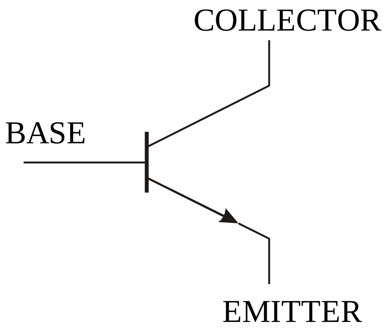
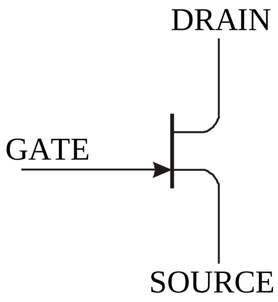
MOSFETS

Although the base current in a transistor is usually small (< 0.1 mA), some input devices (e.g. a crystal microphone) may be limited in their output. In order to overcome this, a Field Effect Transistor (FET) can be used.



BIPOLAR TRANSISTOR



FIELD EFFECT TRANSISTOR

Applying a voltage to the Gate connection allows current to flow between the Drain and Source connections.

This is a Voltage operated device. It has a very high input resistance (unlike the transistor) and therefore requires very little current to operate it (typically 10-12 □A).

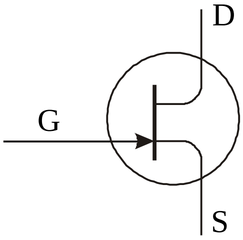
Since it operates using very little current, it is easy to destroy a FET just by the static electricity built up in your body.

FET's also have the advantage that they can be designed to drive large currents, they are therefore often used in transducer driver circuits.

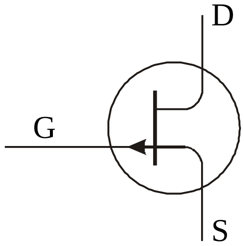
Two different types of FET's are available:
JFET (Junction Field Effect Transistor); and
MOSFET (Metal Oxide Semiconductor Field Effect Transistor).

All FET's can be N-channel or P-channel.

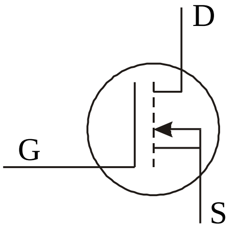
MOSFET's can be "depletion type" or "enhancement type".



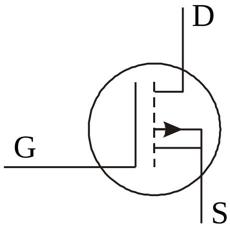
N-CHANNEL JFET



P-CHANNEL JFET



N-CHANNEL ENHANCEMENT MOSFET



P-CHANNEL ENHANCEMENT MOSFET

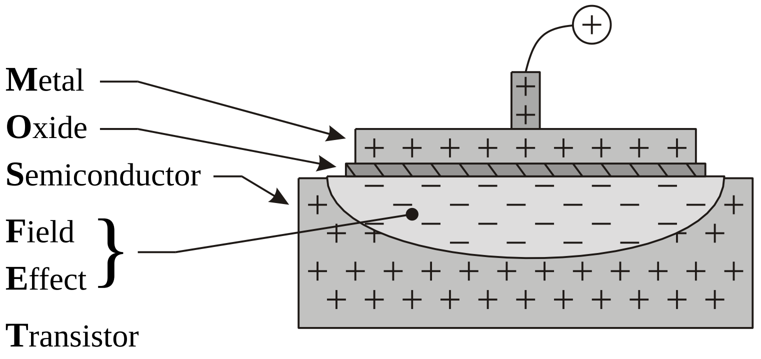
The simplicity in construction of the MOSFET means that it occupies very little space. It can also be designed to be used as a resistor or capacitor.
Because of its small size, many thousands of MOSFET's can easily be incorporated into a single integrated circuit. The high input resistance means extremely low power consumption compared with bipolar transistors.
All these factors mean that MOS technology is widely used within the electronics industry today.

Enhancement-type MOSFET's can be used in a similar way to bipolar transistors.

N-channel enhancement MOSFET's allow a current to flow between Drain and Source when the Gate is made Positive (similar to an NPN transistor).
P-channel enhancement MOSFET's allow a current to flow between Drain and Source when the Gate is made Positive (similar to an PNP transistor).

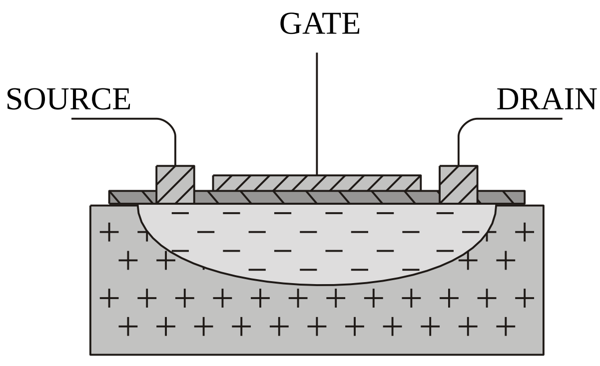
N-channel enhancement MOSFET - theory

The MOSFET transistor is constructed on a piece of p-type Semiconductor, an Oxide insulating layer separates this from the Metal 'Gate' contact.



Making the metal contact positive will produce a Field, repelling the positive majority carriers leaving negatives behind (to produce an N-channel).

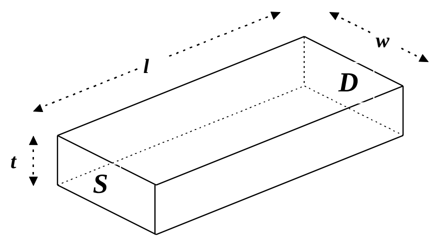
If the field produced by the Gate voltage is large enough, a channel is produced connecting the Drain and Source. When a voltage is applied between the Drain and Source, current will flow along the channel.



(In practice, the Drain and Source metal plates are connected to n-type semiconductor within the p-type substrate).

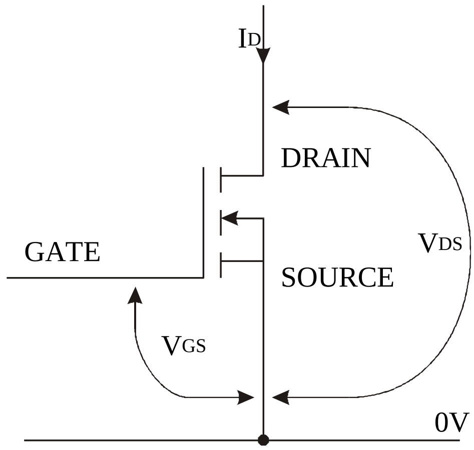
The channel acts as a resistance between the Source and Drain. The size of which depends on:

- the length (l) of the channel between D and S
- the width (w) of the channel
- the thickness (t) of the channel



l and *w* are determined during manufacture of the MOSFET, *t* is adjusted by altering the gate voltage.

For a given MOSFET, the size of the current between the Drain and Source will therefore depend on the Gate voltage (V_{GS}) and the voltage between the Drain and Source (V_{DS}).



Like a bipolar transistor, if the Gate voltage is below a certain level (the threshold value, V_T), no current will flow between the Drain and Source (the MOSFET will be switched off).

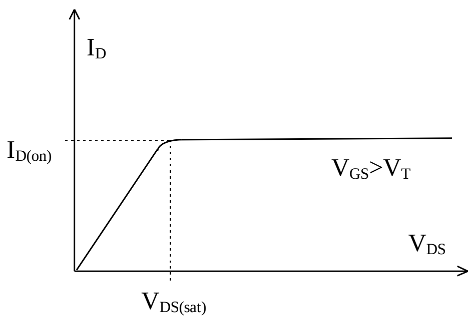
If the Gate voltage is above V_T, the MOSFET will start to switch on.
Increasing the Gate voltage will increase the thickness of the channel, increasing the number of charge carriers in the channel and hence increasing I_D.

For a given value of V_{GS} (above V_T), increasing V_{DS} increases the current until saturation occurs. Any further increase will cause no further increase in I_D. The MOSFET is fully ON and can therefore be used as a switch.

Saturation occurs when $V_{DS} = V_{GS} - V_T$.

If V_{DS} is $\geq V_{DSsaturation}$, I_D is constant (for a given value of V_{GS})
(I_D is then known as $I_{D(on)}$).

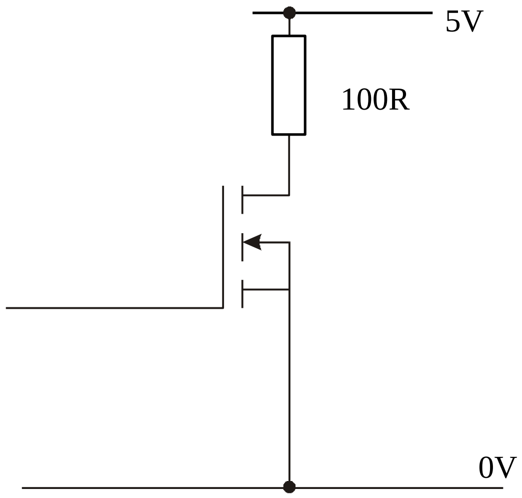
When saturation occurs $I_D = I_{D(on)}$



When saturation occurs, the resistance of the channel, R_{DS}, is normally low ($R_{DS(on)}$ less than 1Ω for power MOSFET's)

WORKED EXAMPLE

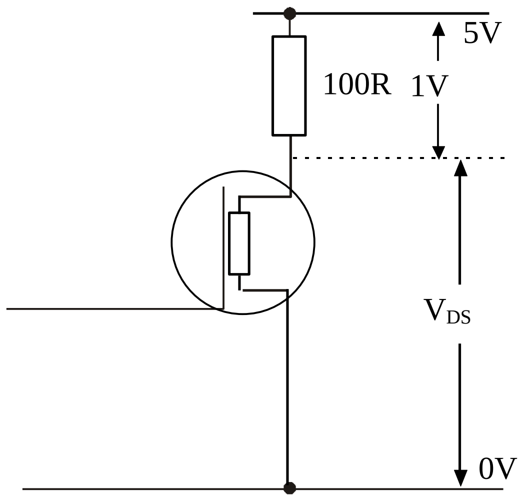
The threshold gate voltage for the MOSFET shown below is 2 V. Calculate the gate voltage required to ensure that a saturation current of 10 mA flows through the load resistor.



Step 1

The Drain - Source channel acts as a series resistor with the 100R, since the current is the same in a series circuit, the voltage over the 100R can be calculated using Ohm's law

V = IR = 10 mA x 100 = 1 Volt



Step 2

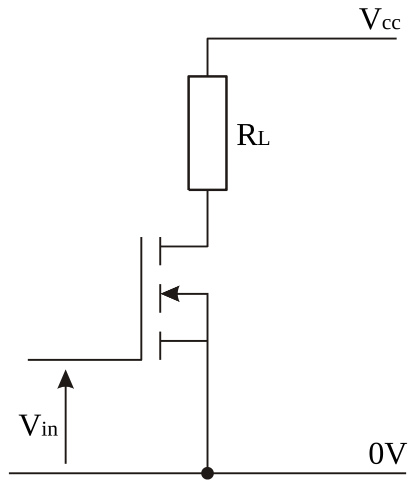
Using Kirchoff's 2nd law,

the voltage over the channel + the voltage over the load resistor = supply voltage

hence V_{DS} = 5 - 1 = 4 Volts

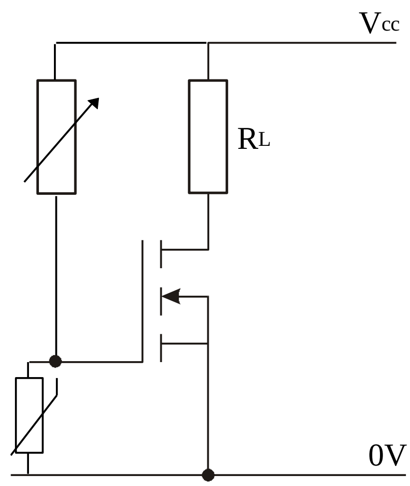
Step 3
For saturation to occur,
$V_{DS} = V_{GS} - V_T$
$V_{GS} = V_{DS} + V_T$
$V_{GS} = 4 + 2 =$ **6 Volts**.

MOSFET's can be designed to handle **very high drain currents**, this means that they can be used to drive high current output transducers drivers without the need for relay switching circuits (unlike the bipolar transistor). MOSFET's connected as shown below are said to be in common-source mode (c.f. common-emitter mode for bipolar transistors).



The load resistor could be any output transducer, bulb, motor, relay etc. Since MOSFET's are particularly sensitive to high voltages, care must be taken to include a reverse biased diode over transducers that may cause a back emf when switched off.

A variable resistor can be used in a voltage divider circuit and adjusted to ensure that the input voltage to the gate = V_T



Changes in V_{GS} (ΔV_{GS}) above the threshold value causes changes in I_D (ΔI_D)
Whereas the performance of a bipolar transistor is measured by its' amplification (h_{fe}), the performance of a FET is measured by its *transconductance* (g_m) and is calculated by

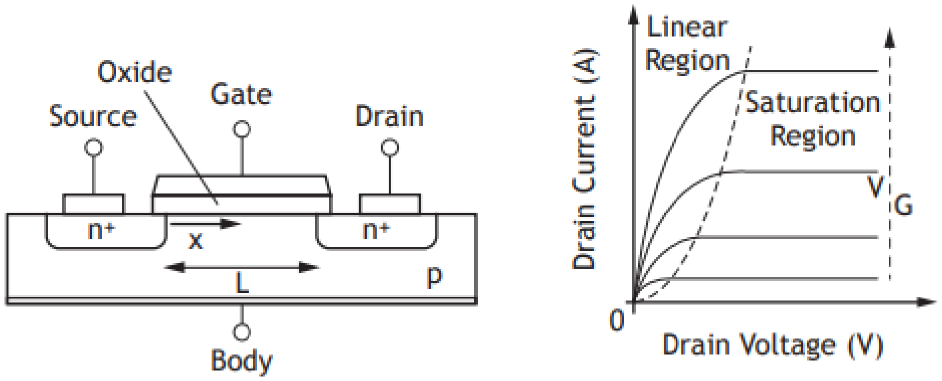
$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

g_m is measured in Amps per Volt (AV^{-1})
[These units are sometimes referred to as siemens or mhos]

Practice Questions

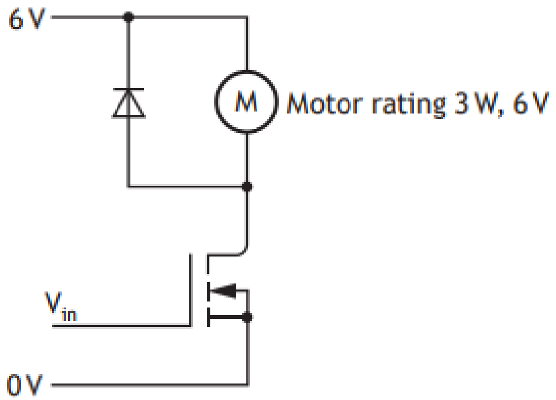
MARK

3. Diagrams of a MOSFET and its characteristic operation curves are shown below. A MOSFET can be connected as a voltage operated switch.



Describe the basic operation of a MOSFET switching device, making reference to the diagrams shown. **3**

1. The motor driver circuit shown below is used to switch a motor on and off.



(a) Calculate the resistance of the motor.

Show all working and final unit. **2**

When the circuit is switched on, the resistance of the MOSFET is 0·5 Ω.

(b) Calculate the MOSFET drain current.

Show all working and final unit. **2**

(c) Calculate the power dissipated in the MOSFET when it is switched on.

Show all working and final unit. **1**

6. An electronic engineer is designing the control system for a food mixer. Transistors are required to drive the mixer's outputs.

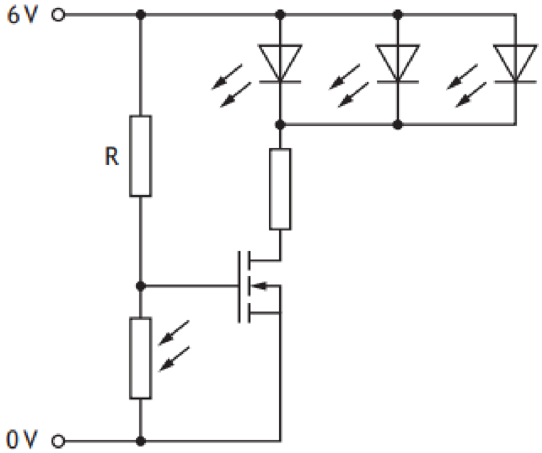
(a) Describe the difference in the way that MOSFETs and bi-polar junction transistors (BJT) control their output current. **1**

(b) The engineer chooses a MOSFET to drive the electric motor.

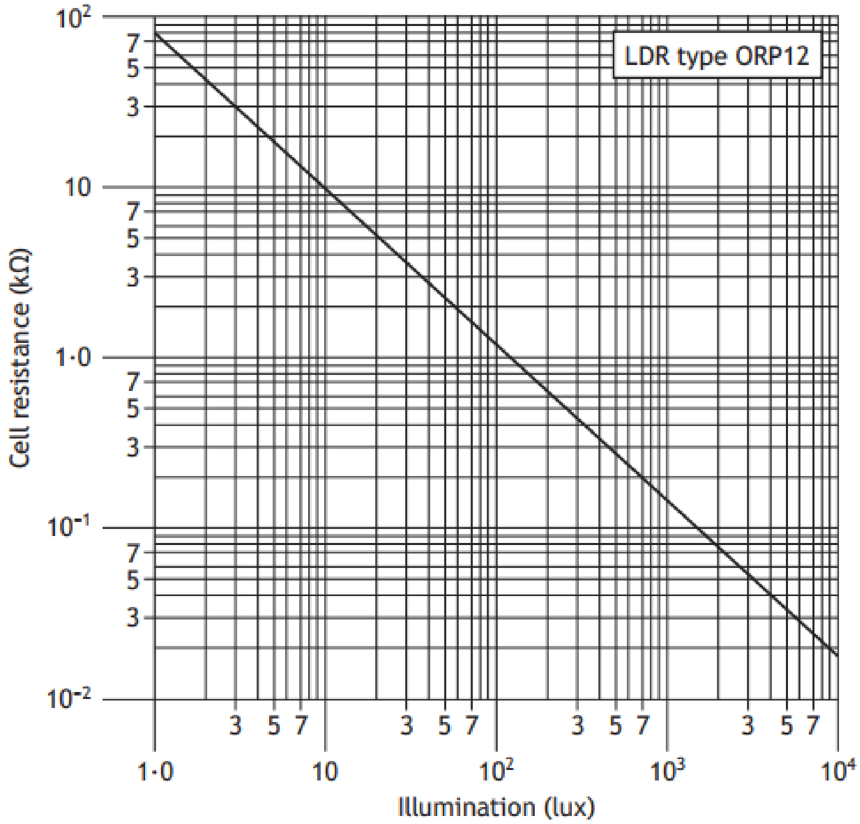
Explain why a MOSFET was chosen instead of a BJT. **1**

8. (continued)

(f) The diagram below shows a further sub-system which will light a series of LEDs when light levels are low



The characteristics of the LDR are shown in the graph below.



8. (f) (continued)

The LEDs must switch on when the light level drops to 200 lux. The MOSFET switches on when Vgs = 3·6 V

Calculate, with reference to the graph opposite, the required value of R. **2**