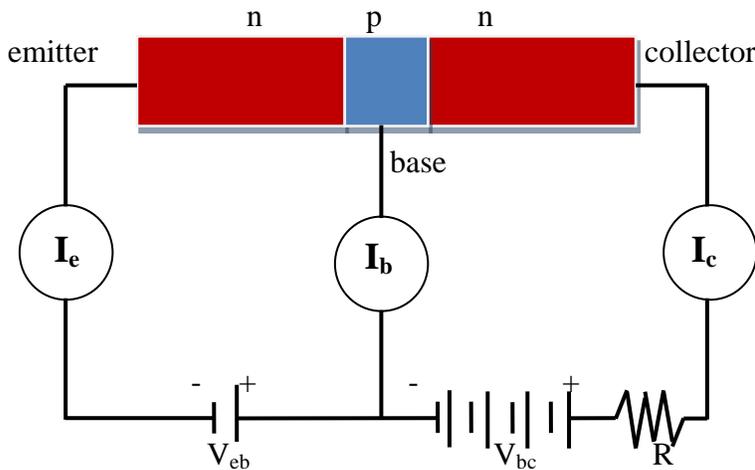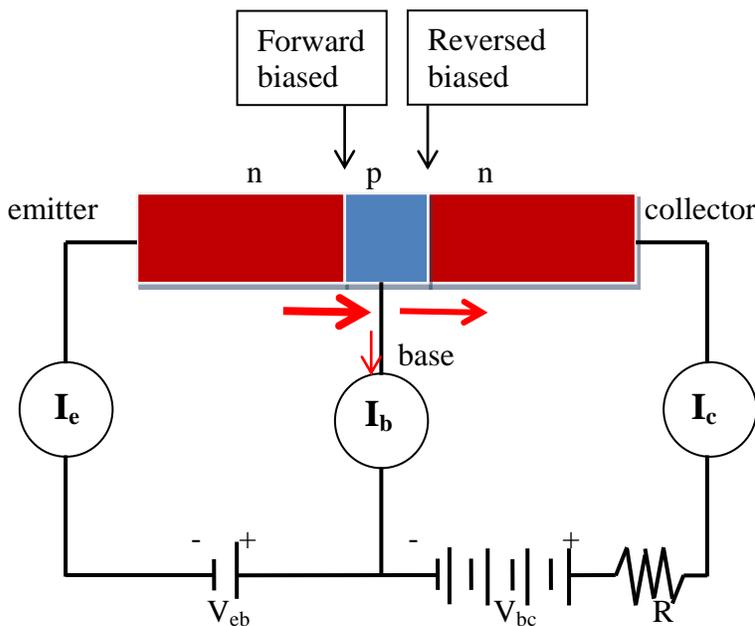# TRANSISTORS

1) Basic npn or pnp junctions - one example

Instead of using just one pn junction, we now use three doped materials so that we have two junctions; from this we can **get amplification of power, current or voltage**. I'll show one case in which we get **power** amplification. Consider the following circuit:

The often high V_{bc} makes the base-collector junction reverse biased (since the p side is negative and the n side is positive); this voltage is often high but causes little current due to the reverse bias. The V_{eb} makes the emitter-base junction forward biased (since the p side is positive and the n side is negative); this voltage is often low but controls I_e which can be fairly large due to the forward bias of the emitter base junction. But due to the thinness of the base and the high V_{bc}, **most of the current, I_e, flows through to the collector to become I_c** while only a small percent flows in I_b. Now recall that power is current times voltage (P=IV). Therefore, **since I_e controls I_c ($I_e \approx I_c$), and V_{bc} can be much larger than V_{eb} ($V_{bc} \gg V_{eb}$), a low power from $I_e V_{eb}$ controls a large power in $I_c V_{bc}$** .

(Red arrows indicate direction of **electron flow**. Traditional current flow will be opposite.)

By creatively using the pn and np junctions in the pnp or npn transistor (many of these now being standard), we can get not only power amplification as in the above situation, but also current or voltage amplification. I expect that you will (or already have) run into these in your electronics courses.

2. Depletion layer (important in the JFET and MOSFET transistors in the next two parts)

We now consider the pn junction from another aspect, one that has been mentioned before in connection with matching Fermi levels between the two differently doped semiconductor materials (the n and p regions). In the n region, there are many electrons in the conduction band and few holes in the valence band due to the presence of the donor atoms. Some of the electrons near the junction will diffuse over to the p region which is low in electrons and high in holes due to the presence of acceptor atoms (which easily accept electrons from the valence band). In the same way, some of the holes near the junction will drift over to the n region which is low in holes and high in electrons due to the presence of donor atoms (which easily give up their electrons to the conduction band). This has the consequence we have already discussed: it lowers the Fermi level in the n region and raises the Fermi level in the p region so that they match. **But in the junction region, the extra electrons in the p region will easily find plenty of holes and so they will be depleted. In the n region the extra holes will easily be found by the many electrons and so they also will be depleted in the junction region. This causes the junction region to be depleted of most of the mobile charges** (the conduction electrons and the valence holes).

Further, if we apply **a reverse bias** voltage (positive voltage applied to the n region, negative voltage applied to the p region), we will pull electrons from the n region away from the junction, and we will pull holes from the p region away from the junction, **thus increasing the size of the junction region that is depleted of the mobile charge carriers.** Conversely, if we apply a forward bias, we will reduce the depleted region.

We still get a little current in the reverse bias case because of the "minority" carriers: the few electrons in the conduction band of the p type and the few holes in the valence band of the n type will be able to move across the junction. But these are limited by the low probability of electrons jumping up due to heat. The "majority" carriers, on the other hand, are due to the electrons provided by the donor atoms in the n type and the holes provided by the acceptor atoms in the p type regions; but these have been depleted in the depletion region!

In the forward bias, the majority carriers have very little depletion region to "cross" and so do so with little problem. As the depletion region gets smaller, the probability of crossing it becomes higher (exponentially as indicated by the Boltzmann probability idea).

3. JFET transistors: Junction-gate Field-Effect Transistors

We **use the depletion region idea to explain the JFET transistor behavior**. Consider the pnp transistor shown below:
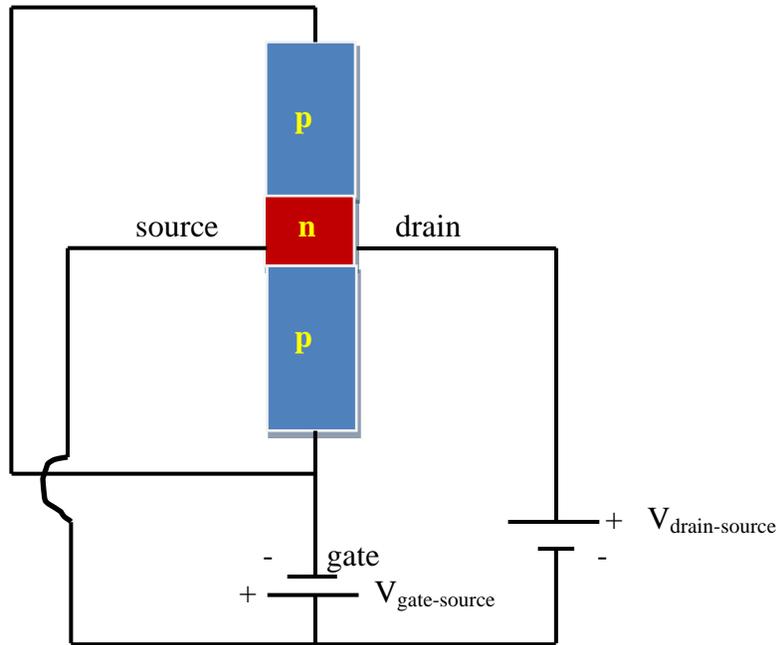

Note that the direction of the current in the source-drain circuit is from drain to source, but that the electron flow is from source to drain (hence the names). **The current from the source to the drain depends on the σ (conductivity) of the n region. The σ of the n region depends on the level of doping but also on the width of the "channel".** The channel is the area through the n region that has the majority charge carriers (in other words, the area that is not part of the depletion layer between the np region at the top and the np region at the bottom of the diagram). **We can control the two depletion regions, and hence the width of the channel, and hence the amount of current in the drain-source circuit by controlling the reverse bias voltage due to the gate-source voltage. A small change in the gate-source voltage will lead to a big change in the drain-source current!**
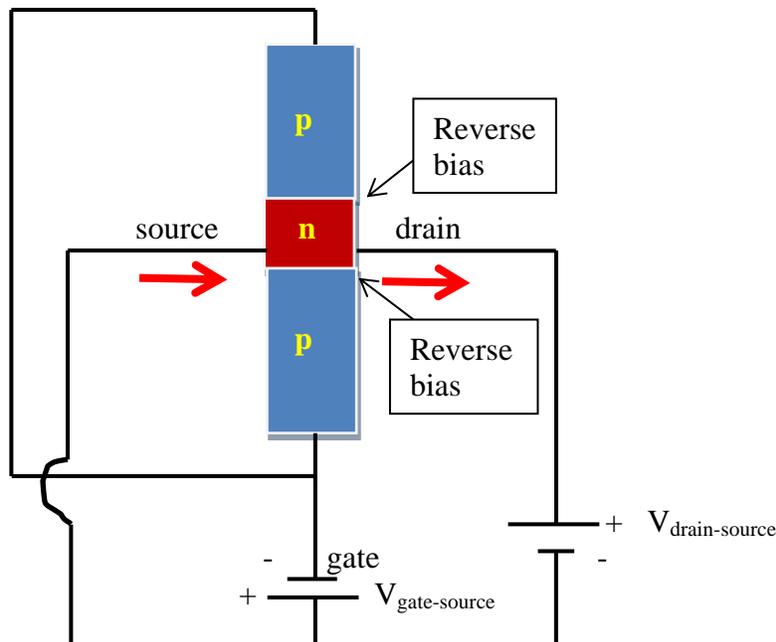
(Again, red is the direction of the electron flow.)

4. MOSFET transistors: Metal-Oxide-Semiconductor Field-Effect Transistors

      This type of transistor operates in the same way as the JFET, using a voltage (to create an electric field) to adjust the size of the depletion layer, but it uses different materials in its construction (Metal-Oxide-Semiconductor). Consider the following diagram:
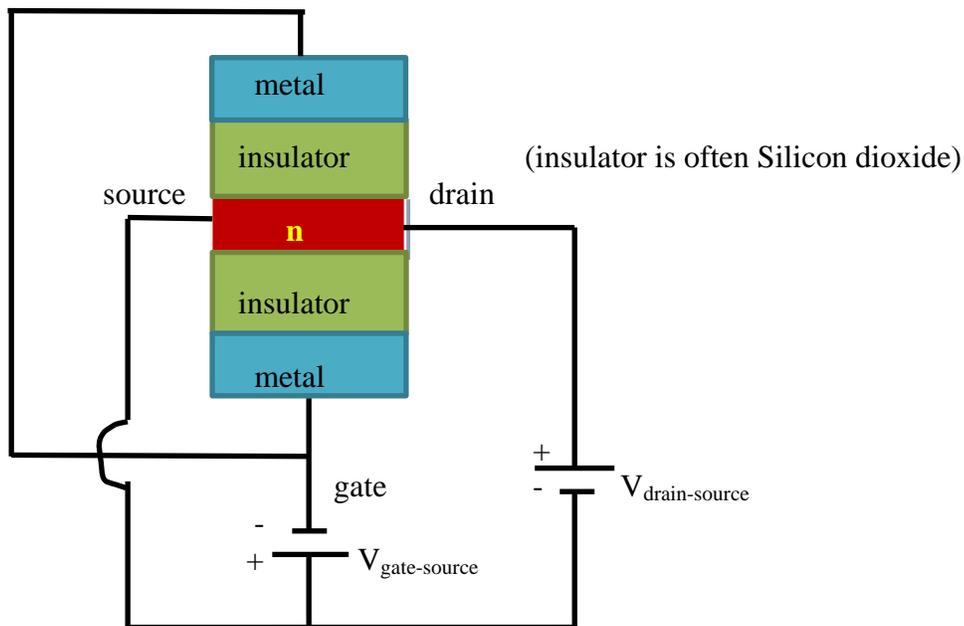
A negative voltage at the gate repels electrons away from both edges of the channel in the n-type semiconductor. This effectively adds to the depletion layers at the two n-insulator junctions which limits the current in the drain-source circuit, just as in the JFET above.