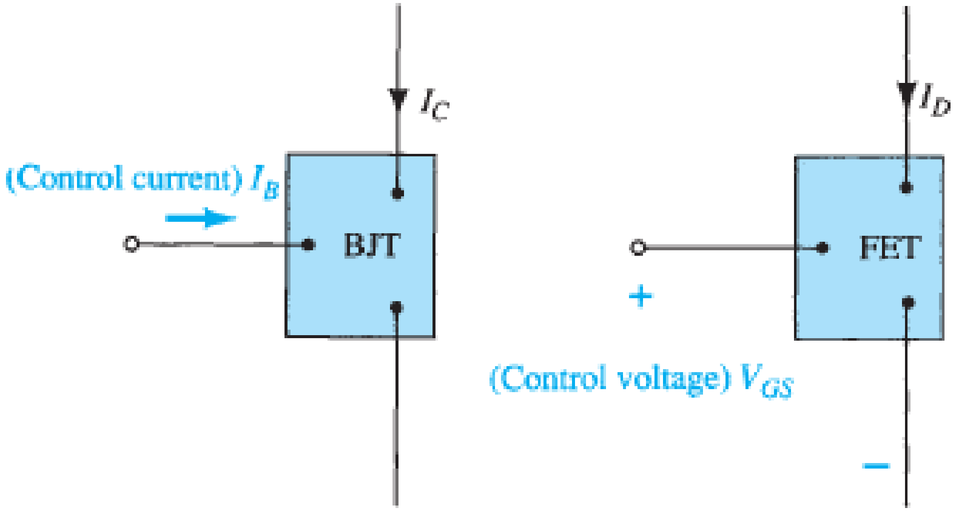
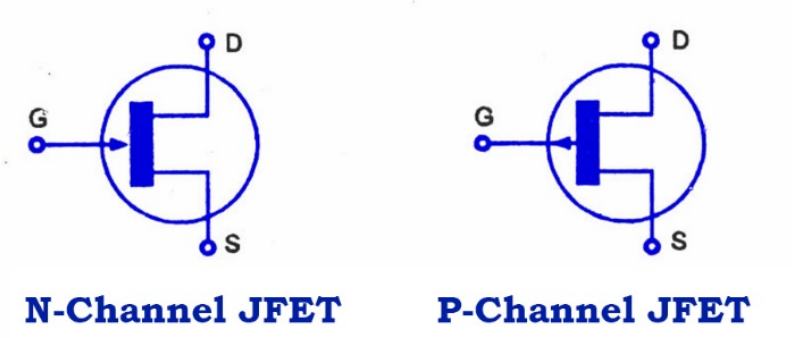
Field-Effect Transistor (FET)

BJT vs FET





N-Channel JFET **P-Channel JFET**

- ➢ *FET has high input impedance.*
- ➢ *Typical ac voltage gains for BJT amplifiers are a great deal more than for FETs.*
- ➢ *FETs are more temperature stable than BJTs, and FETs are usually smaller than BJTs, making them particularly useful in integrated-circuit (IC) chips.*

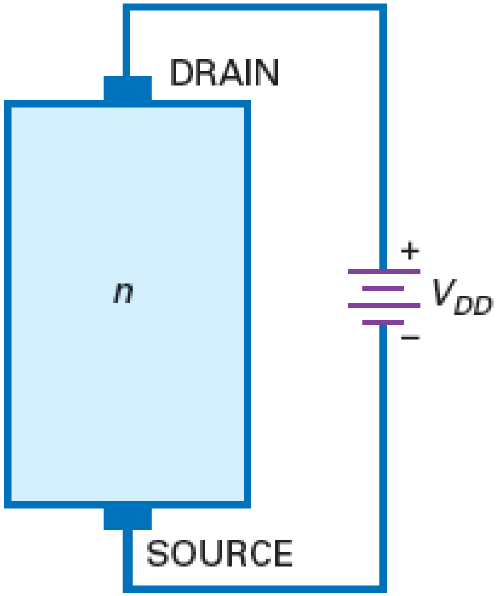
FET

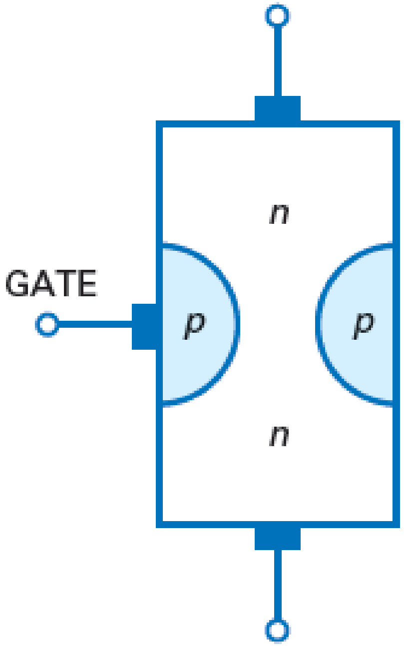
FET, is a three terminal active device that uses an electric field to control the current flow and it has a high input impedance which is useful in many circuits.

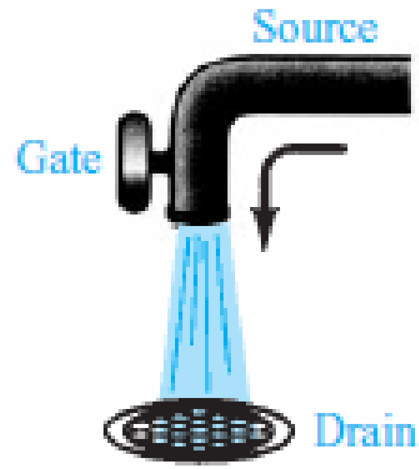
FET is an unipolar device because its operation depends on only one type of charge, either free electrons or holes. In other words, an FET has majority carriers but not minority carriers.

Furthermore, the FET is the preferred device for most switching applications. Because there are no minority carriers in FET. As a result, it can switch off faster since no stored charge has to be removed from the junction area.

There are three kinds of FETS: junction field-effect transistor (JFET), metal-oxide semiconductor FET (MOSFET) and metal – semiconductor FET (MESFET).

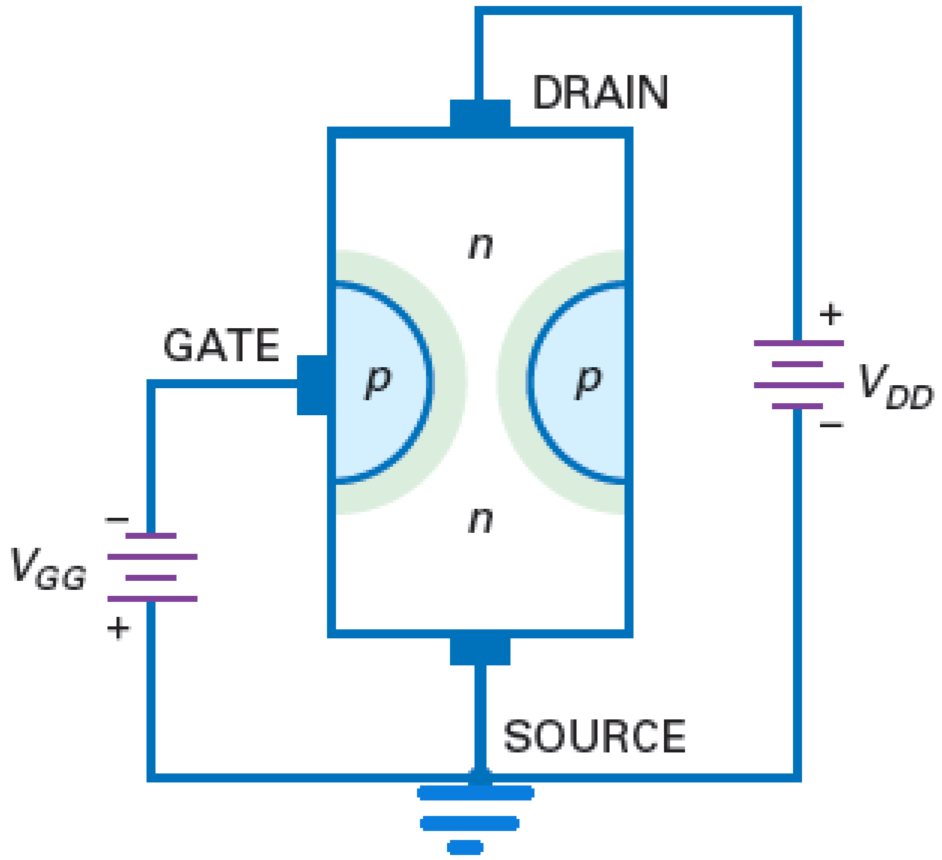






The lower end of the n-type semiconductor is called the source, and the upper end is called the drain. The supply voltage V_{DD} forces free electrons to flow from the source to the drain. To produce a JFET, a manufacturer diffuses two areas of p-type semiconductor into the n-type semiconductor. These p regions are connected internally to get a single external gate lead.

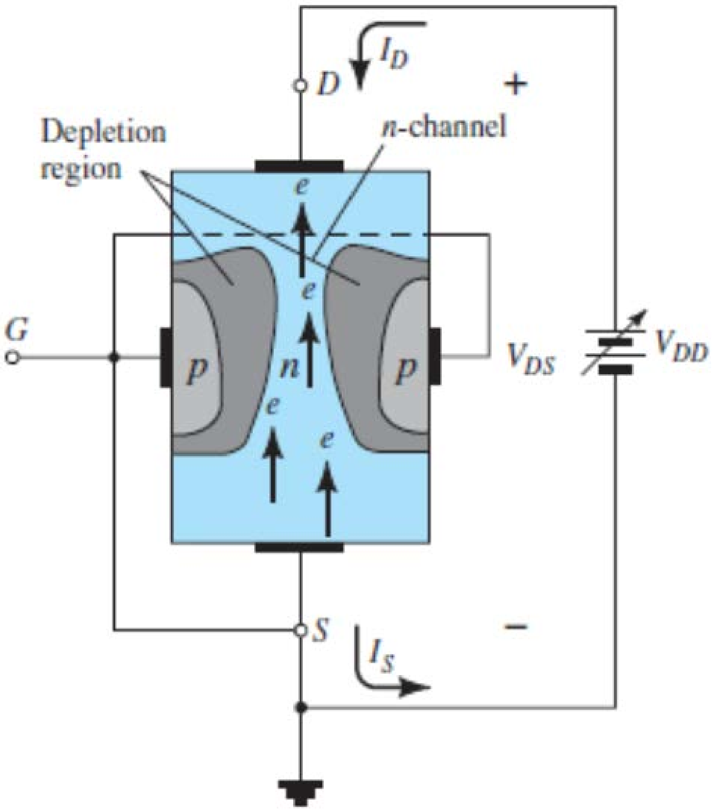
Normal biasing of JFET

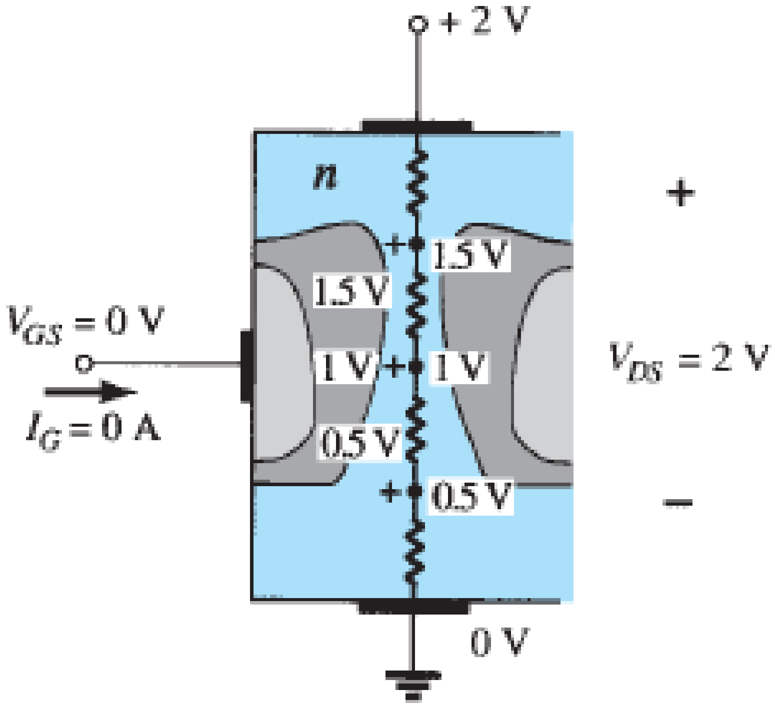


The drain supply voltage is positive, and the gate supply voltage is negative. The term field effect is related to the depletion layers around each *p* region. These depletion layers exist because free electrons diffuse from the *n* regions into the *p* regions. The recombination of free electrons and holes creates the depletion layers

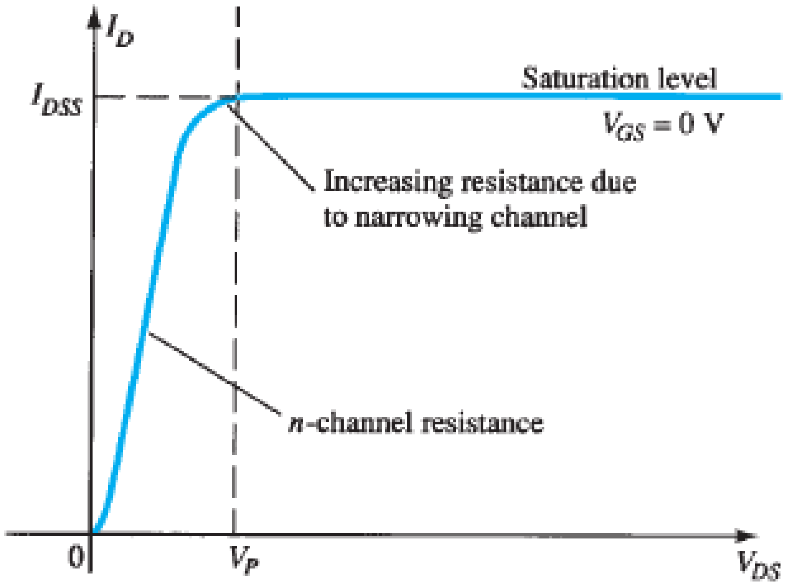
The *p*-type gate and the *n*-type source form the gate-source diode. With a JFET, we always *reverse-bias* the gate-source diode. Because of reverse bias, the gate current I_G is approximately zero, which is equivalent to saying that the JFET has an almost infinite input resistance. It is the reason that JFETs excel in applications in which a high input impedance is required.

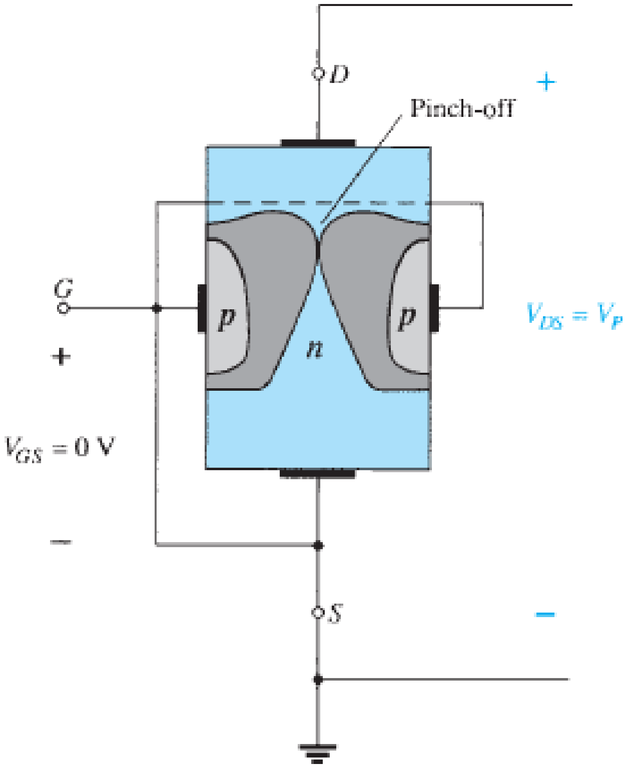
Electrons flowing from the source to the drain must pass through the narrow channel between the depletion layers. When the gate voltage becomes more negative, the depletion layers expand and the conducting channel becomes narrower. The more negative the gate voltage, the smaller the current between the source and the drain. The JFET is a voltage-controlled device because an input voltage controls an output current.





Assuming a uniform resistance in the *n* -channel, we can break down the resistance of the channel into few divisions. The upper region of the *p* -type material will be reverse-biased by about 1.5 V, with the lower region only reverse-biased by 0.5 V. The greater the applied reverse bias, the wider is the depletion region—hence the distribution of the depletion region will be like the above figure

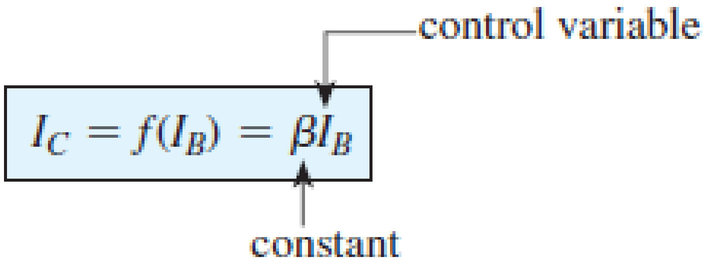




If V_{DS} is increased to a level where it appears that the two depletion regions would "touch" is called pinch-off. The level of V_{DS} that establishes this condition is referred to as the pinch-off voltage and is denoted by $V_{P.}$

I_{DSS} is the maximum drain current for a JFET and is defined by the conditions: $V_{GS} = 0$ V and $V_{DS} > V_P$.

For the BJT transistor the output current I_C and the input controlling current I_B are related by beta and the relation is linear.

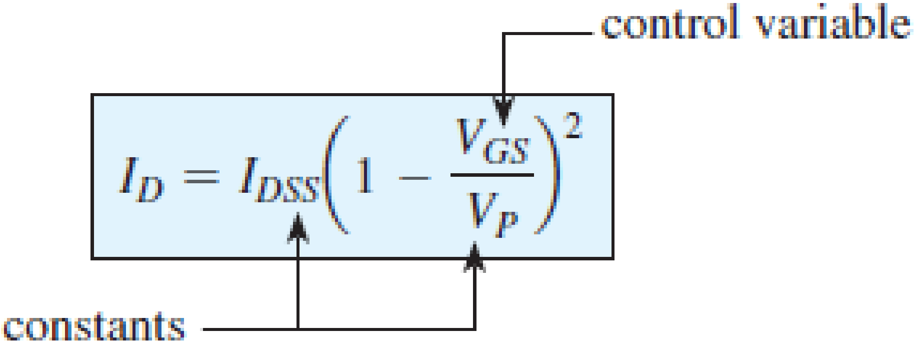


control variable

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

constant

But this linear relationship does not exist between the output and input quantities of a JFET. The relationship between I_D and V_{GS} is defined by *Shockley's equation*



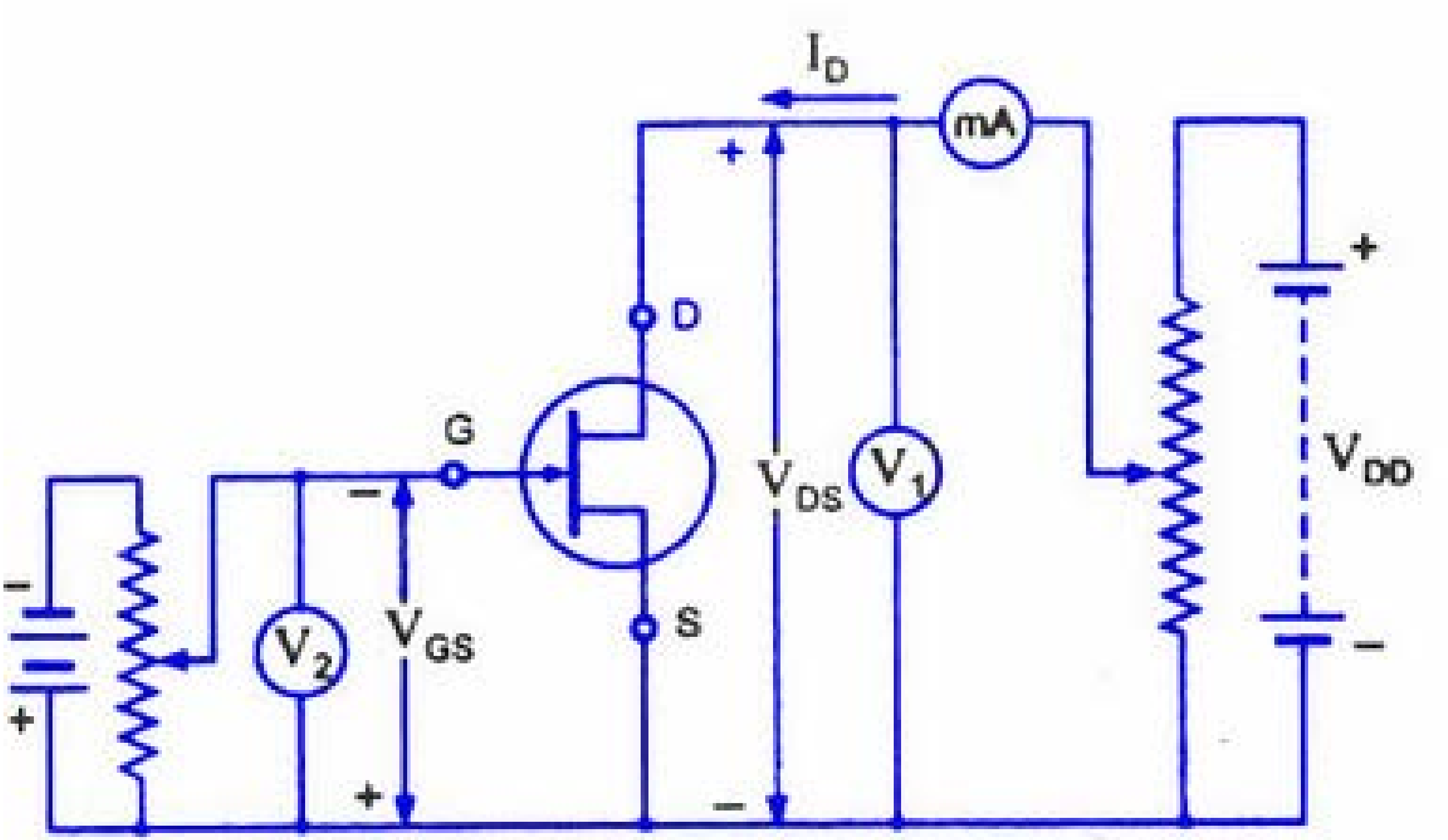
control variable

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

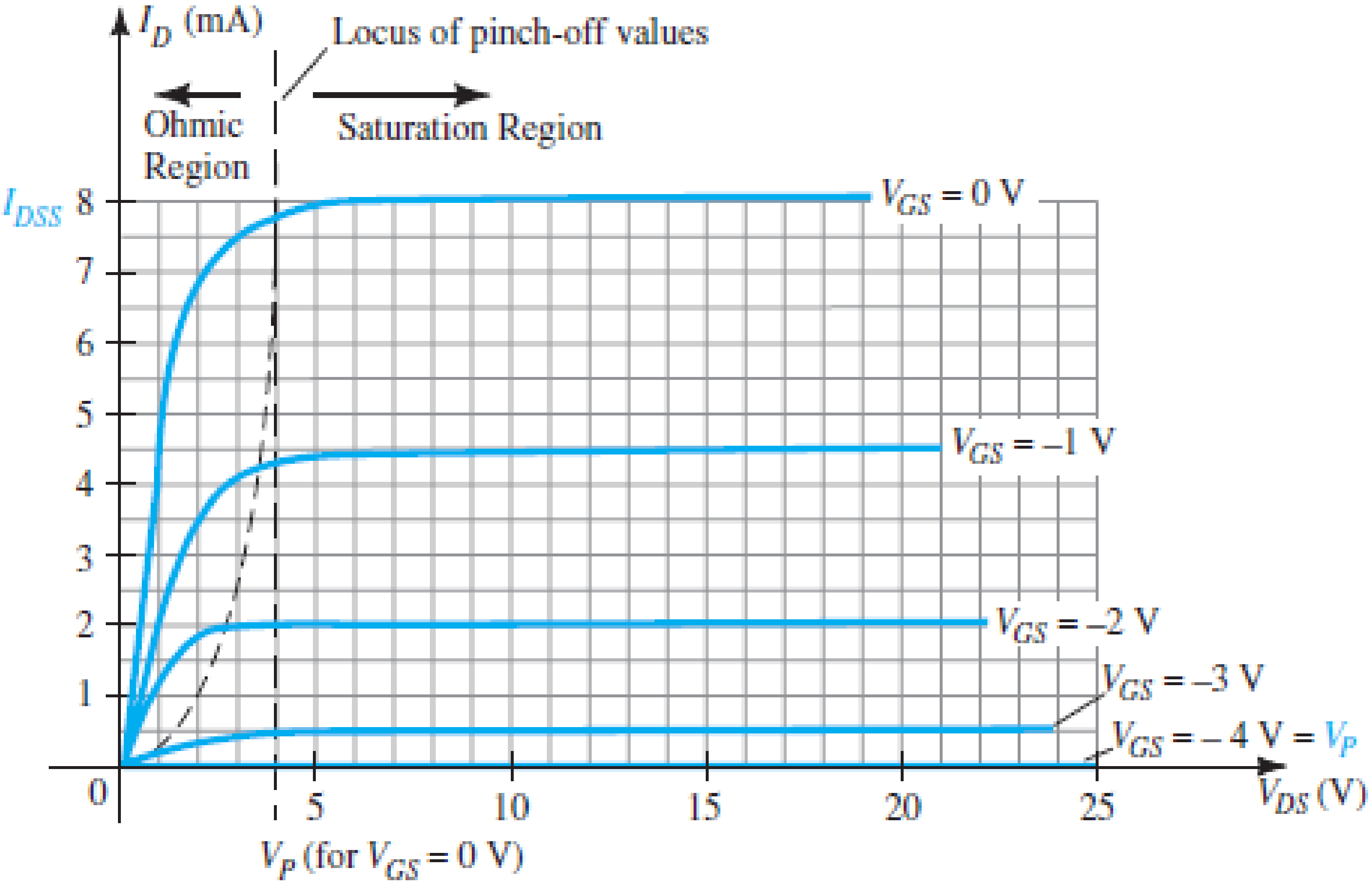
constants

I_{DSS} stands for the current drain to source with a shorted gate. This is the maximum drain current a JFET can produce.

Circuit diagram to measure JFET characteristics

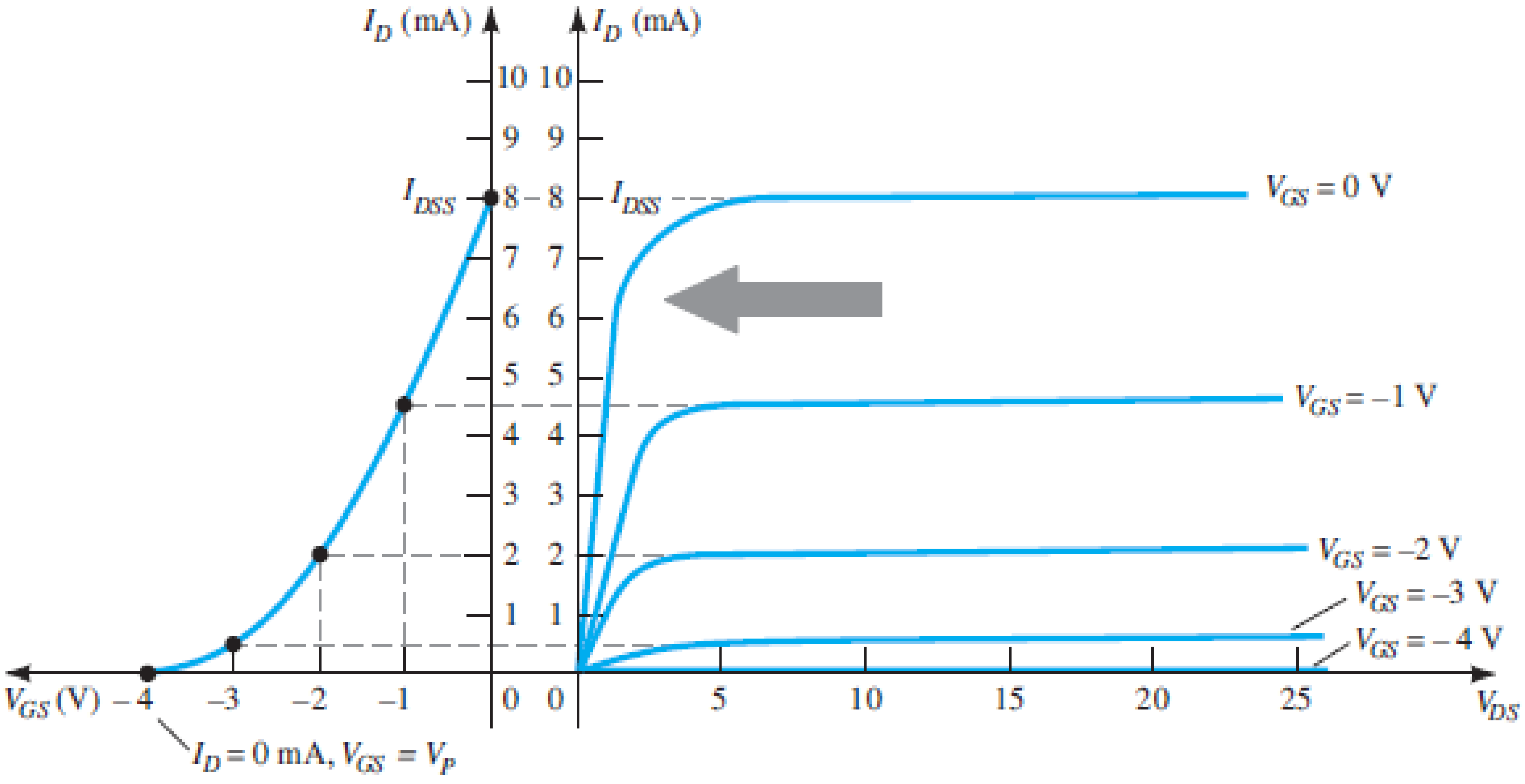


N-channel JFET characteristics



The level of V_{GS} that results in $I_D = 0$ mA is defined by $V_{GS} = V_P$, with V_P being a negative voltage for n-channel devices and a positive voltage for p-channel JFETs.

Transfer Characteristic curve from drain characteristics curve



When $V_{GS} = 0$ V, $I_D = I_{DSS}$

When $V_{GS} = V_P$, $I_D = 0$ mA

Parameters of JFET and their relation

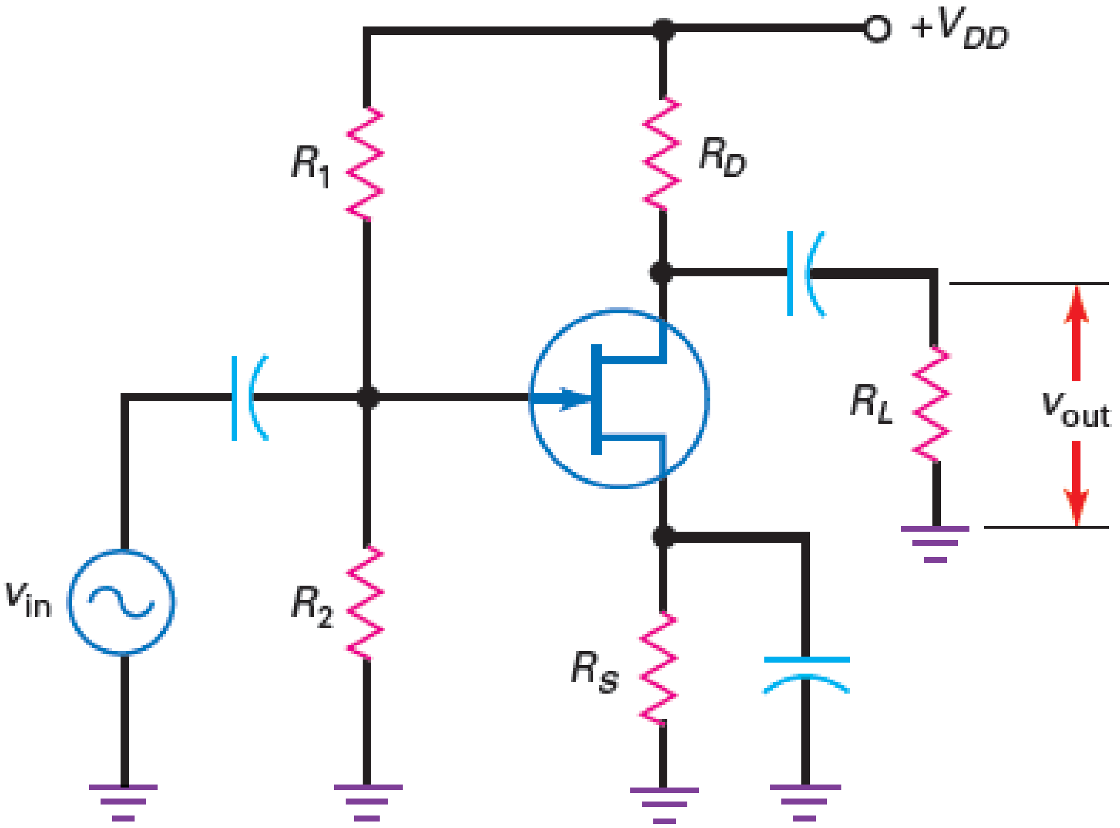
(*i*) Drain resistance (r_d): $$r_d = \frac{\Delta V_{DS}}{\Delta I_D} \text{ at constant } V_{GS}$$

(*ii*) Transconductance (g_{fs}): $$g_{fs} = \frac{\Delta I_D}{\Delta V_{GS}} \text{ at constant } V_{DS}$$

(*iii*) Amplification factor (μ): $$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}} \text{ at constant } I_D$$

$$\boxed{\mu = r_d \times g_{fs}}$$

JFET Amplifier – Common Source mode with VDB



Transconductance: Transconductance equals the ac drain current divided by the ac gate-source voltage. Transconductance tells us *how effective the gate-source voltage is in controlling the drain current.* The higher the transconductance, the more control the gate voltage has over the drain current. $g_{fs}=i_d/v_{gs}$

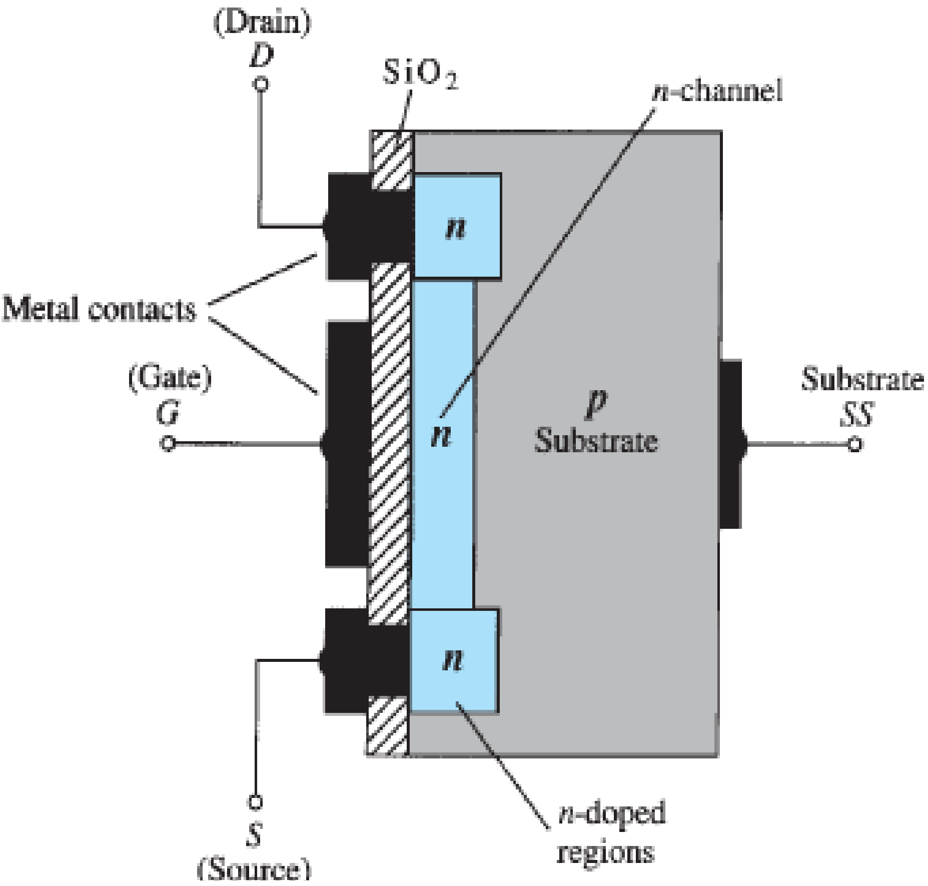
Metal-oxide semiconductor FET (MOSFET)

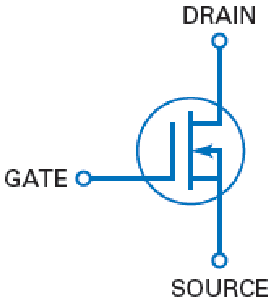
MOSFET, has a source, gate, and drain. The MOSFET differs from the JFET, however, in that the gate is insulated from the channel. Because of this, the gate current is even smaller than it is in a JFET.

There are two kinds of MOSFETs, the depletion-mode type and the enhancement-mode type.

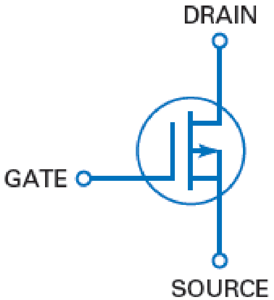
The enhancement-mode MOSFET is widely used in both discrete and integrated circuits. In discrete circuits, the main use is in power switching, which means turning large currents on and off. In integrated circuits, the main use is in digital switching.

n-Channel Depletion-type MOSFET (D-MOSFET)





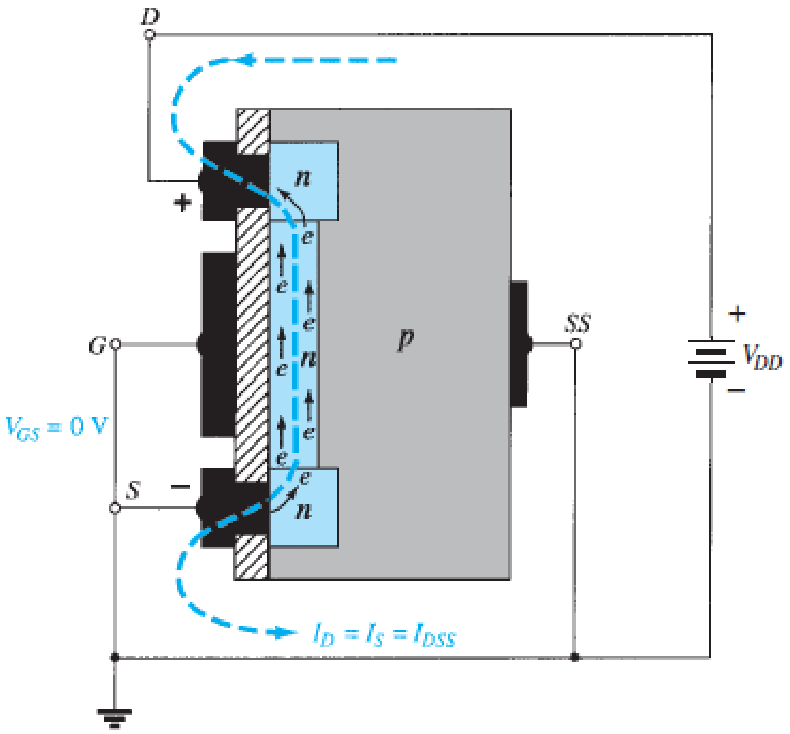
n-channel

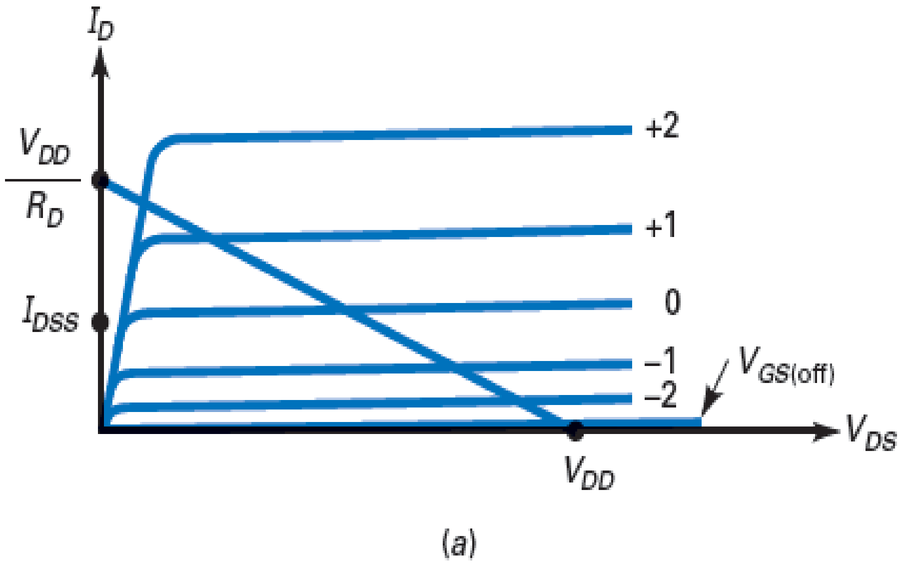


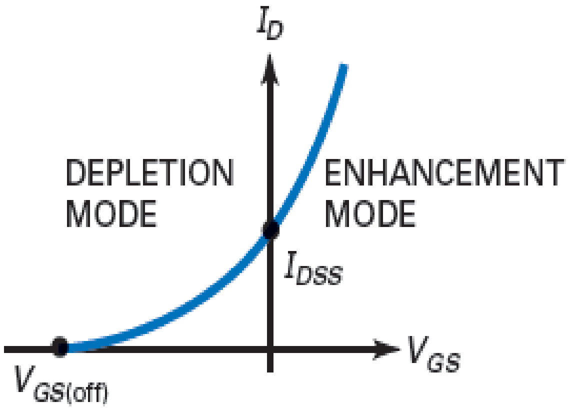
p-channel

A piece of *n* material with an insulated gate on the left and a *p* region on the right. The *p* region is called the substrate. Electrons flowing from source to drain must pass through the narrow channel between the gate and the *p* substrate.

A thin layer of silicon dioxide (SiO$_2$) is deposited on the left side of the channel. Silicon dioxide is a dielectric.

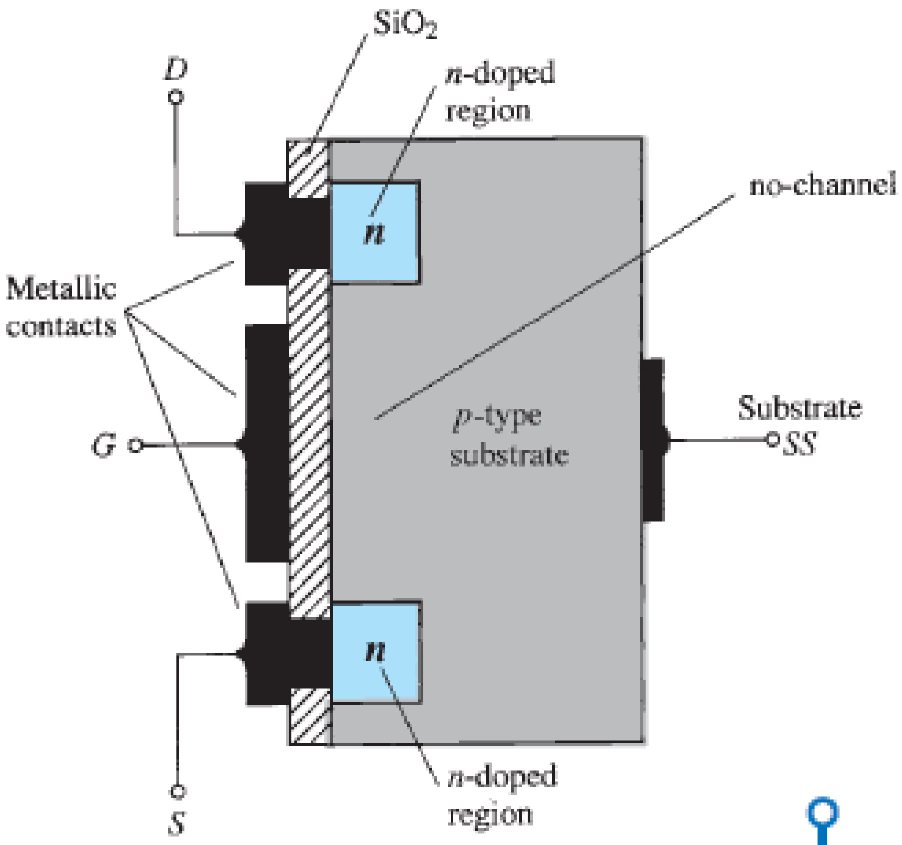






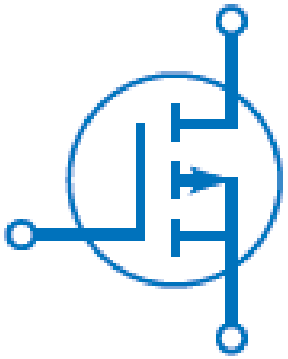
Drain and transfer characteristics for an n-channel depletion-type MOSFET

Enhancement type MOSFET (E-MOSFET)

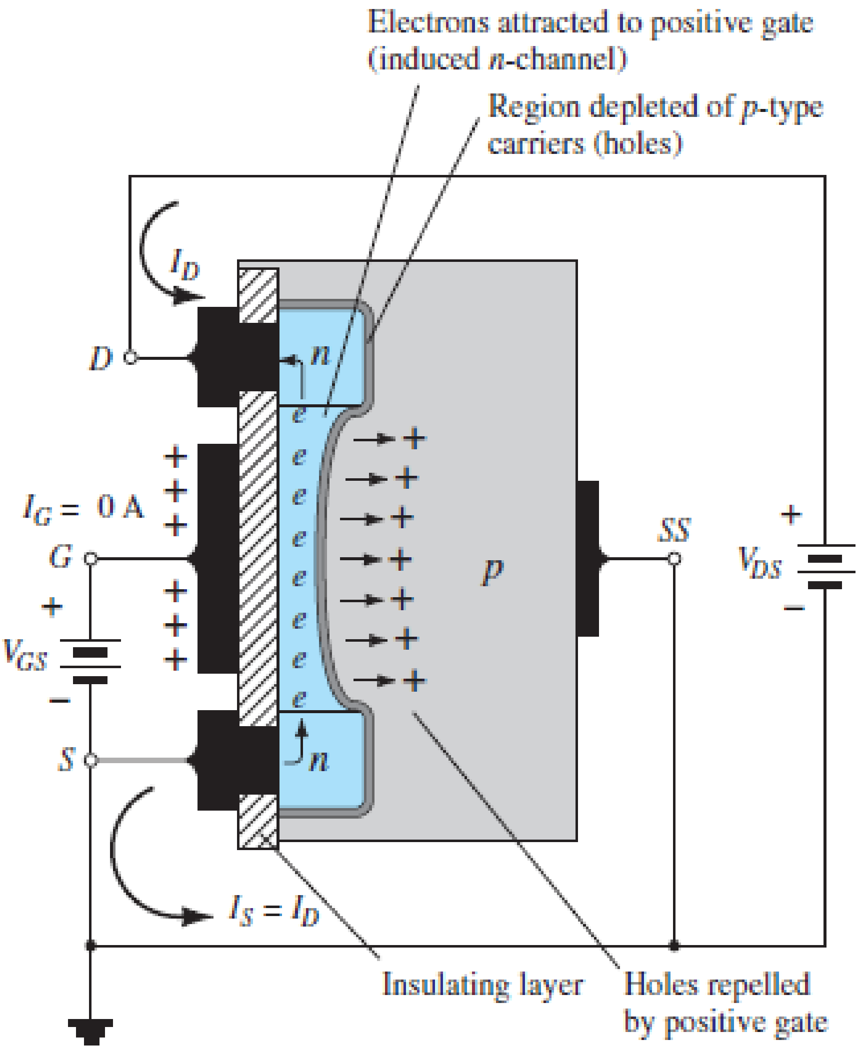


Construction of an enhancement-type MOSFET is quite similar to that of the depletion-type MOSFET, except for the absence of a channel between the drain and source terminals.

n-channel E-MOSFET

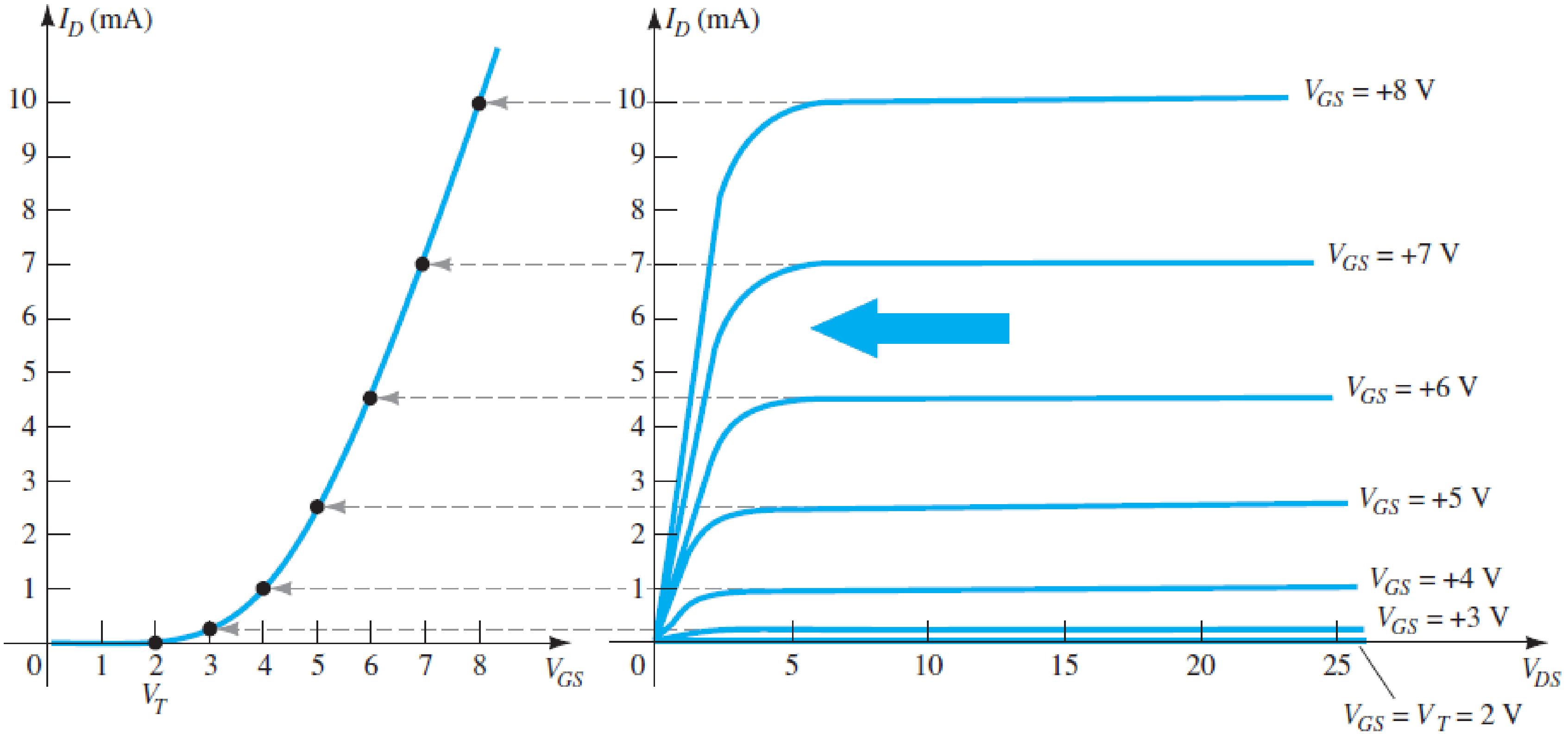


p-channel E-MOSFET



When the gate is positive, it attracts free electrons into the *p* region. The free electrons recombine with the holes next to the silicon dioxide. When the gate voltage is positive enough, all the holes touching the silicon dioxide are filled, and free electrons begin to flow from the source to the drain. The effect is the same as creating a thin layer of *n*-type material next to the silicon dioxide. This thin conducting layer is called the *n-type inversion layer.*

When it exists, free electrons can flow easily from the source to the drain. The minimum V_{GS} that creates the *n*-type inversion layer is called the threshold voltage, $V_{GS(\text{th})}$. When $V_{GS} < V_{GS(\text{th})}$, the drain current is zero.



Characteristic curves of an n-channel enhancement-type MOSFET