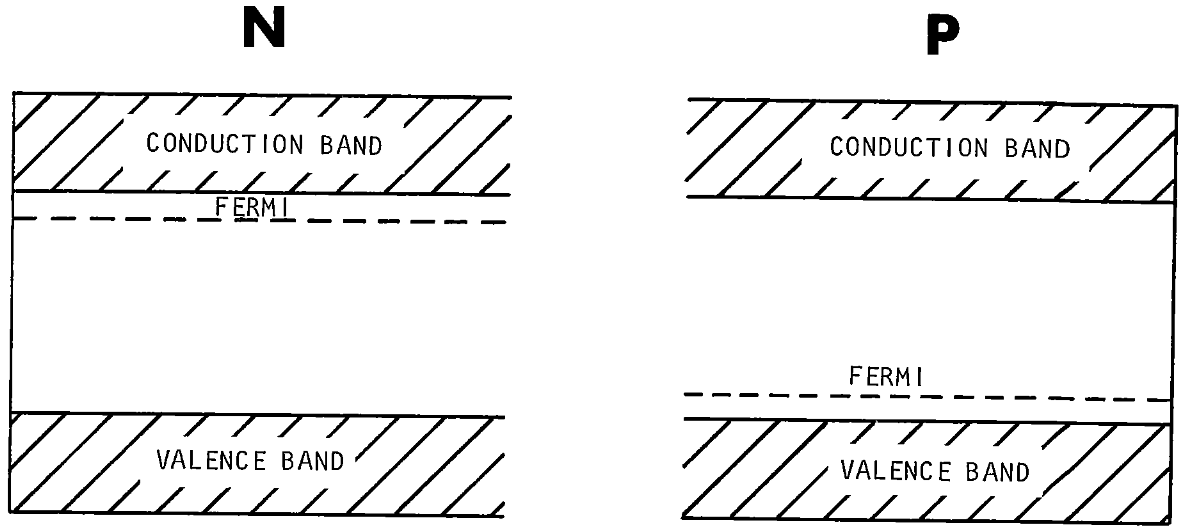
potential difference

18.21 The junction potential difference must be overcome by external energy before current carriers can cross the junction. The net current flow will be zero without external __________ applied.

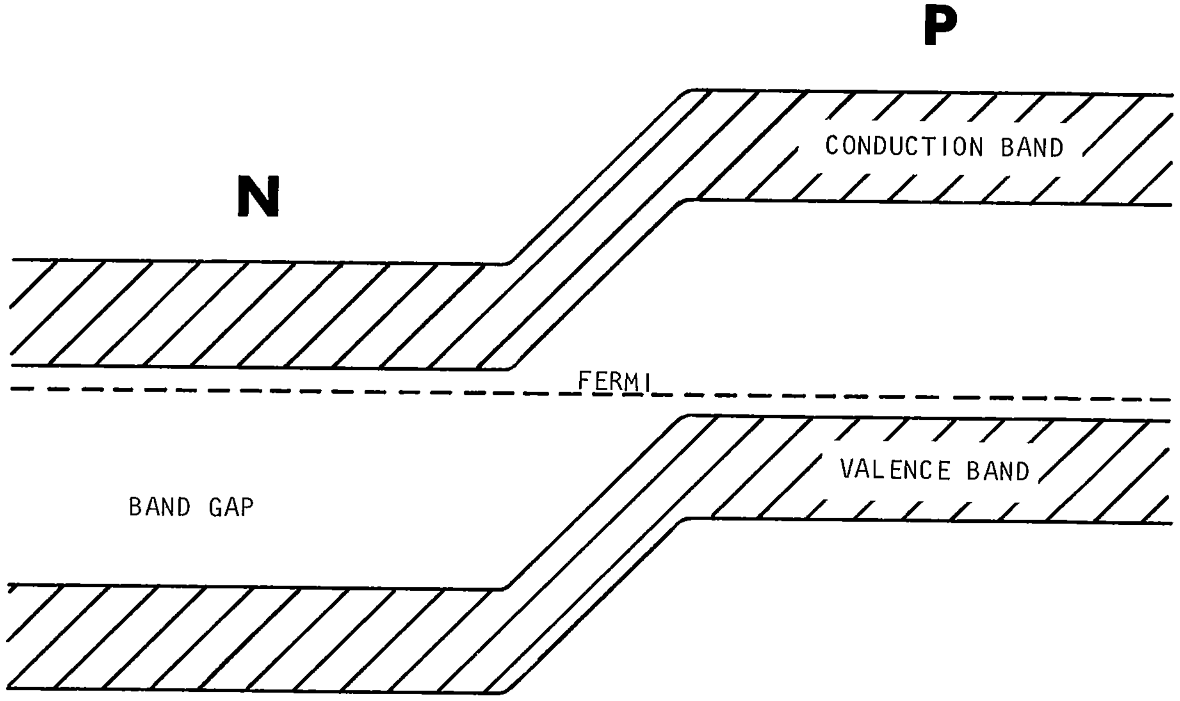
silicon

18.22 Application of external energy misaligns the Fermi levels and allows carriers to cross the junction. When the Fermi levels are lined up, a state of ___________ exists and no net carriers cross the junction.

energy



BEFORE JUNCTION IS FORMED



AFTER JUNCTION IS FORMED

FIGURE 18

18.23 Figure 18 shows the energy bands of P and N semiconductors before and after a junction is formed. The diagram after the junction is formed indicates no external energy is being applied since the ____________ levels are lined up.

equilibrium, balance, etc.

18.24 Semiconductor junctions are formed by doping opposite ends of semiconductors with P and N impurities. With no external energy applied, a state of equilibrium exists and the Fermi levels of the two sides are ____________ ____________.

Fermi

18.25** Aligned Fermi levels in an energy band diagram of a PN junction indicates that no ____________ ____________ is being applied and the junction is in a state of ____________. ____________ of holes and electrons occurs when the junction is formed until the Fermi levels line up. The N and P properties are not lost during recombination since the dopent atoms are immobile and become ____________ which gives the material an electrical charge. The two (N & P) sides take on opposite polarity charges during recombination which results in a ____________ difference existing across the junction when recombination ceases.

lined up

18.26 END OF SET

external energy
equilibrium, balance, etc.
recombination
ions
potential

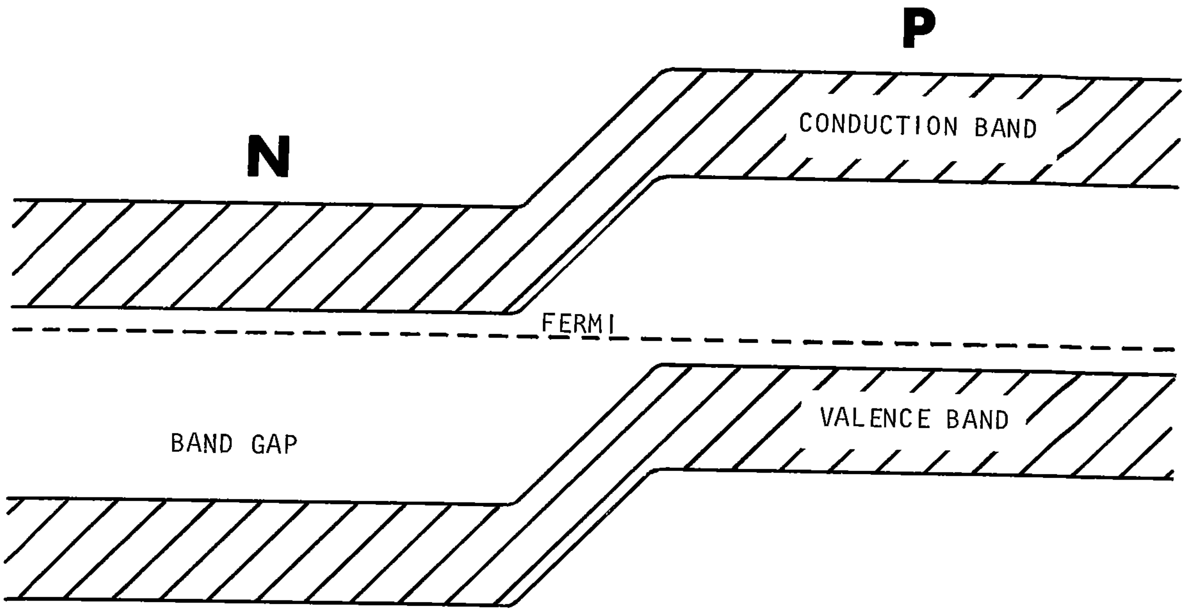


FIGURE 19A 0 BIAS

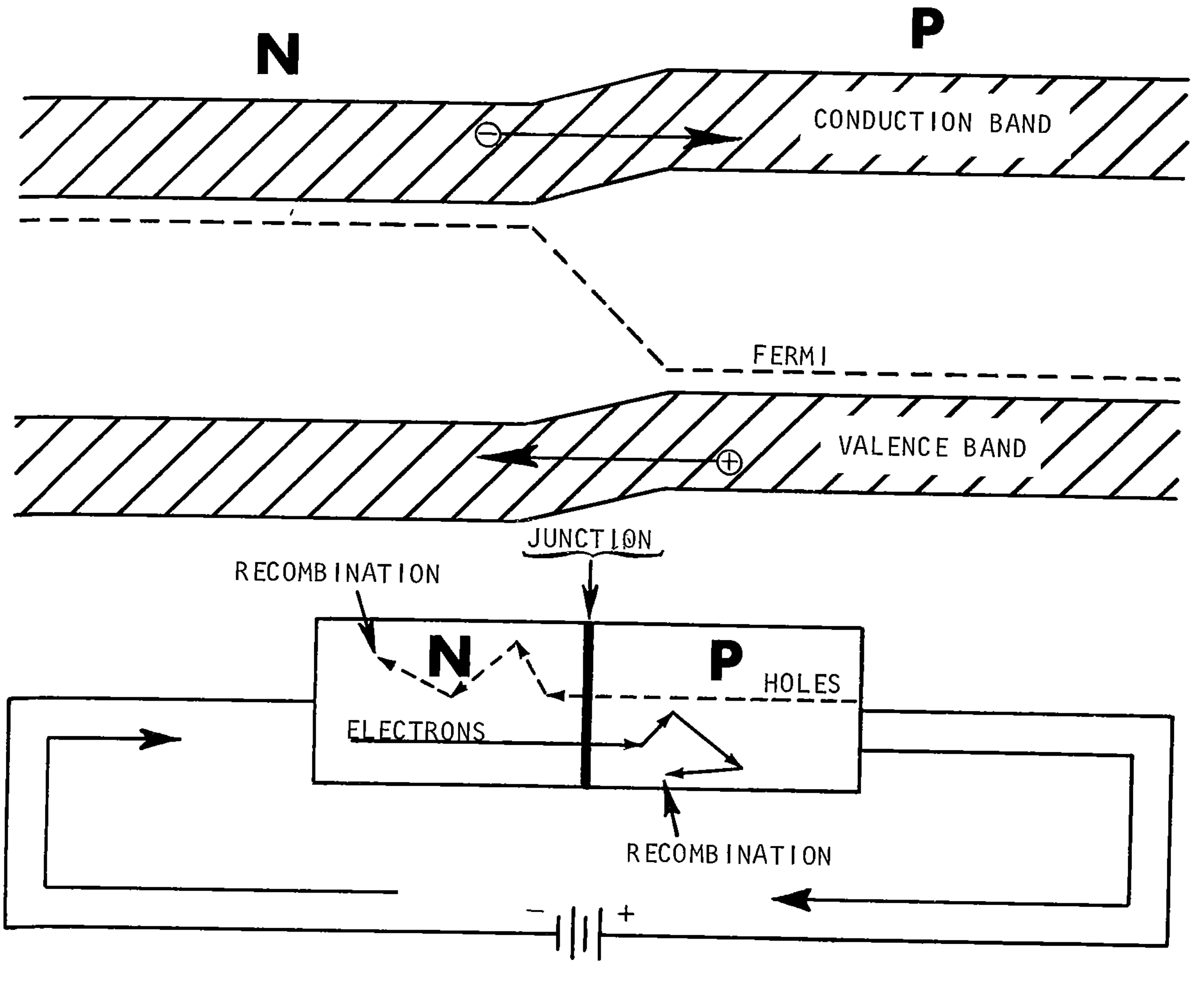
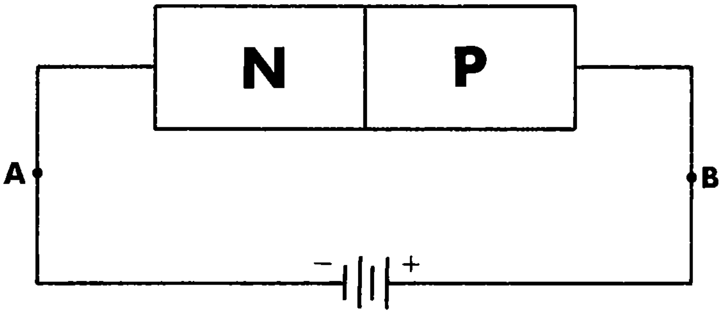


FIGURE 19B FORWARD BIAS

19. A battery of the polarity shown will ________________ (increase, decrease) the potential difference across the PN junction. This is referred to as __________ bias. Electrons in the external circuit will flow from point ________ to point __________ through the battery. The magnitude of the current in the circuit, external to the diode, is equal to the sum of electron ___________ current and hole ____________ current.



19.1 Figure 19A shows the energy band diagram of a PN junction with no external energy applied. A potential ____________ exists across the junction.

---

decrease
forward
B
A
recombination
recombination

19.2 To have current some external energy must be applied to overcome the ___________ ____________ of the junction.

---

difference

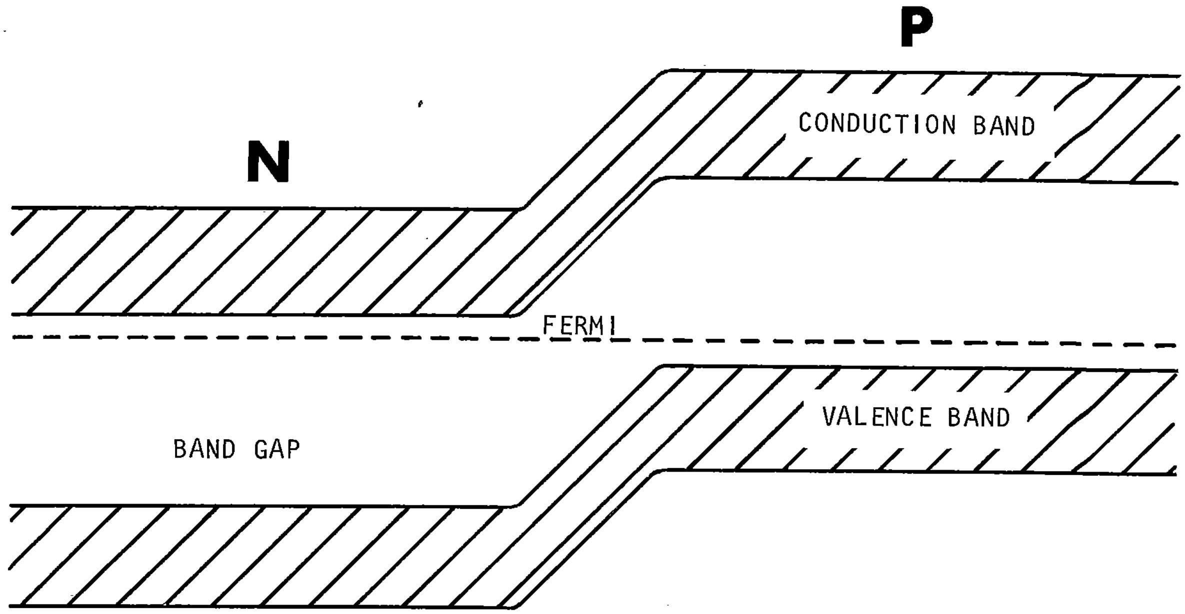


FIGURE 19A 0 BIAS

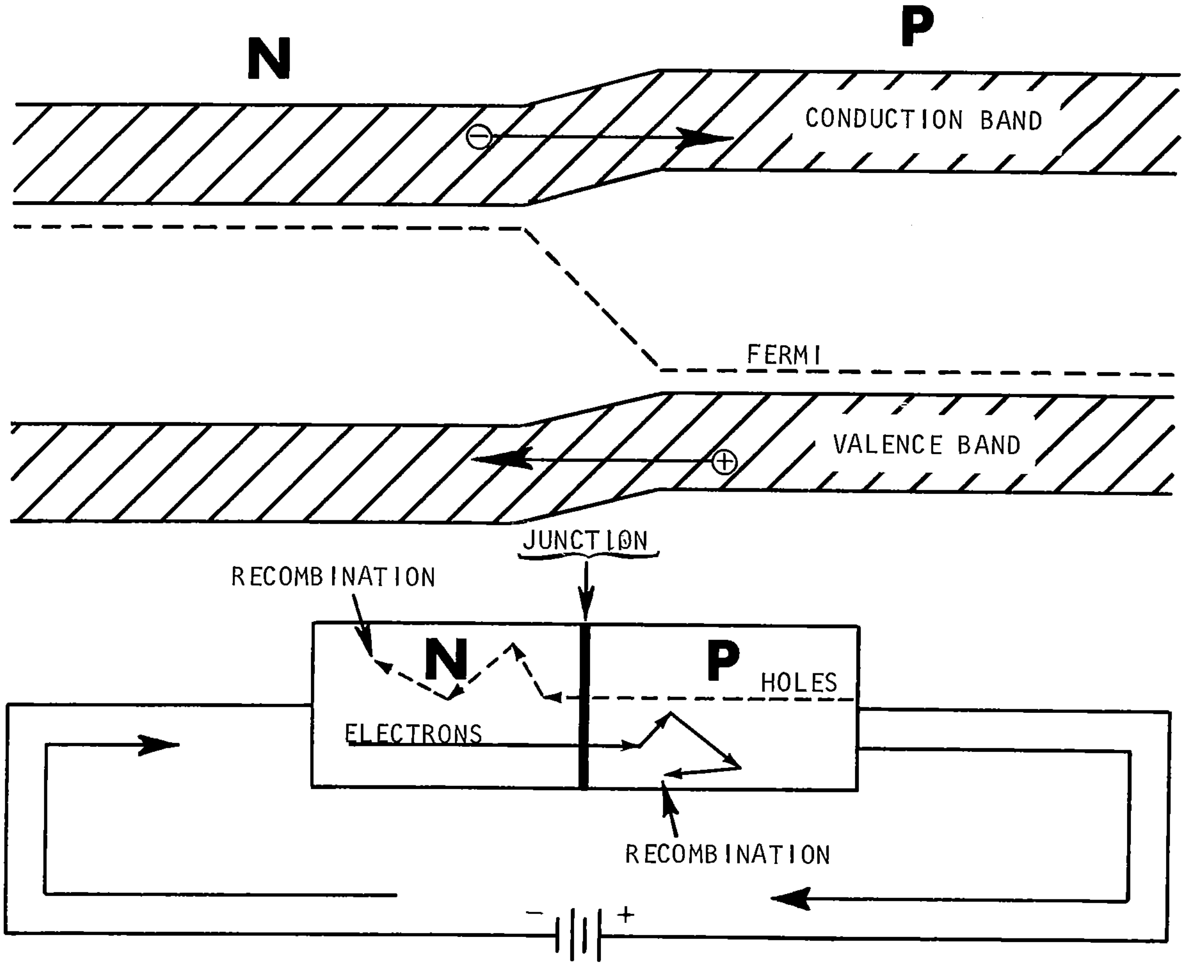


FIGURE 19B FORWARD BIAS

19.3 When the junction potential difference is overcome, the ________________ in the N side will move as current carriers in the conduction band and the ______________ in the P side will move as current carriers in the valence band.

---

potential difference

19.4 Carriers can cross the junction when the N & P valence bands are opposite each other and the N & P conduction bands are opposite each other. This occurs when the junction ____________ _____________ has been overcome by some external source of energy.

---

electrons
holes

19.5 Overcoming the junction potential difference to allow electrons in the N side and holes in the P side to cross the junction is termed forward _______________ the junction.

---

potential difference

19.6 Figure 19B show the energy band diagram of a junction that is forward biased and the battery connected properly to forward bias the junction. The battery is ______________________ (reducing, increasing) the potential difference across the junction.

---

biasing

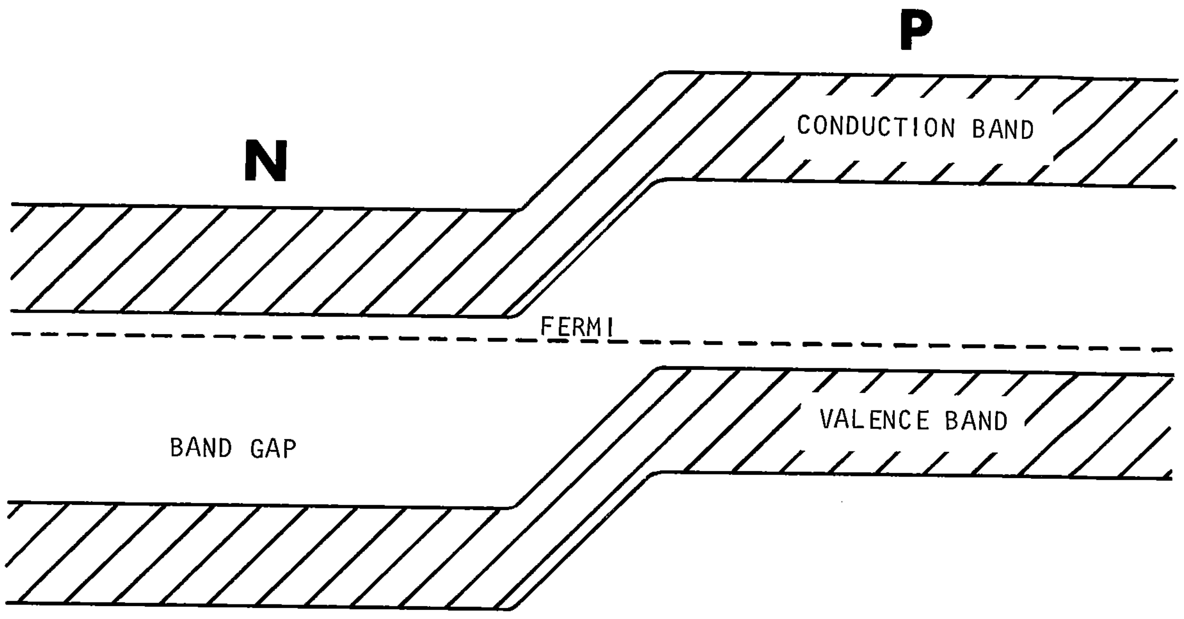


FIGURE 19A O BIAS

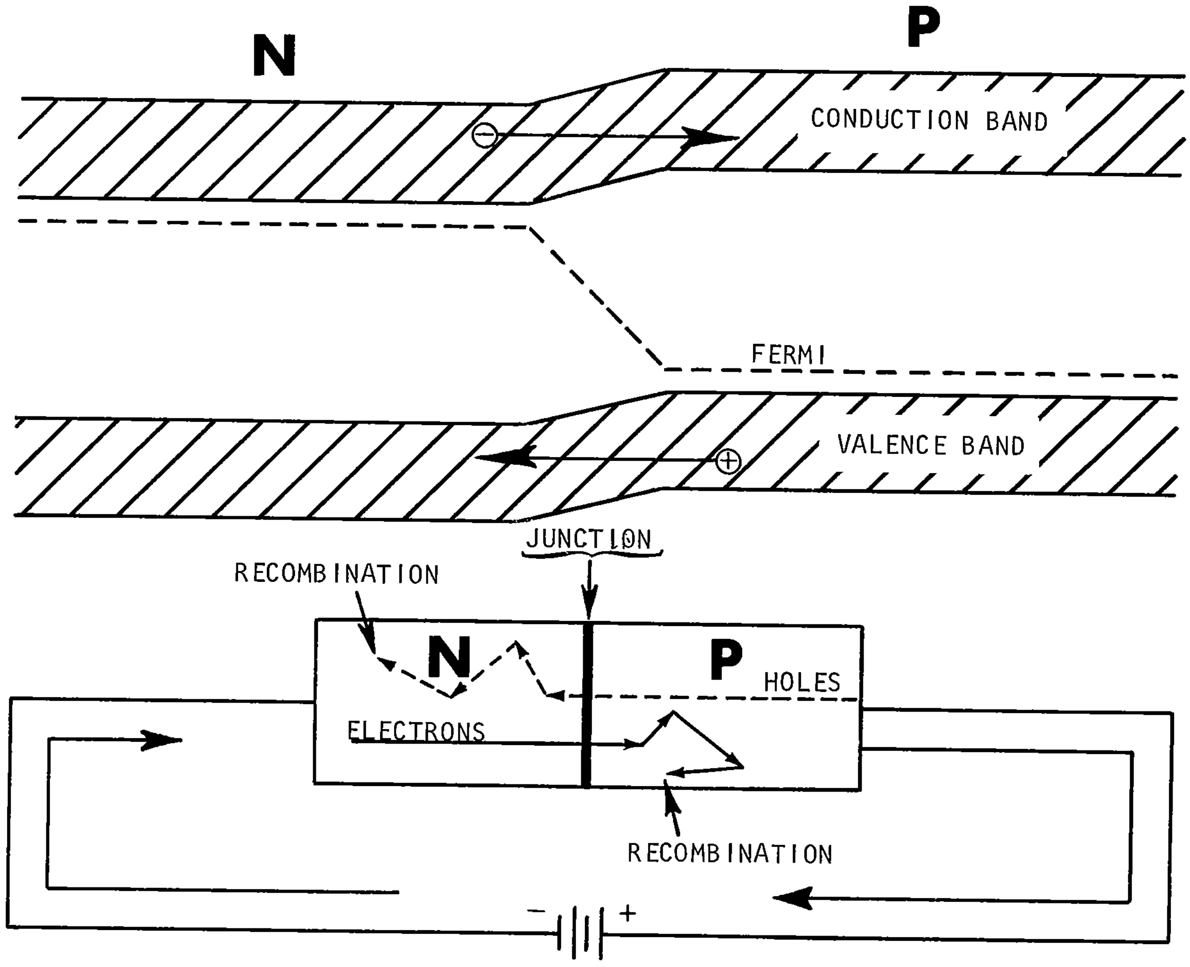


FIGURE 19B FORWARD BIAS

19.7 In figure 19B, the positive terminal of the battery is reducing the negative ionic charge of the P side and the negative terminal of the battery is ____________________ the positive ionic charge of the N side. This
(increasing, reducing)
is ____________________ bias.

---

reducing

19.8 Forward bias enhances the movement of electrons from the N side into the P side. An electron leaving the N side to cross the junction will be replaced from the negative terminal of the battery in figure 19B. Electrons move from the negative terminal of the battery through the ______________ band of the N side and move into the ____________ side.

---

reducing
forward

19.9 Holes crossing the junction from the valence band of the P side to the valence band of the N side in figure 19B must be replaced from the positive terminal of the battery. A _________________ is formed or injected at the battery contact with the P side by removing an electron. An __________ leaves the P side and moves to the positive terminal of the battery when a hole is formed or injected.

---

conduction
P

19.10 Forward bias ____________________ the potential difference across the
(reduces, increases)
junction, allowing majority carriers to cross. Majority carriers in the N side are electrons moving in the conduction band. Majority carriers in the P side are holes moving in the valence band. The holes and electrons cross the junction when it is _________________ biased.

---

hole
electron

19.11 When an electron crosses the junction from the N side to the P side, it becomes a minority carrier on entering the conduction band on the P side.

reduces
forward

19.12 A hole on crossing the junction from the P side to the N side becomes a ______________ carrier on entering the valence band on the N side.

no answer needed

19.13 Forward bias causes majority carriers to cross the junction and become ______________ carriers in the opposite side.

minority

19.14 Minority carriers are transported by diffusion. When forward bias moves majority carriers across the junction, these carriers must then travel by diffusion.

minority

19.15 Carriers moved across the junction by forward bias must find imperfections in the opposite side to accomplish recombination.

no answer needed

19.16 Carriers moved across the junction by forward bias will diffuse until they find an imperfection and accomplish recombination. A large number of imperfections near the junction will result in most of the recombination occuring near the junction.

no answer needed

19.17 The external current with forward bias applied is a result of the electrons that are moved into the P side and recombine and the holes that are moved into the N side and recombine.

no answer needed

19.18 Forward bias, reduces the potential difference of the PN junction and allows majority carriers to cross the junction. Once across, these carriers become ______________ carriers and travel by ________________.

no answer needed

19.19 There are minority carriers present in both sides of a PN junction with forward bias applied. Some are present due to thermal energy and some are present due to forward bias allowing majority carriers to cross the junction and become ___________ carriers.

---

minority
diffusion

19.20 Electrons diffuse in the P side until they find imperfections and accomplish ______________ when forward bias is applied.

---

minority

19.21 Holes diffuse in the N side until they find imperfections and accomplish ______________ when forward bias allows them to cross the junction.

---

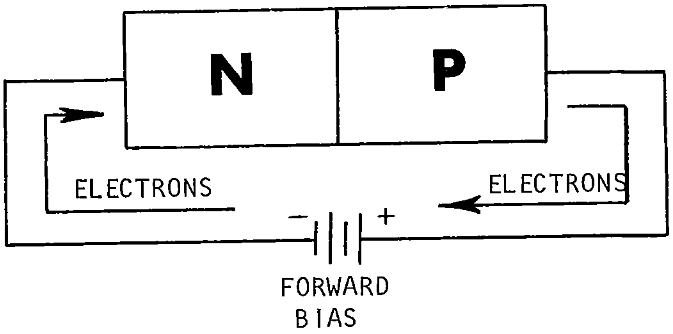
recombination

19.22 The current in the external circuit depends on the sum of the __________ recombination current and the ________________ recombination current.

---

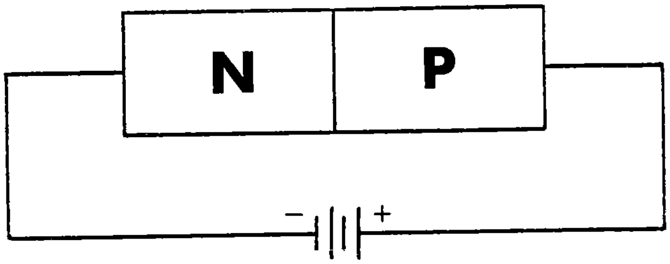
recombination

19.23 The electron current in the circuit, external of the diode, will flow toward the positive side of the bias source and away from the negative side of the bias source.



electron (either order)
hole

19.24** The junction shown is ________ biased. Current in the junction diode occurs as a result of carriers crossing the junction and ________. Electron current in the external circuit flows toward the ________ side of the bias source. The magnitude of the external current is dependent on the sum of the ________ recombination current and the ________ recombination current.



no answer needed

19.26 END OF SET

forward
recombining
positive
electron (either order)
hole

20 During recombination of holes and electrons, ____________ and __________ are generated as a result of electrons giving up energy. This raises the ________________ temperature above that of the surrounding air.

20.1 An electron must give up energy to move from the conduction band to the valence band because the valence band is a lower energy band than the conduction band. This energy is released during recombination of minority carriers.

heat
light
junction

20.2 During recombination, electrons must move from the conduction band to the valence band. To do this, the electron must give up ________________.

no answer needed

20.3 The energy given up by the electron moving to the valence band from the conduction band is in the form of heat and light. Recombination generates ____________ and ______________ energy.

energy

20.4 Forward biasing a PN junction results in minority carrier recombination which generates heat and light. The more recombination that occurs, the more ____________ and ____________ are generated.

---

heat
light

20.5 Silicon and germanium PN junctions generate heat, primarily, when current carriers recombine. The heat is a result of ____________ giving up energy during recombination.

---

heat
light

20.6 Gallium Arsenide PN junctions generate considerable light when current carriers recombine, and are employed as sources of ____________ in some devices recently invented.

---

electrons

20.7 The heat generated by recombination in a PN junction raises the temperature of the junction above that of the surrounding air (ambient) temperature. The temperature of the junction ____________ (increases, decreases) when current carriers recombine.

---

light

20.8** The junction temperature increases when current carriers recombine as a result of electrons releasing __________ during ______________ in the form of _________ and light.

---

increases

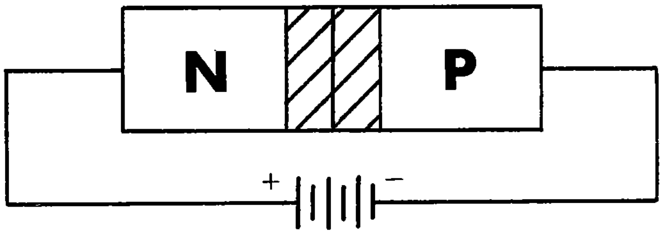
20.9 END OF SET

---

energy
recombination
heat

---

21 The battery shown in the figure is ____________ (increasing, decreasing) the potential difference across the PN junction. This is referred to as ________ bias. The area indicated by the slanted lines is referred to as the ____________ region. The ____________ can serve as a capacitor.



21.1 Connecting the positive side of a voltage source to the N side and the negative side of the voltage source to the P side of a PN junction is termed reverse bias. Reverse bias ____________ (increases, decreases) the potential difference across a PN junction.

increasing
reverse
depletion
junction or diode

21.2 Holes in the P side and electrons in the N side are pulled back from the junction by reverse bias increasing the area about the junction that is depleted of majority carriers. This area is termed the "depletion region".

increases

21.3 Majority carriers are moved away from the junction by ______________ bias, increasing the potential difference across the junction.

no answer needed

21.4 The depletion region is an area of effective insulation separating two conductors (the N and P areas where electrons and holes as carriers exist). The width of the ____________________ region is increased with an increase in reverse bias.

reverse

21.5 A PN junction will exhibit capacitance because the two ends are conductors separated by an insulating material (the depletion region). Varying the applied bias varies the width of the _________________ region.

depletion

21.6 A PN junction can serve as a variable capacitor because the junction has capacitance that can be varied by changing the amount of bias applied. Changing the amount of bias varies the width of the depletion region and essentially the distance between the plates of the ________________ across the junction.

depletion

21.7 Minority carriers are holes in the N side and electrons in the P side. They are present primarily due to the formation of __________ __________ __________ due to heat energy when the junction is at equilibruim with no bias applied.

capacitance

21.8 Reverse bias opposes the movement of majority carriers across the junction but enhances the movement of the minority carriers across the junction.

hole electron pairs

21.9 A small number of current carriers will flow with reverse bias applied due to the movement of __________ carriers (present as a result of thermal energy) across the junction.

no answer needed

21.10 The number of hole-electron pairs in the two sides, limits the maximum current with __________ bias applied as long as sufficient bias is not applied to break down the semiconductor structure.

minority

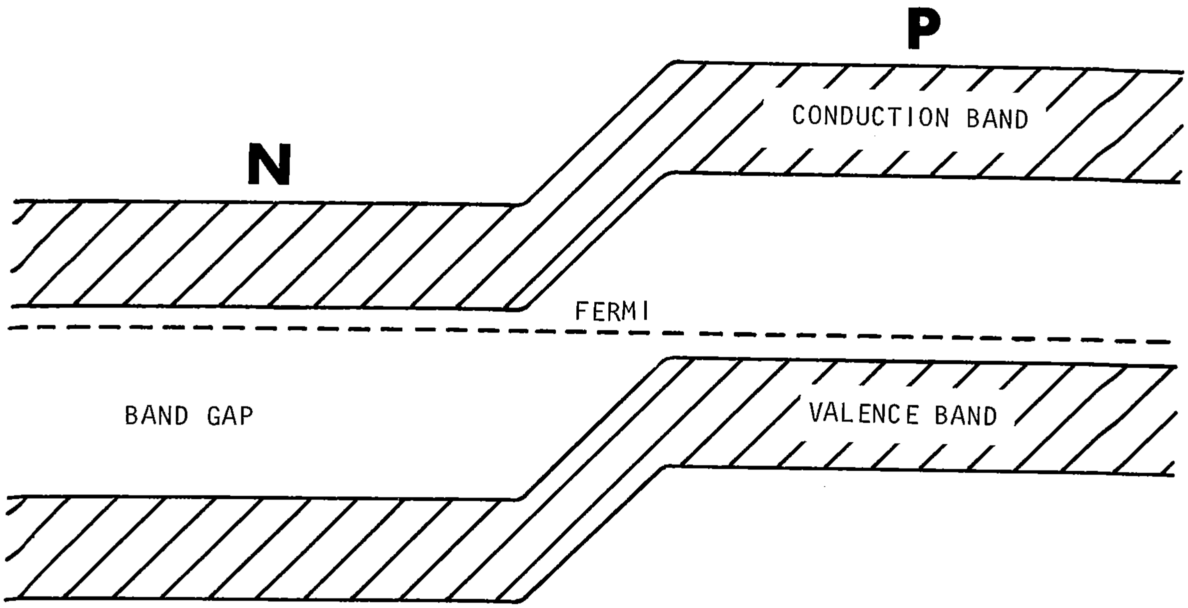


FIGURE 21A 0 BIAS

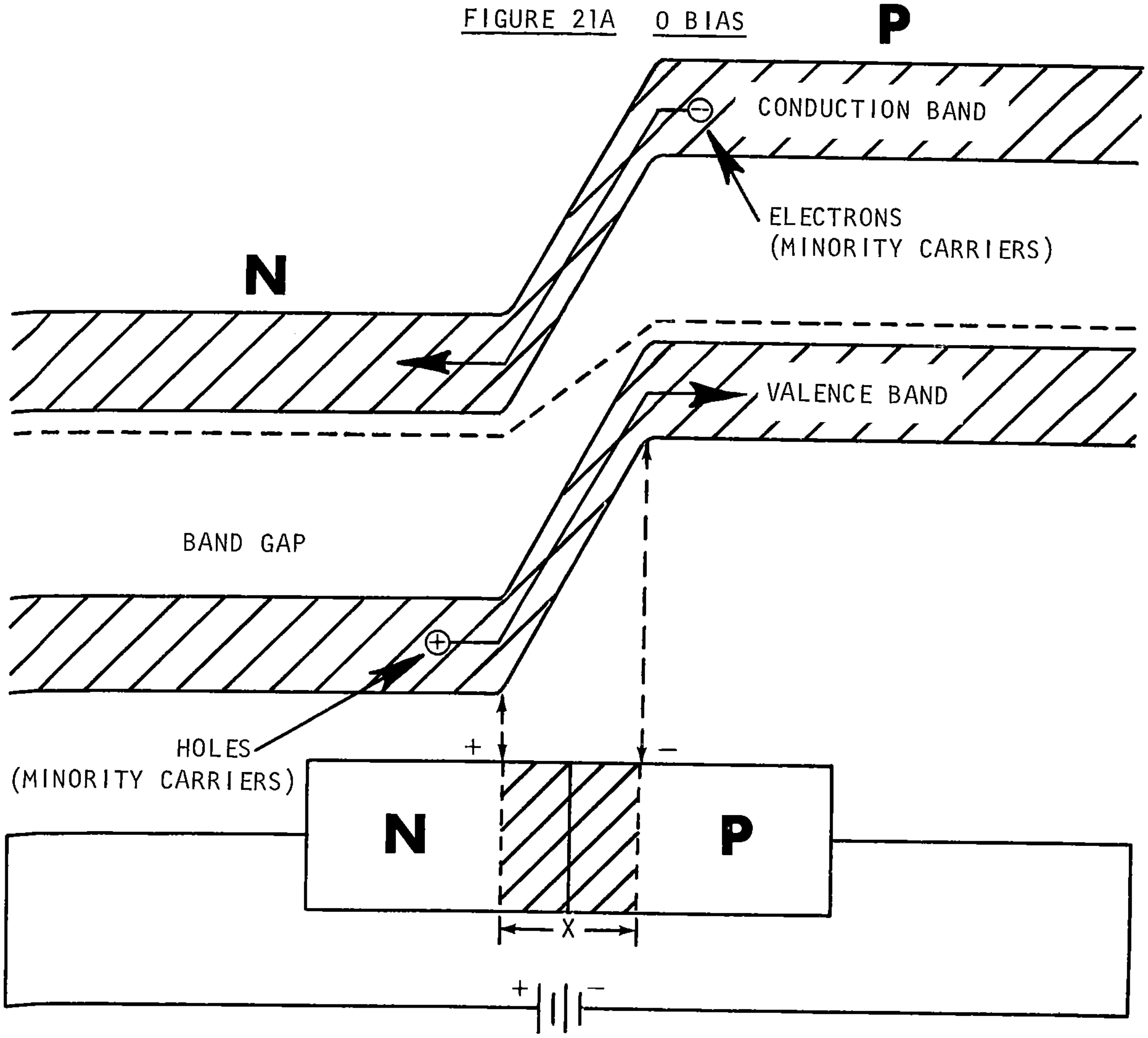
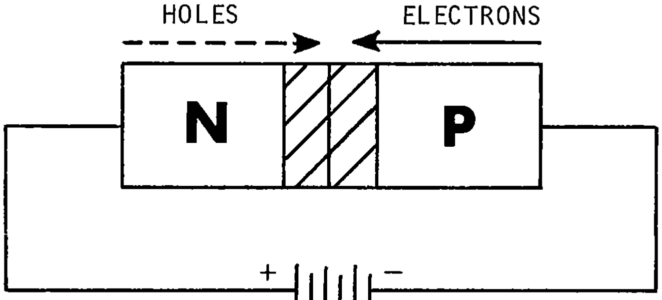


FIGURE 21B REVERSE BIAS

21.11 When minority carriers flow, electrons diffuse in the conduction band of the P side and holes diffuse in the valence band of the N side. Electrons move towards the __________ side of the bias source shown.



REVERSE BIAS

reverse

21.12 Figure 21A shows the energy band diagram of the PN junction at equilibrium (0 bias). The energy band diagram in figure 21B has the Fermi levels misaligned due to the application of ____________ bias.

positive

21.13 The misalignment of the Fermi levels as shown in figure 21B indicates that the potential difference across the PN junction has been

__________________ and the majority carriers pulled away from the
(increased, decreased)
junction.

reverse

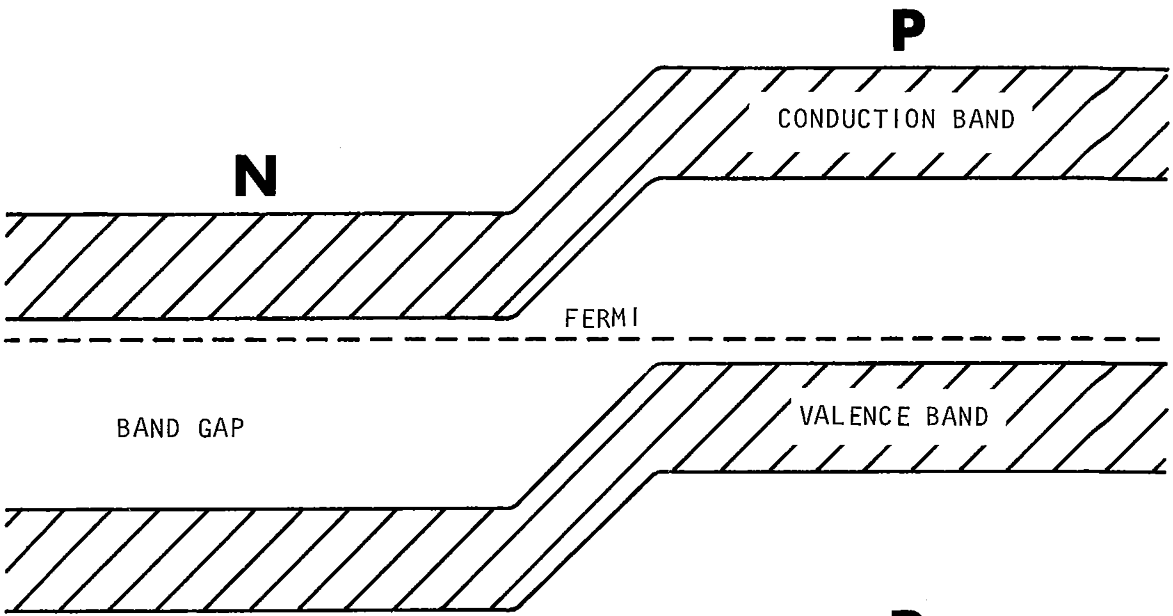


FIGURE 21A 0 BIAS

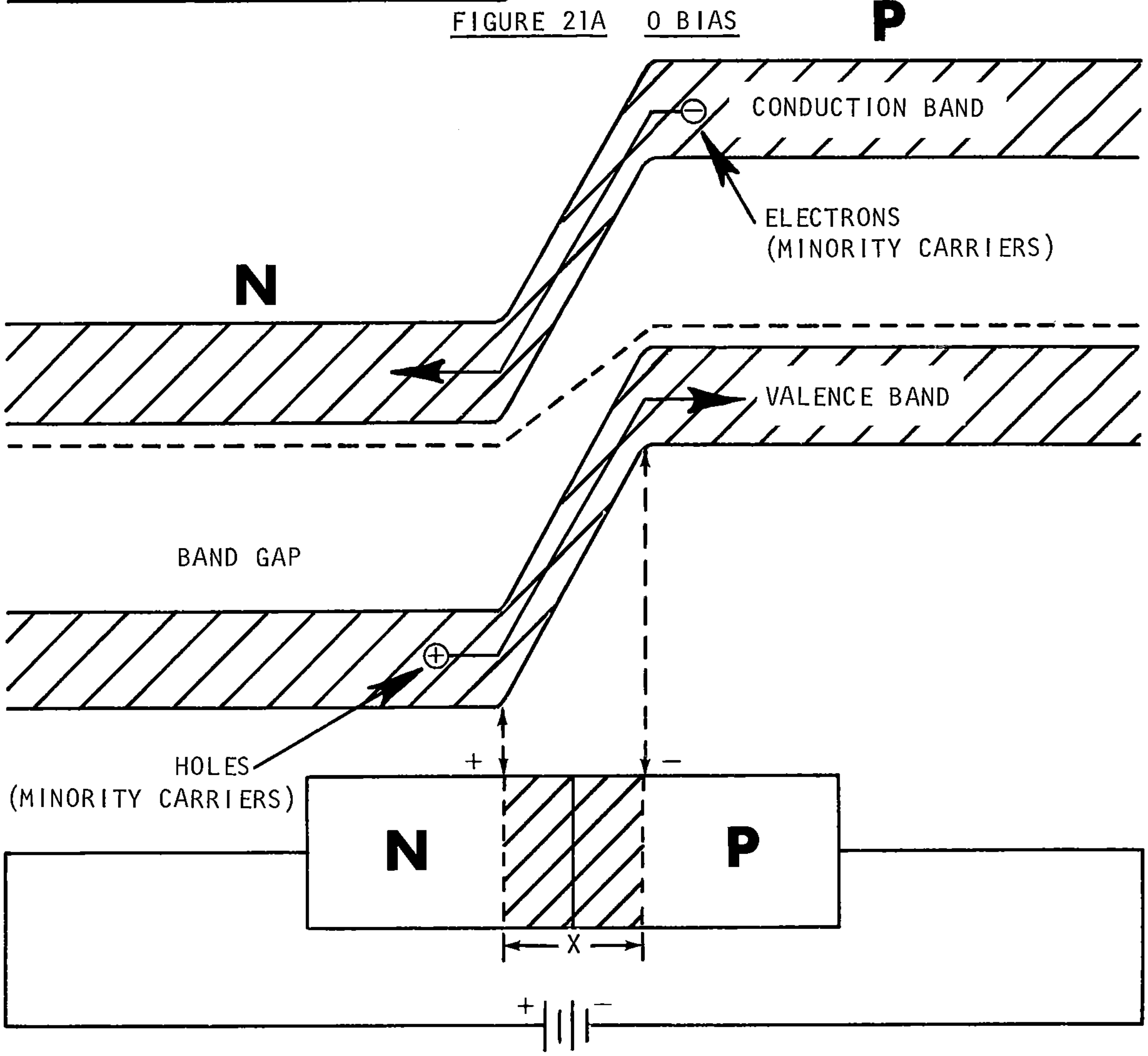


FIGURE 21B REVERSE BIAS

21.14 The depletion region is an area of very high resistance, while tne N and P regions with their high density of majority carriers are areas of __________ resistance.

increased

21.15 Most of the applied reverse voltage will be across the depletion region since it has a __________ resistance with respect to the N and P regions.
(high, low)

low

21.16 The width of the depletion region varies with variations in applied reverse bias. The voltage (or charge) across the depletion region will also vary.

high

21.17 Reverse bias causes any available minority carriers to move toward the depletion region. Most of the applied reverse voltage is across the

______________ __________.

no answer needed

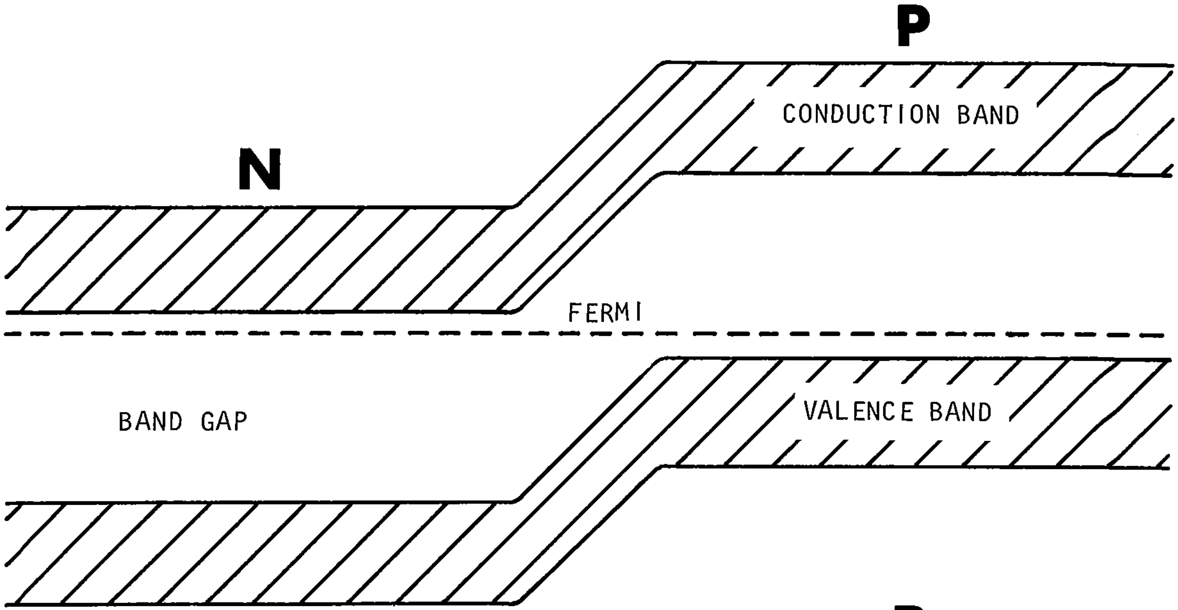


FIGURE 21A 0 BIAS

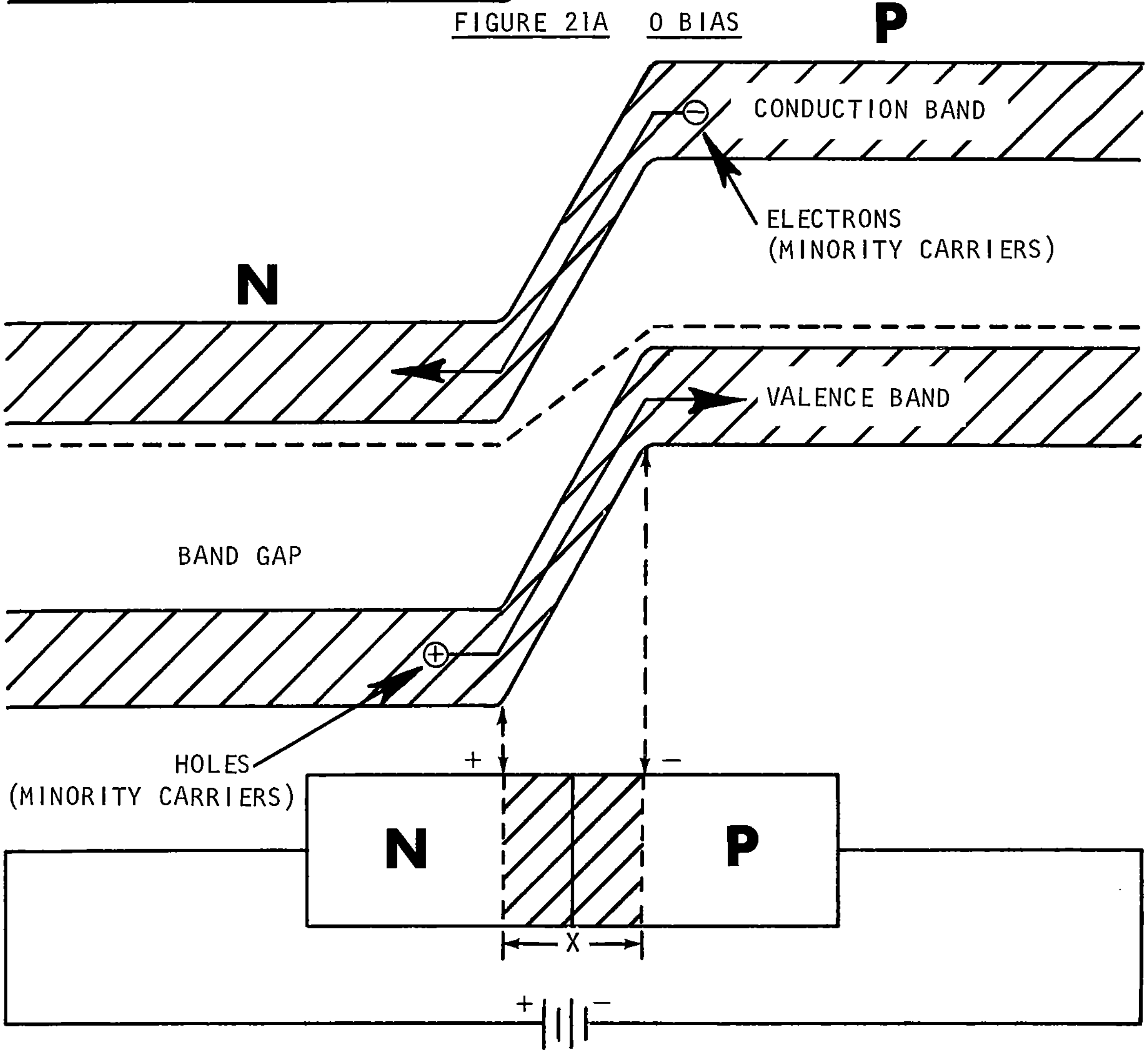


FIGURE 21B REVERSE BIAS

21.18 Any minority carriers existing in the N and P regions will be forced toward the depletion region when ______________ bias is applied.

depletion region

21.19 Since most of the applied reverse voltage is across the depletion region, there is a fairly high electric field across depletion region.

reverse

21.20 Current carriers are accelerated when they enter an electric field. The greater the magnitude of the electric field, the more the carriers are ____________________.

no answer needed

21.21 An electron in the conduction band of the P side will be forced toward the depletion region when reverse voltage is applied. On entering the depletion region, the electron will be ________________ into the conduction band of the N side.

accelerated

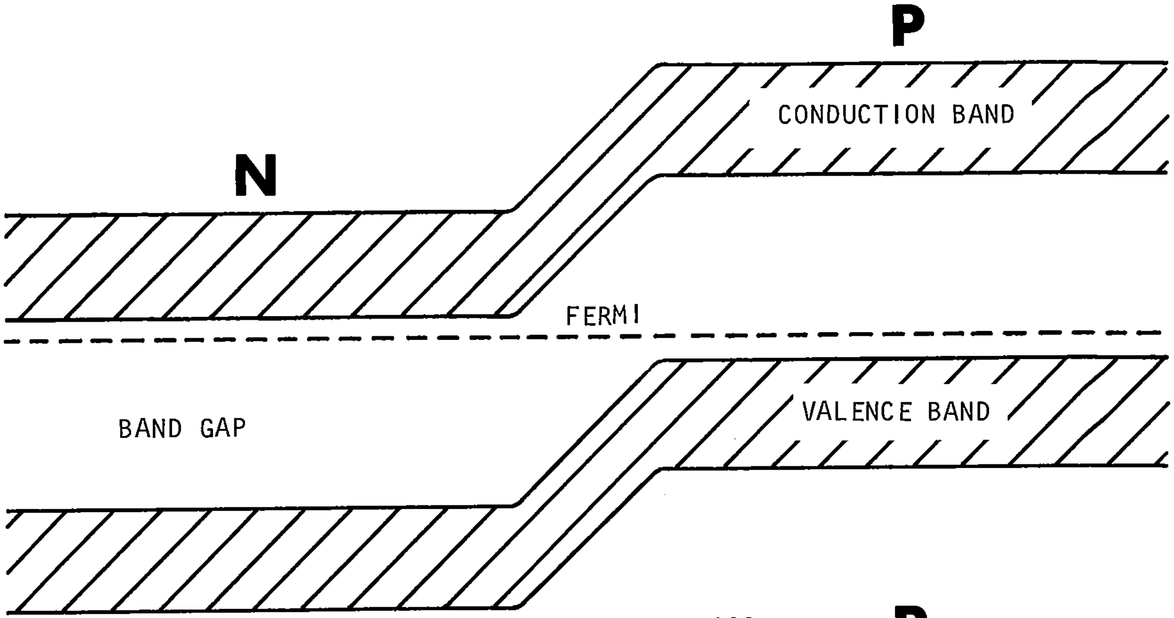


FIGURE 21A 0 BIAS

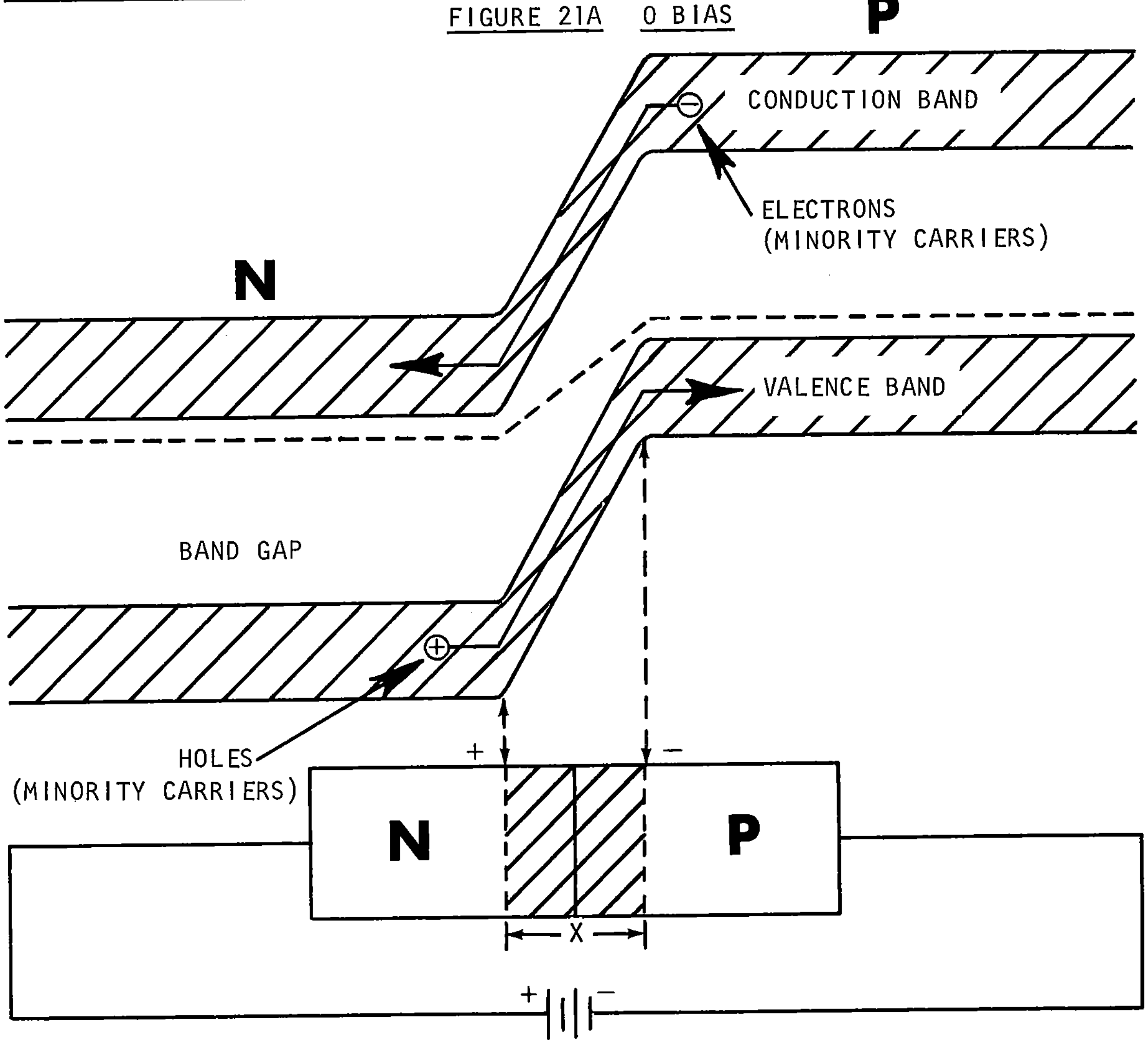


FIGURE 21B REVERSE BIAS

21.22 A hole in the valence band of the N side will be forced toward the depletion region by the application of reverse bias. On entering the depletion region, the hole will be accelerated into the ____________________ band of the P side.

---

accelerated

21.23 The area indicated by the X in figure 21B is the depletion region. Minority carriers are accelerated across the junction by the reverse bias when they enter the ____________________ region.

---

valence

21.24 Increasing the magnitude of the applied reverse bias will cause the width of the ____________________ region, shown by the X in figure 21B, to ____________________. This increases the electric ______________ across
(increase, decrease)
the depletion region.

---

depletion

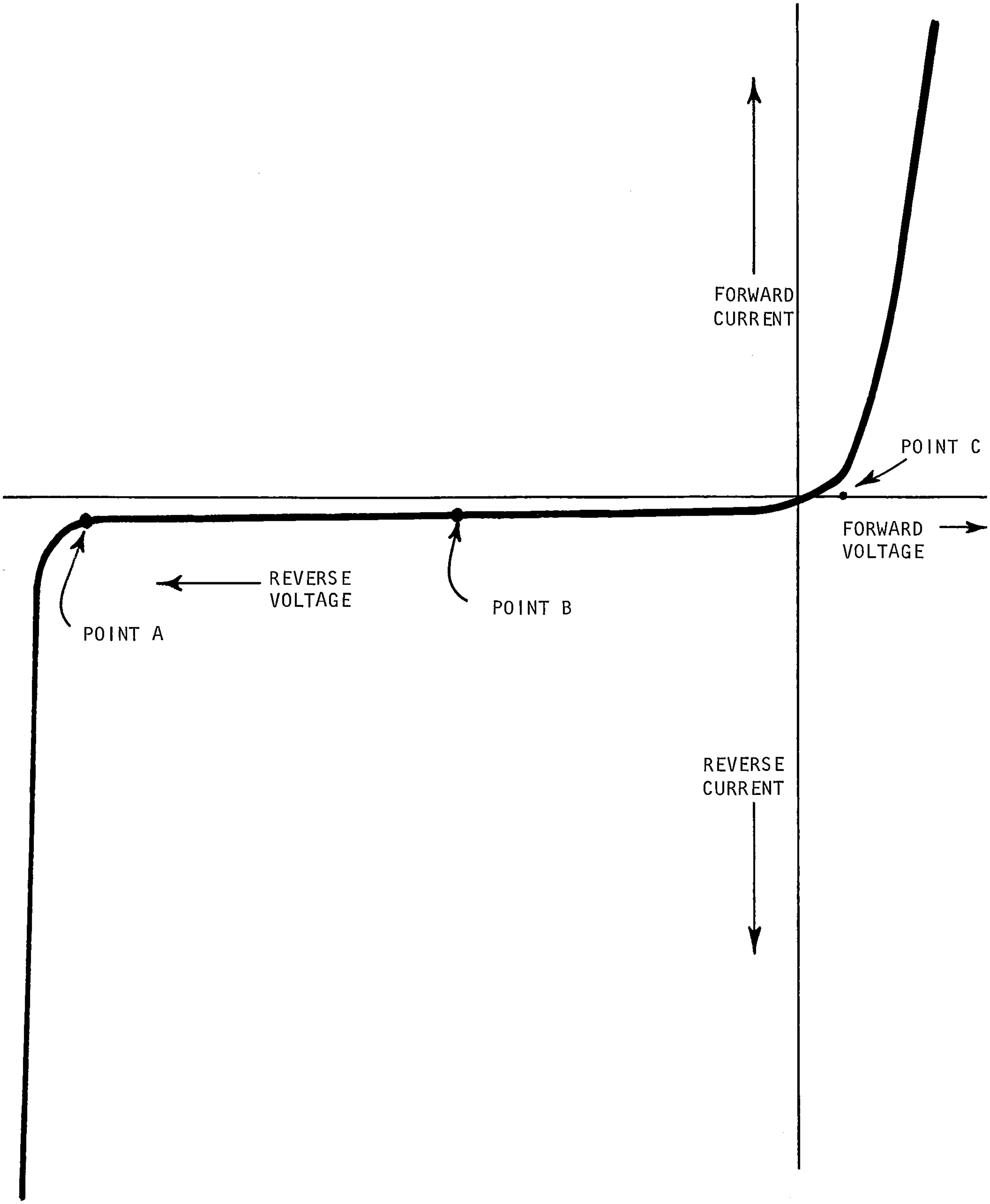

FORWARD CURRENT
POINT C
FORWARD VOLTAGE
REVERSE VOLTAGE
POINT A
POINT B
REVERSE CURRENT

FIGURE 22

21.25** Reverse bias ____________________ the difference in potential across a
(increases, decreases)
PN junction, moving majority carriers away from the junction. This opposes the movement of majority carriers across the junction and widens the __________________ ______________. There is capacitance across the junction that may be varied by changing the applied ___________________. Reverse bias results in ___________________ carriers crossing the junction and a small reverse current.

---

increase
depletion
field

21.26 END OF SET

---

increases
depletion region
voltage
minority

---

22 Figure 22 is a voltage versus current curve for a semiconductor diode. Point A is the ____________ __________ point. Point C occurs at approximately ___________ volts for a germanium diode and at approximately _____________ volts for a silicon diode. To the left of point A, the diode is termed in ____________.

22.1 Forward bias enhances the movement of majority carriers across the junction unless potential difference of the PN junction has been overcome. The potential difference across a germanium PN junction is approximately 0.3 volts. A germanium diode requires approximately ____________ volts to turn it on in the forward direction.

---

reverse breakdown (avalanche)
0.3
0.7
avalanche (reverse breakdown)

22.2 The forward voltage point at which there is a significant forward current, as shown on a characteristic (voltage versus current) curve for a germanium diode, is approximately 0.3 volts. This voltage overcomes the junction potential ______________.

0.3

22.3 Reverse bias opposes majority carriers crossing the junction. Minority carriers cross the junction when reverse bias is applied. The amount of current at point B in figure 22 is limited by the number of ___________ _____________ present in the two sides.

---

difference

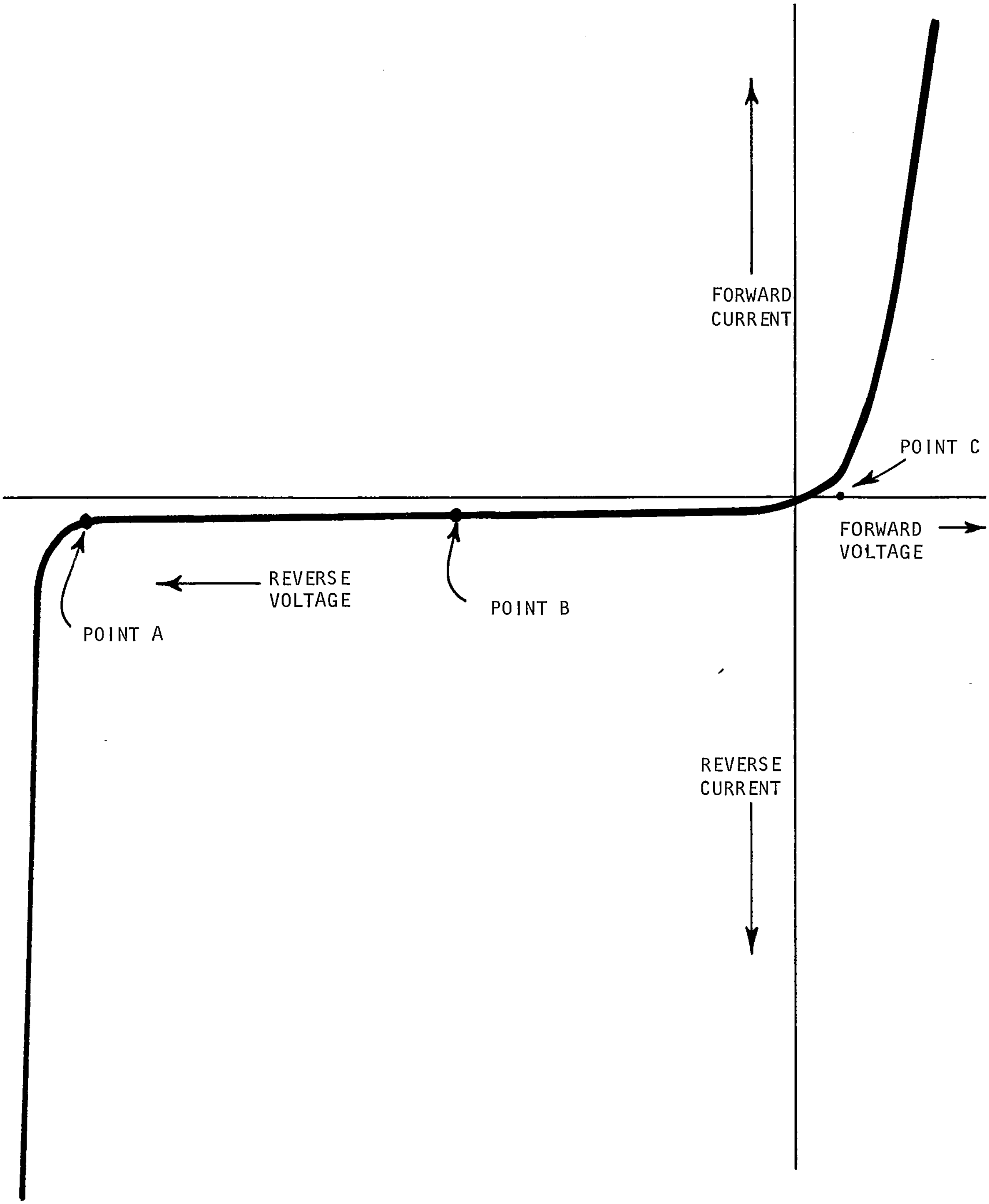

FORWARD CURRENT
POINT C
FORWARD VOLTAGE
REVERSE VOLTAGE
POINT A
POINT B
REVERSE CURRENT

FIGURE 22

22.4 A high value of reverse bias voltage will <u>accelerate</u> the electrons in the conduction band of the "P" side in their movement across the junction once they enter the depletion region.

minority carriers

22.5 A high value of reverse bias adds energy to the diffusing electrons in the P side when they enter the depletion region. This ______________ them through the depletion region.

no answer needed

22.6 Electrons (minority carriers) that are accelerated across the junction from the P side as a result of a high value of reverse voltage being applied, collide with electrons in atoms in the structure. They impart some of their ______________ to electrons in the structure on contact.

accelerates

22.7 The accelerated electrons will free other electrons on contact if they possess sufficient energy. This only occurs when the accelerated electron has sufficient ___________ to break the covalent bond.

energy

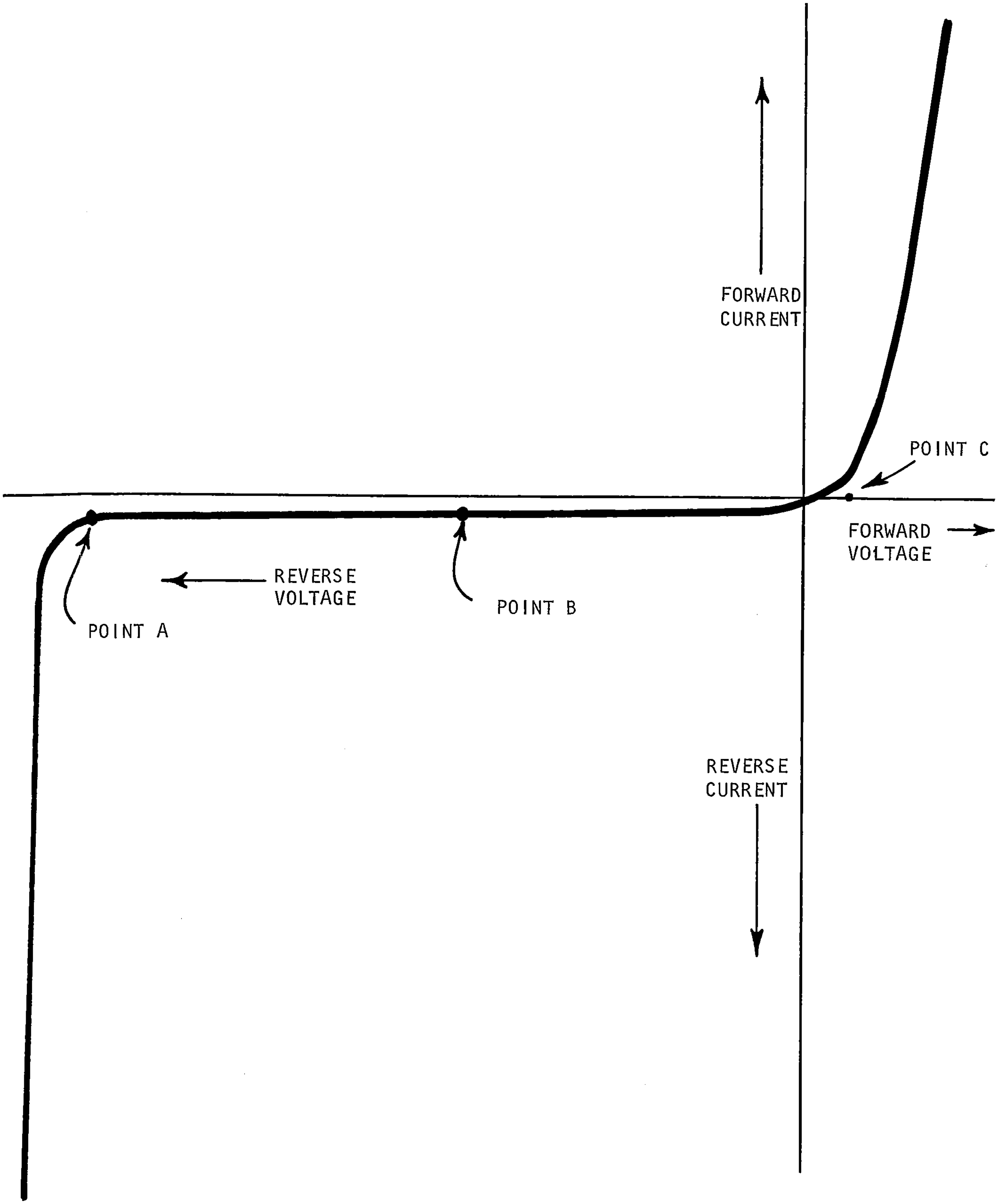

FORWARD CURRENT
POINT C
FORWARD VOLTAGE
REVERSE VOLTAGE
POINT B
POINT A
REVERSE CURRENT

FIGURE 22

22.8 The electrons that are set free when struck by accelerated electrons, are also accelerated by the high reverse voltage and electric field. They, in turn, strike other electrons which are set ______________ on contact. The process continues and current is limited primarily by the resistance in series with the diode.

energy

22.9 The accelerated carriers freeing other carriers, etc., results in a multiplication of the current carriers available with reverse voltage applied. This multiplication of carriers is termed avalanche breakdown. ____________________ breakdown occurs when carriers are set free or multiplied as a result of receiving energy from accelerated minority carriers.

free

22.10 The reverse breakdown point of a diode is shown at point A in figure 22. Avalanche breakdown results in only small voltage changes across the diode for large changes in current. The current curve is steep to the left of the reverse breakdown point in figure 22 as a result of _________________ __________________ occuring.

avalanche

22.11** Refer to figure 22: Point A is the _____________ _______________ point. The amount of current at point B is limited by the number of ____________ carriers present in the two sides, and point C occurs at about ________(#) volts with a germanium diode. Increasing the reverse voltage beyond point A forces the diode into a condition termed ______________ ______________.

avalanche breakdown
of reverse breakdown

22.12 END OF SET

reverse or avalanche breakdown
minority
0.3
avalanche breakdown

23 The two major differences between avalanche and zener breakdown are, zener breakdown is the result of ____________ and an increase in temperature results in a decrease in the voltage point at which __________ breakdown occurs, which is just the opposite of the temperature effect on the voltage at which _______________ breakdown occurs.

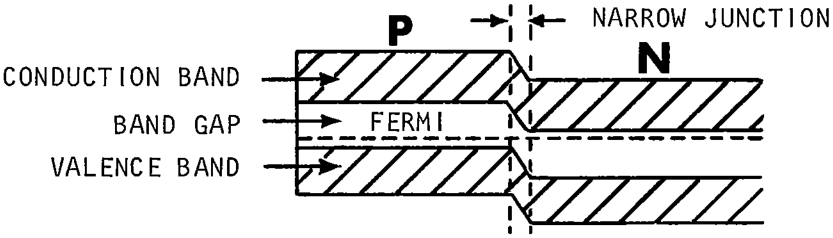
23.1 The actual junction is the area of transition between the portion of N semiconductor containing majority carriers and the portion of the P semiconductor containing majority carriers. The width of this transition region (or depletion region) varies with applied voltage.

tunneling
zener
avalanche

23.2 Increasing the amount of donor and acceptor impurities added in the doping process will also narrow the transition region.

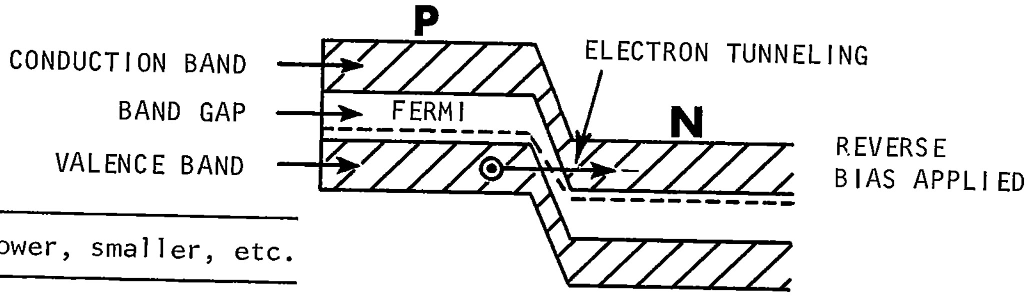
no answer needed

23.3 Zener breakdown occurs in narrow junctions where the width of the junction (or transition region) between N and P sides is made very narrow by heavy doping. As the amount of doping is increased, the junction width becomes ______________.



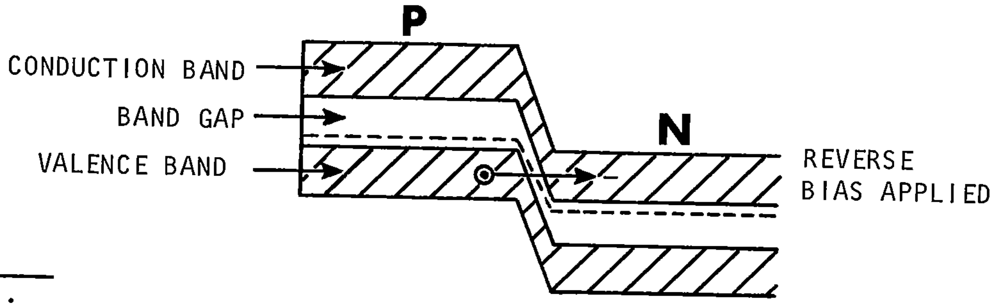
no answer needed

23.4 When a junction is heavily doped, a process known as "tunneling" is enhanced. Reverse bias moves the valence band of the P side opposite the conduction band of the N side separated by the narrow junction. Tunneling occurs when the electron jumps or crosses the narrow __________.



narrower, smaller, etc.

23.5 Electrons that do not seem to have sufficient energy to do so, cross the transition region of a heavily doped PN junction when reverse bias is applied. This is called zener breakdown or __________.



junction

23.6 There is a sharp increase in current when sufficient reverse voltage is applied to enhance tunneling. The reverse voltage point at which tunneling occurs in termed the "zener breakdown voltage".

tunneling

23.7 The voltage versus current curve of a diode in zener breakdown and a diode in avalanche breakdown are similar, because the voltage across the diode changes very little for large changes in current in both cases.

no answer needed

23.8 Increasing the amount of impurities added in the doping process, reduces the reverse voltage point at which breakdown occurs in a PN diode.

no answer needed

23.9 A PN diode will breakdown at a lower reverse voltage, if the amount of doping ____________ is increased.

no answer needed

23.10 Junctions doped sufficiently heavy to enhance tunneling, have breakdown occuring at voltages below 6 volts. Junctions whose reverse breakdown occurs above 6 volts, probably breakdown as a result of ___________ occuring.

inpurities

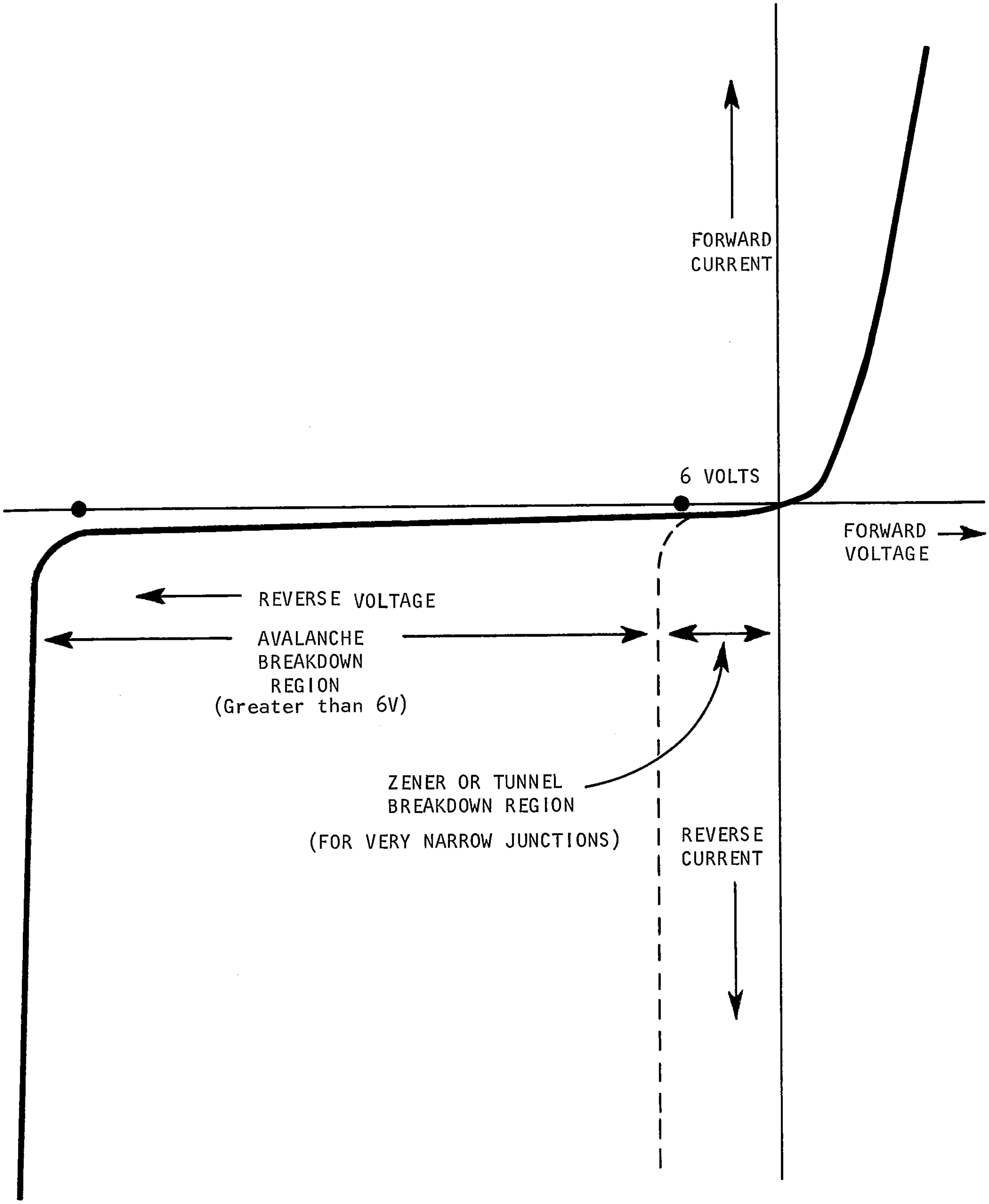

FORWARD
CURRENT
6 VOLTS
FORWARD
VOLTAGE
REVERSE VOLTAGE
AVALANCHE
BREAKDOWN
REGION
(Greater than 6V)
ZENER OR TUNNEL
BREAKDOWN REGION
(FOR VERY NARROW JUNCTIONS)
REVERSE
CURRENT

FIGURE 23

23.11 Breakdown as a result of tunneling, occurs at a lower reverse voltage than avalanche breakdown. Zener breakdown occurs at reverse voltages below 6 volts in heavily ____________ junctions.

avalanche

23.12 Diodes in avalanche breakdown have greater than 6 volts across their terminals and diodes in ____________ breakdown have less than 6 volts across their terminals as shown in figure 23.

doped

23.13 An increase in temperature decreases the width of the junction (or transition region) between the N and P sides, reducing the reverse voltage requirements to cause tunneling. Zener breakdown voltage is reduced with a/an ____________________ in temperature.
(increase, decrease)

zener or tunneling

23.14 An increase in temperature forms more hole-electron pairs and narrows the depletion region. It then takes a greater applied reverse voltage to cause avalanche to occur. Avalanche breakdown occurs at a higher reverse voltage when temperature ____________________.
(increases, decreases)

increase

23.15 Avalanche breakdown voltage varies directly as temperature varies and zener breakdown voltage varies indirectly as temperature varies. When temperature goes up, the voltage across the terminals of a diode in ______________ breakdown decreases and the voltage across the terminals of a diode in ____________ breakdown increases.

---

increases

23.16** Avalanche breakdown and zener breakdown differ because zener breakdown is a result of __________. The voltage across the terminals of a diode in avalanche breakdown varies ____________ with temperature changes while the voltage across the terminals of a diode in zener breakdown varies ______________ with temperature changes.

---

zener
avalanche

23.17 END OF SET

---

tunneling
directly
indirectly

---

24 Carriers giving off energy during recombination in a diode, raise the junction temperature above the ____________ temperature. The maximum temperature the junction may reach without damage limits the maximum ____________ ____________ of the junction.

24.1 Some of the heat generated at the junction is transferred to the surrounding air. The remaining ____________ raises the junction temperature above the ambient (surrounding air) temperature.

ambient or surrounding air
power dissipation

24.2 The amount of heat generated is directly related to the power the junction is dissipating. The more power (current x voltage) that the junction is dissipating, the more ______________ is generated.

heat (energy)

24.3 Maximum operating junction termperature without damage to the diode is approximately 100°C for germanium junctions and 175°C for silicon junctions. Diodes made of ______________ will be damaged if their operating temperature exceeds approximately 100°C.

heat

24.4 The difference between surrounding air temperature and the maximum allowable operating temperature of the junction will limit the amount of power the junction can dissipate. The allowable increase in junction temperature limits diode ____________ dissipation.

germanium

24.5 When ambient temperature increases, the maximum power dissipation capability of the junction is reduced. An increase in ambient temperature reduces the allowable increase in junction temperature that the diode can tolerate. The increase in junction temperature over ambient temperature will result from dissipating ____________.

power

24.6 If more of the heat generated by power dissipation is transferred to the surrounding air, more power can be dissipated by the diode. Moving more ______________ away from the junction increases the ___________ dissipation capabilities of the diode.

power

24.7 Dissipating power generates heat at the junction. The amount of heat the junction can tolerate, limits the power that can be dissipated. Ambient temperature and maximum allowable ____________ temperature limit the junction power dissipating capabilities.

heat
power

24.8** Recombination in a diode raises junction ____________ above ambient. Heat transfer from the junction to the surrounding air is important in semiconductor diodes because maximum junction _____________ _____________ is limited by the allowable increase in junction _____________.

junction

24.9 END OF SET

temperature
power dissipation
temperature

25 Most junctions are mounted in a case and there is opposition to the transfer of heat from the junction to the surrounding air. This opposition is termed ____________ ____________. There are individual values which ______________ to give the total.

25.1 The case of a diode or transistor is generally small without much surface area to radiate heat. There is opposition offered in the path of heat transfer and this is termed <u>thermal</u> <u>resistance</u>.

thermal resistance
add

25.2 The term <u>thermal</u> <u>resistance</u> results from assigning electrical terms, analogically, to the thermal (heat or temperature) characteristics of the device. ______________ ______________ is associated analogically with electrical resistance.

no answer needed

25.3 The opposition shown the transfer of heat from the junction to its case or encapsulation is analogically termed thermal ____________.

thermal resistance

25.4 The opposition to the transfer of heat from the case or encapsulation to the surrounding air is also termed ____________ ____________.

resistance

25.5 Total thermal resistance, junction to ambient (surrounding air), is given the symbol θ_{JA}. More than one individual thermal resistance makes up thermal resistance ____________ to ____________ (θ_{JA}).

thermal resistance

25.6 A diode or transistor that depends on the radiation of heat from the case to the surrounding air has two predominate thermal resistances; one thermal resistance from the junction to the case and one thermal resistance from the case to ____________ (surrounding air).

junction
ambient

25.7 Thermal resistance, junction to case, and thermal resistance, case to ambient, are in series and add to give total thermal resistance, junction to ambient. The sum of the series thermal resistances gives total thermal resistance.

ambient

25.8 The opposition to the transfer of heat, junction to ambient, is termed total __________ __________ and the individual series values __________ to give the total.

---

no answer needed

25.9** θ_{JA} is the symbol given total thermal resistance, __________ to __________. The individual values of thermal resistance, __________ to case and thermal resistance case to __________ add to give the total.

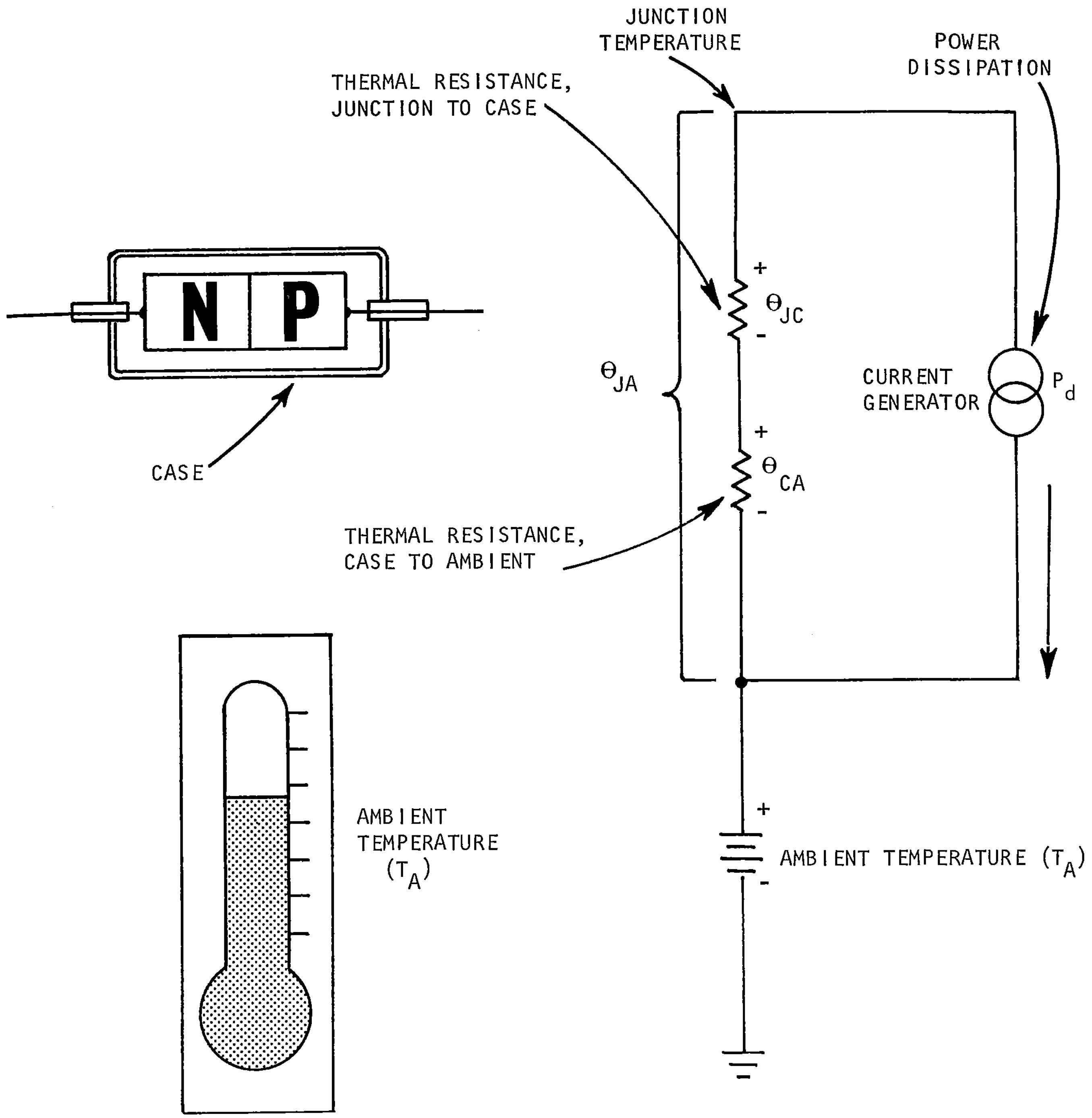
---

thermal resistance
add

25.10 END OF SET

---

junction
ambient
junction
ambient



JUNCTION POWER DISSIPATION = CURRENT

OPPOSITION TO HEAT TRANSFER = RESISTANCE

AMBIENT TEMPERATURE = VOLTAGE

JUNCTION TEMPERATURE = VOLTAGE

ANALOGICAL ASSOCIATION OF ELECTRICAL AND THERMAL CHARACTERISTICS

FIGURE 26

26 The product of θ_{JA} and ____________ ____________ gives the rise in junction temperature above ambient. This is added to ____________ temperature to give the temperature of the junction. Thermal resistance is measured in ____________.

26.1 Junction temperature is expressed analogically as a voltage in figure 26 and is measured from the point shown to ground.

---

power dissipation
ambient
degrees centigrade/watt (°C/W)

26.2 Power dissipation is expressed analogically as a current. The voltage drops due to power dissipation in the thermal resistances in figure 26 (as a continuance of the analogy) are aiding in polarity to ambient temperature.

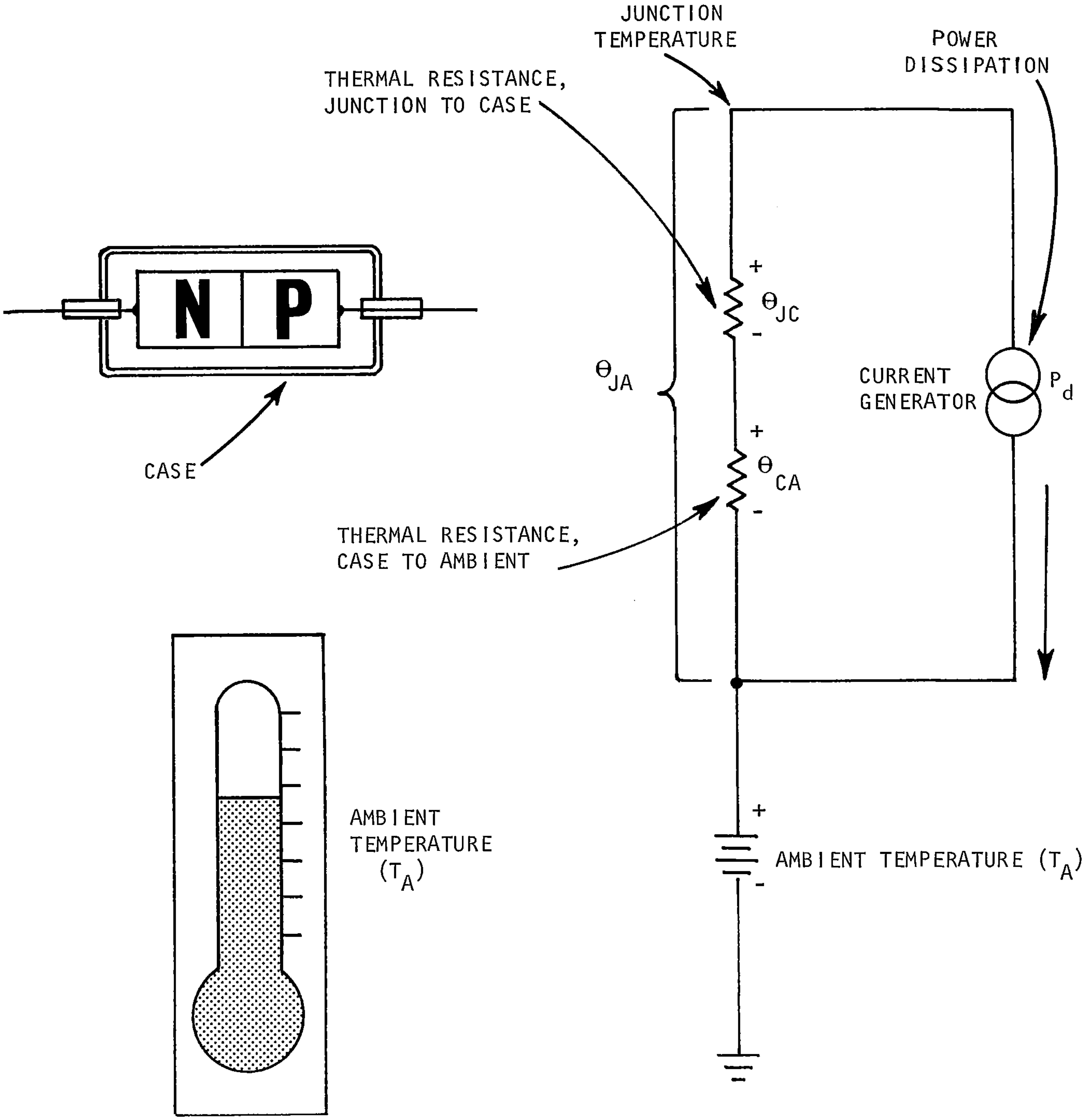
---

no answer needed

26.3 Ambient temperature is expressed analogically as a ____________ and power dissipation as a ____________ in figure 26.

---

no answer needed



JUNCTION POWER DISSIPATION = CURRENT

OPPOSITION TO HEAT TRANSFER = RESISTANCE

AMBIENT TEMPERATURE = VOLTAGE

JUNCTION TEMPERATURE = VOLTAGE

ANALOGICAL ASSOCIATION OF ELECTRICAL
AND THERMAL CHARACTERISTICS

FIGURE 26

26.4 Thermal resistance is given in degrees centigrade per watt (°C/W) and is a ratio of temperature increase at the junction in degrees centigrade to the power dissipation in ____________ at the junction.

---

voltage
current

26.5 Taking the product of thermal resistance (°C/W) and junction power dissipation (watts) will give the increase in junction temperature above ambient as a result of ____________ dissipation.

---

watts

26.6 A diode with a total thermal resistance (Θ_{JA}) of 25 degrees centigrade per watt (°C/W) and dissipating 2 watts of power, will have a junction temperature 50°C above ______________.

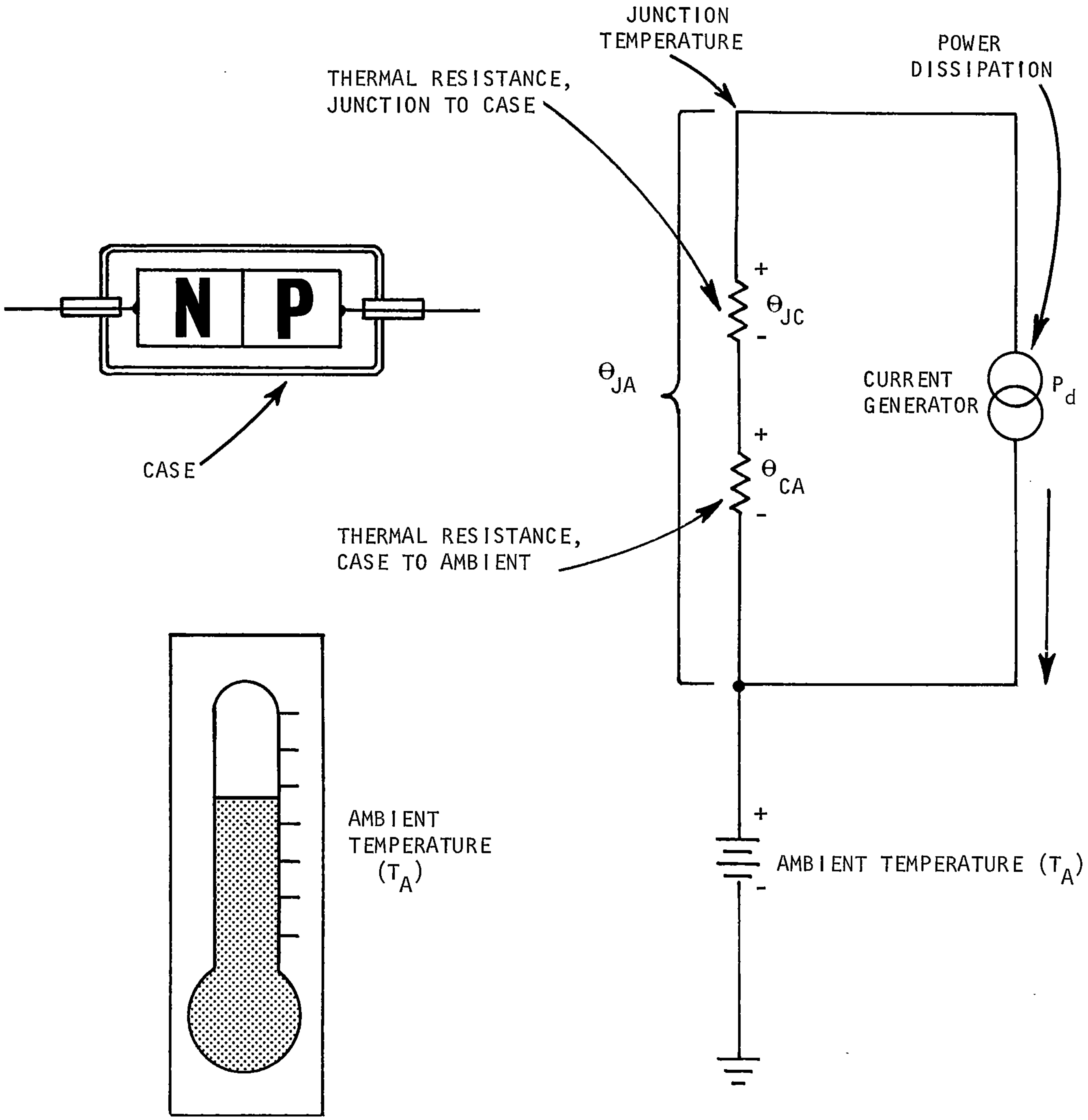
---

power

26.7 With zero power dissipation, the junction temperature is equal to ambient temperature. The temperature of a conducting junction is always greater than ambient temperature, since ______________ dissipation increases the __________________ of the junction.

---

ambient



JUNCTION POWER DISSIPATION = CURRENT

OPPOSITION TO HEAT TRANSFER = RESISTANCE

AMBIENT TEMPERATURE = VOLTAGE

JUNCTION TEMPERATURE = VOLTAGE

ANALOGICAL ASSOCIATION OF ELECTRICAL AND THERMAL CHARACTERISTICS

FIGURE 26

26.8 Thermal resistance can be used to find the ________________ (increase, decrease) in junction temperature above ambient that results from power dissipation.

power
temperature

26.9 The product of power dissipation (P_d) in watts and total ______________ ______________ (θ_{JA}) in OC/W, (when using the analogy in figure 26) gives the increase in junction temperature above ambient.

increase

26.10 In figure 26, two thermal resistances are shown; thermal resistance, junction to case, and thermal resistance, case to ambient. These ______________ to give total thermal resistance (θ_{JA}).

thermal resistance

26.11 Analogically relating θ_{JA} to electrical resistance and P_d to electrical current, as shown in figure 26, temperature rise at the junction can be calculated using ohms law. ______________ temperature of the diode is then expressed as $\theta_{JA} P_d + T_A$.

add

26.12** The sum of ambient temperature (T_A) and the product of P_d and θ_{JA} gives the operating ____________ of the junction. θ_{JA} is given in ___________.

---

junction

26.13 END OF SET

---

temperature
degrees centigrade/watt (°C/W)

---

27 Mounting a diode or transistor on a ____________ ____________ will reduce the total thermal resistance (θ_{JA}) and increase the maximum allowable power dissipation for a given ____________ temperature. An increase in ambient temperature results in an/a ____________ (increase, reduction) in maximum allowable junction power dissipation (all other variables held constant).

27.1 When the case of a diode or transistor is connected directly to a larger piece of metal or material that will conduct heat easily, the thermal resistance, case to ambient, is reduced.

heat sink
ambient
reduction

27.2 The material to which a diode or transistor is attached to reduce the thermal resistance is termed a heat sink. A heat sink aids in transfer of ____________ to the surrounding air.

no answer needed

27.3 Often one end of the diode or transistor is connected electrically and thermally to the case to reduce thermal resistance, ____________ to case (θ_{JC}).

heat

27.4 With the semiconductor device connected electrically to the case, the case must often be electrically insulated from the heat sink. The electrical insulator used must be a good ______________ conductor.

junction

27.5 Mounting a semiconductor device on a heat sink allows it to dissipate more power for a given ambient temperature. The more efficient the heat sink in transferring the heat to the surrounding air, the more ______________ can be dissipated for a given ambient temperature.

heat

27.6 A semiconductor device can dissipate more power at the lower ambient temperatures than the high. Maximum allowable power dissipation is reduced if ambient temperature goes _________ (up, down) (assuming all other variables are held constant).

power

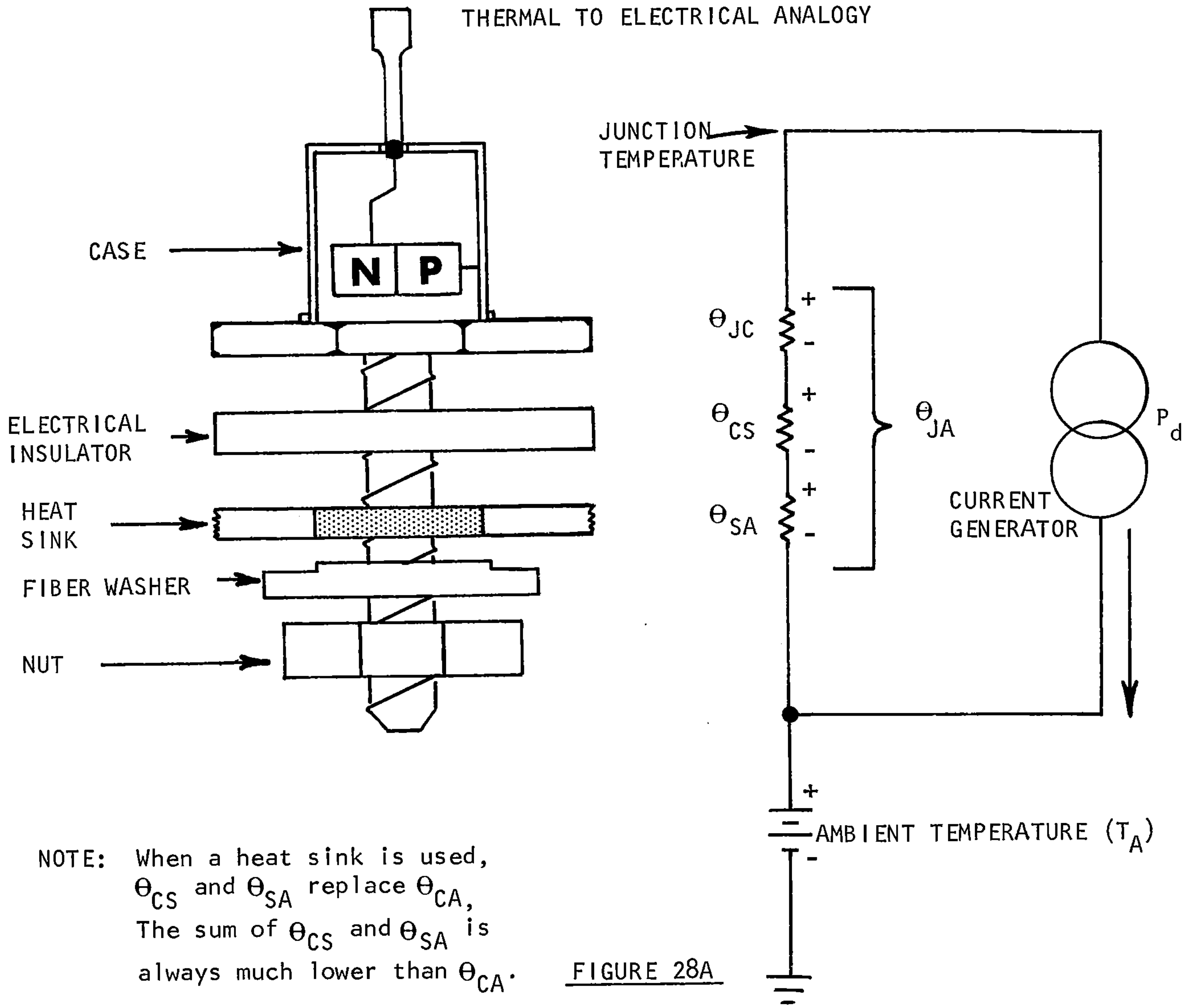
27.7** Connecting a semiconductor device thermally to a heat sink rather than relying on the encapulation to radiate the heat, results in a lower ______________________ temperature for a given ambient temperature, and ________________ dissipation. Maximum junction power dissipation varies ____________________ (directly, inversely) as ambient temperature varies for a given diode.

up

27.8 END OF SET

junction
power
inversely

THERMAL TO ELECTRICAL ANALOGY



NOTE: When a heat sink is used, θ_{CS} and θ_{SA} replace θ_{CA}, The sum of θ_{CS} and θ_{SA} is always much lower than θ_{CA}.

FIGURE 28A

JUNCTION POWER DISSIPATION = CURRENT
OPPOSITION TO HEAT TRANSFER = RESISTANCE
AMBIENT TEMPERATURE = VOLTAGE
JUNCTION TEMPERATURE = VOLTAGE

Insulating Washer	Typical Thermal Resistance (θ_{CS}) in °C/W	
	Dry	W/Silicon Lubricant
None	0.2	0.1
Teflon	1.45	0.8
Mica	0.8	0.4
Anodized Aluminum	0.4	0.35

FIGURE 28B

28 When a heat sink is used, __________(#) dominant thermal resistances add to give total thermal resistance. Insulating washer thermal resistance is often reduced by applying _______________ ___________________.

28.1 A heat sink in the path of heat transfer, case to ambient, improves the transfer of heat. When a heat sink is used, thermal resistance, case to heat sink and heat sink to ambient, replace thermal resistance, case to ambient.

3
silicon lubricant

28.2 Ambient temperature (T_A) and the maximum allowable junction operating temperature (T_{Jmax}) still govern maximum power, even with a heat sink. The heat sink allows more ____________ ____________ for same T_A and T_{Jmax}.

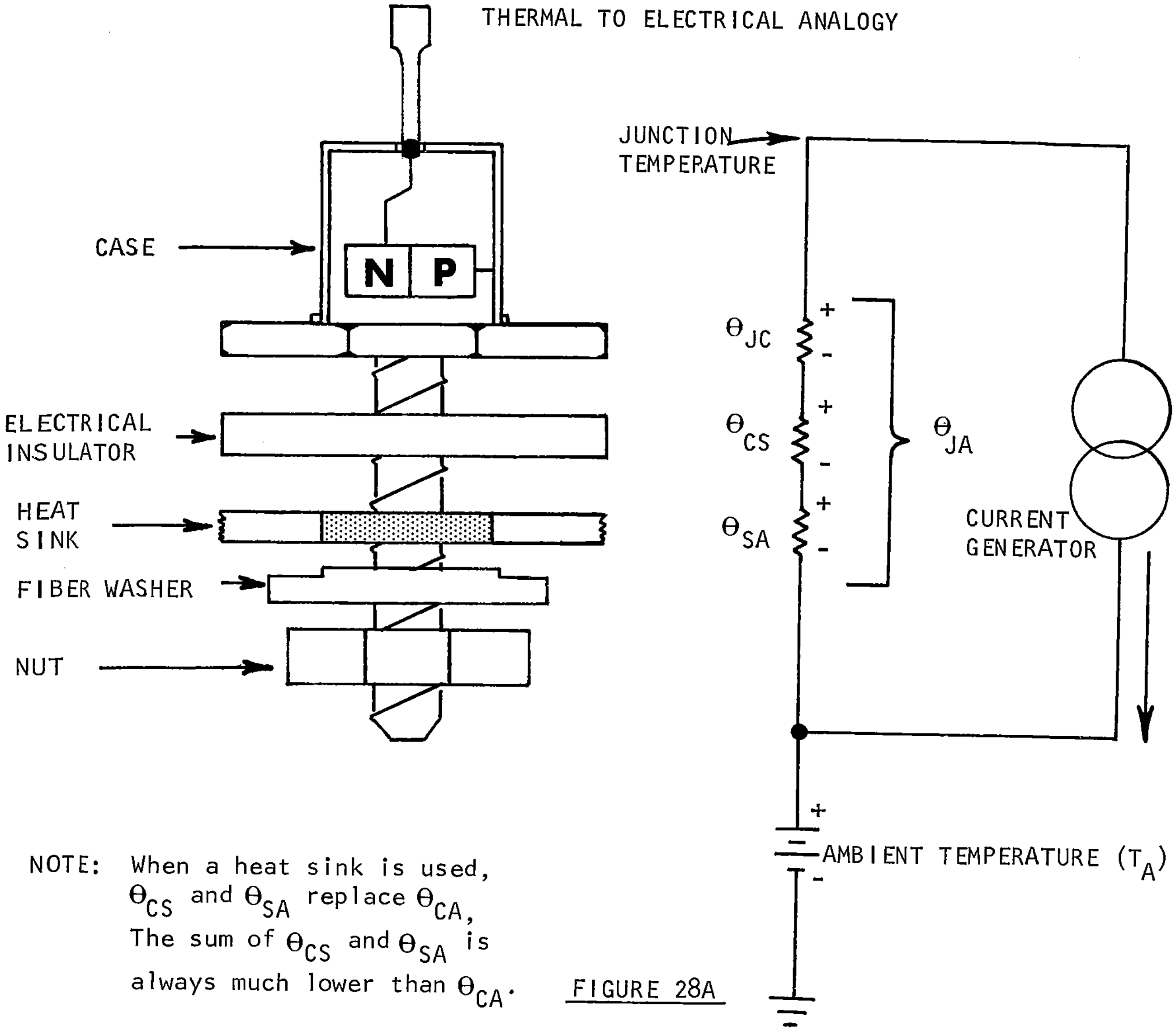
---

no answer needed

28.3 Figure 28A shows a analogy of the thermal considerations in electrical terms. The total termal resistance (θ_{JA}) is equal to the ____________ of all the thermal resistances.

---

power dissipation



NOTE: When a heat sink is used, θ_{CS} and θ_{SA} replace θ_{CA}, The sum of θ_{CS} and θ_{SA} is always much lower than θ_{CA}.

FIGURE 28A

JUNCTION POWER DISSIPATION = CURRENT
OPPOSITION TO HEAT TRANSFER = RESISTANCE
AMBIENT TEMPERATURE = VOLTAGE
JUNCTION TEMPERATURE = VOLTAGE

Insulating Washer	Typical Thermal Resistance (θ_{CS}) in °C/W	
	Dry	W/Silicon Lubricant
None	0.2	0.1
Teflon	1.45	0.8
Mica	0.8	0.4
Anodized Aluminum	0.4	0.35

FIGURE 28B

28.4 There is a thermal resistance between the case and heat sink that limits power dissipation. Thermal resistance, case to sink (θ_{CS}), makes up a part of total __________ __________.

sum

28.5 Silicon lubricant on the insulating washer may be used to reduce the thermal resistance, case to sink (θ_{CS}). Maximum power dissipation may be increased for a given ambient temperature by using __________ __________ on the insulating washer (for a given diode and heat sink).

thermal resistance (θ_{JA})

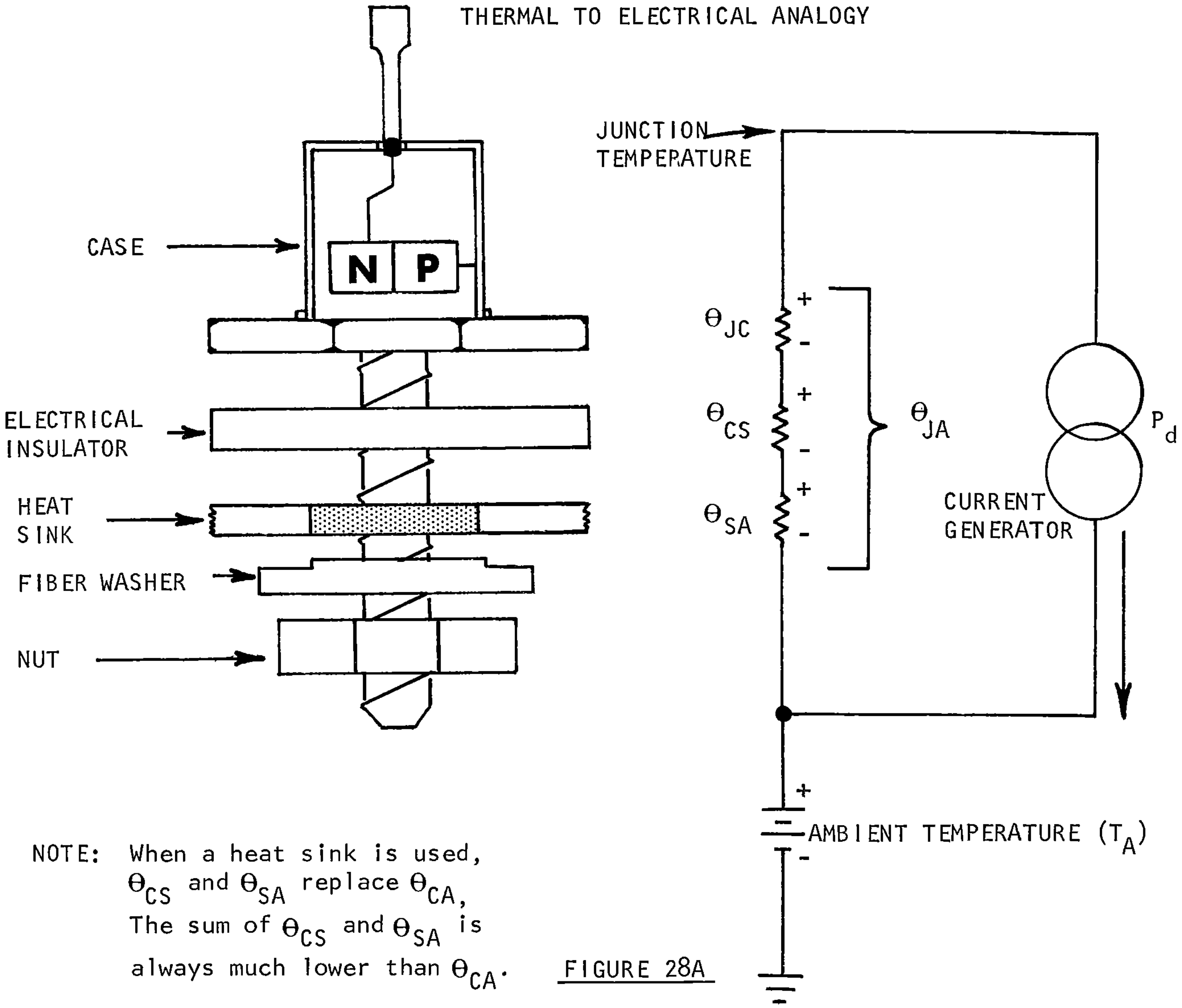
28.6 If no electrical insulation is needed, the semiconductor case may be connected directly to the heat sink. Silicon lubricant will still reduce thermal resistance and increase __________ dissipation capabilities.

silicon lubricant

28.7 Thermal resistance, junction to case (θ_{JC}), plus thermal resistance, case to sink (θ_{CS}), plus thermal resistance, heat sink to ambient (θ_{SA}), gives total thermal resistance. $\theta_{JC} + \theta_{CS} + \theta_{SA} =$ __________(symbol).

power

THERMAL TO ELECTRICAL ANALOGY



NOTE: When a heat sink is used, θ_{CS} and θ_{SA} replace θ_{CA}, The sum of θ_{CS} and θ_{SA} is always much lower than θ_{CA}.

FIGURE 28A

JUNCTION POWER DISSIPATION = CURRENT
OPPOSITION TO HEAT TRANSFER = RESISTANCE
AMBIENT TEMPERATURE = VOLTAGE
JUNCTION TEMPERATURE = VOLTAGE

Insulating Washer	Typical Thermal Resistance (θ_{CS}) in °C/W	
	Dry	W/Silicon Lubricant
None	0.2	0.1
Teflon	1.45	0.8
Mica	0.8	0.4
Anodized Aluminum	0.4	0.35

FIGURE 28B

28.4 There is a thermal resistance between the case and heat sink that limits power dissipation. Thermal resistance, case to sink (θ_{CS}), makes up a part of total ________ ________.

sum

28.5 Silicon lubricant on the insulating washer may be used to reduce the thermal resistance, case to sink (θ_{CS}). Maximum power dissipation may be increased for a given ambient temperature by using ________ ________ on the insulating washer (for a given diode and heat sink).

thermal resistance (θ_{JA})

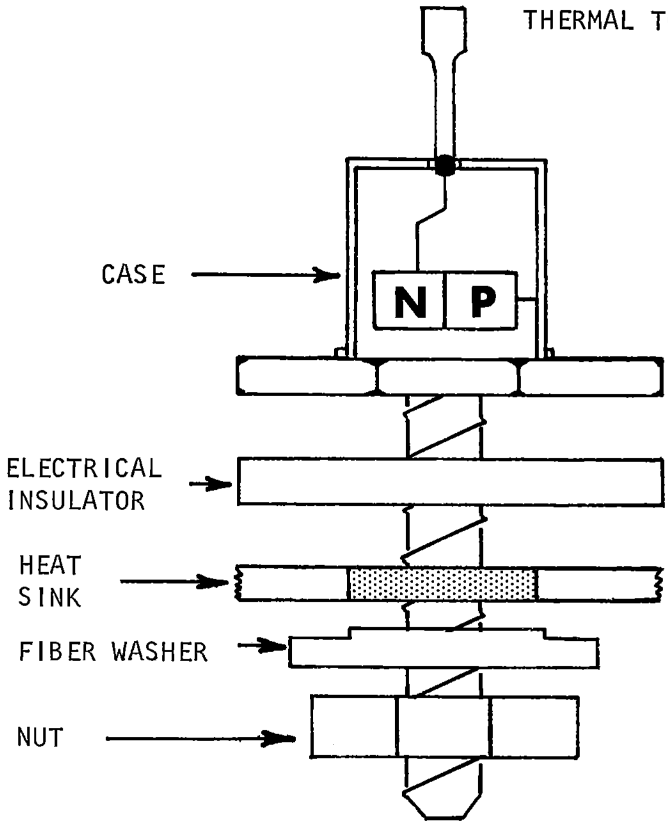
28.6 If no electrical insulation is needed, the semiconductor case may be connected directly to the heat sink. Silicon lubricant will still reduce thermal resistance and increase ________ dissipation capabilities.

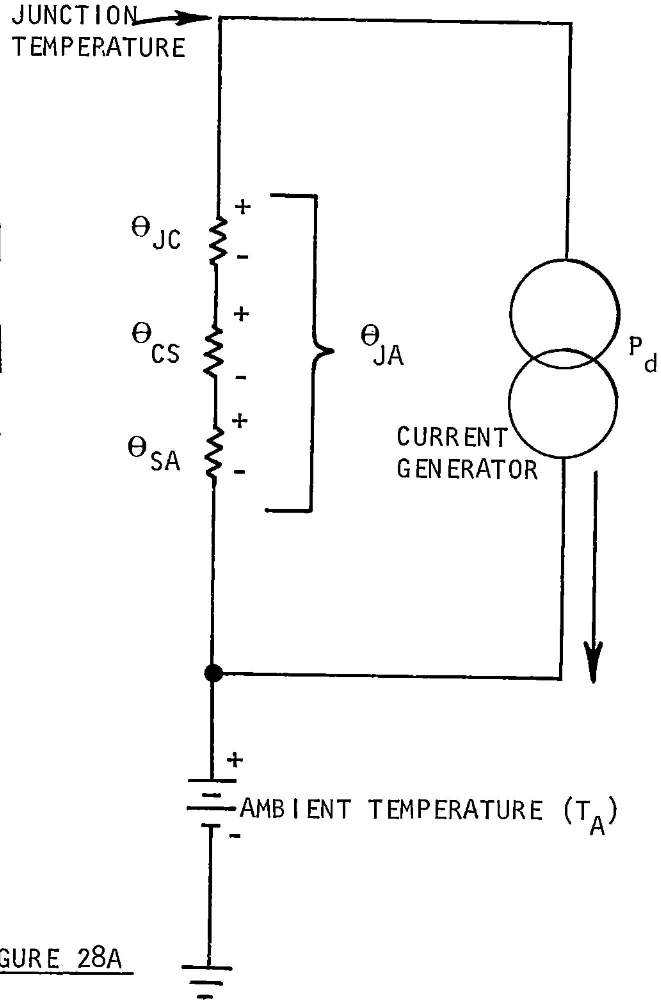
silicon lubricant

28.7 Thermal resistance, junction to case (θ_{JC}), plus thermal resistance, case to sink (θ_{CS}), plus thermal resistance, heat sink to ambient (θ_{SA}), gives total thermal resistance. $\theta_{JC} + \theta_{CS} + \theta_{SA} =$ ________(symbol).

power

THERMAL TO ELECTRICAL ANALOGY





NOTE: When a heat sink is used, θ_{CS} and θ_{SA} replace θ_{CA}, The sum of θ_{CS} and θ_{SA} is always much lower than θ_{CA}.

FIGURE 28A

JUNCTION POWER DISSIPATION = CURRENT
OPPOSITION TO HEAT TRANSFER = RESISTANCE
AMBIENT TEMPERATURE = VOLTAGE
JUNCTION TEMPERATURE = VOLTAGE

Insulating Washer	Typical Thermal Resistance (θ_{CS}) in °C/W	
	Dry	W/Silicon Lubricant
None	0.2	0.1
Teflon	1.45	0.8
Mica	0.8	0.4
Anodized Aluminum	0.4	0.35

FIGURE 28B

28.8 The operating temperature of the junction (T_J) is equal to the sum of ambient temperature (T_A) and the increase in junction temperature as a result of a power dissipation (P_d). $T_A + (P_d\ \theta_{JA}) =$ __________.

θ_{JA}

28.9 The sum of the three thermal resistances involved when a heat sink is used, is lower than the total thermal resistance without the heat sink. This can be further reduced by using silicon lubricant on the insulating washer. Silicon lubricant reduces thermal resistance from __________ to __________ and as a result, reduces total thermal resistance (θ_{JA}).

junction temperature (T_J)

28.10 Figure 28B is a chart showing the thermal resistance of typical insulating washers with and without silicon lubricant. Silicon lubricant __________ thermal resistance, case to sink.

case
sink

28.11** Three thermal resistances make up total thermal resistance when a heat sink is used. Thermal resistance from the __________ to the __________ __________ is reduced by silicon lubricant which results in a __________ total thermal resistance.

lowers, reduces, etc.

28.12 END OF SET

case
heat sink
lower

29 $P_{d\ (max)} = \frac{T_{J\ (max)} - T_A}{\Theta_{JA}}$

This formula allows the calculation of maximum allowable junction ______________ ________________. $T_{J\ (max)}$ is the maximum allowable junction temperature. T_A is ____________ temperature and Θ_{JA} is total ______________ ________________.

29.1 The allowable increase in junction temperature as a result of power dissipation may be found by subtracting the ambient temperature (T_A) from the maximum allowable junction temperature ($T_{J\ max}$). Allowable increase in junction temperature = $T_{J\ max}$ - ________________.

---

power dissipation
ambient
thermal resistance

29.2 Dividing the allowable change in junction temperature by the total thermal resistance gives the maximum power the junction can dissipate ($P_{d\ max}$).

$$\frac{T_{J\ max} - T_A}{\Theta_{JA}} = \underline{\qquad\qquad\qquad}$$

T_A

29.3 Knowing that: $P_{d\ max} = \frac{T_{J\ max} - T_A}{\Theta_{JA}}$;

if P_{max} is known, Θ_{JA} can be solved by transposing the formula to solve for Θ_{JA}: Θ_{JA} = ________________.

$P_{d\ max}$

29.4 $\Theta_{JA} = \frac{T_{J\ max} - T_A}{P_d}$

This is the formula for finding maximum allowable thermal resistance for a given ____________ ____________ (P_d) and ________________ ________________ (T_A).

$\frac{T_{J\ max} - T_A}{P_{d\ max}}$

29.5 Since $P_{d\ max} = \frac{T_{J\ max} - T_A}{\Theta_{JA}}$, an increase in ambient temperature

________________ $P_{d\ max}$.
(increases, decreases)

---

power dissipation
ambient temperature

29.6 $P_{d\ max} = \frac{T_{J\ max} - T_A}{\Theta_{JA}}$

T_J and Θ_{JA} are constant for given device and heat sink. In this case, the maximum power dissipation is set by the __________ ____________.

---

decreases

29.7** $P_{d\ max} = \frac{T_{J\ max} - T_A}{\Theta_{JA}}$

Maximum junction power dissipation can be calculated with this formula for a given value of ____________ and _____________ (symbols) when maximum allowable junction temperature is known.

---

ambient temperature (T_A)

29.8 END OF SET

Θ_{JA}

T_A

---

30 $$\theta_{SA} = \left(\frac{T_{J\ max} - T_A}{P_d}\right) - \theta_{JC} - \theta_{CS}$$

This is the formula for solving for the maximum thermal resistance of a __________ __________ for a given ambient temperature and power dissipation.

30.1 $$\theta_{JA} = \frac{T_{J\ max} - T_A}{P_d}$$

This is the formula for total thermal resistance in terms of allowable temperature rise and power dissipation. Total __________ __________ $(\theta_{JA}) = \theta_{JC} + \theta_{CS} + \theta_{SA}$.

heat sink

30.2 Since $\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}$, the formula for total termal resistance can read:

$$\theta_{JC} + \theta_{CS} + \_\_\_\_\_\_\_\_ = \frac{T_{J\ max} - T_A}{P_d}$$

thermal resistance

30.3 $$\theta_{JC} + \theta_{CS} + \theta_{SA} = \frac{T_{J\ max} - T_A}{P_d}$$

Then rearranging to solve for θ_{SA}: $\theta_{SA} = \left(\frac{T_{J\ max} - T_A}{P_d}\right) - \theta_{JC} - \_\_\_\_\_\_\_\_$.

θ_{SA}

30.4 Maximum thermal resistance of a heat sink for a given ambient temperature and power dissipation can be found using the formula:

$$\theta_{SA} = \left(\frac{T_{J\ max} - T_A}{P_d}\right) - \underline{\qquad\qquad} - \underline{\qquad\qquad}$$

θ_{JC}

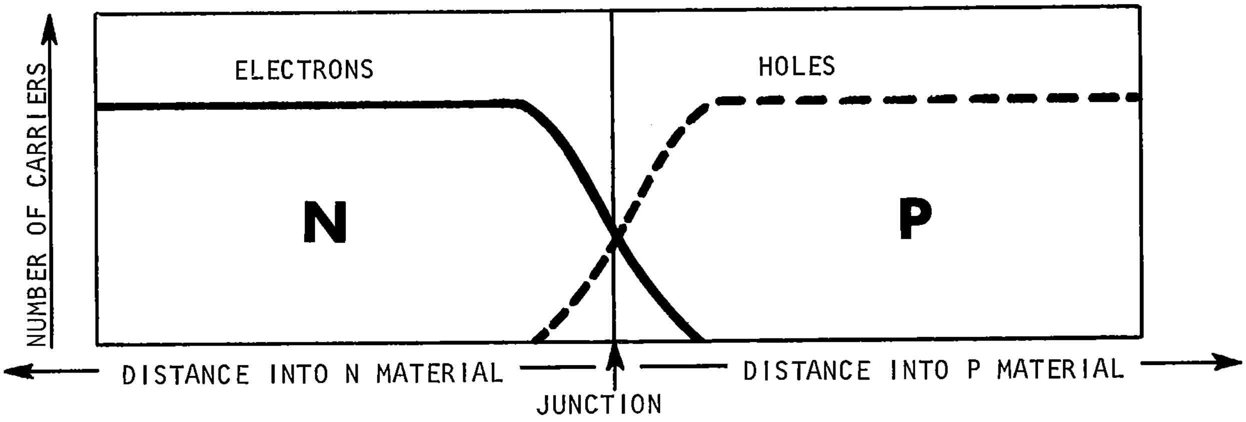
θ_{CS}

30.5 A junction diode has a θ_{JC} of 0.8° C/W, a $T_{J\ max}$ of 150° C, a θ_{CS} of 0.6° C/W and will dissipate 40 watts of power. The maximum θ_{SA} of the heat sink is __________ ° C/W if the ambient temperature is 50° C.

θ_{JC}
θ_{CS}

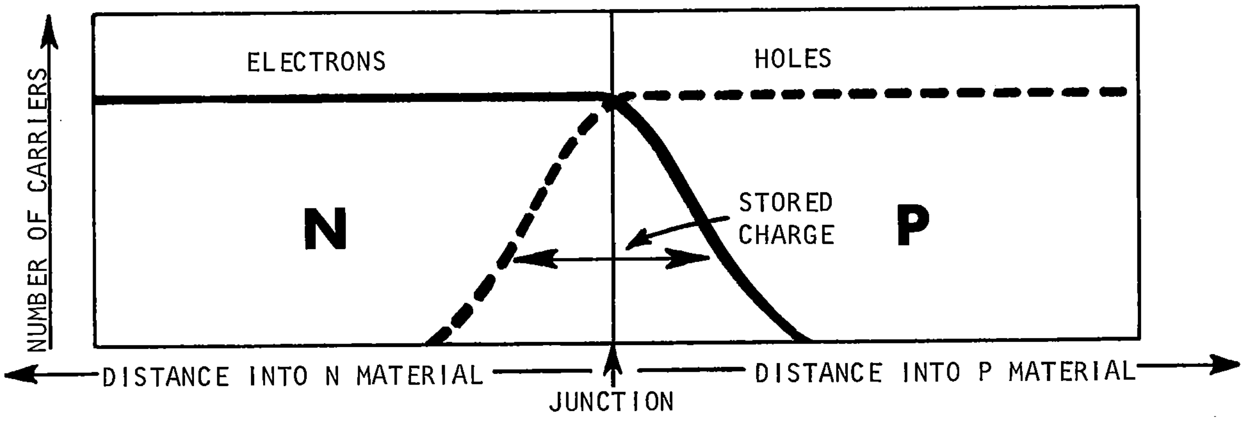
30.6 END OF SET

1.1



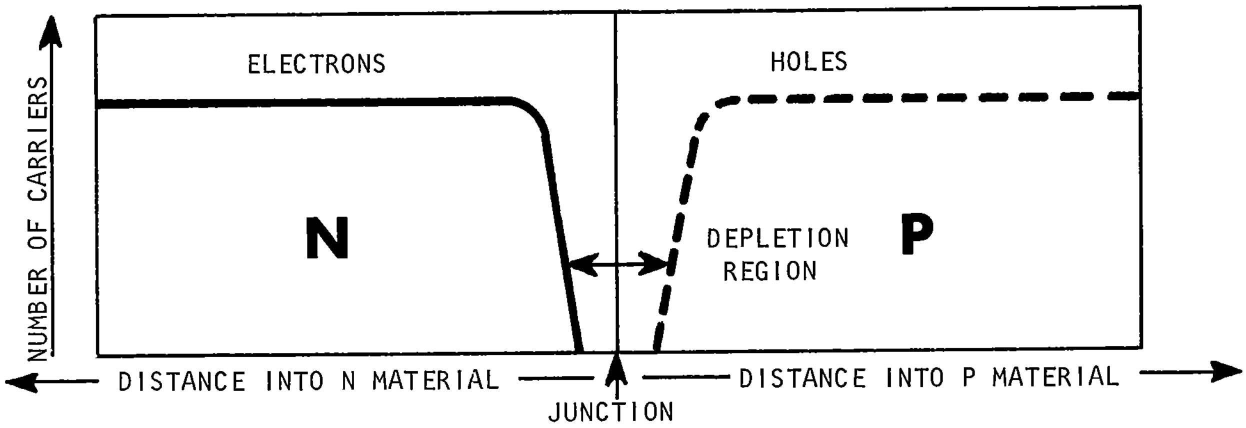
CARRIER DISTRIBUTION DIAGRAM   0 BIAS

A



CARRIER DISTRIBUTION DIAGRAM   FORWARD BIAS

B



CARRIER DISTRIBUTION DIAGRAM   REVERSE BIAS

C

FIGURE 31

31 Forward bias, which enhances majority carrier movement across the junction, results in a ____________ charge in the diode. Reverse bias increases the width of the _______________ region.

31.1 Figure 31A is a carrier distribution diagram for a PN junction with equal amounts of doping in the two sides (symmetrically doped) and with 0 bias applied. The number of ________________ is plotted vertically.

---

stored
depletion

31.2 In figure 31A, the horizontal is a plot of the _____________ into the materials from the ______________.

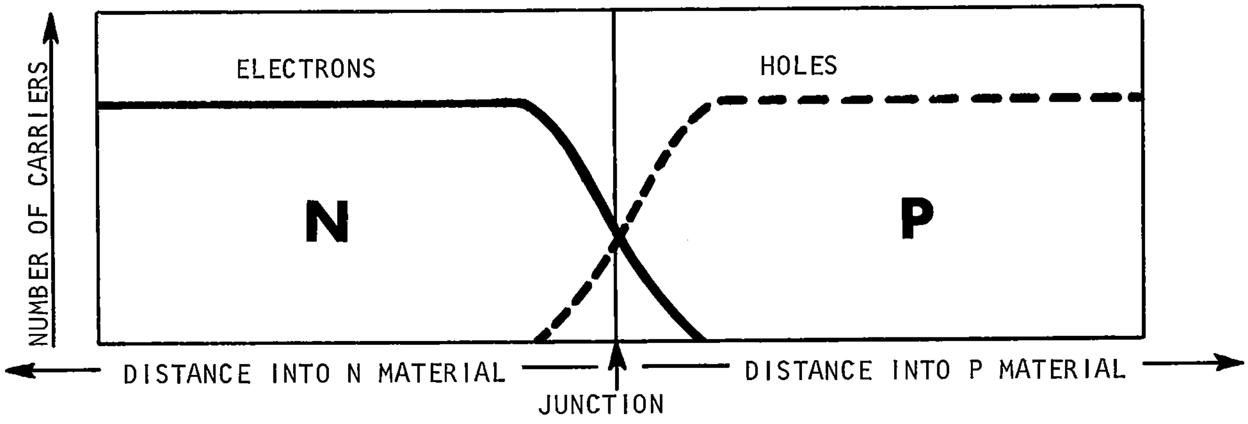
---

carriers or holes and electrons

31.3 The solid curve in figure 31A indicates the number of electrons. The slope of the solid line near the junction indicates a decrease in the number of ________________ near the junction.

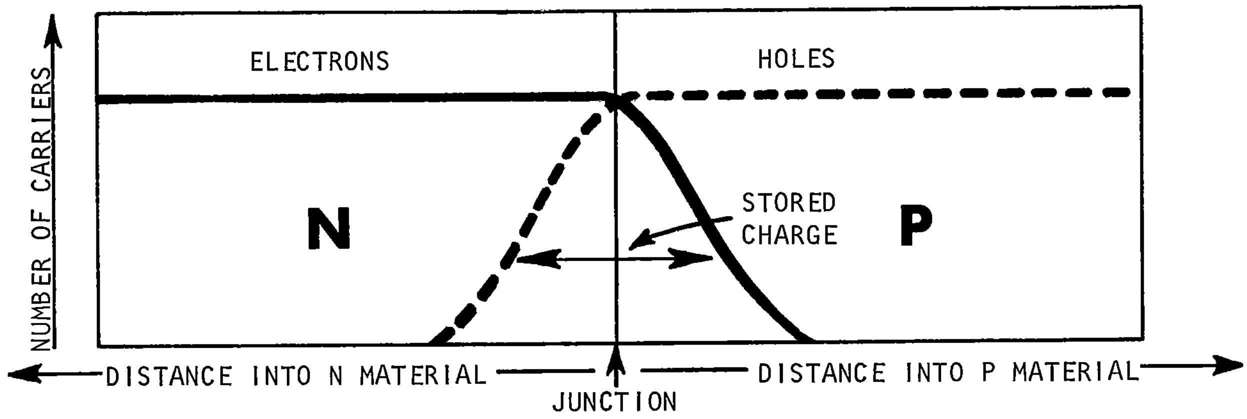
---

distance
junction



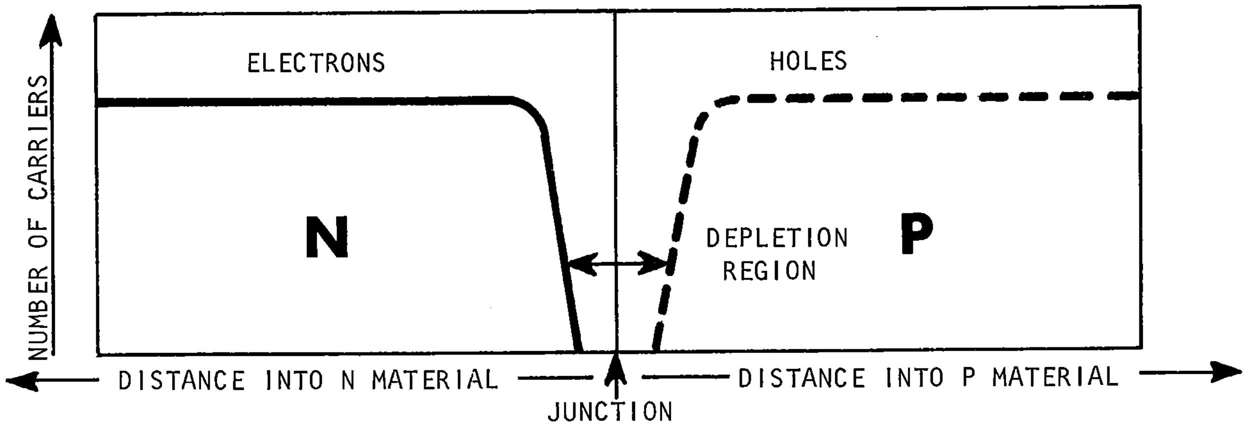
CARRIER DISTRIBUTION DIAGRAM 0 BIAS

A



CARRIER DISTRIBUTION DIAGRAM FORWARD BIAS

B



CARRIER DISTRIBUTION DIAGRAM REVERSE BIAS

C

FIGURE 31

31.4 In figure 31A, the solid curve extends into the P material. This indicates that there are some ________________ in the P side with no bias applied.

electrons

31.5 The solid line indicating electrons in figure 31A extends into the P material indicating that there are ________________ carriers
(minority, majority)
existing in the P side of the diode with zero bias applied.

electrons

31.6 The dotted line in figure 31A represents the number of holes present in the materials. The dotted line extends into the N side indicating that ________________ are existing in the N side at zero bias.

minority

31.7 Figure 31B shows the carrier distribution diagram with forward bias applied. More electrons and holes have been moved into the respective sides. These carriers, when moved across the junction, become ______________ carriers.

holes or minority carriers

31.8 Some of the carriers do not recombine right at the junction but diffuse into the opposite side before recombining. Once they cross the junction, they become minority carriers. Forward bias moves more ______________ carriers into the two sides.

minority

31.9 Some of the carriers diffuse well beyond the junction before recombining. This results in a charge of minority carriers, effectively stored in the diode. Applied forward bias results in a ____________ ____________ of minority carriers in the two sides.

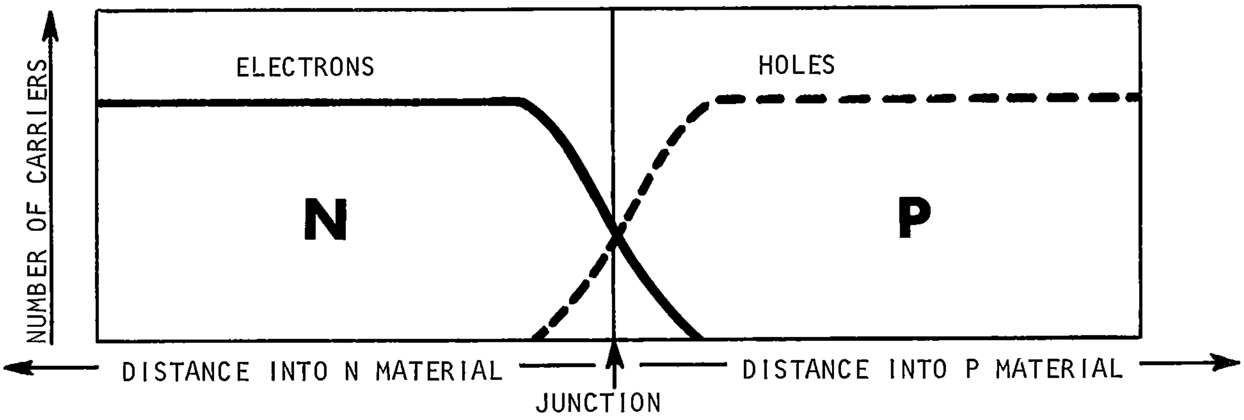
minority

31.10 Forward biasing causes a stored charge of minority carriers in the two sides of the diode. This is the result of carriers having to diffuse beyond the junction before __________________ can occur.

stored charge

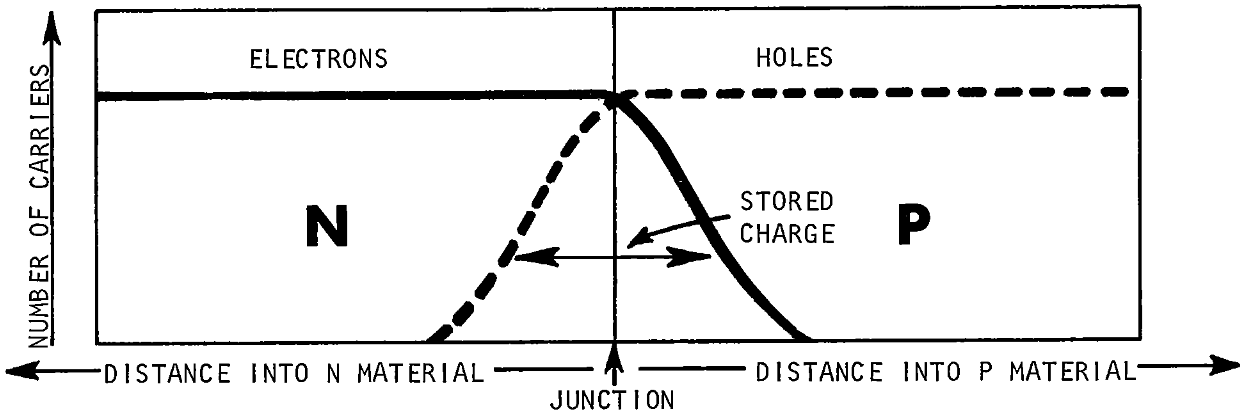
31.11 Reverse biase moves majority carriers away from the junction and forms an area that is depleted of majority ________________.

recombination



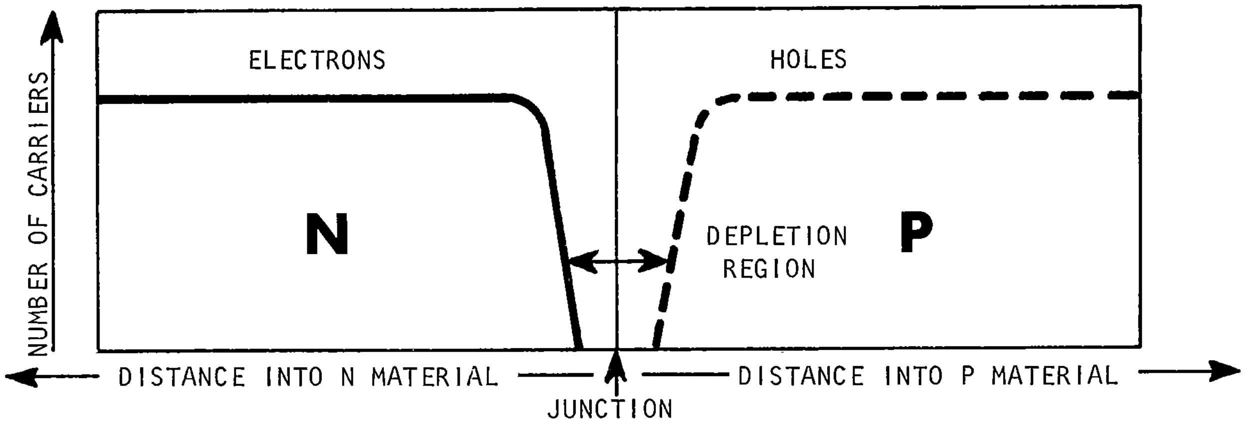
CARRIER DISTRIBUTION DIAGRAM 0 BIAS

A



CARRIER DISTRIBUTION DIAGRAM FORWARD BIAS

B



CARRIER DISTRIBUTION DIAGRAM REVERSE BIAS

C

FIGURE 31

31.12 Figure 31C shows the carrier distribution diagram with reverse bias applied. There is an area about the junction without majority carriers called the ______________ ______________.

carriers

31.13 Increasing the forward current of a conducting diode increases the number of carriers crossing the junction and becoming minority carriers. This increases the ____________ charge (for a given diode).

depletion region

31.14 Increasing the reverse voltage applied, pulls the majority carriers farther from the center and increases the width of the ______________ ______________.

stored

31.15** A forward conducting diode has a stored charge of ______________ carriers in the two sides of the junction. Reverse bias results in an area that is depleted of majority carriers, termed the ______________ ______________.

depletion region

31.16 END OF SET

---

minority
depletion region

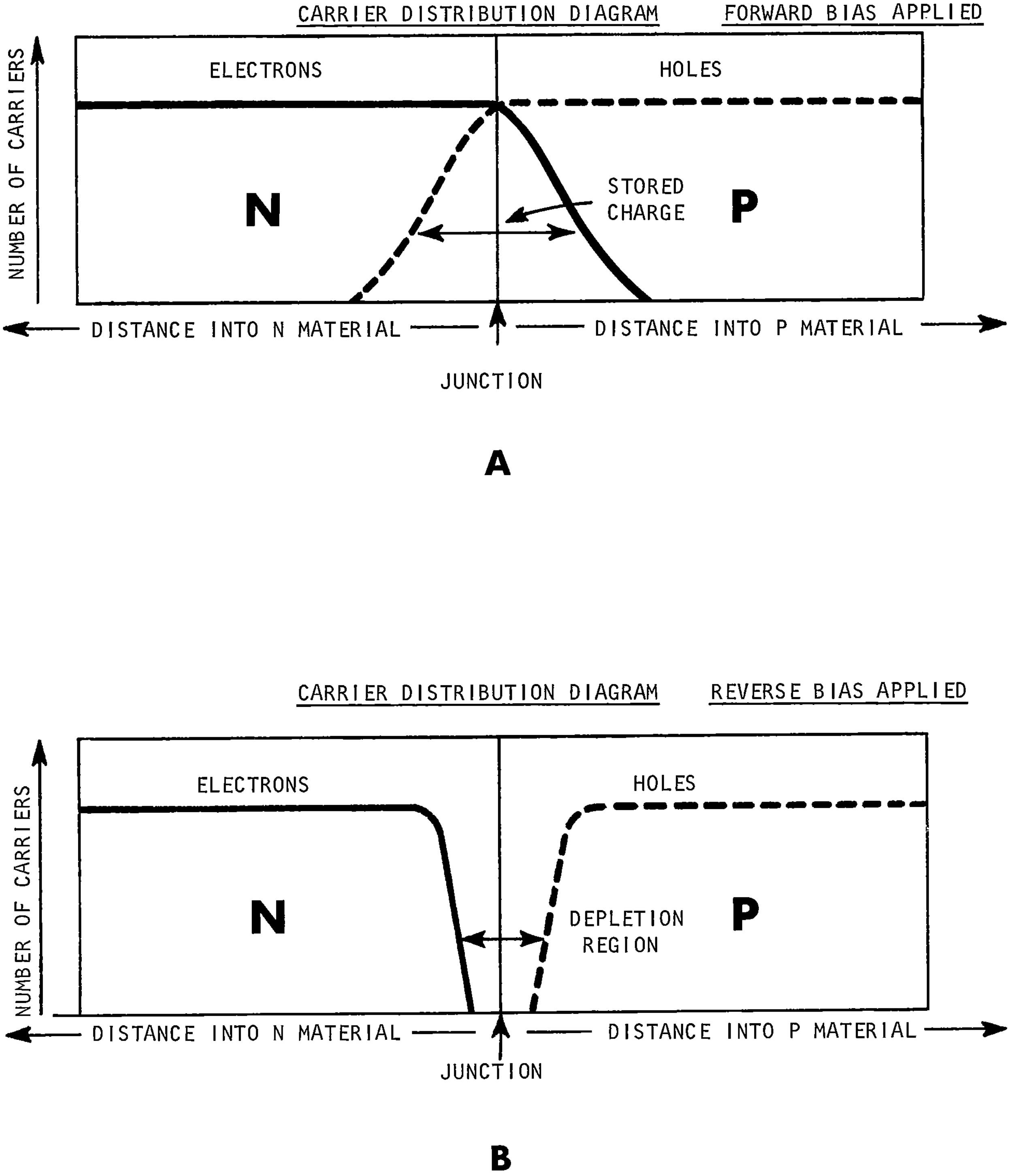

CARRIER DISTRIBUTION DIAGRAM
FORWARD BIAS APPLIED
NUMBER OF CARRIERS
ELECTRONS
HOLES
N
STORED CHARGE
P
DISTANCE INTO N MATERIAL
DISTANCE INTO P MATERIAL
JUNCTION
A
CARRIER DISTRIBUTION DIAGRAM
REVERSE BIAS APPLIED
NUMBER OF CARRIERS
ELECTRONS
HOLES
N
DEPLETION REGION
P
DISTANCE INTO N MATERIAL
DISTANCE INTO P MATERIAL
JUNCTION
B

FIGURE 32

32 A period of time is required to turn off a forward conducting junction due to the __________ __________ in the two sides of the diode. Stored charge can be calculated using the factor "τ_q" which indicates the amount of stored charge in __________-__________ per __________ of __________ current.

32.1 To turn on a diode in the forward direction, sufficient carriers must first be supplied to establish the charge that is termed "stored charge". To turn off a conducting diode, the stored charge in the two sides must be removed.

stored charge
pico-coulombs
milliampere
forward

32.2 Figure 32A shows the stored charge in the two sides with forward bias applied. To change from a forward biased state to a reversed biased (off) state as in figure 32B, the __________ __________ must be removed.

no answer needed

32.3 Changing from applied forward bias to reverse bias in an attempt to turn off a forward conducting diode, finds the stored charge supplying minority carriers and providing a rather large reverse __________.

stored charge

32.4 Changing from forward bias to reverse bias in an attempt to turn off a forward conducting junction, results in current continuing until the stored charge is removed and the ______________ region is formed.

current

32.5 It takes a period of time to remove the stored charge and establish the depletion region. The amount of time being dependent on the amount of __________ ____________ and the opposition in the path of the stored current carriers.

depletion

32.6 The more forward current, the more stored charge for a given junction. Amounts of stored charge and forward current are __________________ (directly, indirectly) related for a given junction.

stored charge

32.7 A factor termed "τ_q" is generally given for a diode in "pico-coulombs per milliampere". This indicates that for each milliampere of forward current, there will be a given number of __________-_____________ of stored charge.

directly

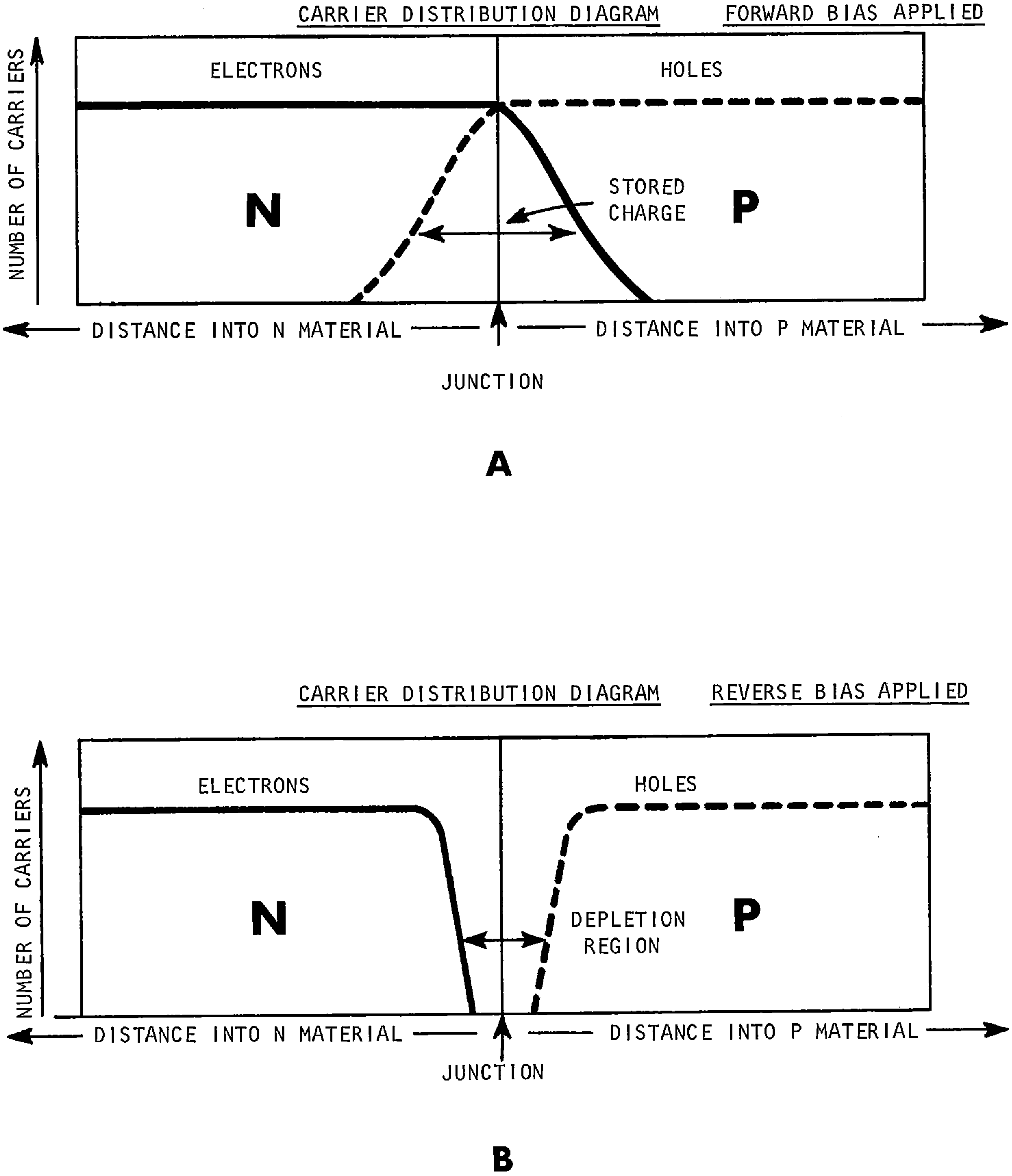

CARRIER DISTRIBUTION DIAGRAM
FORWARD BIAS APPLIED
NUMBER OF CARRIERS
ELECTRONS
HOLES
N
STORED
CHARGE
P
DISTANCE INTO N MATERIAL
DISTANCE INTO P MATERIAL
JUNCTION
A
CARRIER DISTRIBUTION DIAGRAM
REVERSE BIAS APPLIED
NUMBER OF CARRIERS
ELECTRONS
HOLES
N
DEPLETION
REGION
P
DISTANCE INTO N MATERIAL
DISTANCE INTO P MATERIAL
JUNCTION
B

FIGURE 32

32.8 A diode has a τ_q of 70 pico-coulombs per milliampere. Operating at a forward bias current of 8 milliamperes results in a stored charge of __________ pico-coulombs.

____

pico-coulombs

32.9 The diode in frame 32.8 would have to have 560 pico-coulombs of charge swept out plus the carriers removed to establish a depletion region in order to go to a non-conducting state (figure 32B).

560

32.10** To turn off a forward conducting diode, the __________ __________ must be removed. The amount of __________ charge can be calculated using the factor "____" which indicates the number of pico-coulombs per __________ of forward current.

No answer needed

32.11 END OF SET

stored charge
stored
τ_q
milliampere

33 For a given forward current, stored charge about the junction is directly proportional to the ______________ of the minority carriers. Adding imperfections or impurities near the junction __________________ minority carrier __________________.
(increases, reduces)

33.1 Majority carriers move across the junction when forward bias is applied. The magnitude of stored charge is dependent on the number of holes and electrons that cross the junction and are existing as __________________ carriers.

lifetime
reduces
lifetime

33.2 Majority carriers become ______________ carriers after crossing the junction. Increasing the forward current increases the number of carriers crossing the junction and increases the _____________ charge.

minority

33.3 The holes and electrons must find impurities or imperfections in the covalent bond structure before they can recombine. ______________ bias allows majority carriers to cross the junction, but they must find ________________ before recombination can occur.

minority
stored

33.4 The more time the carriers must spend as minority carriers before recombining, the greater the ______________ charge for a given forward current.

forward
impurities, imperfections, etc.

33.5 The average time that the carriers exist as minority carriers before recombination is termed "minority carrier lifetime".

stored

33.6 The greater the average time that minority carriers take to recombine, the longer the _________________ carrier lifetime.

No answer needed

33.7 A relatively pure or intrinsic piece of semiconductor has a long minority carrier lifetime. Since there are few imperfections, the minority carriers spend considerable time before finding imperfections and recombining.

minority

33.8 A heavily doped semiconductor has many imperfections and any minority carriers present tend to recombine rapidly. It can be said that this material has a short minority carrier ________________.

No answer needed

33.9 Minority carrier lifetime is a measure of the purity of a semiconductor. The greater the purity, the ________________ (longer, shorter) the minority carrier lifetime.

lifetime

33.10 Stored charge varies directly with minority carrier lifetime for a given forward current. A longer lifetime results in a ________________ (greater, smaller) stored charge for a given forward current.

longer

33.11 Diodes that must turn on and off rapidly cannot tolerate a large stored charge. Reducing the minority carrier ________________, reduces the stored charge for a given forward current.

greater

33.12 Carriers crossing the junction to recombine must find imperfections in the semiconductor structure to do so. Some carriers diffuse well beyond the junction before finding ______________________ in the crystal.

lifetime

33.13 The less imperfections near the junction, the longer the minority carrier lifetime. The lifetime of minority carriers may be reduced by adding ______________________ near the junction.

imperfections

33.14 Impurities or imperfections are added near the junction in diodes that must turn on and off rapidly. This reduces the _______________ carrier _________________.

imperfections

33.15** For a given forward current, lifetime of the minority carriers governs the amount of _____________ ____________. Imperfections or impurities are often added near the junction to reduce the _______________ ______________ _________________.

minority
lifetime

33.16 END OF SET

stored charge
minority carrier lifetime

SELF TEST

Study each question carefully, including any diagrams provided, and select the most correct answer.

1. Electrons exist in energy levels about the nucleus of an atom. An electron that gives up some of its energy will move to an orbit __________ to/from the nucleus.

   a. farther
   b. 90 degrees
   c. 45 degrees
   d. closer
   e. at right angles

2. Atoms in structures are bonded together in the __________ __________ band.

   a. conduction energy
   b. valence energy
   c. nucleus energy
   d. kinetic energy
   e. forbidden energy

3. Atoms in structures can be excited by heat energy. This moves electrons from the __________ band to the __________ band.

   a. valence, conduction
   b. valence, forbidden
   c. conduction, valence
   d. conduction, forbidden
   e. forbidden, conduction

4. The band gap between the valence and conduction band is __________ in conductors and __________ in insulators.

   a. wide, narrow
   b. filled, empty
   c. narrow, wide
   d. empty, narrow
   e. filled, narrow

5. Atoms bonded tightly in a pure covalent bond structure provide carriers of current at room temperature due to __________ energy forming __________ __________ __________.

   a. electrical
      high field emission
   b. kinetic
      accelerated proton action
   c. heat
      fermi tunneling electrons
   d. heat
      hole-electron pairs
   e. electrical
      high potential deceleration

6. Heat energy lowers the resistance of a pure covalent bond structure by providing __________ __________ __________ as current carriers.

   a. holes and electrons
   b. electrons, not holes
   c. holes, not electrons
   d. free excited protons
   e. free light photons

7. Electrons moving between energy bands in a structure must take on or give up energy. The electron gives up its energy in the form of __________.

   a. Kinetic energy
   b. heat
   c. light
   d. both b and c
   e. both a and b

8. Doping intrinsic semiconductor with donor impurities results in forming __________ type semiconductor.

   a. P
   b. N
   c. P and N
   d. junction
   e. intrinsic

9. Doping intrinsic semiconductor with acceptor impurities provides __________ as majority current carriers.

   a. electrons
   b. photons
   c. phonons
   d. holes
   e. protons

10. At room temperature (25°C), there will be __________ as current carriers in N type semiconductor.

   a. electrons
   b. holes
   c. phonons
   d. photons
   e. both a and b

11. Doping a pure semiconductor with donor impurities provides current carriers as a <u>result of the doping process</u> that will travel in the __________ energy band of the material.

   a. valence
   b. equilibrium
   c. fermi
   d. conduction
   e. lowest

12. An increase in temperature will provide more __________ as current carriers in P type semiconductors.

a. electrons
b. holes
c. both a and b
d. both a and b but more of b
e. both a and b but more of a

13. The N and P properties of doped semiconductors are not lost due to forcing electrons in or out of the material since the dopent atoms are immobile and become ____________.

a. hole-electron pairs.
b. ions
c. thermally excited.
d. charged
e. either b or d

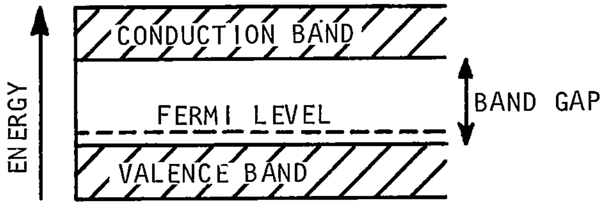
14. Forcing electrons into P material without a path for them to leave results in forming ______________.

a. positive ions
b. negative ions
c. neutral atoms
d. no charge
e. a state of equilibrium

15. The fermi level is the ____________ electron probability level and exists ______________ the valence and conduction bands in an intrinsic semiconductor.

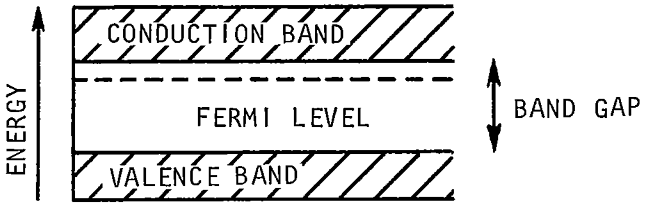
a. 100%, near the bottom of the band gap between
b. 0%, midway in the band gap between
c. 50%, near the top of the band gap between
d. 50%, midway in the bandgap between
e. 100%, near the top of the band gap between

16. The energy band diagram shown indicates ___________ type semiconductor.



a. P
b. intrinsic
c. either a or b
d. N
e. either a or d

17. The energy band diagram shown is a semiconductor material which has had _________________ inpurities added.

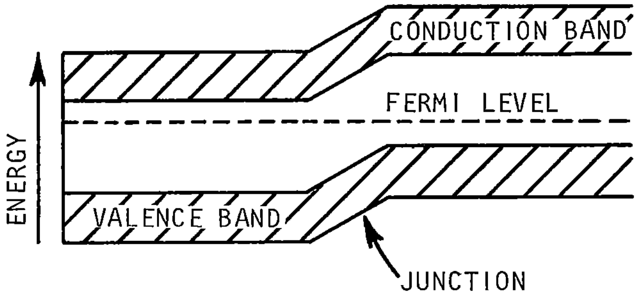


a. acceptor
b. donor
c. N type
d. P type
e. either a or d
f. either b or c

18. When a PN junction is formed, recombination of holes and electrons takes place until ___________ is reached (with no external energy applied).

a. tunneling
b. avalanche
c. equilibrium
d. zener breakdown
e. carrier lifetime

19. The diagram shown indicates a PN junction with __________ bias applied.

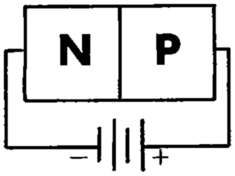


a. 0
b. forward
c. reverse
d. high reverse
e. either c or d

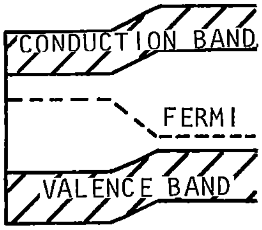
20. In the diagram in question 19, the P material is on the ________ and the N material is on the _________ of the junction shown.

a. left, right
b. top, bottom
c. bottom, top
d. right, left

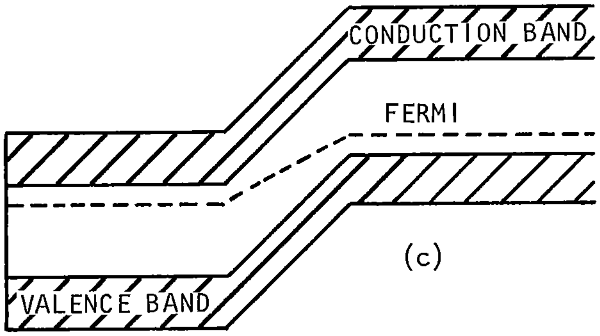
21. The battery in diagram (a) would result in ______________ carriers crossing the junction and the energy band diagram in diagram __________.



(a)



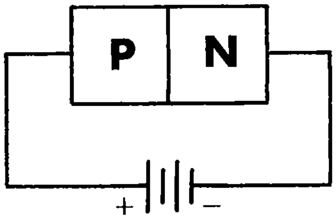
(b)



(c)

a. majority, (c)
b. minority, (b)
c. minority, (c)
d. majority, (b)

22. The external current due to the application of the battery of the polarity shown in the diagram (assuming insufficient voltage to cause breakdown) are the result of _______________ carriers crossing the junction.



a. majority
b. minority

23. The current that flows when reverse bias is applied is primarily carried by carriers which are present as a result of _______________ (after any stored charge has been removed).

a. the formation of hole-electron pairs
b. doping
c. heat energy
d. added impurities
e. either a or c
f. either b or d

24. Holes from the P side and electrons from the N side cross the junction when _______________ bias is applied.

a. forward
b. reverse
c. either a or b

25. The resistance of a reverse biased diode that is not in a breakdown condition, varies ______________.

a. directly with temperature
b. inversely with temperature
c. not at all with temperature
d. sometimes a, sometimes b
e. the surrounding air temperature

26. There are two distinct types of breakdown with reverse bias applied. They are ___________ and ___________.

a. avalanche, zener
b. zener, tunneling
c. zener, thermal
d. tunneling, avalanche
e. either a or d

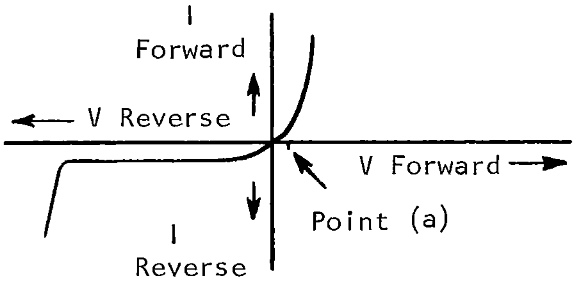
27. The voltage across the terminals of a diode in avalanche breakdown varies ___________ as temperature varies and the voltage across the terminals of a diode in ____________ breakdown varies ___________ as temperature varies.

a. directly, zener, directly
b. inversely, tunneling, directly
c. directly, zener, inversely
d. inversely, zener, directly
e. either b or d

28. An increase in temperature ___________ the voltage level at which tunneling occurs and an increase in temperature ____________ the voltage at which avalanche occurs.

a. reduces, increases
b. increases, increases
c. reduces, reduces
d. increases, reduces

29. The curve shown is a voltage versus current curve for a semiconductor diode. Point (a) is about _________ volts for a silicon diode and about _________ volts for a germanium diode.



a. 7, 3
b. 0.03, 0.07
c. 3, 7
d. 0.7 0.3
e. 0.3, 0.7

30. Carriers recombining in a junction diode release heat energy. The maximum temperature the junction can reach without damage limits ____________.

a. forward voltage times current
b. reverse voltage times current
c. forward and reverse power dissipation
d. all of the above
e. none of the above

31. The opposition offered in the path of heat transfer is termed ____________ ____________ and the symbol assigned is Θ.

a. radiation resistance
b. heat sink
c. radiation conductance
d. thermal resistance
e. thermal radiation

32. A junction diode has the following thermal characteristics: $\Theta_{JC} = 0.8°$ C/W, $\Theta_{CS} = 0.6°$ C/W, $\Theta_{SA} = 1.6°$ C/W, $T_{J\ max} = 150°$ C, $T_A = 60°$C. What is the maximum allowable power dissipation at the junction.

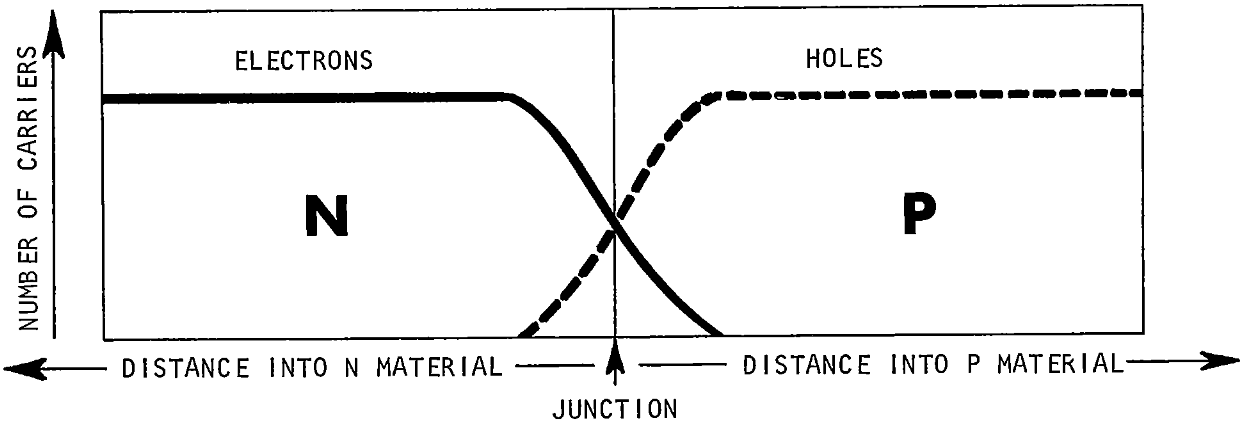
a. 3 watts
b. 10 watts
c. 90 watts
d. 9 watts
e. 30 watts

33. Forward bias applied to a junction moves majority carriers across the junction. Once across the junction, these carriers become ______________.

a. recombined
b. minority carriers
c. holes
d. current in the external circuit
e. majority carriers

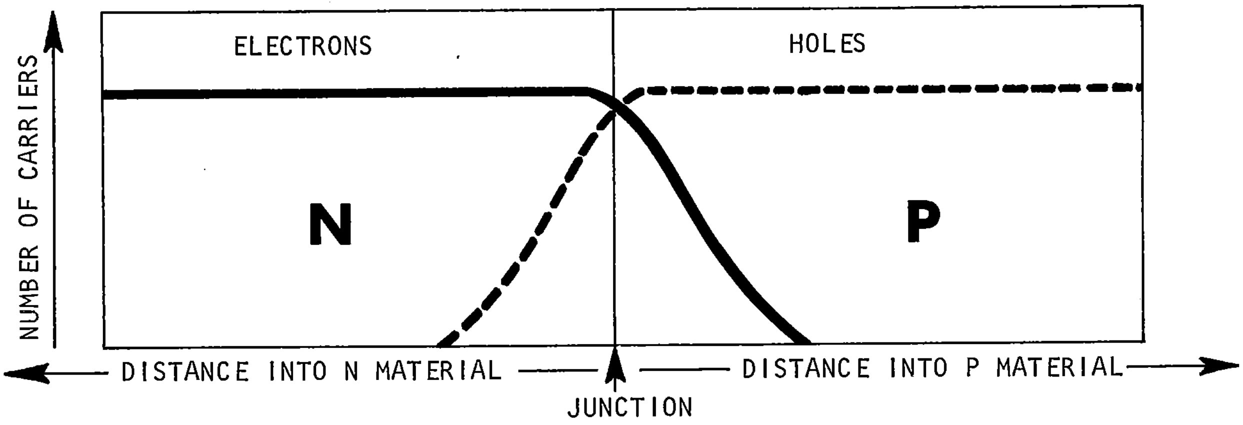
34. Majority carriers that have been moved beyond the junction by forward bias must find impurities before they can recombine. Once across the junction and before recombination occurs, the carriers are existing as ______________ carriers and result in a ______________ about the junction.

a. majority, stored charge
b. electron, ionic charge
c. minority, stored charge
d. majority, ionic charge
e. hole, stored charge



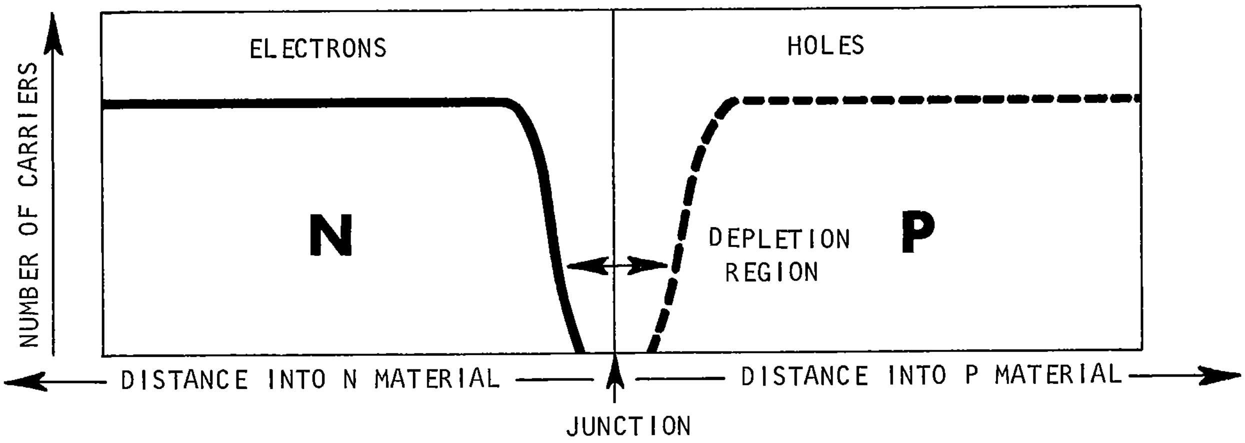
CARRIER DISTRIBUTION DIAGRAM   0 BIAS

FIGURE 31A



CARRIER DISTRIBUTION DIAGRAM   FORWARD BIAS

FIGURE 31B



CARRIER DISTRIBUTION DIAGRAM   REVERSE BIAS

FIGURE 31C
TEST

35. The amount of stored charge about the junction is determined by the amount of forward current and the ___________.

a. minority carrier lifetime
b. majority carrier lifetime
c. junction width time constant
d. thermal time constant
e. minority carrier time constant.

36. In figure 31A, the lines indicating holes in the P side and electrons in the N side extend into the opposite sides of the material indicating the existence of ____________ in the two sides of the junction.

a. current flow
b. minority carriers
c. majority carriers
d. a thermal resistance
e. a thermal time constant

37. The solid and dashed lines in figure 31B show that more holes and electrons have been moved across the junction with forward bias applied. These carriers are existing as ___________ carriers, and represent a ______________________ about the junction.

a. majority, ionic charge
b. majority, stored charge
c. minority, thermal charge
d. minority, stored charge
e. majority, depletion region

38. In figure 31C, the area about the junction is depleted of carriers as a result of applied reverse bias. To change from the condition in figure 31B to the condition in 31C, the ___________ must be removed.

a. donor impurities
b. bias source
c. stored charge
d. impurities near the junction
e. ions in the two sides

39. Impurities may be added near the junction to reduce the _________ and the ___________ for a given forward current.

a. minority carrier lifetime, stored charge
b. majority carrier transit time, junction voltage
c. junction voltage, power dissipation
d. junction voltage, junction temperature

40. τ_q is given in __________ per ___________ and can be used to calculate ___________.

a. pico-farads, volt, junction capacity
b. pico-coulombs, milli-ampere, stored charge
c. nano-seconds, centimeter, risetime
d. pico-seconds, μinch, recovery time

ANSWER MASTER

SELF TEST

1. d
2. b
3. a
4. c
5. d
6. a
7. d
8. b
9. d
10. e
11. d
12. c
13. e
14. b
15. d
16. a
17. f
18. c
19. a
20. d
21. d
22. a
23. e
24. a
25. b
26. e
27. c
28. a
29. d
30. d
31. d
32. e
33. b
34. c
35. a
36. b
37. d
38. c
39. a
40. b

VOL
1

SEMICONDUCTOR DIODES & TRANSISTORS

BASICS

P. I.