

Chapter 3

3.1

Diagram (a) shows a Karnaugh map for the function $F = xy + x'z'$. The map is a 2x4 grid with rows labeled x (0, 1) and columns labeled yz (00, 01, 11, 10). The cells are labeled m_0 through m_7 . The cells m_0 (00, 0), m_1 (01, 0), m_3 (11, 0), and m_2 (10, 0) are shaded. The cells m_4 (00, 1), m_5 (01, 1), m_7 (11, 1), and m_6 (10, 1) are also shaded. The shaded cells form two groups: a group of four cells in the top row (m_0, m_1, m_3, m_2) and a group of four cells in the bottom row (m_4, m_5, m_7, m_6).

(a) $F = xy + x'z'$

Diagram (b) shows a Karnaugh map for the function $F = z' + x'y$. The map is a 2x4 grid with rows labeled x (0, 1) and columns labeled yz (00, 01, 11, 10). The cells are labeled m_0 through m_7 . The cells m_0 (00, 0), m_1 (01, 0), m_3 (11, 0), and m_2 (10, 0) are shaded. The cells m_4 (00, 1), m_5 (01, 1), m_7 (11, 1), and m_6 (10, 1) are also shaded. The shaded cells form two groups: a group of four cells in the top row (m_0, m_1, m_3, m_2) and a group of four cells in the bottom row (m_4, m_5, m_7, m_6).

(b) $F = z' + x'y$

Diagram (c) shows a Karnaugh map for the function $F = x' + yz$. The map is a 2x4 grid with rows labeled x (0, 1) and columns labeled yz (00, 01, 11, 10). The cells are labeled m_0 through m_7 . The cells m_0 (00, 0), m_1 (01, 0), m_3 (11, 0), and m_2 (10, 0) are shaded. The cells m_4 (00, 1), m_5 (01, 1), m_7 (11, 1), and m_6 (10, 1) are also shaded. The shaded cells form two groups: a group of four cells in the top row (m_0, m_1, m_3, m_2) and a group of four cells in the bottom row (m_4, m_5, m_7, m_6).

(c) $F = x' + yz$

Diagram (d) shows a Karnaugh map for the function $F = xy + xz + yz$. The map is a 2x4 grid with rows labeled x (0, 1) and columns labeled yz (00, 01, 11, 10). The cells are labeled m_0 through m_7 . The cells m_0 (00, 0), m_1 (01, 0), m_3 (11, 0), and m_2 (10, 0) are shaded. The cells m_4 (00, 1), m_5 (01, 1), m_7 (11, 1), and m_6 (10, 1) are also shaded. The shaded cells form two groups: a group of four cells in the top row (m_0, m_1, m_3, m_2) and a group of four cells in the bottom row (m_4, m_5, m_7, m_6).

(d) $F = xy + xz + yz$

3.2

Diagram (a) shows a Karnaugh map for the function $F = x'y' + xz$. The map is a 2x4 grid with rows labeled x (0, 1) and columns labeled yz (00, 01, 11, 10). The cells are labeled m_0 through m_7 . The cells m_0 (00, 0), m_1 (01, 0), m_3 (11, 0), and m_2 (10, 0) are shaded. The cells m_4 (00, 1), m_5 (01, 1), m_7 (11, 1), and m_6 (10, 1) are also shaded. The shaded cells form two groups: a group of four cells in the top row (m_0, m_1, m_3, m_2) and a group of four cells in the bottom row (m_4, m_5, m_7, m_6).

(a) $F = x'y' + xz$

Diagram (b) shows a Karnaugh map for the function $F = y + x'z$. The map is a 2x4 grid with rows labeled x (0, 1) and columns labeled yz (00, 01, 11, 10). The cells are labeled m_0 through m_7 . The cells m_0 (00, 0), m_1 (01, 0), m_3 (11, 0), and m_2 (10, 0) are shaded. The cells m_4 (00, 1), m_5 (01, 1), m_7 (11, 1), and m_6 (10, 1) are also shaded. The shaded cells form two groups: a group of four cells in the top row (m_0, m_1, m_3, m_2) and a group of four cells in the bottom row (m_4, m_5, m_7, m_6).

(b) $F = y + x'z$

Diagram (c) shows a Karnaugh map for the function $F = x'y' + xy$. The map is a 2x4 grid with rows labeled x (0, 1) and columns labeled yz (00, 01, 11, 10). The cells are labeled m_0 through m_7 . The cells m_0 (00, 0), m_1 (01, 0), m_3 (11, 0), and m_2 (10, 0) are shaded. The cells m_4 (00, 1), m_5 (01, 1), m_7 (11, 1), and m_6 (10, 1) are also shaded. The shaded cells form two groups: a group of four cells in the top row (m_0, m_1, m_3, m_2) and a group of four cells in the bottom row (m_4, m_5, m_7, m_6).

(c) $F = x'y' + xy$

Diagram (d) shows a Karnaugh map for the function $F = y' + x'z$. The map is a 2x4 grid with rows labeled x (0, 1) and columns labeled yz (00, 01, 11, 10). The cells are labeled m_0 through m_7 . The cells m_0 (00, 0), m_1 (01, 0), m_3 (11, 0), and m_2 (10, 0) are shaded. The cells m_4 (00, 1), m_5 (01, 1), m_7 (11, 1), and m_6 (10, 1) are also shaded. The shaded cells form two groups: a group of four cells in the top row (m_0, m_1, m_3, m_2) and a group of four cells in the bottom row (m_4, m_5, m_7, m_6).

(d) $F = y' + x'z$

| | | | | | | | |
|-----|---|-------|--|-----|----|----|----|
| | | yz | | y | | | |
| | | x | | 00 | 01 | 11 | 10 |
| x | 0 | m_0 | | | 1 | 1 | |
| | 1 | m_4 | | | 1 | 1 | |
| | | | | z | | | |

(e) $F = z$

| | | | | | | | |
|-----|---|-------|--|-----|----|----|----|
| | | yz | | y | | | |
| | | x | | 00 | 01 | 11 | 10 |
| x | 0 | m_0 | | | 1 | | |
| | 1 | m_4 | | 1 | 1 | 1 | 1 |
| | | | | z | | | |

(f) $F = x + y'z$

3.3

| | | | | | | | |
|-----|---|-------|--|-----|----|----|----|
| | | yz | | y | | | |
| | | x | | 00 | 01 | 11 | 10 |
| x | 0 | m_0 | | 1 | | | 1 |
| | 1 | m_4 | | | | 1 | 1 |
| | | | | z | | | |

(a) $F = xy + x'y'z' + x'yz'$
 $F = xy + x'z'$

| | | | | | | | |
|-----|---|-------|--|-----|----|----|----|
| | | yz | | y | | | |
| | | x | | 00 | 01 | 11 | 10 |
| x | 0 | m_0 | | 1 | 1 | 1 | 1 |
| | 1 | m_4 | | | | 1 | |
| | | | | z | | | |

(b) $F = x'y' + yz + x'yz'$
 $F = x' + yz$

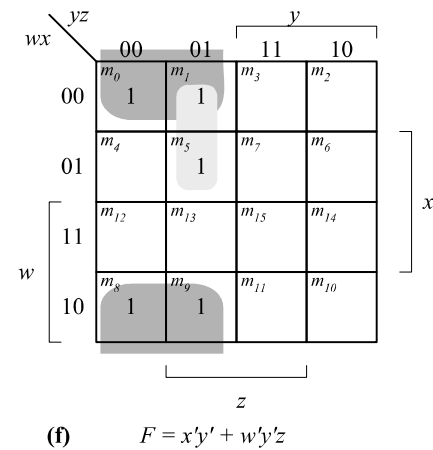
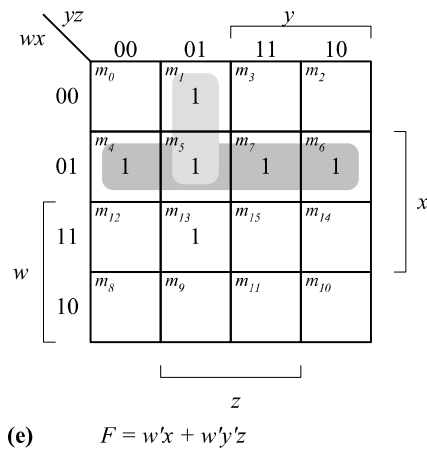
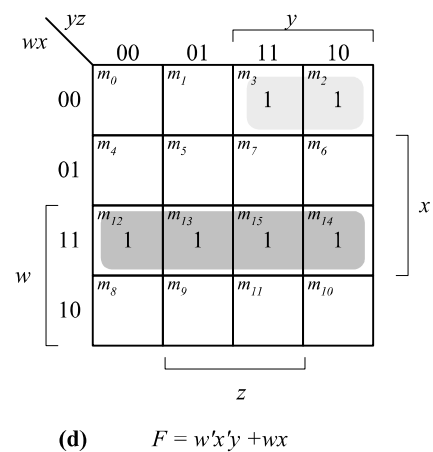
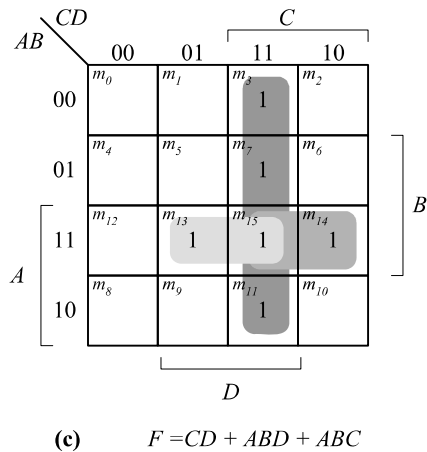
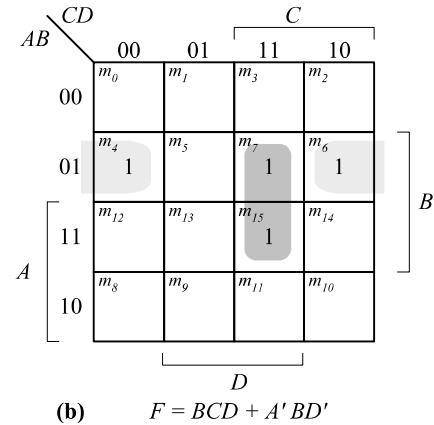
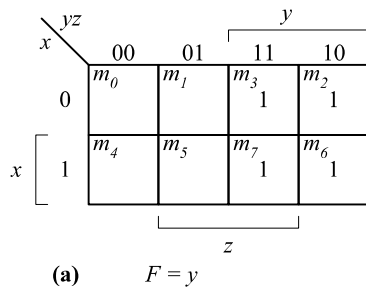
| | | | | | | | |
|-----|---|-------|--|-----|----|----|----|
| | | yz | | y | | | |
| | | x | | 00 | 01 | 11 | 10 |
| x | 0 | m_0 | | 1 | | 1 | 1 |
| | 1 | m_4 | | 1 | | | 1 |
| | | | | z | | | |

(c) $F = x'y + yz' + y'z'$
 $F = x'y + z'$

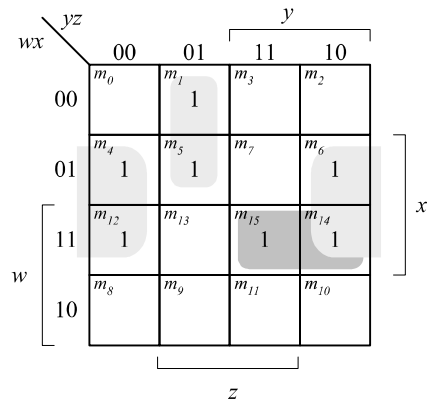
| | | | | | | | |
|-----|---|-------|--|-----|----|----|----|
| | | yz | | y | | | |
| | | x | | 00 | 01 | 11 | 10 |
| x | 0 | m_0 | | | 1 | | |
| | 1 | m_4 | | | | 1 | 1 |
| | | | | z | | | |

(d) $F = xyz + x'y'z + xyz'$
 $F = x'y'z + xy$

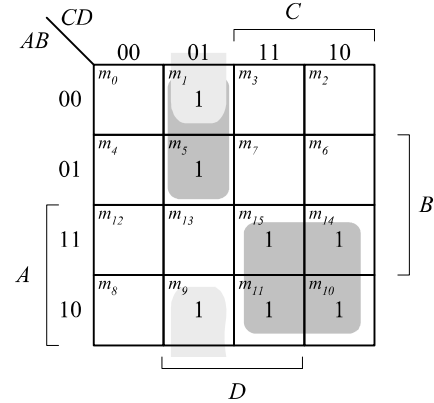
3.4



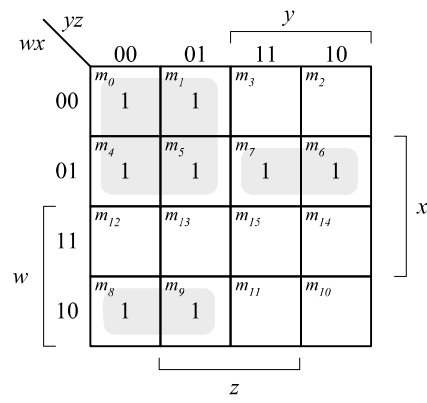
3.5



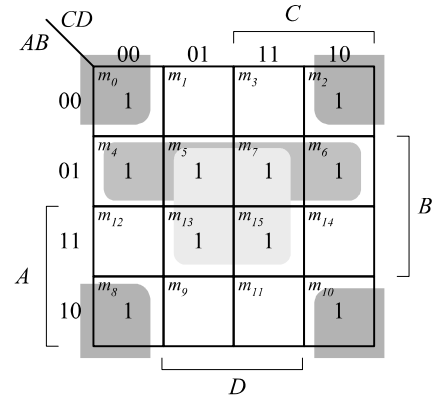
(a) $F = xz' + w'y'z + wxxy$



(b) $F = A'C + A'C'D + B'C'D$

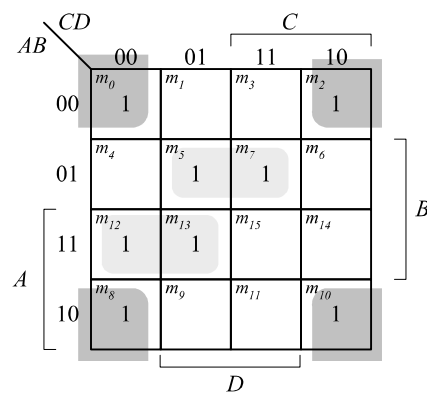


(c) $F = w'y' + wx'y' + w'xy$

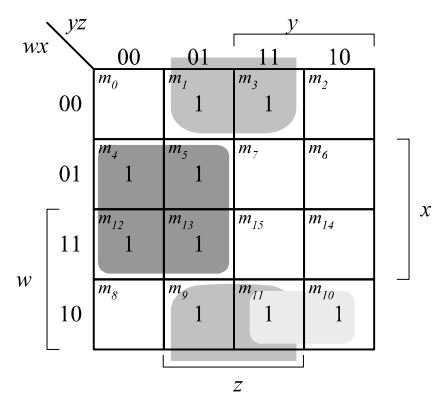


(d) $F = BD + A'B + B'D'$
or $F = BD + B'D' + A'D'$

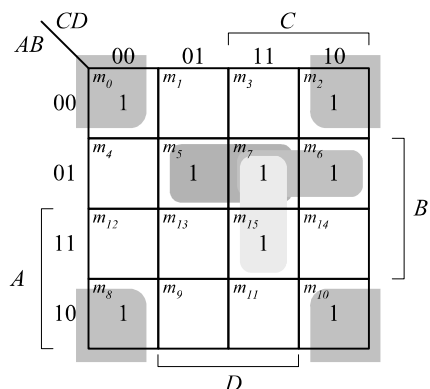
3.6



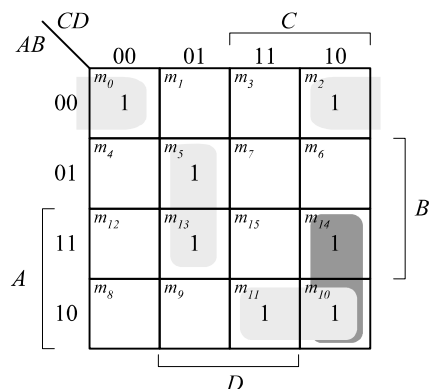
(a) $F = B'D' + A'BD + ABC'$



(b) $F = xy' + x'z + wx'y$

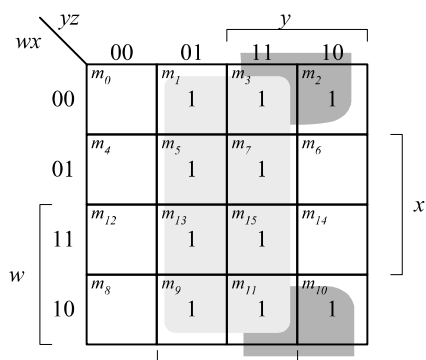


(c) $F = B'D' + BCD + A'BD + A'BC$

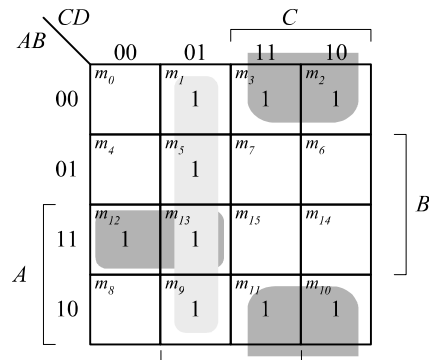


(d) $F = A'B'D' + BC'D + ACD' + AB'C$

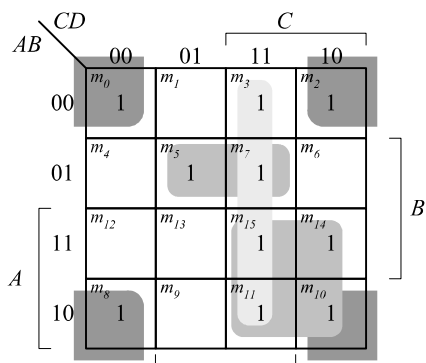
3.7



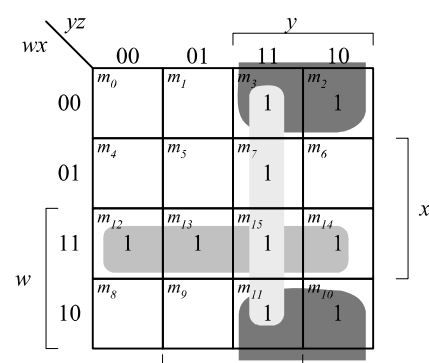
(a) $F = z + x'y$



(b) $F = C'D + B'C + ABC'$



(c) $F = B'D' + AC + A'BD + CD$ (or $B'C$)



(d) $F = wx + x'y + yz$

3.8

(a) $F(x, y, z) = \Sigma(3, 5, 6, 7)$

| | | y | | | |
|---|---|-------|-------|-------|-------|
| | | 00 | 01 | 11 | 10 |
| x | 0 | m_0 | m_1 | m_3 | m_2 |
| | 1 | m_4 | m_5 | m_7 | m_6 |

z

(b) $F = \Sigma(1, 3, 5, 9, 12, 13, 14)$

| | | C | | | |
|---|----|----------|----------|----------|----------|
| | | 00 | 01 | 11 | 10 |
| A | 00 | m_0 | m_1 | m_3 | m_2 |
| | 01 | m_4 | m_5 | m_7 | m_6 |
| | 11 | m_{12} | m_{13} | m_{15} | m_{14} |
| | 10 | m_8 | m_9 | m_{11} | m_{10} |

D

(c) $F = \Sigma(0, 1, 2, 3, 11, 12, 14, 15)$

| | | y | | | |
|---|----|----------|----------|----------|----------|
| | | 00 | 01 | 11 | 10 |
| w | 00 | m_0 | m_1 | m_3 | m_2 |
| | 01 | m_4 | m_5 | m_7 | m_6 |
| | 11 | m_{12} | m_{13} | m_{15} | m_{14} |
| | 10 | m_8 | m_9 | m_{11} | m_{10} |

z

(d) $F = \Sigma(3, 4, 5, 7, 11, 12)$

| | | | | | |
|------|----|----------|----------|----------|----------|
| | | CD | | | |
| | | C | | | |
| AB | | 00 | 01 | 11 | 10 |
| | 00 | m_0 | m_1 | m_3 | m_2 |
| | 01 | m_4 | m_5 | m_7 | m_6 |
| | 11 | m_{12} | m_{13} | m_{15} | m_{14} |
| A | 10 | m_8 | m_9 | m_{11} | m_{10} |

D

3.9

(a)

| | | | | | |
|------|----|----------|----------|----------|----------|
| | | yz | | | |
| | | y | | | |
| wx | | 00 | 01 | 11 | 10 |
| | 00 | m_0 | m_1 | m_3 | m_2 |
| | 01 | m_4 | m_5 | m_7 | m_6 |
| | 11 | m_{12} | m_{13} | m_{15} | m_{14} |
| w | 10 | m_8 | m_9 | m_{11} | m_{10} |

z

Essential: $xz, x'z'$
Non-essential: $w'x, w'z'$
 $F = xz + x'z' + (w'x \text{ or } w'z')$

(b)

| | | | | | |
|------|----|----------|----------|----------|----------|
| | | CD | | | |
| | | C | | | |
| AB | | 00 | 01 | 11 | 10 |
| | 00 | m_0 | m_1 | m_3 | m_2 |
| | 01 | m_4 | m_5 | m_7 | m_6 |
| | 11 | m_{12} | m_{13} | m_{15} | m_{14} |
| A | 10 | m_8 | m_9 | m_{11} | m_{10} |

D

Essential: $B'D', AC, A'BD$
Non-essential: $CD, B'C$
 $F = B'D' + AC + A'BD + (CD \text{ OR } B'C)$

(c)

| | | | | | |
|------|----|----------|----------|----------|----------|
| | | CD | | | |
| | | C | | | |
| AB | | 00 | 01 | 11 | 10 |
| | 00 | m_0 | m_1 | m_3 | m_2 |
| | 01 | m_4 | m_5 | m_7 | m_6 |
| | 11 | m_{12} | m_{13} | m_{15} | m_{14} |
| A | 10 | m_8 | m_9 | m_{11} | m_{10} |

D

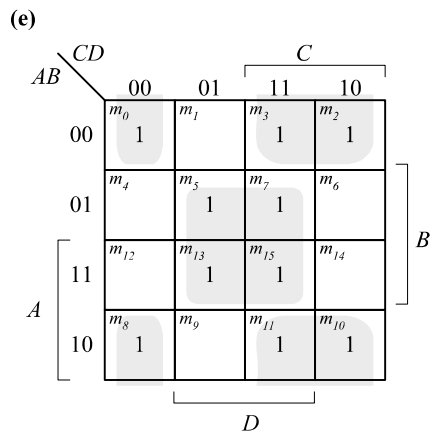
Essential: $BC', AC, A'B'D$
 $F = BC' + AC + A'B'D$

(d)

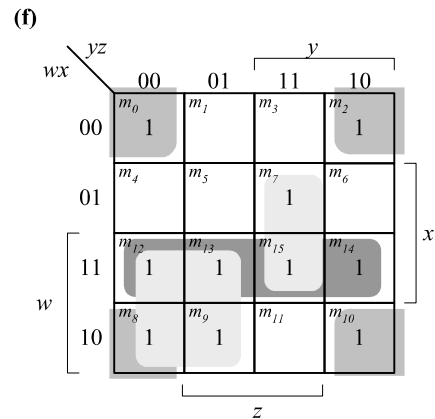
| | | | | | |
|------|----|----------|----------|----------|----------|
| | | yz | | | |
| | | y | | | |
| wx | | 00 | 01 | 11 | 10 |
| | 00 | m_0 | m_1 | m_3 | m_2 |
| | 01 | m_4 | m_5 | m_7 | m_6 |
| | 11 | m_{12} | m_{13} | m_{15} | m_{14} |
| w | 10 | m_8 | m_9 | m_{11} | m_{10} |

z

Essential: $wy', xy, w'x'z$
 $F = wy' + xy + w'x'z$

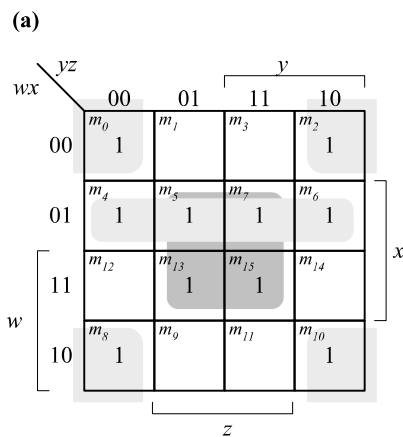


Essential: $BD, B'C, B'C'D'$
 $F = BD + B'C + B'C'D'$

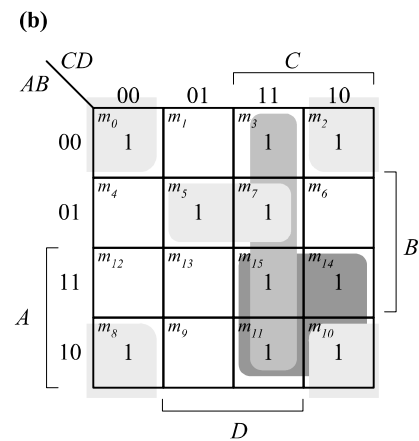


Essential: $wy', wx, x'z', xyz$
 $F = wy' + wx + x'z' + xyz$

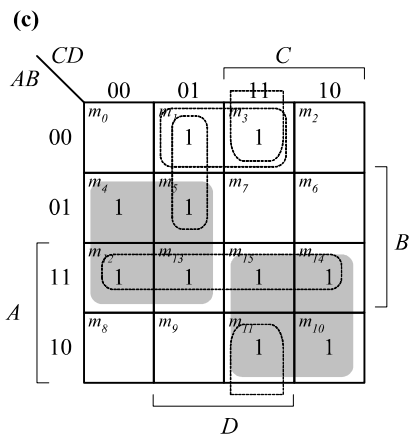
3.10



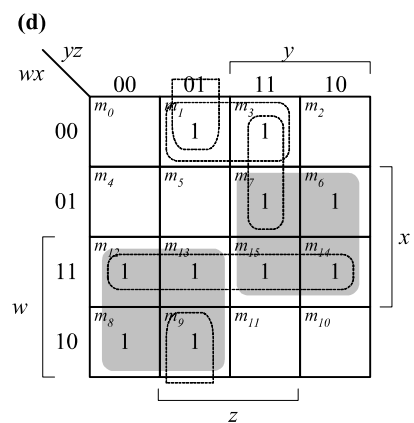
Essential: $xz, w'x, x'z'$
 $F = xz + w'x + x'z'$



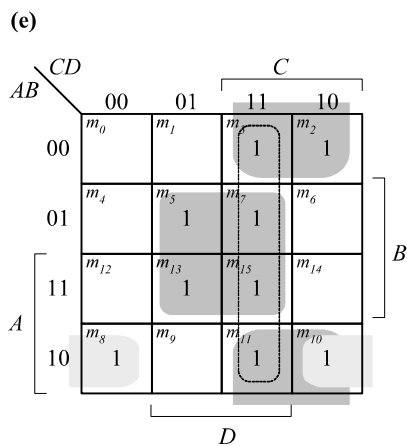
Essential: $AC, B'D', CD, A'BD$
 $F = AC + B'D' + CD + A'BD$



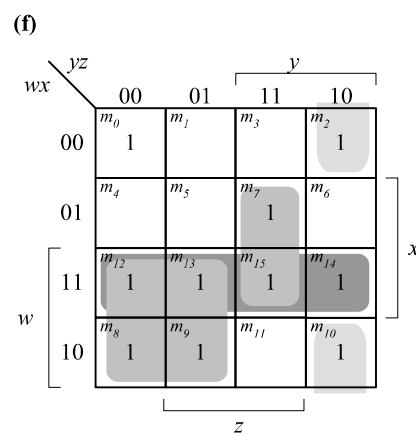
Essential: BC' , AC
Non-essential: AB , $A'B'D$, $B'CD$, $A'C'D$
 $F = BC' + AC + A'B'D$



Essential: wy' , xy
Non-essential: wx , $x'y'z$, $w'wz$, $w'x'z$
 $F = wy' + xy + w'x'z$



Essential: BD , $B'C$, $AB'C$
Non-essential: CD
 $F = BD + B'C + AB'C$

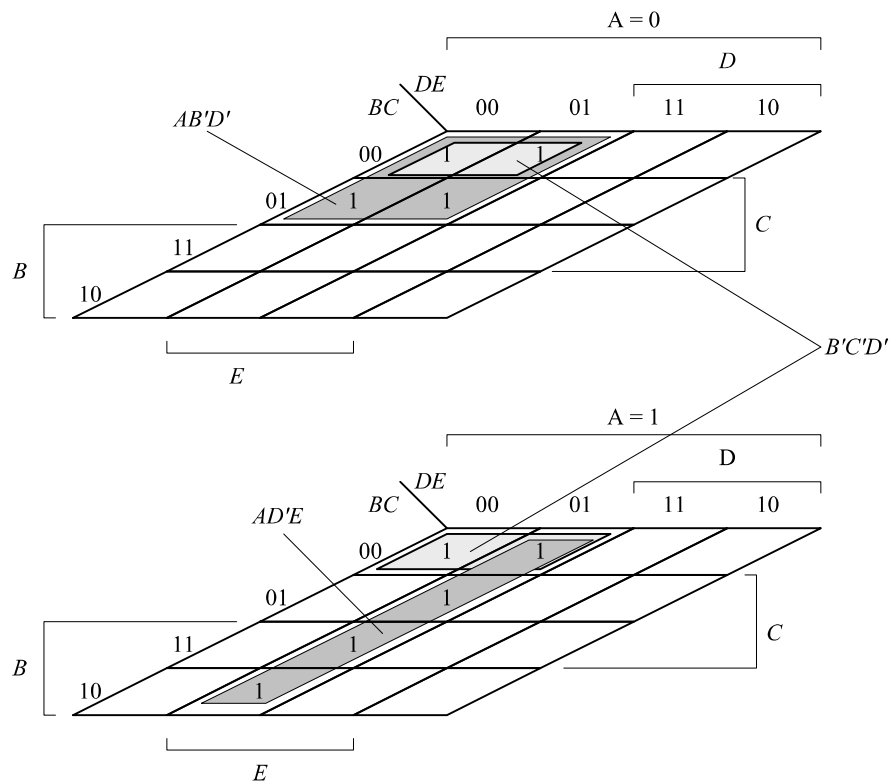


Essential: wy' , wx , xyz , $x'yz'$
 $F = wy' + wx + xyz + x'yz'$

3.11 (a) $F(A, B, C, D, E) = \sum (0, 1, 4, 5, 16, 17, 21, 25, 29)$

$$F = A'B'D' + AD'E + B'C'D'$$

| | | | |
|------------|--------------|---|-------|
| m_0 : | $A'B'C'D'E'$ | = | 00000 |
| m_1 : | $A'B'C'D'E$ | = | 00001 |
| m_4 : | $A'B'CD'E'$ | = | 00100 |
| m_5 : | $A'B'CD'E$ | = | 00101 |
| m_{16} : | $AB'C'D'E'$ | = | 10000 |
| m_{17} : | $AB'C'D'E$ | = | 10001 |
| m_{21} : | $AB'CD'E$ | = | 10101 |
| m_{25} : | $ABC'D'E$ | = | 11001 |
| m_{29} : | $ABCDE$ | = | 11101 |



(b) $F(A, B, C, D, E) = A'B'CE' + B'C'D'E' + A'B'D' + B'CD' + A'CD + A'BD$
 $F(A, B, C, D, E) = A'B'D' + B'D'E' + B'CD' + A'CD + A'BD$

$A'B'CE'$: $AB'CDE' + A'B'CD'E'$

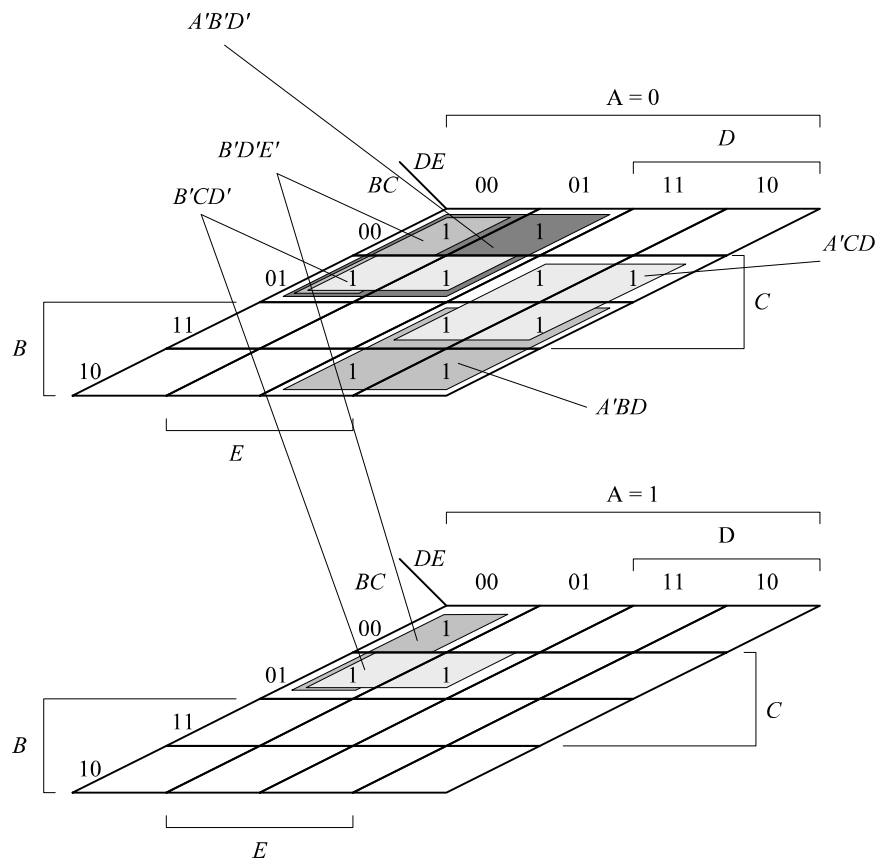
$B'C'D'E'$: $AB'C'D'E' + A'B'C'D'E'$

$A'B'D'$: $A'B'CD'E + A'B'CD'E' + A'B'C'D'E + A'B'C'D'E'$

$B'CD'$: $AB'CD'E + AB'CD'E' + A'B'CD'E + A'B'CD'E'$

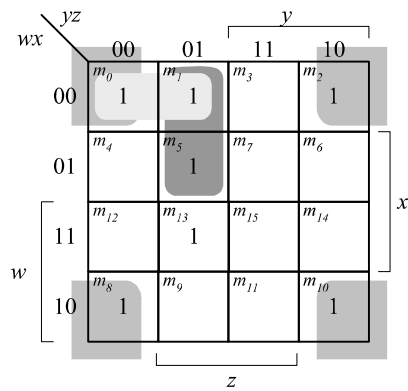
$A'CD$: $A'BCDE + A'BCDE' + A'B'CDE + A'B'CDE'$

$A'BD$: $A'BCDE + A'BCDE' + A'BC'DE + A'BC'DE'$



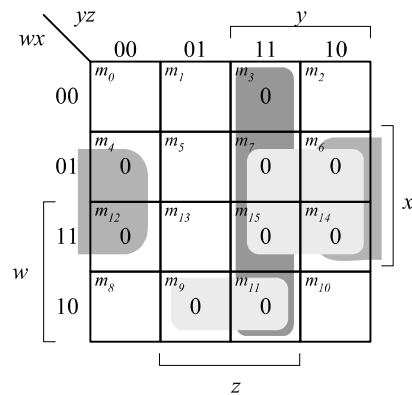
3.12

(a)



$$F = \Sigma(0, 1, 2, 5, 8, 10, 13)$$

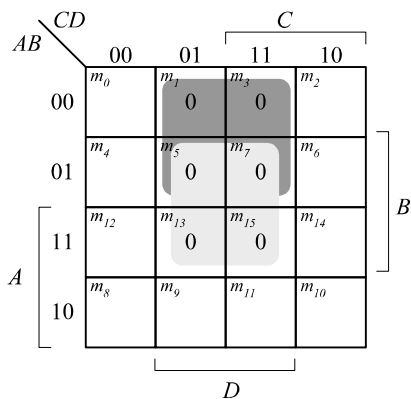
$$F = x'z' + w'x'y' + w'y'z$$



$$F' = yz + xz' + xy + wx'z$$

$$F = (y' + z')(x' + z)(x' + y')(w' + x + z')$$

(b)



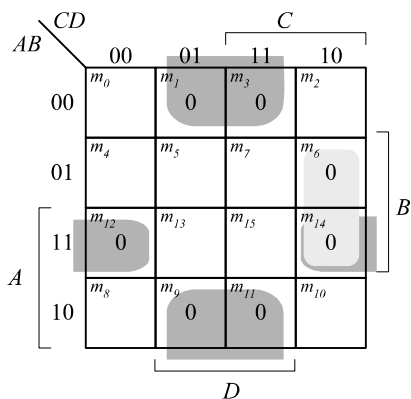
$$F = \Pi(1, 3, 5, 7, 13, 15)$$

$$F' = A'D + B'D$$

$$F = (A + D')(B' + D')$$

$$F = C'D' + AB' + CD'$$

(c)



$$F = \Pi(1, 3, 6, 9, 11, 12, 14)$$

$$F' = B'D + BCD' + ABD'$$

$$F = (B + D')(B' + C' + D)(A' + B' + D)$$

$$F = BD + B'D' + A'CD'$$

3.13 (a) $F = xy + z' = (x + z')(y + z')$

(b)

| AB | | CD | | | |
|----|----|---------------|---------------|---------------|---------------|
| | | 00 | 01 | 11 | 10 |
| A | 00 | m_0 0 | m_1 1 | m_3 0 | m_2 0 |
| | 01 | m_4 0 | m_5 1 | m_7 0 | m_6 0 |
| | 11 | m_{12} 1 | m_{13} 1 | m_{15} 1 | m_{14} 0 |
| | 10 | m_8 1 | m_9 1 | m_{11} 1 | m_{10} 1 |

$$F = AC' + AD + C'D + AB'C$$

| AB | | CD | | | |
|----|----|---------------|---------------|---------------|---------------|
| | | 00 | 01 | 11 | 10 |
| A | 00 | m_0 0 | m_1 1 | m_3 0 | m_2 0 |
| | 01 | m_4 0 | m_5 1 | m_7 0 | m_6 0 |
| | 11 | m_{12} 1 | m_{13} 1 | m_{15} 1 | m_{14} 0 |
| | 10 | m_8 1 | m_9 1 | m_{11} 1 | m_{10} 1 |

$$F' A'D' + A'C + BCD'$$

$$F = (A + D)(A + C')(B' + C' + D)$$

(c)

| AB | | CD | | | |
|----|----|---------------|---------------|---------------|---------------|
| | | 00 | 01 | 11 | 10 |
| A | 00 | m_0 0 | m_1 0 | m_3 0 | m_2 0 |
| | 01 | m_4 0 | m_5 0 | m_7 0 | m_6 0 |
| | 11 | m_{12} 0 | m_{13} 0 | m_{15} 0 | m_{14} 0 |
| | 10 | m_8 0 | m_9 0 | m_{11} 0 | m_{10} 0 |

$$F = (A + C' + D')(A' + B' + D')(A' + B + D')(A' + B + C')$$

$$F' = A'CD + ABD + AB'D + AB'C$$

$$F = A'C + A'D' + BD' + C'D'$$

$$F' = AD + CD + AB'C$$

$$F = (A' + D')(C + D')(A' + B + C')$$

| AB | | CD | | | |
|----|----|---------------|---------------|---------------|---------------|
| | | 00 | 01 | 11 | 10 |
| A | 00 | m_0 1 | m_1 1 | m_3 1 | m_2 1 |
| | 01 | m_4 1 | m_5 1 | m_7 1 | m_6 1 |
| | 11 | m_{12} 1 | m_{13} 1 | m_{15} 1 | m_{14} 1 |
| | 10 | m_8 1 | m_9 1 | m_{11} 1 | m_{10} 1 |

(d)

| AB \ CD | | C | | | |
|---------|----|----------|----------|----------|----------|
| | | 00 | 01 | 11 | 10 |
| A | 00 | m_0 | m_1 | m_3 | m_2 |
| | 01 | m_4 | m_5 | m_7 | m_6 |
| | 11 | m_{12} | m_{13} | m_{15} | m_{14} |
| | 10 | m_8 | m_9 | m_{11} | m_{10} |

Groupings: B (rows 01, 11, 10), D (columns 01, 11, 10), C (columns 11, 10)

$$F = ABC' + AB'D + BCD$$

$$F = AD + ABC' + BCD$$

| AB \ CD | | C | | | |
|---------|----|----------|----------|----------|----------|
| | | 00 | 01 | 11 | 10 |
| A | 00 | m_0 | m_1 | m_3 | m_2 |
| | 01 | m_4 | m_5 | m_7 | m_6 |
| | 11 | m_{12} | m_{13} | m_{15} | m_{14} |
| | 10 | m_8 | m_9 | m_{11} | m_{10} |

Groupings: B (rows 01, 11, 10), D (columns 01, 11, 10), C (columns 11, 10)

$$F' = A'C' + A'B' + CD' + B'C'D'$$

$$F = (A + C)(A + B)(C' + D)(B + C + D)$$

3.14

| AB \ CD | | C | | | |
|---------|----|----------|----------|----------|----------|
| | | 00 | 01 | 11 | 10 |
| A | 00 | m_0 | m_1 | m_3 | m_2 |
| | 01 | m_4 | m_5 | m_7 | m_6 |
| | 11 | m_{12} | m_{13} | m_{15} | m_{14} |
| | 10 | m_8 | m_9 | m_{11} | m_{10} |

Groupings: B (rows 01, 11, 10), D (columns 01, 11, 10), C (columns 11, 10)

| AB \ CD | | C | | | |
|---------|----|----------|----------|----------|----------|
| | | 00 | 01 | 11 | 10 |
| A | 00 | m_0 | m_1 | m_3 | m_2 |
| | 01 | m_4 | m_5 | m_7 | m_6 |
| | 11 | m_{12} | m_{13} | m_{15} | m_{14} |
| | 10 | m_8 | m_9 | m_{11} | m_{10} |

Groupings: B (rows 01, 11, 10), D (columns 01, 11, 10), C (columns 11, 10)

SOP form (using 1s): $F = B'C'D' + AB'D' + BC'D + A'BD$

$$F = B'D'(A + C') + BD(A' + C')$$

POS form (using 0s): $F' = BD' + B'D + A'CD' + ACD$

$$F = [(B' + D)(B + D')][(A + C' + D)(A' + C' + D')]$$

Alternative POS: $F' = BD' + B'D + A'CD' + A'B'C$

$$F = [(B' + D)(B + D')][(A + C' + D)(A' + B + C)]$$

3.15

(a)

| | | | | | |
|-----|---|------------|------------|------------|------------|
| | | yz | | y | |
| | | 00 | 01 | 11 | 10 |
| x | 0 | m_0 x | m_1 x | m_3 1 | m_2 1 |
| | 1 | m_4 1 | m_5 x | m_7 1 | m_6 1 |

z

$$F = 1$$

$$F = \Sigma(0,1, 2, 3, 4, 5, 6, 7)$$

(b)

| | | | | | |
|------|----|------------|---------------|----------|---------------|
| | | CD | | C | |
| | | 00 | 01 | 11 | 10 |
| AB | 00 | m_0 1 | m_1 | m_3 | m_2 x |
| | 01 | m_4 x | m_5 | m_7 | m_6 1 |
| | 11 | m_{12} | m_{13} 1 | m_{15} | m_{14} 1 |
| | 10 | m_8 1 | m_9 | m_{11} | m_{10} x |

D

$$F = B'D' + ABC'D$$

$$F = \Sigma(0, 2, 6, 8, 10, 13, 14)$$

(c)

| | | | | | |
|------|----|---------------|---------------|---------------|---------------|
| | | CD | | C | |
| | | 00 | 01 | 11 | 10 |
| AB | 00 | m_0 | m_1 x | m_3 | m_2 |
| | 01 | m_4 1 | m_5 1 | m_7 1 | m_6 |
| | 11 | m_{12} 1 | m_{13} 1 | m_{15} x | m_{14} 1 |
| | 10 | m_8 | m_9 x | m_{11} x | m_{10} |

D

$$F = BC' + BD + AB$$

$$F = \Sigma(4, 5, 7, 12, 13, 14, 15)$$

(d)

| | | | | | |
|------|----|------------|------------|---------------|---------------|
| | | CD | | C | |
| | | 00 | 01 | 11 | 10 |
| AB | 00 | m_0 x | m_1 1 | m_3 1 | m_2 x |
| | 01 | m_4 | m_5 | m_7 | m_6 |
| | 11 | m_{12} | m_{13} | m_{15} 1 | m_{14} |
| | 10 | m_8 1 | m_9 x | m_{11} | m_{10} 1 |

D

$$F = B'D' + A'B' + ABCD$$

$$F = \Sigma(0, 1, 2, 3, 8, 10, 15)$$

3.16

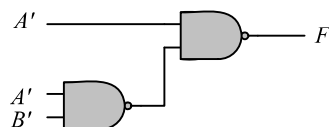
(a)

| | | | | | |
|------|----|---------------|---------------|---------------|---------------|
| | | CD | | C | |
| | | 00 | 01 | 11 | 10 |
| AB | 00 | m_0 1 | m_1 1 | m_3 1 | m_2 1 |
| | 01 | m_4 | m_5 | m_7 | m_6 |
| | 11 | m_{12} 1 | m_{13} 1 | m_{15} 1 | m_{14} 1 |
| | 10 | m_8 1 | m_9 1 | m_{11} 1 | m_{10} 1 |

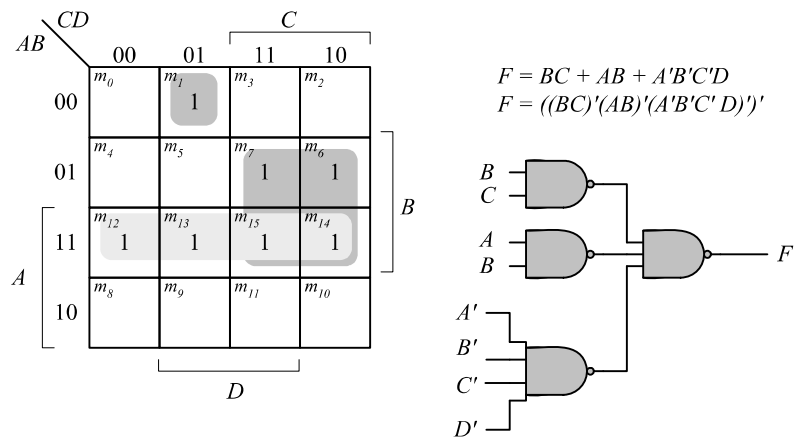
D

$$F = A + A'B'$$

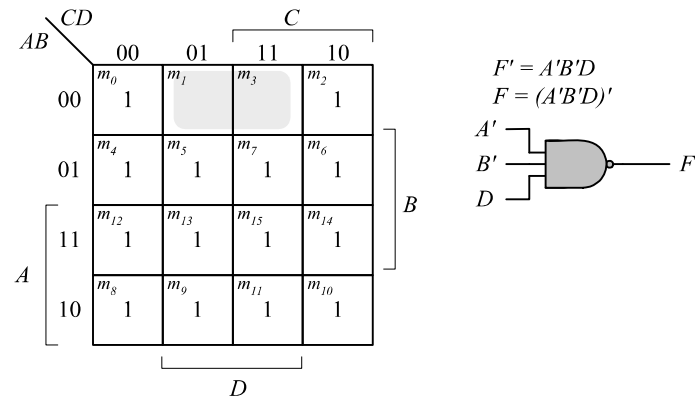
$$F = (A'(A'B'))'$$



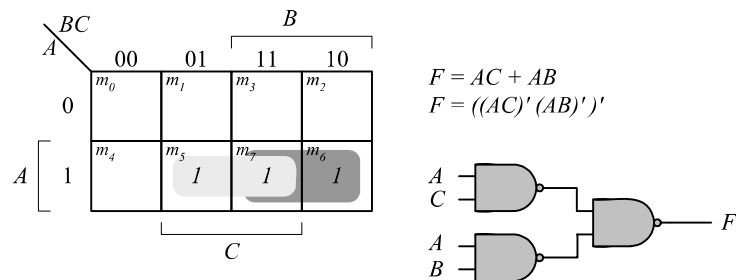
(b)



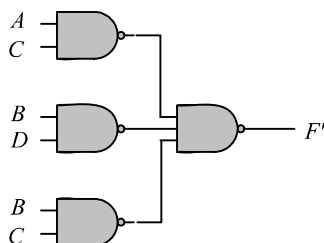
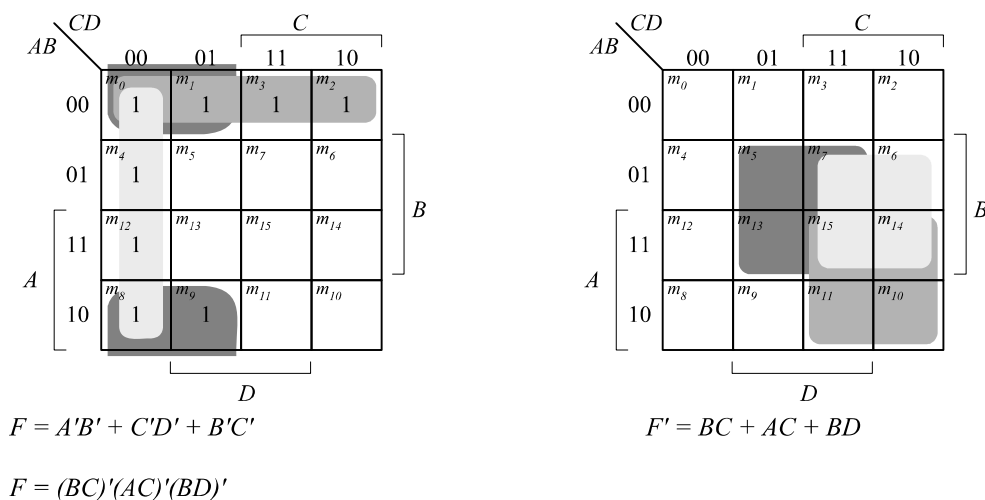
(c)



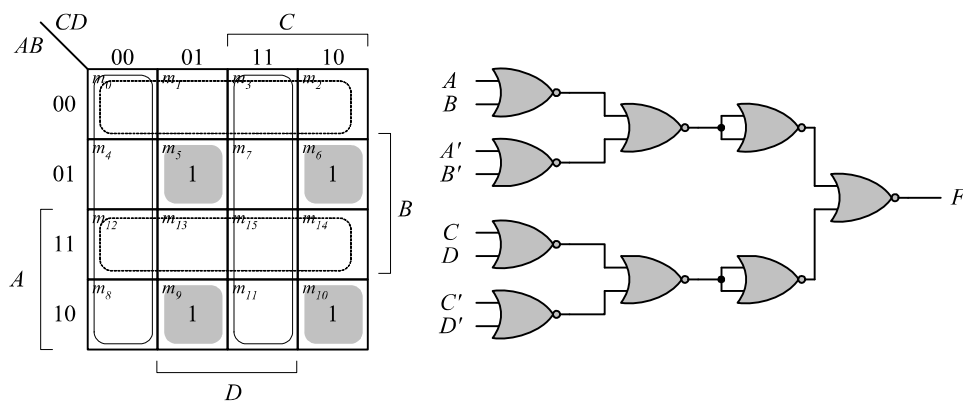
(d)



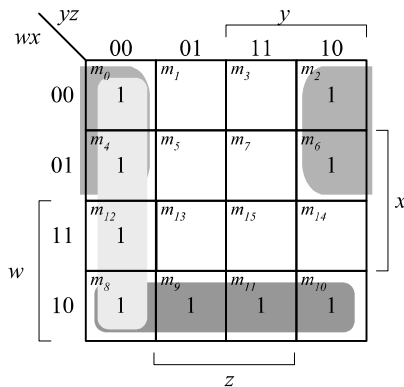
3.17



3.18 $F = (A \oplus B)'(C \oplus D) = (AB' + A'B)(CD' + C'D) = AB'CD' + AB'C'D + A'BCD' + A'BC'D$



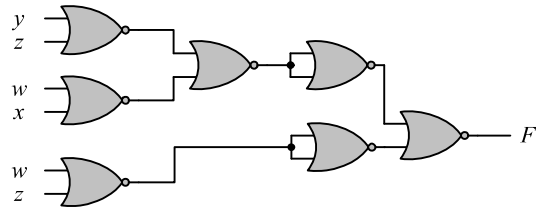
3.19 (a) $F = (w + z')(x' + z')(w' + x' + y')$



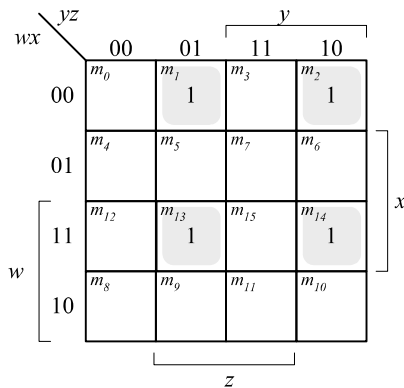
$$F = y'z' + wx' + w'z'$$

$$F = [(y + z)' + (w' + x)' + (w + z)']'$$

$$F' = [(y + z)' + (w' + x)' + (w + z)']'$$



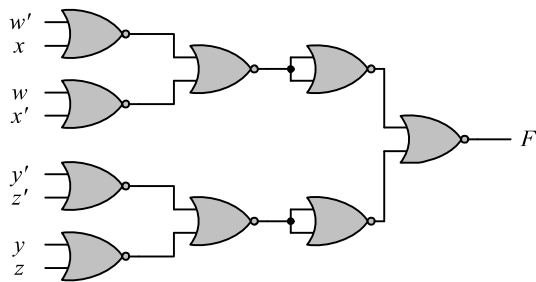
(b)



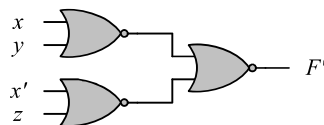
$$F = \Sigma(1, 2, 13, 14)$$

$$F' = w'x + wx' + y'z' + yz = [(w + x')(w' + x)(y + z)(y' + z')]'$$

$$F = (w + x')' + (w' + x)' + (y + z)' + (y' + z)'$$



(c) $F = [(x + y)(x' + z)]' = (x + y)' + (x' + z)'$
 $F' = [(x + y)' + (x' + z)']'$



3.20

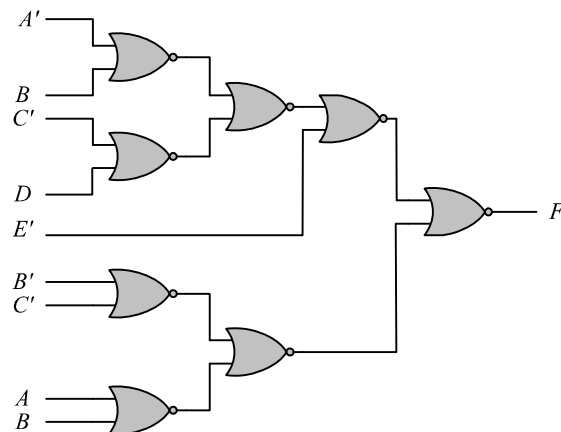
Multi-level NOR:

$$F = (AB' + CD'E) + BC(A + B)$$

$$F' = [(AB' + CD'E) + BC(A + B)]'$$

$$F' = [[(AB' + CD'E)' + E']' + [(BC)' + (A + B)']']'$$

$$F' = [([(A' + B)' + (C' + D)')' + E']' + [(B' + C)' + (A + B)']']'$$

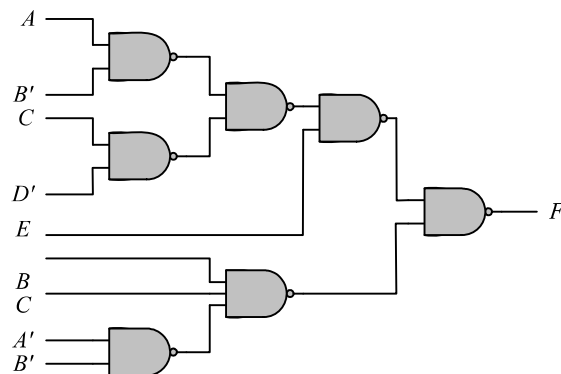


Multi-level NAND:

$$F = (AB' + CD'E) + BC(A + B)$$

$$F' = [(AB' + CD'E)E]' [BC(A + B)]'$$

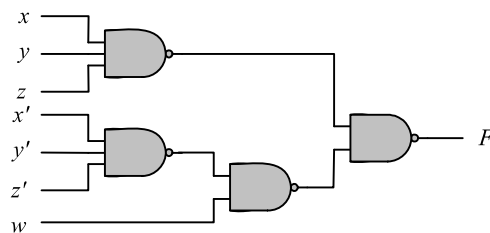
$$F' = [((AB')'(CD')')E]' [BC(A'B')']'$$



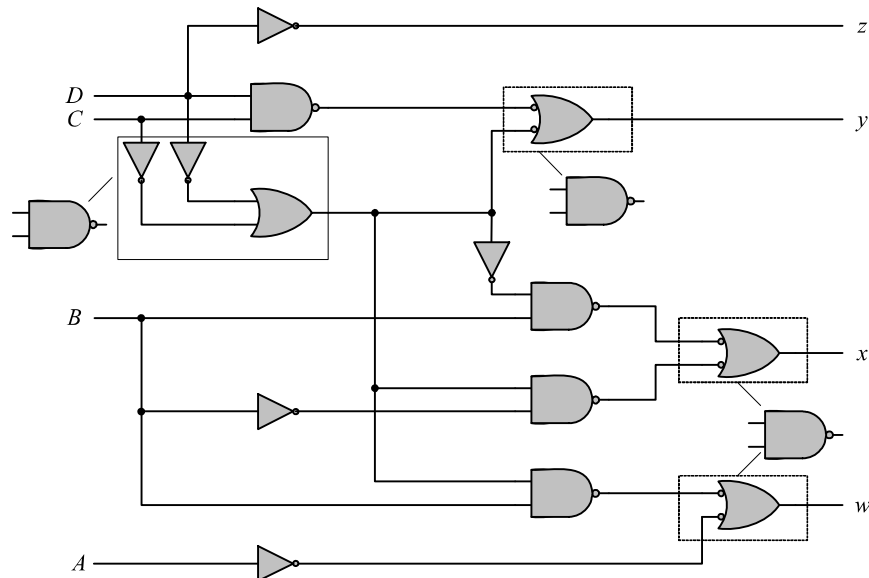
3.21

$$F = w(x + y + z) + xyz$$

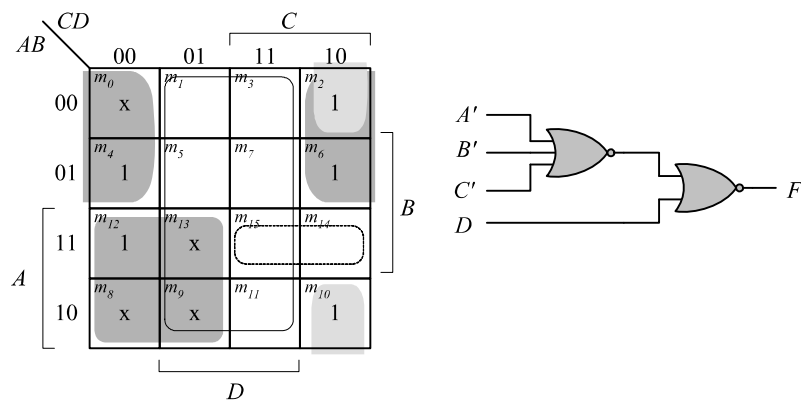
$$F' = [w(x + y + z)]'[xyz]' = [w(x'y'z')]'(xyz)'$$



3.22



3.23

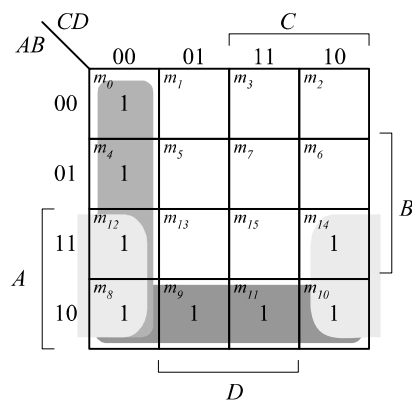


$$F = AC' + A'D' + B'CD'$$

$$F' = D + ABC$$

$$F = [D + ABC]' = [D + (A' + B' + C')]'$$

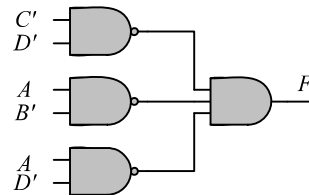
3.24



$$(a) F = C'D' + AB' + AD'$$

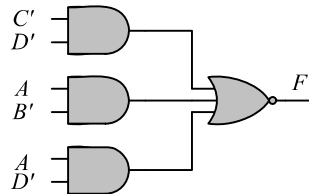
$$F' = (C'D')'(AB')'(AD')'$$

AND-NAND:



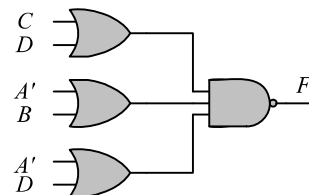
(b) $F' = [C'D' + AB' + AD']'$

AND-NOR:



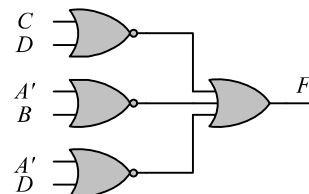
(c) $F = C'D' + AB' + AD' = (C + D)' + (A' + B)' + (A' + D)'$
 $F' = (C'D')'(AB')'(AD')' = (C + D)(A' + B)(A' + D)$
 $F = [(C + D)(A' + B)(A' + D)]'$

OR-NAND:

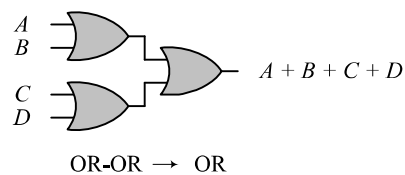
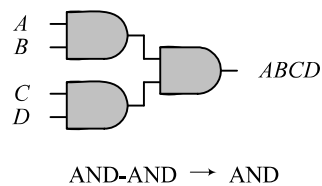


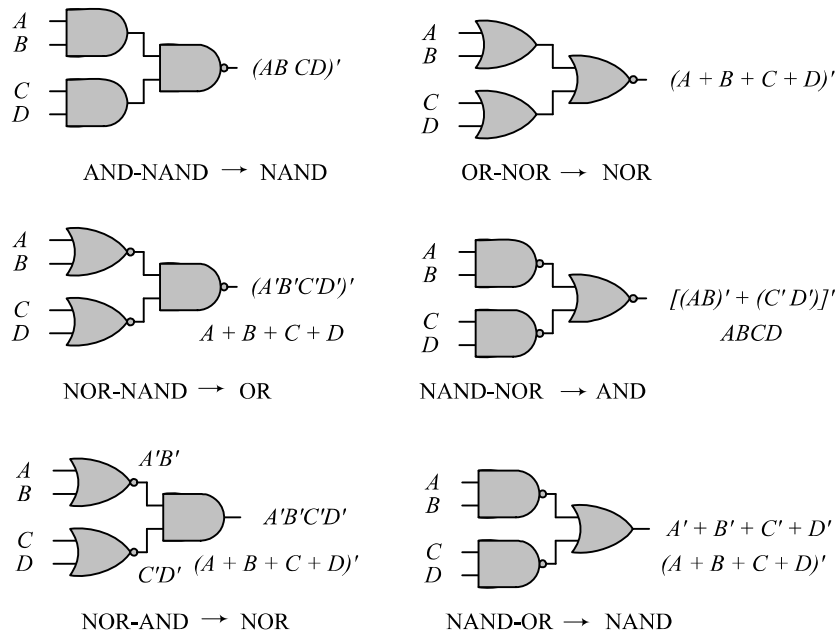
(d) $F = C'D' + AB' + AD' = (C + D)' + (A' + B)' + (A' + D)'$

NOR-OR:



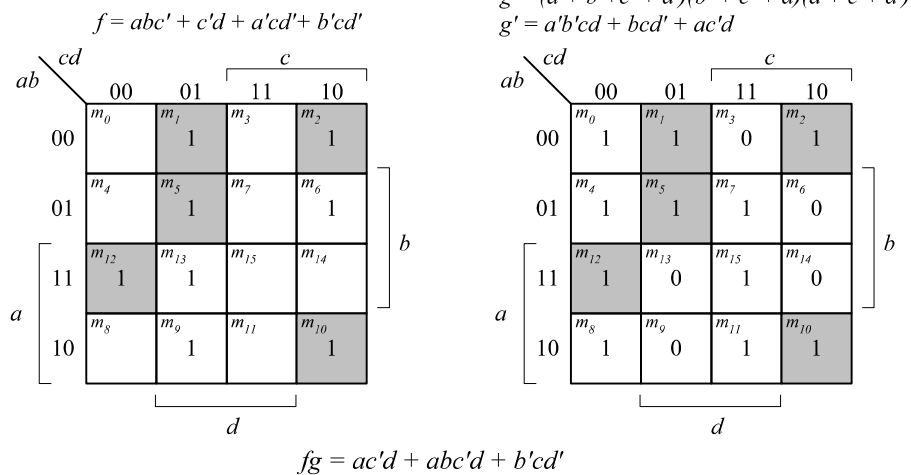
3.25





The degenerate forms use 2-input gates to implement the functionality of 4-input gates.

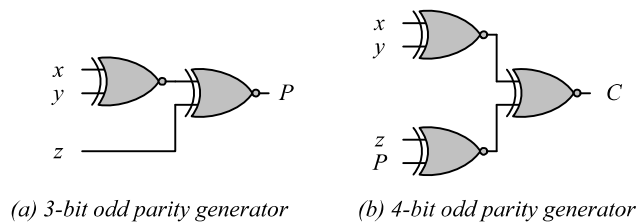
3.26



3.27

$$x \oplus y = x'y + xy'; \text{ Dual} = (x' + y)(x + y') = (x \oplus y)'$$

3.28



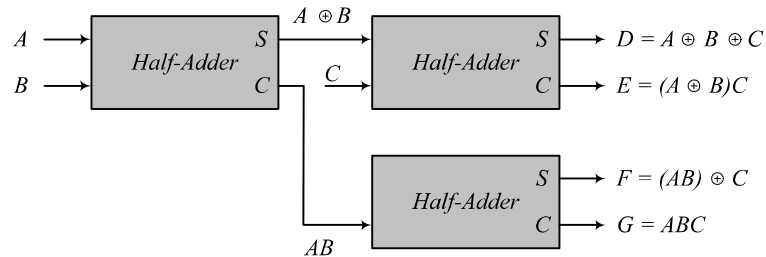
3.29

$$D = A \oplus B \oplus C$$

$$E = A'BC + AB'C = (A \oplus B)C$$

$$F = ABC' + (A' + B')C = ABC' + (AB)'C = (AB) \oplus C$$

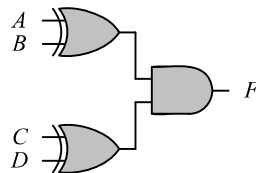
$$G = ABC$$



3.30

$$F = AB'CD' + A'BCD' + AB'C'D + A'BC'D$$

$$F = (A \oplus B)CD' + (A \oplus B)C'D = (A \oplus B)(C \oplus D)$$



3.31

Note: It is assumed that a complemented input is generated by another circuit that is not part of the circuit that is to be described.

```
(a) module Fig_3_22a_gates (F, A, B, C, C_bar, D);
    output F;
    input A, B, C, C_bar, D;
    wire w1, w2, w3, w4;
    and (w1, C, D);
    or (w2, w1, B);
    and (w3, w2, A);
    and (w4, B, C_bar);
    or (F, w3, w4);
endmodule
```

```
(b) module Fig_3_22b_gates (F, A, B, C, C_bar, D);
    output F;
    input A, B, C, C_bar, D;
    wire w1, w2, w3, w4;
    not (w1_bar, w1);
    not (B_bar, B);
    not (w3_bar, w3);
    not (w4_bar, w4);
    nand (w1, C, D);
    or (w2, w1_bar, B_bar);
    nand (w3, w2, A);
    nand (w4, B, C_bar);
    or (F, w3_bar, w4_bar);
endmodule
```