Chapter 41: CONDUCTION OF ELECTRICITY IN SOLIDS

1. In a pure metal the collisions that are characterized by the mean free time τ in the expression for the resistivity are chiefly between:

   A. electrons and other electrons
   B. electrons with energy about equal to the Fermi energy and atoms
   C. all electrons and atoms
   D. electrons with energy much less than the Fermi energy and atoms
   E. atoms and other atoms

   ans: B

   Section: 41–2; Difficulty: E

2. A certain metal has 5.3×10^{29} conduction electrons/m^3 and an electrical resistivity of $1.9 \times 10^{-9}\,\Omega \cdot \mathrm{m}$. The average time between collisions of electrons with atoms in the metal is:

   A. 5.6×10^{-33} s
   B. 1.3×10^{-31} s
   C. 9.9×10^{-22} s
   D. 4.6×10^{-15} s
   E. 3.5×10^{-14} s

   ans: C

   Section: 41–2; Difficulty: E

3. The number density n of conduction electrons, the resistivity ρ, and the temperature coefficient of resistivity α are given below for five materials. Which is a semiconductor?

   A. $n = 10^{29}\,\mathrm{m}^{-3}$, $\rho = 10^{-8}\,\Omega \cdot \mathrm{m}$, $\alpha = +10^{-3}\,\mathrm{K}^{-1}$
   B. $n = 10^{28}\,\mathrm{m}^{-3}$, $\rho = 10^{-9}\,\Omega \cdot \mathrm{m}$, $\alpha = -10^{-3}\,\mathrm{K}^{-1}$
   C. $n = 10^{28}\,\mathrm{m}^{-3}$, $\rho = 10^{-9}\,\Omega \cdot \mathrm{m}$, $\alpha = +10^{-3}\,\mathrm{K}^{-1}$
   D. $n = 10^{15}\,\mathrm{m}^{-3}$, $\rho = 10^{3}\,\Omega \cdot \mathrm{m}$, $\alpha = -10^{-2}\,\mathrm{K}^{-1}$
   E. $n = 10^{15}\,\mathrm{m}^{-3}$, $\rho = 10^{-7}\,\Omega \cdot \mathrm{m}$, $\alpha = +10^{-3}\,\mathrm{K}^{-1}$

   ans: D

   Section: 41–2; Difficulty: E

4. A certain material has a resistivity of $7.8 \times 10^{3}\,\Omega \cdot \mathrm{m}$ at room temperature and it increases as the temperature is raised by 100° C. The material is most likely:

   A. a metal
   B. a pure semiconductor
   C. a heavily doped semiconductor
   D. an insulator
   E. none of the above

   ans: C

   Section: 41–2; Difficulty: E

5. A certain material has a resistivity of $7.8 \times 10^3\,\Omega \cdot \mathrm{m}$ at room temperature and it decreases as the temperature is raised by 100° C. The material is most likely:
   A. a metal
   B. a pure semiconductor
   C. a heavily doped semiconductor
   D. an insulator
   E. none of the above

   ans: B

   Section: 41–2; Difficulty: E

6. A certain material has a resistivity of $7.8 \times 10^{-8}\,\Omega \cdot \mathrm{m}$ at room temperature and it increases as the temperature is raised by 100° C. The material is most likely:
   A. a metal
   B. a pure semiconductor
   C. a heavily doped semiconductor
   D. an insulator
   E. none of the above

   ans: A

   Section: 41–2; Difficulty: E

7. The energy gap (in eV) between the valence and conduction bands of an insulator is of the order of:
   A. 10^{-19}
   B. 0.001
   C. 0.1
   D. 10
   E. 1000

   ans: D

   Section: 41–4; Difficulty: E

8. Electrons in a full band do not contribute to the current when an electric field exists in a solid because:
   A. the field cannot exert a force on them
   B. the individual contributions cancel each other
   C. they are not moving
   D. they make transitions to other bands
   E. they leave the solid

   ans: B

   Section: 41–4; Difficulty: E

9. Which one of the following statements concerning electron energy bands in solids is true?
   A. The bands occur as a direct consequence of the Fermi-Dirac occupancy probability function
   B. Electrical conduction arises from the motion of electrons in completely filled bands
   C. Within a given band, all electron energy levels are equal to each other
   D. An insulator has a large energy separation between the highest filled band and the lowest empty band
   E. Only insulators have energy bands

   ans: D

   Section: 41–3, 4; Difficulty: E

10. If E_0 and E_T are the average energies of the "free" electrons in a metal at 0 K and room temperature, respectively, then the ratio E_T/E_0 is approximately:
    A. 0
    B. 1
    C. 100
    D. 10^6
    E. infinity

    ans: B

    Section: 41–5; Difficulty: E

11. Possible units for the density of states function $N(E)$ are:
    A. J/m^3
    B. $1/J$
    C. m^{-3}
    D. $J^{-1} \cdot m^{-3}$
    E. kg/m^3

    ans: D

    Section: 41–5; Difficulty: E

12. The density of states for a metal depends primarily on:
    A. the temperature
    B. the energy
    C. the density of the metal
    D. the volume of the sample
    E. none of these

    ans: B

    Section: 41–5; Difficulty: E

13. The Fermi-Dirac occupancy probability $P(E)$ varies between:
    A. 0 and 1
    B. 0 and infinity
    C. 1 and infinity
    D. -1 and 1
    E. 0 and E_F

    ans: A

    Section: 41–5; Difficulty: E

14. For a metal at absolute temperature T, with Fermi energy E_F, the occupancy probability is given by:
   A. $e^{(E-E_F)/kT}$
   B. $e^{-(E-E_F)/kT}$
   C. $\dfrac{1}{e^{(E-E_F)/kT}+1}$
   D. $\dfrac{1}{e^{-(E-E_F)/kT}+1}$
   E. $\dfrac{1}{e^{(E-E_F)/kT}-1}$
   ans: C
   Section: 41–5; Difficulty: E

15. In a metal at 0 K, the Fermi energy is:
   A. the highest energy of any electron
   B. the lowest energy of any electron
   C. the mean thermal energy of the electrons
   D. the energy of the top of the valence band
   E. the energy at the bottom of the conduction band
   ans: A
   Section: 41–5; Difficulty: E

16. The occupancy probability for a state with energy equal to the Fermi energy is:
   A. 0
   B. 0.5
   C. 1
   D. 1.5
   E. 2
   ans: B
   Section: 41–5; Difficulty: M

17. The Fermi energy of a metal depends primarily on:
   A. the temperature
   B. the volume of the sample
   C. the mass density of the metal
   D. the size of the sample
   E. the number density of conduction electrons
   ans: E
   Section: 41–5; Difficulty: E

18. The speed of an electron with energy equal to the Fermi energy for copper is on the order of:
   A. 10^6 m/s
   B. 10^{-6} m/s
   C. 10 m/s
   D. 10^{-1} m/s
   E. 10^9 m/s
   ans: A
   Section: 41–5; Difficulty: M

19. At $T = 0\,\mathrm{K}$ the probability that a state $0.50\,\mathrm{eV}$ below the Fermi level is occupied is:
   A. 0
   B. 5.0×10^{-9}
   C. 5.0×10^{-6}
   D. 5.0×10^{-3}
   E. 1

   ans: E
   Section: 41–5; Difficulty: M

20. At $T = 0\,\mathrm{K}$ the probability that a state $0.50\,\mathrm{eV}$ above the Fermi level is occupied is:
   A. 0
   B. 5.0×10^{-9}
   C. 5.0×10^{-6}
   D. 5.0×10^{-3}
   E. 1

   ans: A
   Section: 41–5; Difficulty: M

21. At room temperature kT is about $0.0259\,\mathrm{eV}$. The probability that a state $0.50\,\mathrm{eV}$ above the Fermi level is occupied at room temperature is:
   A. 1
   B. 0.05
   C. 0.025
   D. 5.0×10^{-6}
   E. 4.1×10^{-9}

   ans: E
   Section: 41–5; Difficulty: M

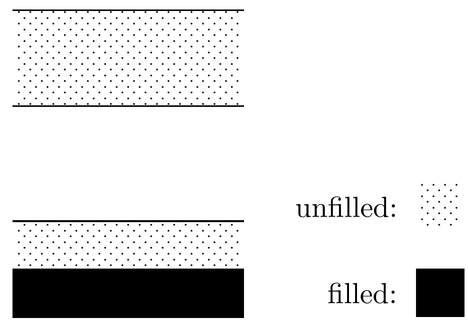
22. At room temperature kT is about $0.0259\,\mathrm{eV}$. The probability that a state $0.50\,\mathrm{eV}$ below the Fermi level is unoccupied at room temperature is:
   A. 1
   B. 0.05
   C. 0.025
   D. 5.0×10^{-6}
   E. 4.1×10^{-9}

   ans: E
   Section: 41–5; Difficulty: M

23. If the density of states is $N(E)$ and the occupancy probability is $P(E)$, then the density of occupied states is:
   A. $N(E) + P(E)$
   B. $N(E)/P(E)$
   C. $N(E) - P(E)$
   D. $N(E)P(E)$
   E. $P(E)/N(E)$

   ans: D
   Section: 41–5; Difficulty: M

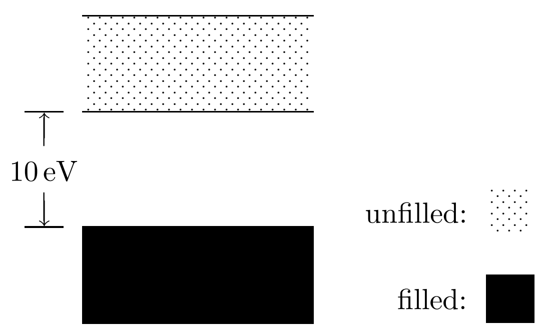
24. The energy level diagram shown applies to:



A. a conductor
B. an insulator
C. a semiconductor
D. an isolated molecule
E. an isolated atom

ans: A
Section: 41–3, 4, 5; Difficulty: E

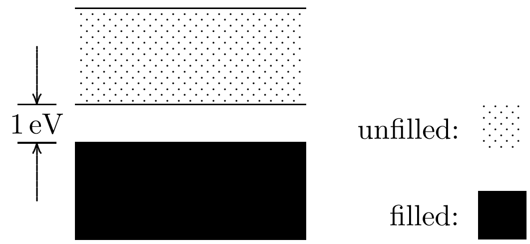
25. The energy level diagram shown applies to:



A. a conductor
B. an insulator
C. a semiconductor
D. an isolated atom
E. a free-electron gas

ans: B
Section: 41–3, 4, 5; Difficulty: E

26. The energy level diagram shown applies to:



A. a conductor
B. an insulator
C. a semiconductor
D. an isolated molecule
E. an isolated atom

ans: C

Section: 41–3, 4, 5; Difficulty: E

27. A hole refers to:

A. a proton
B. a positively charged electron
C. an electron that has somehow lost its charge
D. a microscopic defect in a solid
E. the absence of an electron in an otherwise filled band

ans: E

Section: 41–6; Difficulty: E

28. For a pure semiconductor the Fermi level is:

A. in the conduction band
B. well above the conduction band
C. in the valence band
D. well below the valence band
E. near the center of the gap between the valence and conduction bands

ans: E

Section: 41–6; Difficulty: E

29. A pure semiconductor at room temperature has:

A. more electrons/m^3 in its conduction band than holes/m^3 in its valence band
B. more electrons/m^3 in its conduction band than a typical metal
C. more electrons/m^3 in its valence band than at $T = 0\,\mathrm{K}$
D. more holes/m^3 in its valence band than electrons/m^3 in its valence band
E. none of the above

ans: E

Section: 41–6; Difficulty: E

30. For a metal at room temperature the temperature coefficient of resistivity is determined primarily by:

A. the number of electrons in the conduction band
B. the number of impurity atoms
C. the binding energy of outer shell electrons
D. collisions between conduction electrons and atoms
E. none of the above

ans: D
Section: 41–6; Difficulty: E

31. For a pure semiconductor at room temperature the temperature coefficient of resistivity is determined primarily by:

A. the number of electrons in the conduction band
B. the number of replacement atoms
C. the binding energy of outer shell electrons
D. collisions between conduction electrons and atoms
E. none of the above

ans: A
Section: 41–6; Difficulty: E

32. Donor atoms introduced into a pure semiconductor at room temperature:

A. increase the number of electrons in the conduction band
B. increase the number of holes in the valence band
C. lower the Fermi level
D. increase the electrical resistivity
E. none of the above

ans: A
Section: 41–7; Difficulty: E

33. Acceptor atoms introduced into a pure semiconductor at room temperature:

A. increase the number of electrons in the conduction band
B. increase the number of holes in the valence band
C. raise the Fermi level
D. increase the electrical resistivity
E. none of the above

ans: B
Section: 41–7; Difficulty: E

34. An acceptor replacement atom in silicon might have ______ electrons in its outer shell.

A. 3
B. 4
C. 5
D. 6
E. 7

ans: A
Section: 41–7; Difficulty: E

35. A donor replacement atom in silicon might have _____ electrons in its outer shell.

A. 1
B. 2
C. 3
D. 4
E. 5

ans: E

Section: 41–7; Difficulty: E

36. A given doped semiconductor can be identified as p or n type by:

A. measuring its electrical conductivity
B. measuring its magnetic susceptibility
C. measuring its coefficient of resistivity
D. measuring its heat capacity
E. performing a Hall effect experiment

ans: E

Section: 41–7; Difficulty: E

37. The contact electric field in the depletion region of a p-n junction is produced by:

A. electrons in the conduction band alone
B. holes in the valence band alone
C. electrons and holes together
D. charged replacement atoms
E. an applied bias potential difference

ans: D

Section: 41–8; Difficulty: E

38. For an unbiased p-n junction, the energy at the bottom of the conduction band on the n side is:

A. higher than the energy at the bottom of the conduction band on the p side
B. lower than the energy at the bottom of the conduction band on the p side
C. lower than the energy at the top of the valence band on the n side
D. lower than the energy at the top of the valence band on the p side
E. the same as the energy at the bottom of the conduction band on the p side

ans: B

Section: 41–8; Difficulty: E

39. In an unbiased p-n junction:

A. the electric potential vanishes everywhere
B. the electric field vanishes everywhere
C. the drift current vanishes everywhere
D. the diffusion current vanishes everywhere
E. the diffusion and drift currents cancel each other

ans: E

Section: 41–8; Difficulty: E

40. Application of a forward bias to a p-n junction:
    A. narrows the depletion zone
    B. increases the electric field in the depletion zone
    C. increases the potential difference across the depletion zone
    D. increases the number of donors on the n side
    E. decreases the number of donors on the n side

    ans: A

    Section: 41–8; Difficulty: E

41. Application of a forward bias to a p-n junction:
    A. increases the drift current in the depletion zone
    B. increases the diffusion current in the depletion zone
    C. decreases the drift current on the p side outside the depletion zone
    D. decreases the drift current on the n side outside the depletion zone
    E. does not change the current anywhere

    ans: B

    Section: 41–8; Difficulty: E

42. When a forward bias is applied to a p-n junction the concentration of electrons on the p side:
    A. increases slightly
    B. increases dramatically
    C. decreases slightly
    D. decreases dramatically
    E. does not change

    ans: B

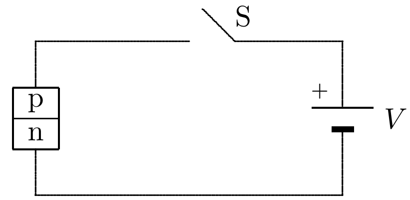
    Section: 41–8; Difficulty: E

43. Which of the following is NOT true when a back bias is applied to a p-n junction?
    A. Electrons flow from the p to the n side
    B. Holes flow from the p to the n side
    C. The electric field in the depletion zone increases
    D. The potential difference across the depletion zone increases
    E. The depletion zone narrows

    ans: B

    Section: 41–8; Difficulty: E

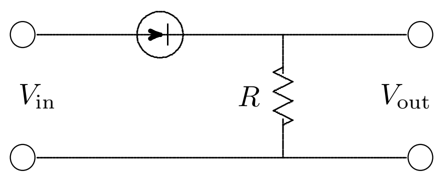
44. Switch S is closed to apply a potential difference V across a p-n junction as shown. Relative to the energy levels of the n-type material, with the switch open, the electron levels of the p-type material are:

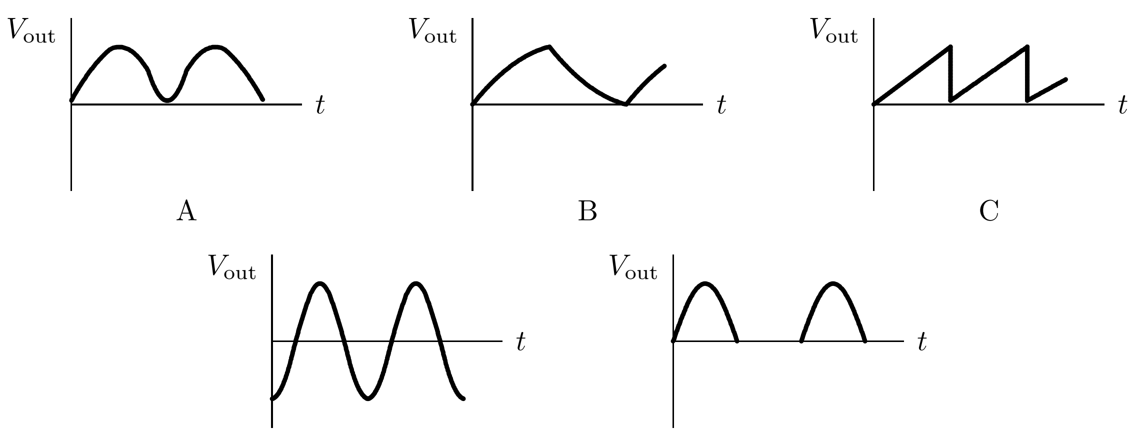


A. unchanged
B. lowered by the amount $e^{-Ve/kT}$
C. lowered by the amount Ve
D. raised by the amount $e^{-Ve/kT}$
E. raised by the amount Ve

ans: C
Section: 41–8; Difficulty: E

45. A sinusoidal potential difference $V_{\text{in}} = V_m \sin(\omega t)$ is applied to the p-n junction as shown. Which graph correctly shows V_{out} as a function of time?





ans: E
Section: 41–9; Difficulty: E

46. "LED" stands for:

A. Less Energy Donated
B. Light Energy Degrader
C. Luminescent Energy Developer
D. Laser Energy Detonator
E. none of the above

ans: E

Section: 41–10; Difficulty: E

47. A light emitting diode emits light when:

A. electrons are excited from the valence to the conduction band
B. electrons from the conduction band recombine with holes from the valence band
C. electrons collide with atoms
D. electrons are accelerated by the electric field in the depletion region
E. the junction gets hot

ans: B

Section: 41–10; Difficulty: E

48. The gap between the valence and conduction bands of a certain semiconductor is $0.85\,\mathrm{eV}$. When this semiconductor is used to form a light emitting diode, the wavelength of the light emitted:

A. is in a range above $1.5 \times 10^{-6}\,\mathrm{m}$
B. is in a range below $1.5 \times 10^{-6}\,\mathrm{m}$
C. is always $1.5 \times 10^{-6}\,\mathrm{m}$
D. is in a range centered on $1.5 \times 10^{-6}\,\mathrm{m}$
E. has nothing to do with the gap

ans: B

Section: 41–10; Difficulty: M