FET and BJT

- Control variable
- Input Impedance
- Sensitivity of output due to change in input
- Size
- Temperature stability
- No. of charge carrier

- JFET
  - n-channel
  - P-channel
- MOSFET
  - Depletion type
  - Enhancement type
- MESFET

For the FET an electric field is established by the charges present, which controls the conduction path of the output circuit without the need for direct contact between the controlling and controlled quantities.

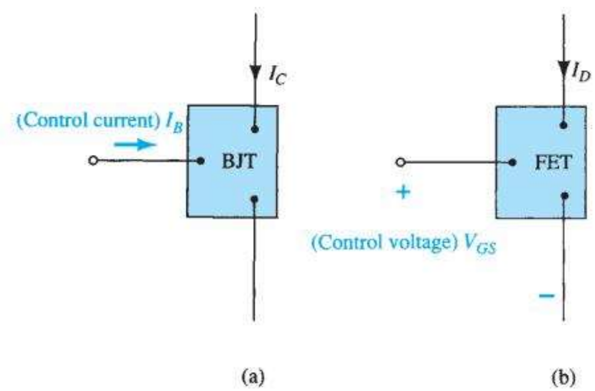

FIG. 6.1
(a) Current-controlled and (b) voltage-controlled amplifiers.

Construction and Characteristics of JFET

In the absence of any applied potentials the JFET has two p–n junctions under no-bias conditions.

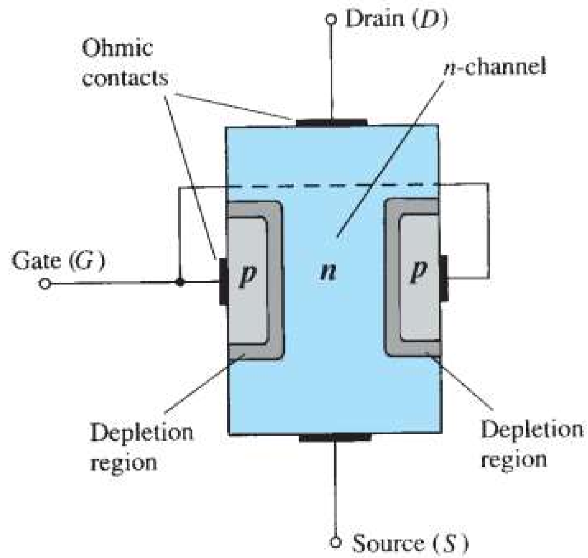

FIG. 6.3
Junction field-effect transistor (JFET).

FIG. 6.4
Water analogy for the JFET control mechanism.

Construction and Characteristics of JFET

V_{GS} = 0 V, V_{DS} Some Positive Value

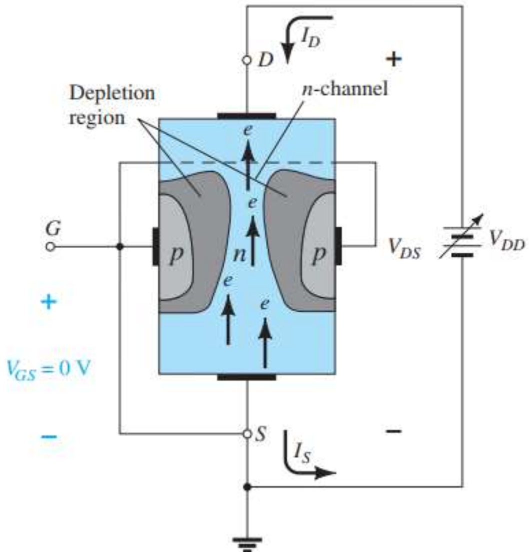

FIG. 6.5
JFET at $V_{GS} = 0$ V and $V_{DS} > 0$ V.

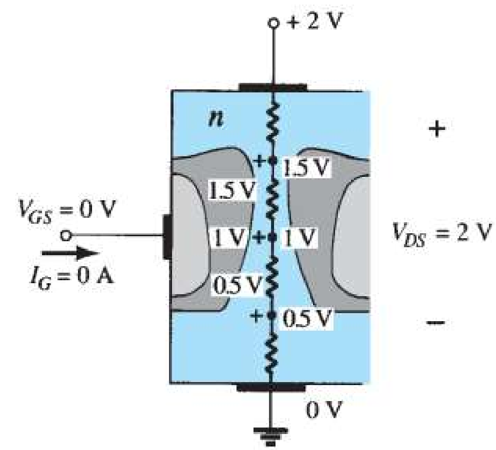

FIG. 6.6
Varying reverse-bias potentials across the p–n junction of an n-channel JFET.

Construction and Characteristics of JFET

$V_{GS} = 0$ V, V_{DS} Some Positive Value

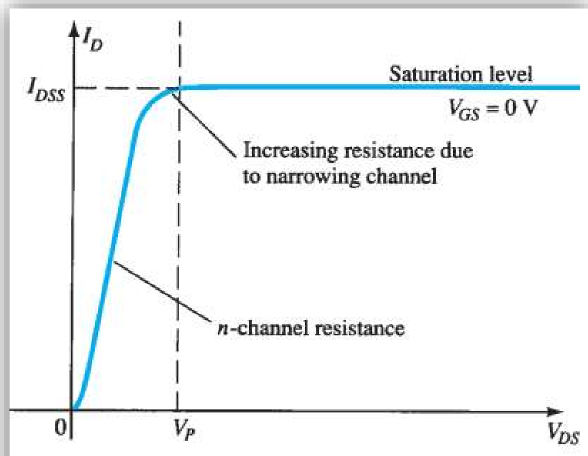

FIG. 6.7
I_D versus V_{DS} for $V_{GS} = 0$ V.

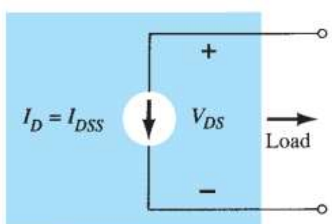

FIG. 6.9
Current source equivalent for $V_{GS} = 0$ V, $V_{DS} > V_P$.

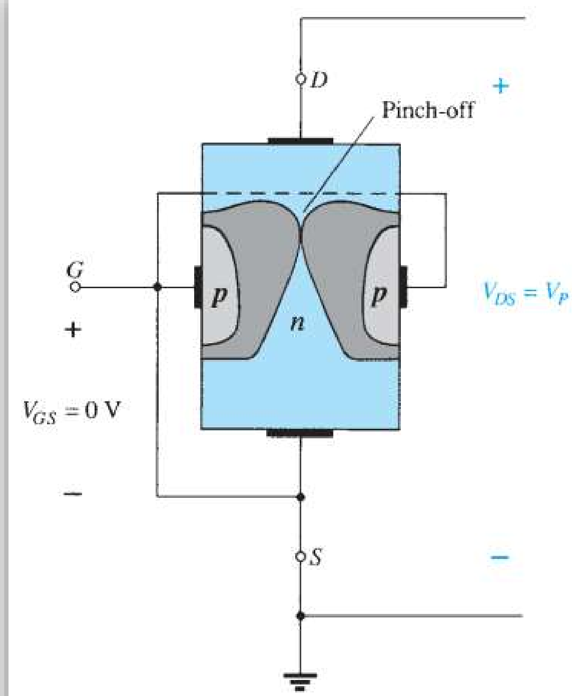

FIG. 6.8
Pinch-off ($V_{GS} = 0$ V, $V_{DS} = V_P$).

Construction and Characteristics of JFET

$V_{GS} < 0$ V

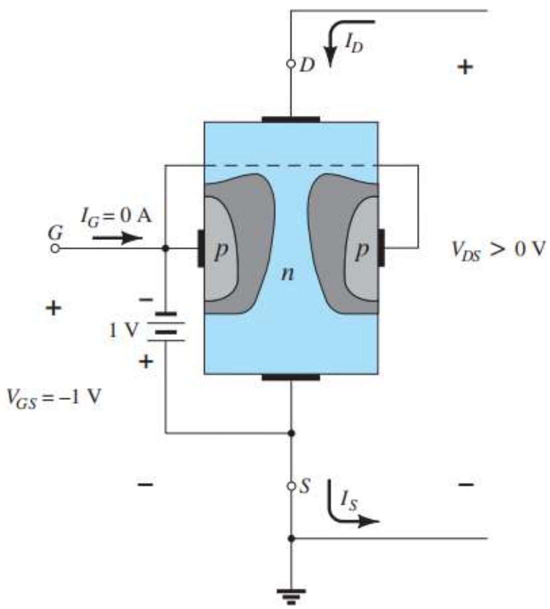

FIG. 6.10
Application of a negative voltage to the gate of a JFET.

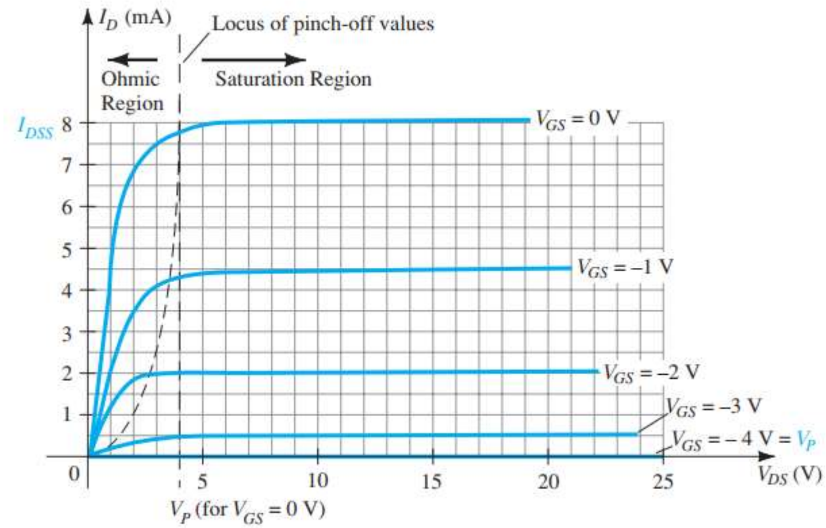

FIG. 6.11
n-Channel JFET characteristics with $I_{DSS} = 8$ mA and $V_P = -4$ V.

Voltage-Controlled Resistor

The region to the left of the pinch-off locus of Fig. 6.11 is referred to as the ohmic or voltage-controlled resistance region. As VGS becomes more and more negative, the slope of each curve becomes more and more horizontal, corresponding to an increasing resistance level.

$$\boxed{r_d = \frac{r_o}{(1 - V_{GS}/V_P)^2}}$$

Construction and Characteristics of JFET

p-Channel Devices

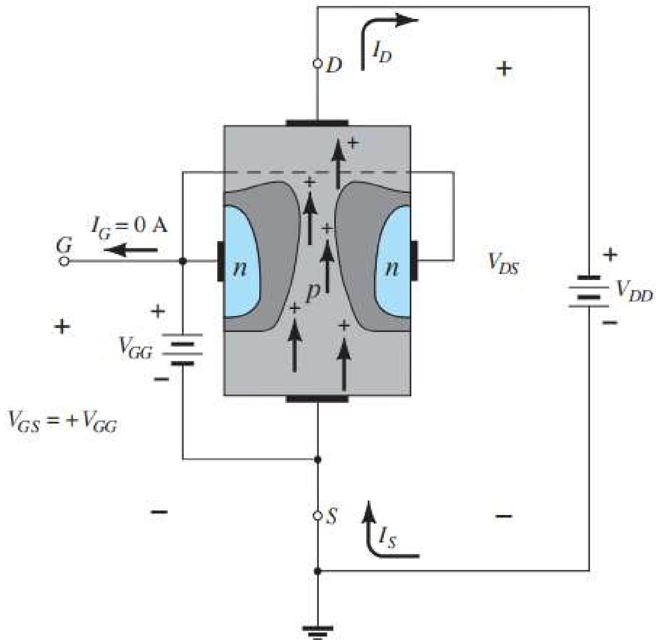

FIG. 6.12
p-Channel JFET.

Symbols

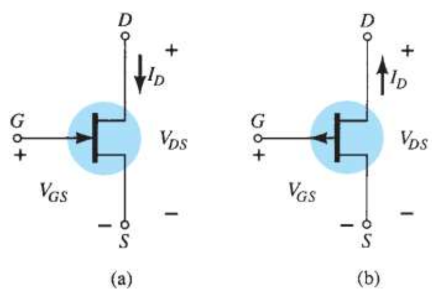

FIG. 6.14
JFET symbols: (a) n-channel; (b) p-channel.

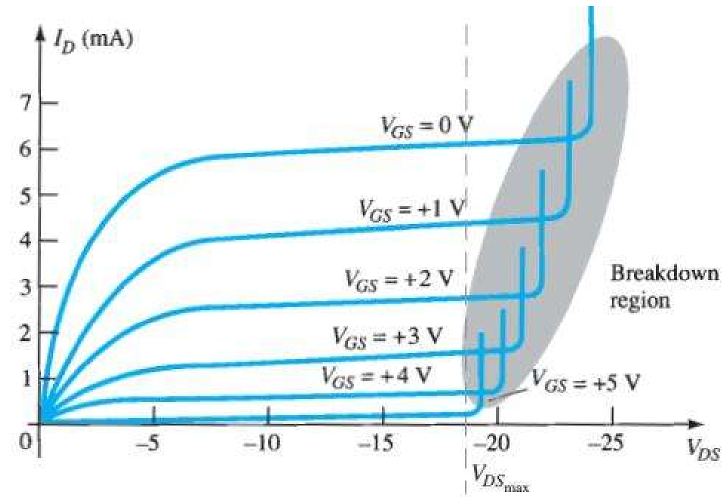

FIG. 6.13
p-Channel JFET characteristics with $I_{DSS} = 6$ mA and $V_P = +6$ V.

Construction and Characteristics of JFET

Summary

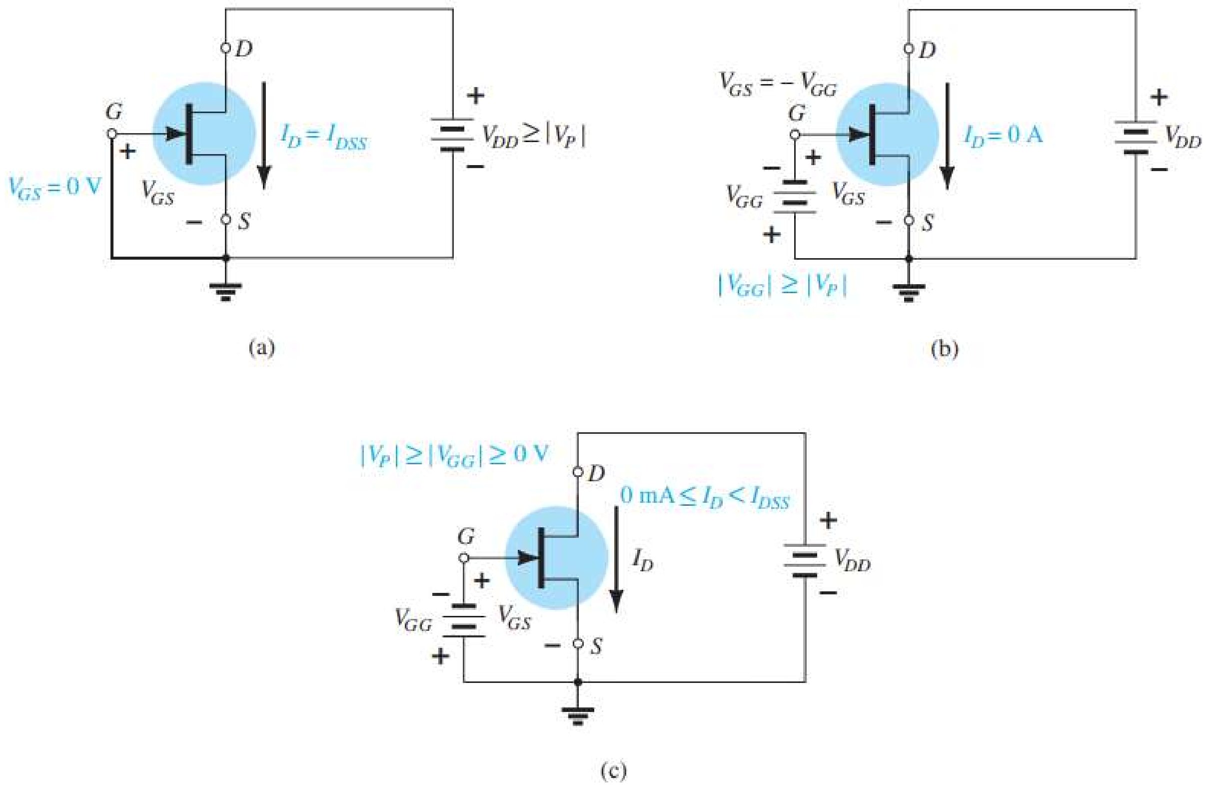

FIG. 6.15

(a) $V_{GS} = 0$ V, $I_D = I_{DSS}$; (b) cutoff ($I_D = 0$ A) V_{GS} less than the pinch-off level; (c) I_D is between 0 A and I_{DSS} for $V_{GS} \leq 0$ V and greater than the pinch-off level.

Transfer Characteristics of JFET

control variable

$$I_C = f(I_B) = \beta I_B \quad (6.2)$$

constant

For the dc analysis to be performed, a graphical rather than a mathematical approach will in general be more direct and easier to apply. The transfer characteristics defined by Shockley's equation are unaffected by the network in which the device is employed.

Shockley's equation

control variable

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 \quad (6.3)$$

constants

In review:

$$\text{When } V_{GS} = 0\text{ V}, \quad I_D = I_{DSS} \quad (6.4)$$

When $V_{GS} = V_P = -4$ V, the drain current is 0 mA, defining another point on the transfer curve. That is:

$$\text{When } V_{GS} = V_P, \quad I_D = 0\text{ mA} \quad (6.5)$$

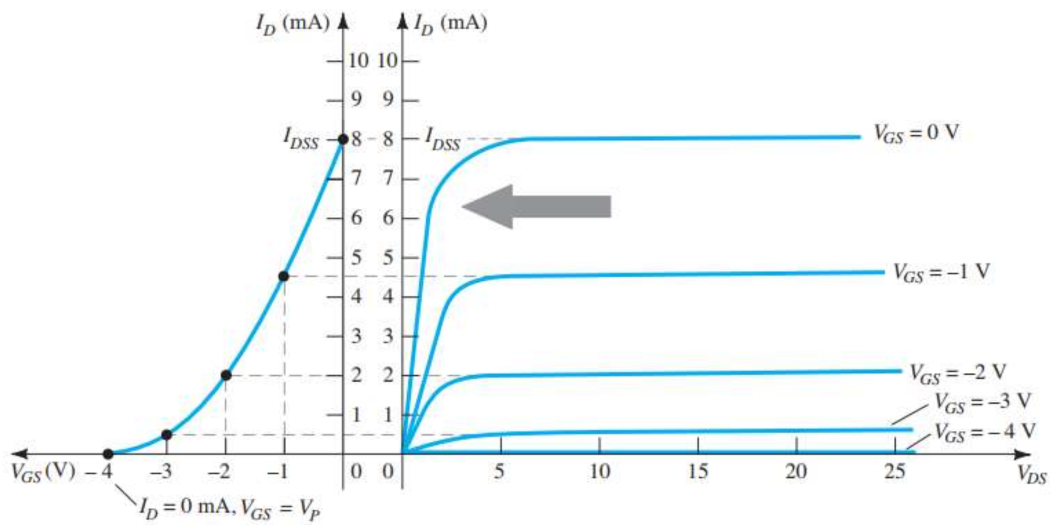

FIG. 6.17
Obtaining the transfer curve from the drain characteristics.

Transfer Characteristics of JFET

Applying Shockley's Equation

Substituting $V_{GS} = 0$ V gives

$$\text{Eq. (6.3):}\quad I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$= I_{DSS}\left(1 - \frac{0}{V_P}\right)^2 = I_{DSS}(1 - 0)^2$$

and

$$\boxed{I_D = I_{DSS}\,|_{V_{GS}=0\,\text{V}}}$$

Substituting $V_{GS} = V_P$ yields

$$I_D = I_{DSS}\left(1 - \frac{V_P}{V_P}\right)^2$$

$$= I_{DSS}(1 - 1)^2 = I_{DSS}(0)$$

$$\boxed{I_D = 0\,\text{A}|_{V_{GS}=V_P}}$$

$$\boxed{V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right)}$$

V_{GS} versus I_D Using Shockley's Equation

V_{GS}	I_D
0	I_{DSS}
$0.3V_P$	$I_{DSS}/2$
$0.5V_P$	$I_{DSS}/4$
V_P	0 mA

Transfer Characteristics of JFET

EXAMPLE 6.1 Sketch the transfer curve defined by $I_{DSS} = 12$ mA and $V_P = -6$ V.

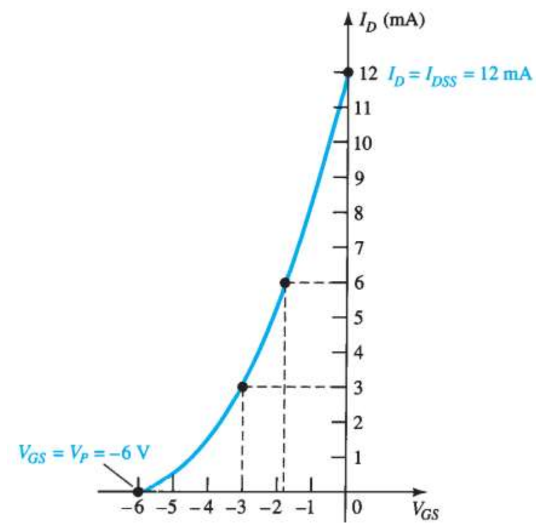

FIG. 6.18
Transfer curve for Example 6.1.

JFET

IMPORTANT RELATIONSHIPS

TABLE 6.2

JFET		BJT
$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$	$\Leftrightarrow$	$I_C = \beta I_B$
$I_D = I_S$	$\Leftrightarrow$	$I_C \cong I_E$
$I_G \cong 0\text{ A}$	$\Leftrightarrow$	$V_{BE} \cong 0.7\text{ V}$

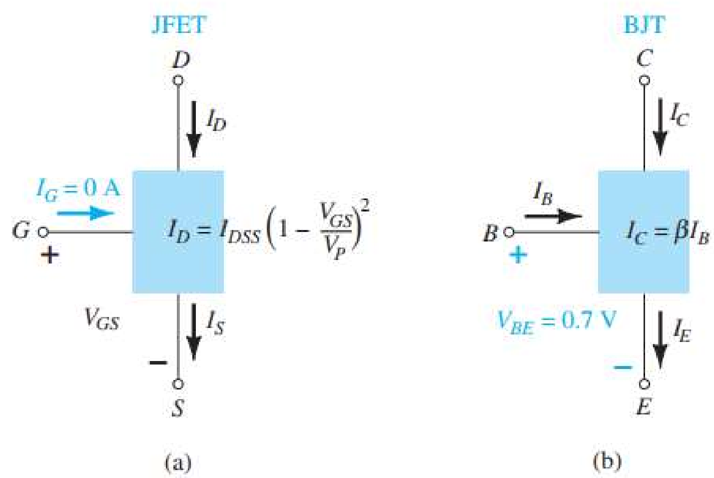

FIG. 6.23
(a) JFET versus (b) BJT.

MOSFET

- MOSFET
  - Depletion type
    - n channel
    - p channel
  - Enhancement type
    - n channel
    - p channel

DEPLETION-TYPE MOSFET

Basic Construction

Metal – Oxide – Semi

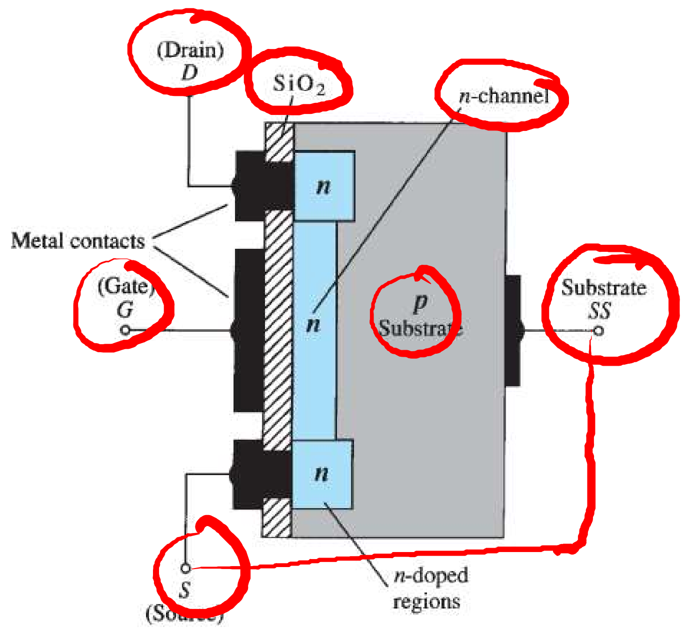

FIG. 6.24
n-Channel depletion-type MOSFET.

MOSFET

Basic Operation and Characteristics

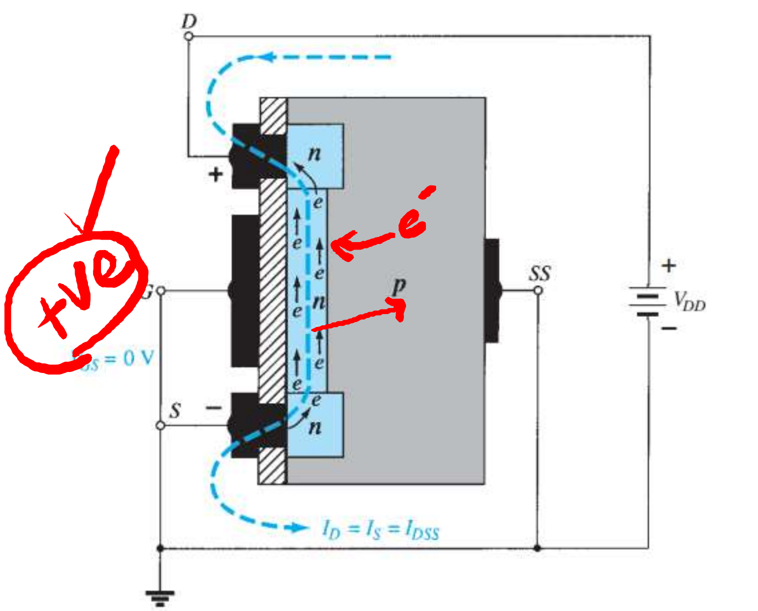

FIG. 6.25
n-Channel depletion-type MOSFET with $V_{GS} = 0$ V and applied voltage V_{DD}.

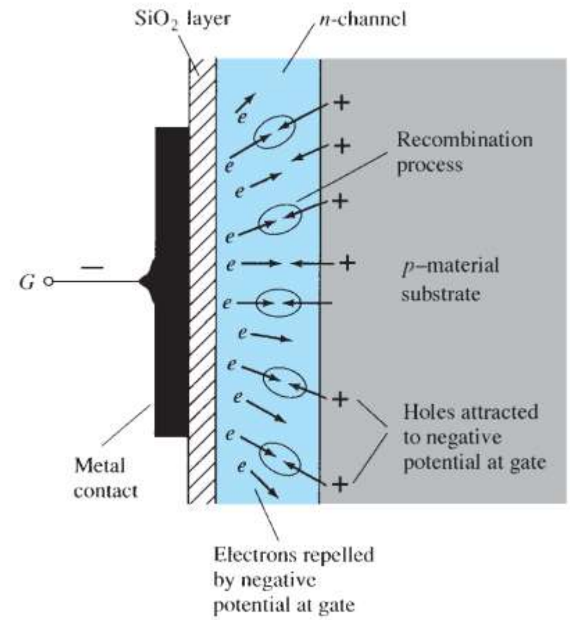

FIG. 6.27
Reduction in free carriers in a channel due to a negative potential at the gate terminal.

Vgs= NA

MOSFET

DEPLETION-TYPE MOSFET

Basic Operation and Characteristics

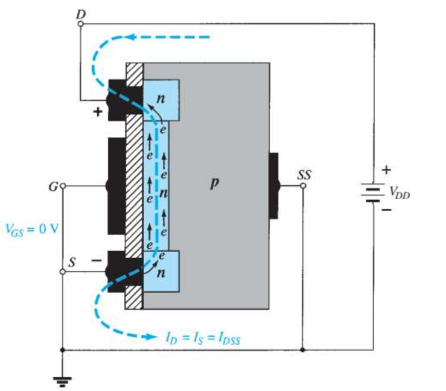

FIG. 6.25
n-Channel depletion-type MOSFET with $V_{GS} = 0$ V and applied voltage V_{DD}.

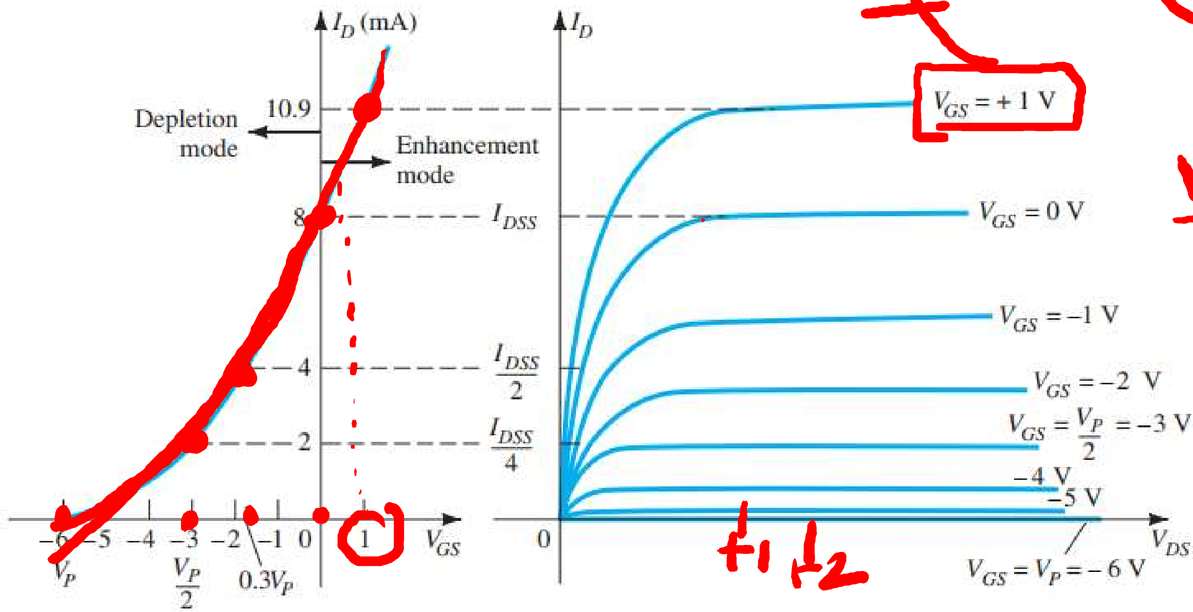

FIG. 6.26
Drain and transfer characteristics for an n-channel depletion-type MOSFET.

$$I_D = I_{DSS}\cdot\left(1-\frac{V_{GS}}{V_P}\right)^2$$

V_{GS}	I_D
0	I_{DSS}
V_P	0
$\frac{V_P}{2}$	$\frac{I_{DSS}}{4}$
$0.3V_P$	$\frac{I_{DSS}}{2}$

MOSFET

EXAMPLE 6.3 Sketch the transfer characteristics for an n-channel depletion-type MOSFET with $I_{DSS} = 10$ mA and $V_P = -4$ V.

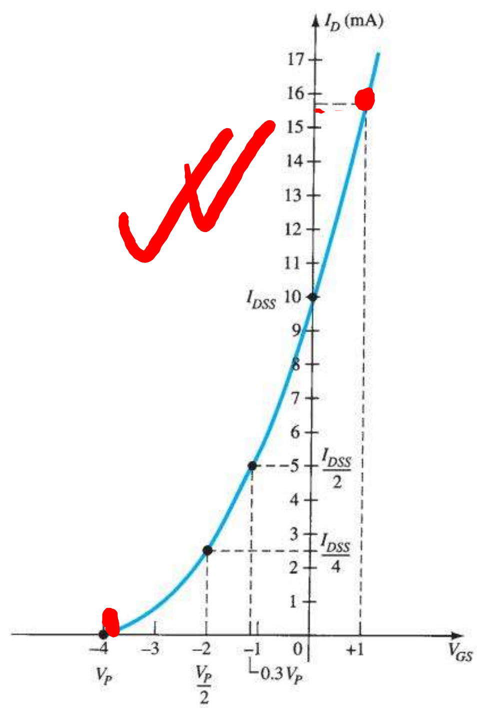

FIG. 6.28
Transfer characteristics for an n-channel depletion-type MOSFET with I_{DSS} = 10 mA and V_P = −4 V.

MOSFET

p-Channel Depletion-Type MOSFET

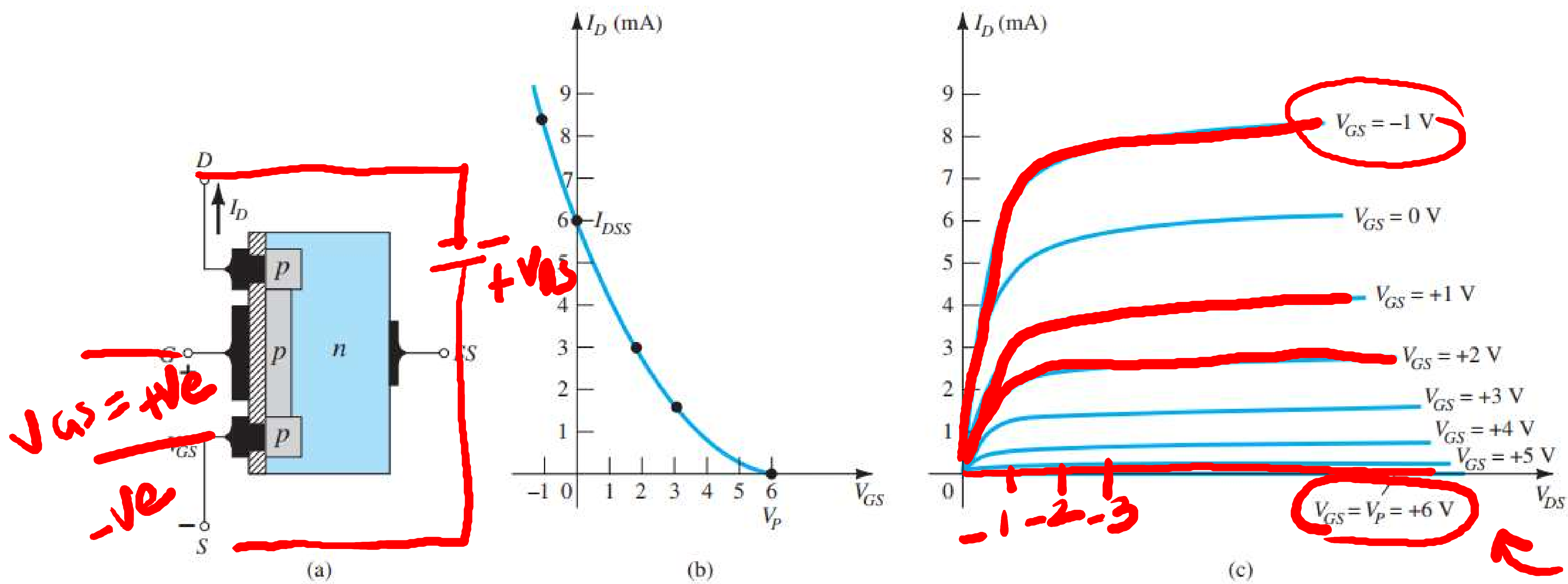

FIG. 6.29
p-Channel depletion-type MOSFET with I_{DSS} = 6 mA and V_P = +6 V.

MOSFET

Symbols

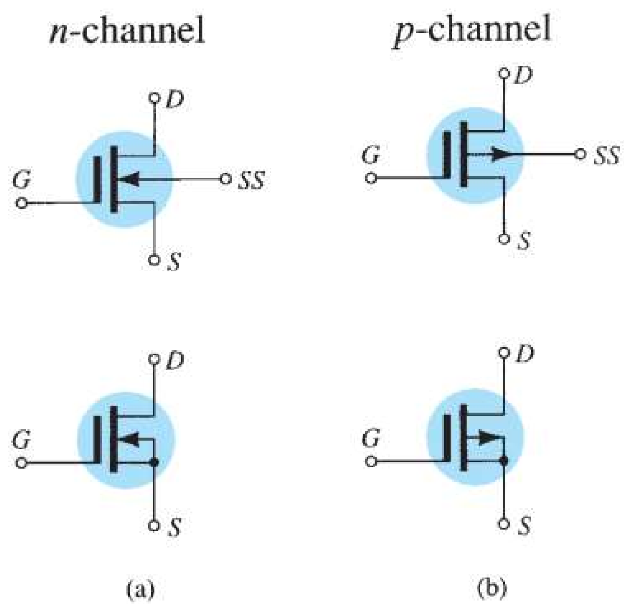

FIG. 6.30
Graphic symbols for: (a) n-channel depletion-type MOSFETs and (b) p-channel depletion-type MOSFETs.

MOSFET

ENHANCEMENT-TYPE MOSFET

Basic Construction

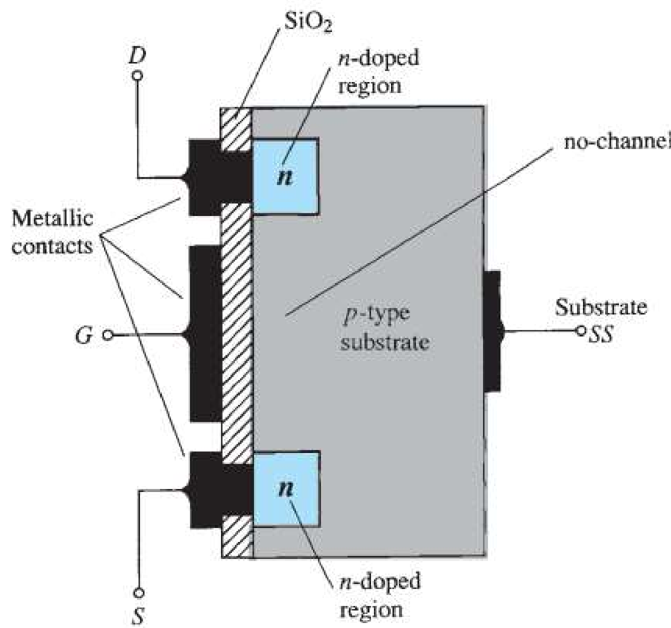

FIG. 6.32
n-Channel enhancement-type MOSFET.

MOSFET

Basic Operation and Characteristics

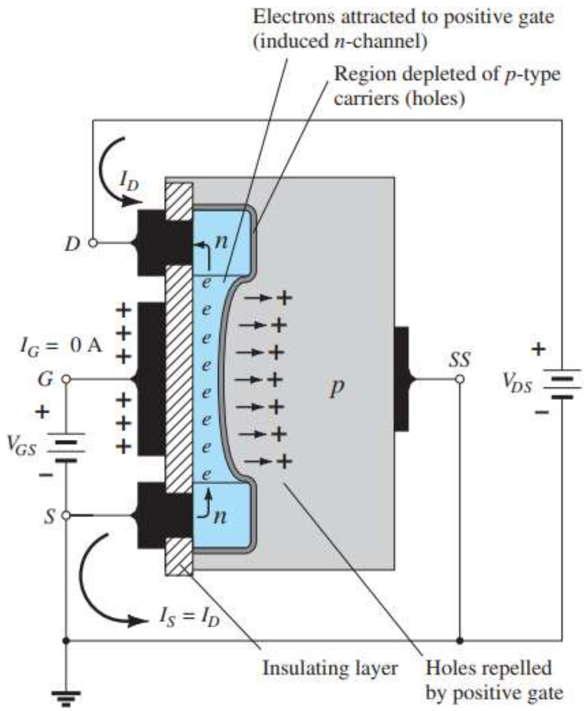

FIG. 6.33

Channel formation in the n-channel enhancement-type MOSFET.

ENHANCEMENT-TYPE MOSFET

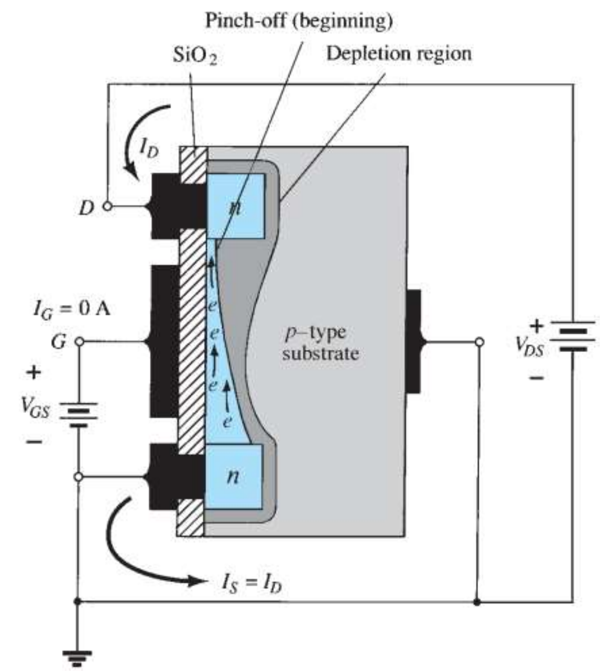

FIG. 6.34

Change in channel and depletion region with increasing level of V_{DS} for a fixed value of V_{GS}.

MOSFET

ENHANCEMENT-TYPE MOSFET

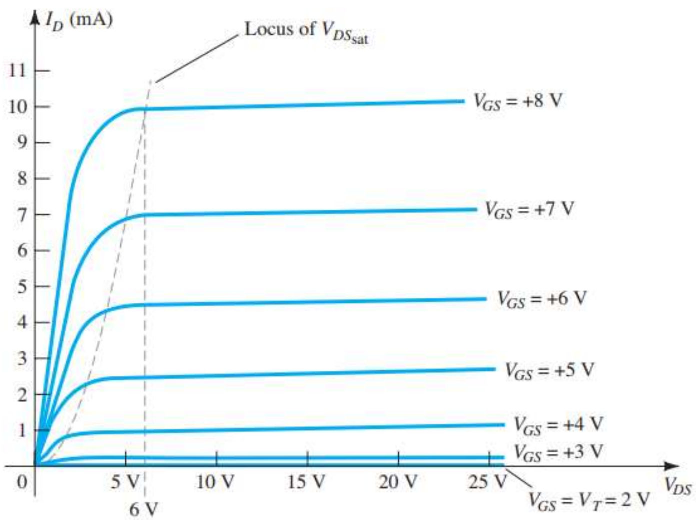

FIG. 6.35

Drain characteristics of an n-channel enhancement-type MOSFET with $V_T = 2$ V and $k = 0.278 \times 10^{-3}$ A/V^2.

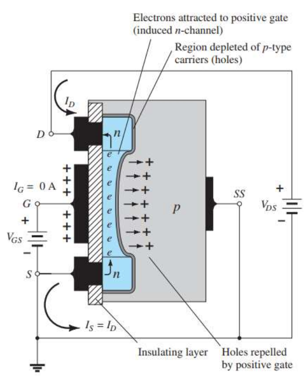

FIG. 6.33

Channel formation in the n-channel enhancement-type MOSFET.

$$\boxed{I_D = k(V_{GS} - V_T)^2}$$

$$\boxed{k = \frac{I_{D(\text{on})}}{(V_{GS(\text{on})} - V_T)^2}}$$

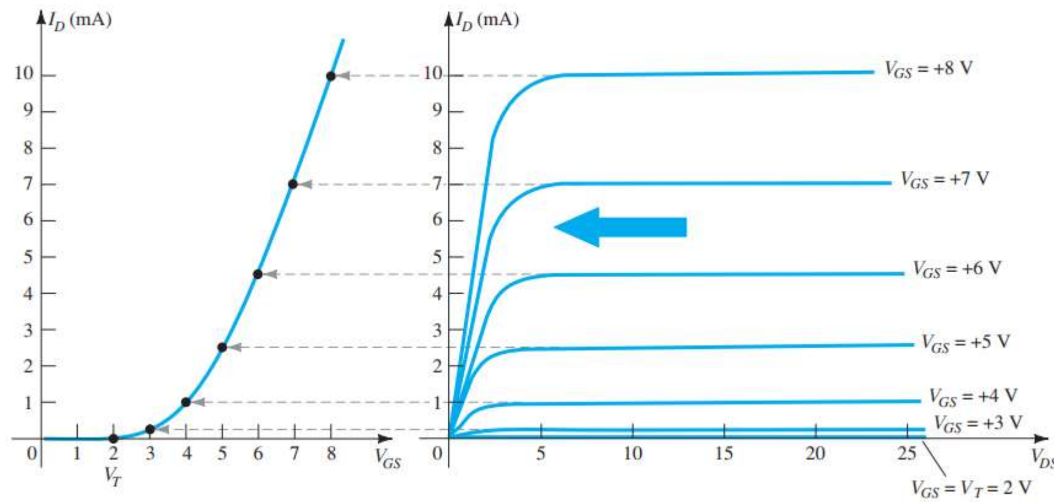

FIG. 6.36

Sketching the transfer characteristics for an n-channel enhancement-type MOSFET from the drain characteristics.

MOSFET

$$I_D = 0.5 \times 10^{-3}(V_{GS} - 4\text{ V})^2$$

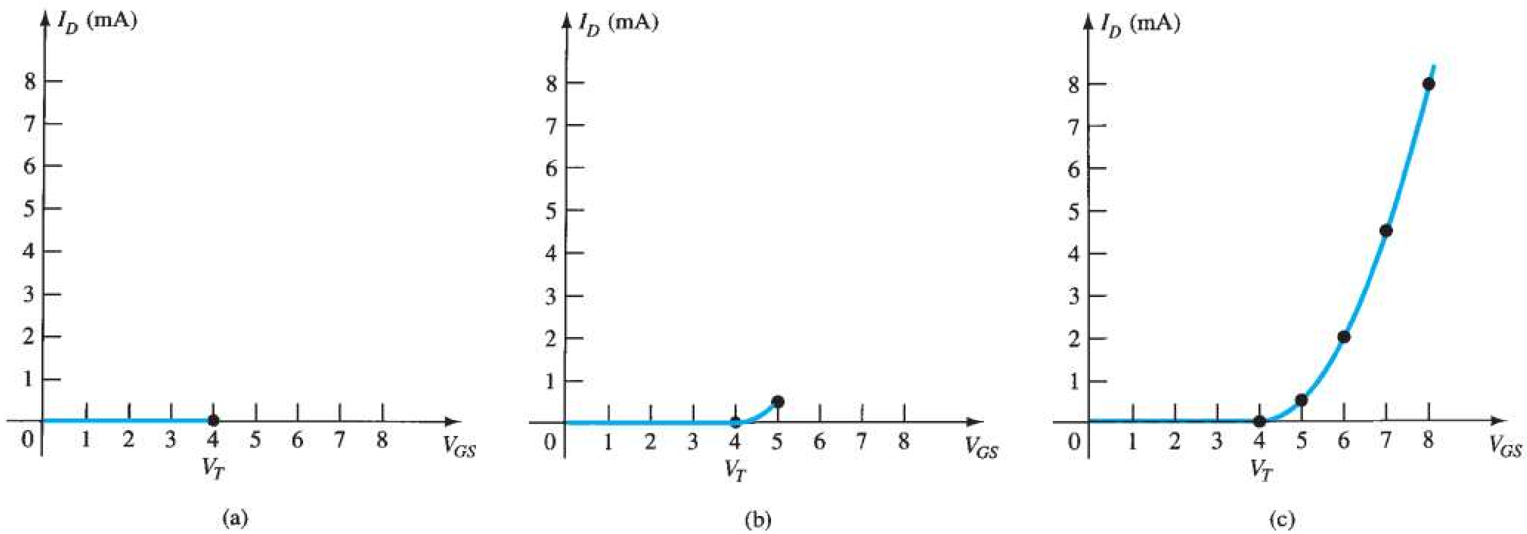

FIG. 6.37

Plotting the transfer characteristics of an n-channel enhancement-type MOSFET with $k = 0.5 \times 10^{-3}\ \text{A/V}^2$ and $V_T = 4$ V.

MOSFET

p-Channel Enhancement-Type MOSFETs

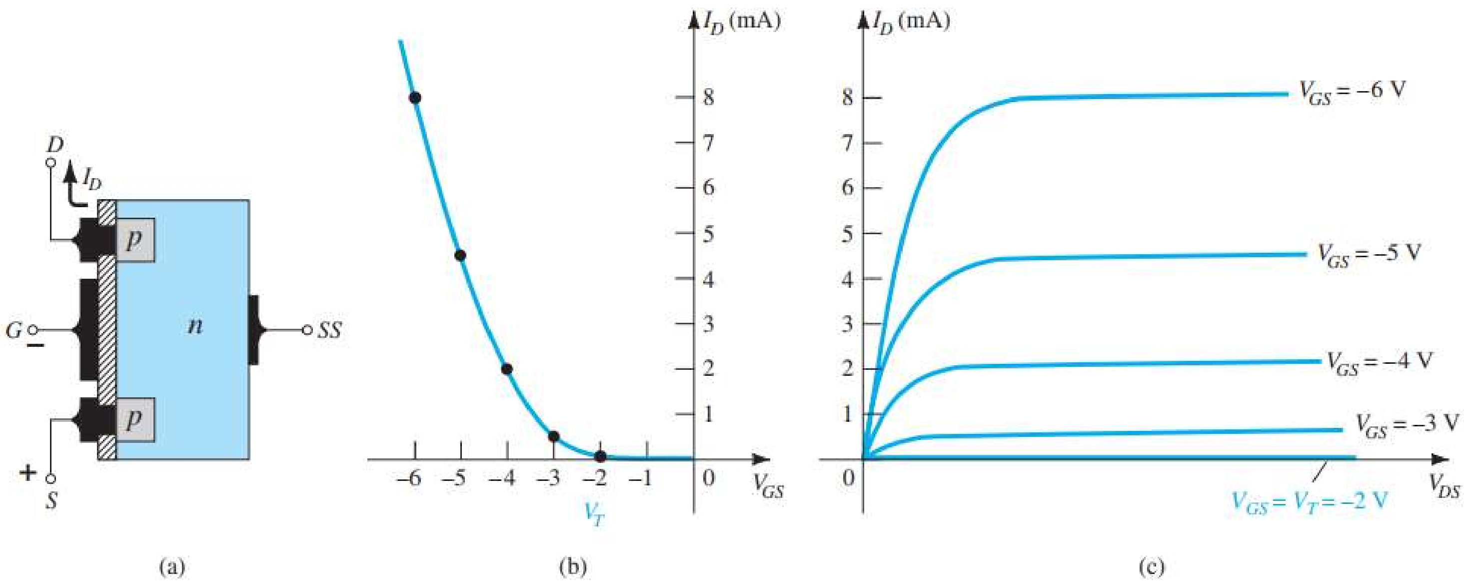

FIG. 6.38
p-Channel enhancement-type MOSFET with $V_T = 2$ V and $k = 0.5 \times 10^{-3}$ A/V^2.

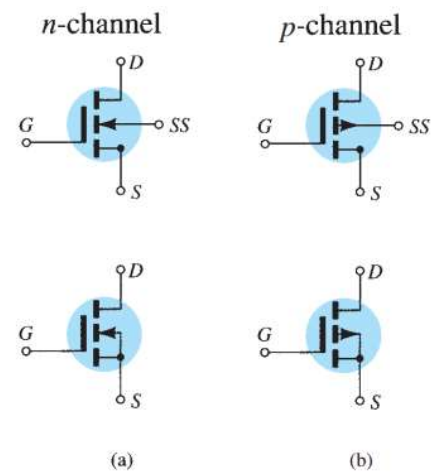

FIG. 6.39
Symbols for: (a) n-channel enhancement-type MOSFETs and (b) p-channel enhancement-type MOSFETs.

EXAMPLE 6.4 Using the data provided on the specification sheet of Fig. 6.40 and an average threshold voltage of $V_{GS(\text{Th})} = 3$ V, determine:

a. The resulting value of k for the MOSFET.
b. The transfer characteristics.

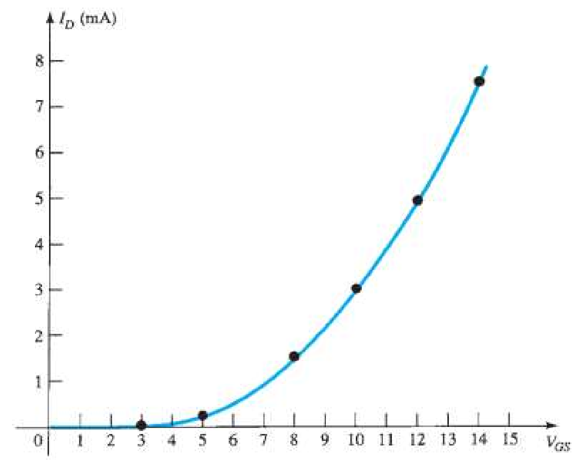

FIG. 6.41
Solution to Example 6.4.

MOSFET

CMOS

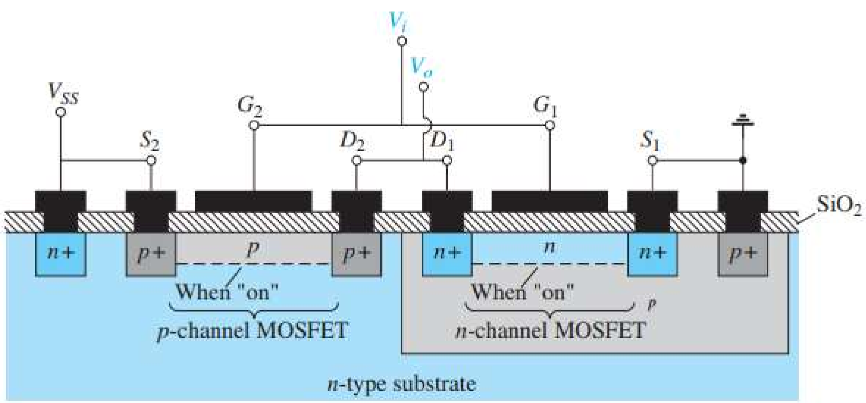

FIG. 6.44
CMOS with the connections indicated in Fig. 6.45.

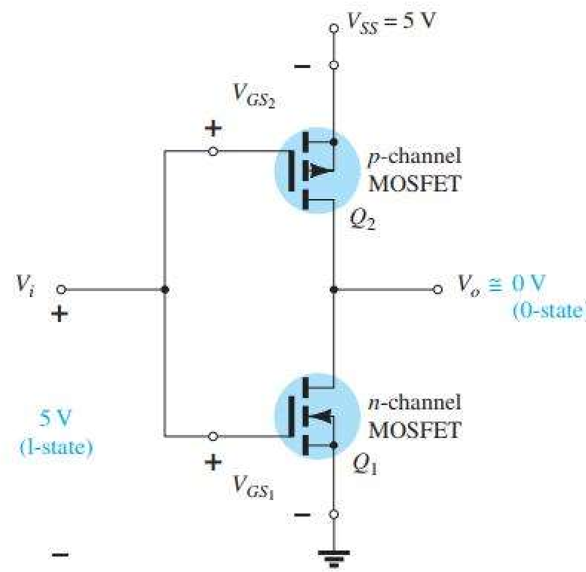

FIG. 6.45
CMOS inverter.

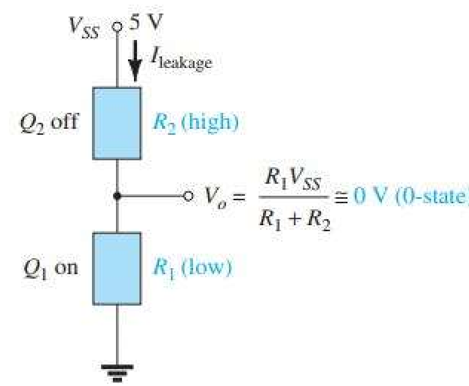

FIG. 6.46
Relative resistance levels for $V_i = 5$ V (1-state).