Introducing Electronics

Chapters 8 & 9
Diodes and Transistors

What is a Diode?

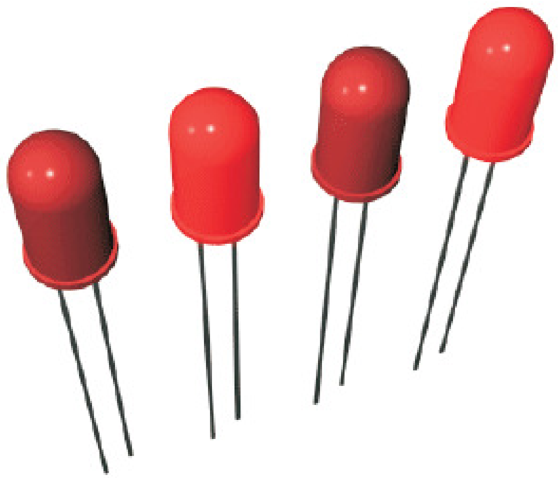


Figure 8.1: *Several Light Emitting Diodes (LEDs).*

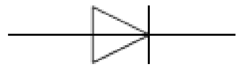
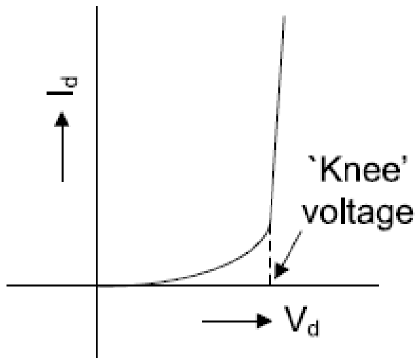


Figure 8.2: *Schematic symbol for a diode.*

- A diode is a one way conductor.
- Power indicators on your computer and lighting for your bicycle

Voltage and Current Relation



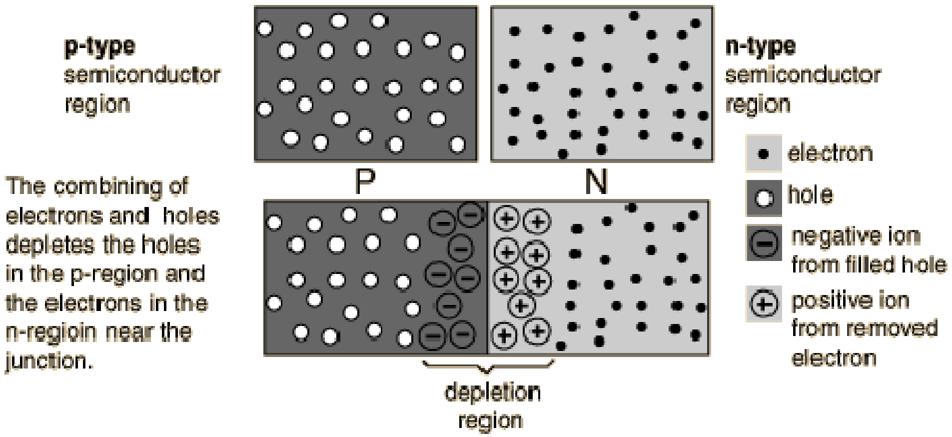
0.6 V

Figure 8.3: *Typical relationship between the voltage across a diode (V_d) and the pass current (I_d).*

> **!** Note
>
> When using a diode in a circuit, make sure that the voltage across the diode does not become much higher than the 'knee' voltage: the energy dissipated in the diode (which is equal to $V_d \cdot I_d$ can become too high easily, thereby destroying the diode).

Background - the P-N Junction

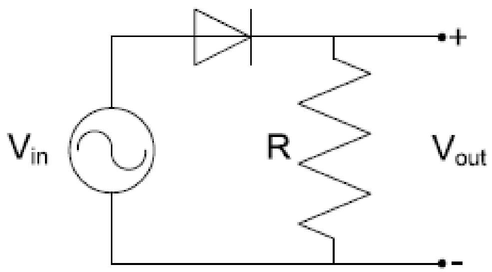
• A diode consists of a series connection of P doped material and N-doped material.
• When a P-N junction is first created, electrons from the N-doped region diffuse into the P-doped region.
• After electrons recombine with holes, the region around P-N junction becomes depleted of charge carriers which slows down/stop the recombination.
• If the polarity of the external voltage opposes the built-in potential, recombination proceeds once again and leads to substantial electrical current through the P-N junction.

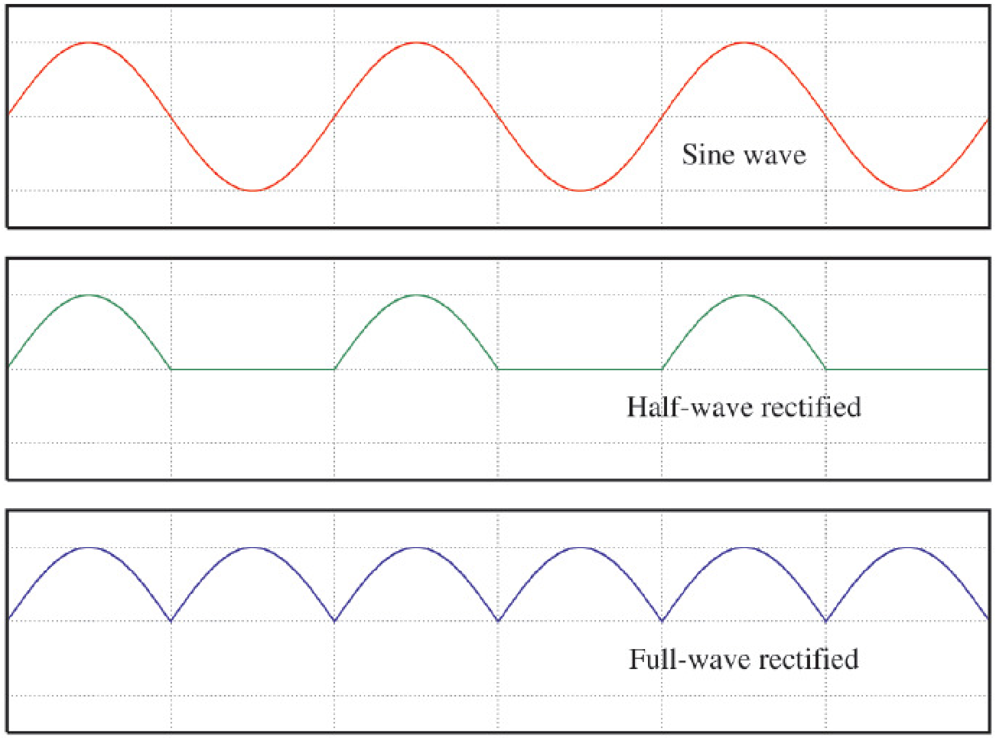


from http://hyperphysics.phy-astr.gsu.edu/hbase/solids/pnjun.html#c2

Diodes and AC Voltage Rectifiers

- Rectification is the first step in converting AC to DC. (see Appendix A)
- Pass through positive values and block negative values or convert the negative values to positive equivalents.





Diodes and "OR"- Circuits

- Diodes can be used to select the higher voltage to pass without influencing the other voltage.

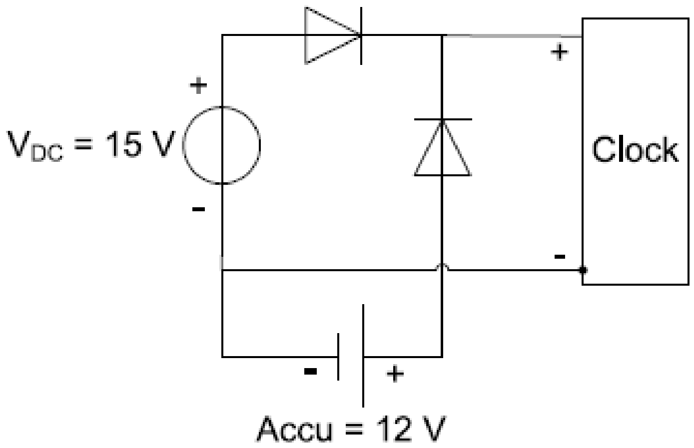


Figure 8.4: *Typical 'OR'-circuit: whenever the source V_{DC} fails, the accu will take over.*

- "OR"- circuit means that either the DC-source or Accu is used.

Diodes and Voltage Limiters

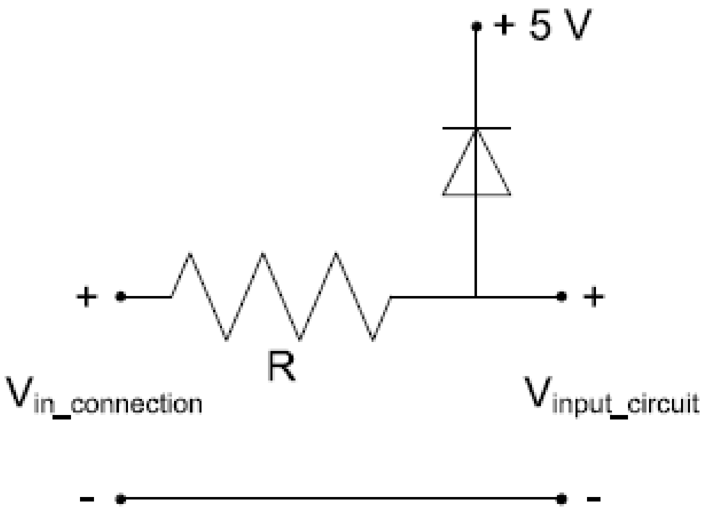


Figure 8.5: *A diode used in a voltage limiter circuit.*

How does the above voltage limiter work?

Diodes and Light

- LEDs can produce high intensities of light.
- LEDs are often used for applications such as indicators and bicycle lighting.

Morden LED headlight (from wikipedia)

- LEDs consume less power than light bulbs and have a much longer life time.
- A regular LED needs a current of 10 - 20 mA.
- The voltage across the LED is usually 1.5 to 2 V depending on colors.

Diodes and Light

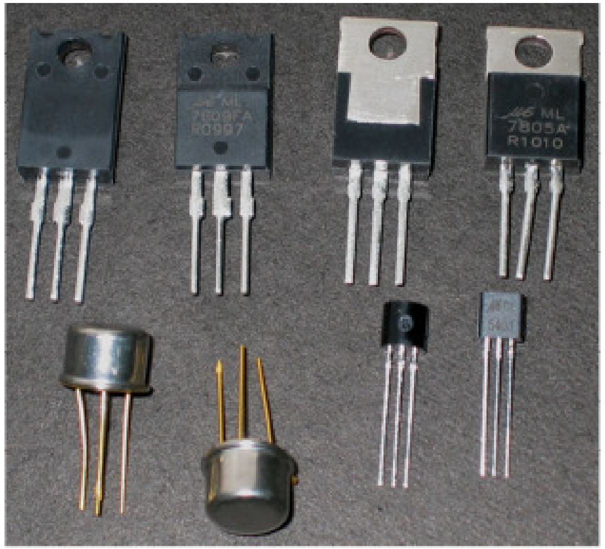
- Blu-ray: capacity 25 Gb (single layer), 50 Gb (dual layer) Philips, Sony, etc.

from www.product-reviews.net

- OLEDs: ultra-thin, light and flexible
- Oximeter: red, infra-red light

from pulseoximetry.info

What is a Transistor?



- Passive components - consume energy.
- Active components - produce energy.
- Transistors are key active components.
- Without transistors, amplification, switching, signal modulation, … would not be possible.

Bipolar Junction Transistor (BJT)

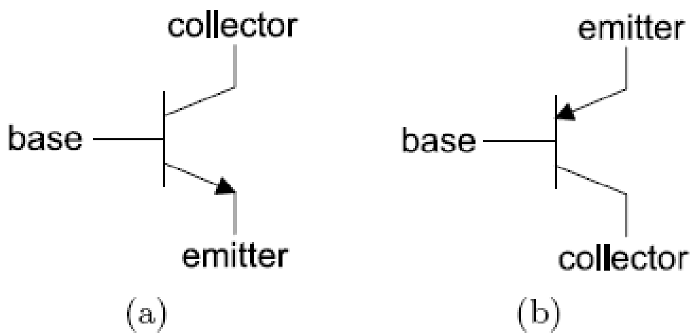


Figure 9.2: *Schematic symbols for (a) NPN and (b) PNP bipolar junction transistors.*

- For a NPN transistor, a small base-emitter current leads to a collector-emitter current.
- For a PNP transistor, a small emitter-base current leads to a negative collector-emitter current.

Bipolar Junction Transistor

$$I_c = \beta \cdot I_b \qquad (9.1)$$

β is the gain (usually in the range of 50 until 500, depending on the type of transistor).

The transistor thus has a gaining property: a small current through the base yields a big current through the collector.

! Note

It was stated that the potential difference between the base and emitter of the **NPN** must be **positive**. Actually, this value must exceed 0.6 V. Recall the discussion about the knee-voltage of a diode. For a **PNP** transistor, the potential difference between emitter and base must be **negative** but also exceed 0.6 V.

BJTs and Switching

- Apply two levels of potential difference between the base and emitter to obtain an amplified collector current or zero collector current.
- Control one circuit by another circuit.

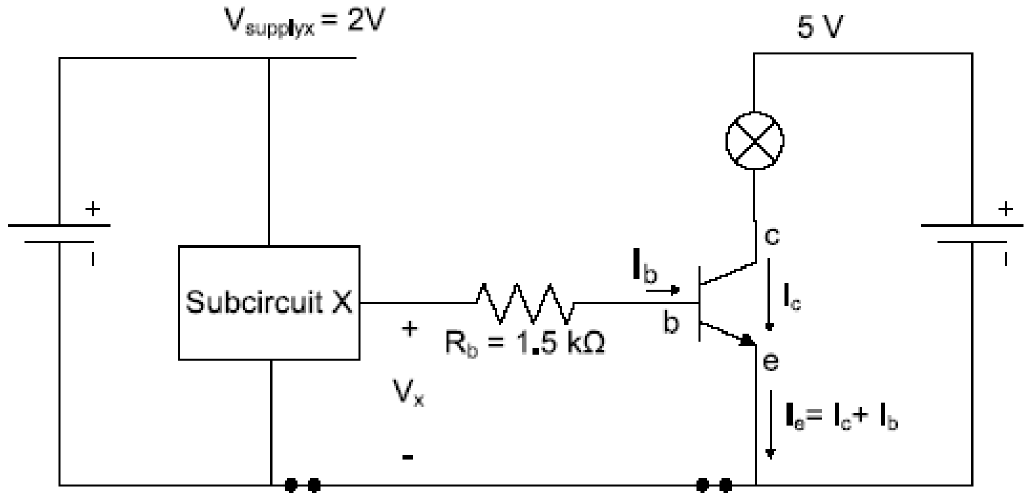
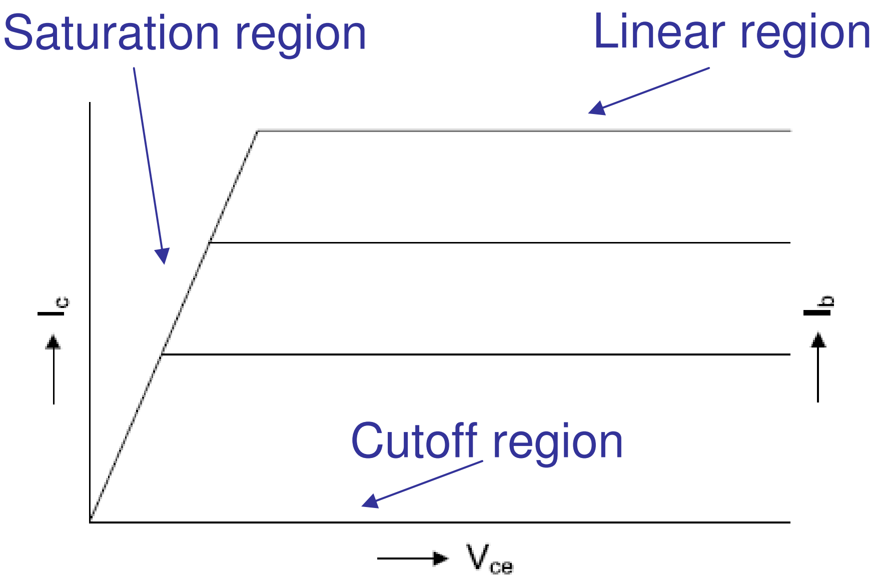
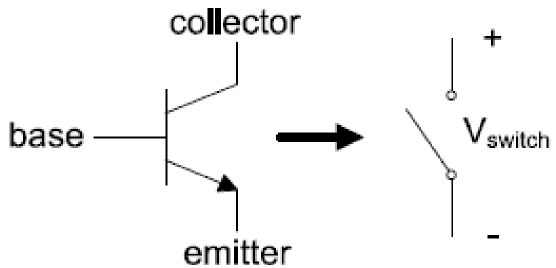


Figure 9.4: *Switching of a lamp by subcircuit X using an NPN-transistor.*

BJTs and Switching



The transistor needs to be in saturation, because we want to use it as an ideal switch.



For a closed switch $V_{switch} = 0$.
V_{ce} is very low (about 0.2 V)

BJTs and Switching

A rule of thumb to make sure that the transistor is in saturation:

$$I_{b,sat} \approx 10. \frac{I_{c,limited}}{\beta}. \qquad (9.2)$$

- Adjust I_b (and so R_b)
- Find I_b and the increase it by a factor of 10 to put the transistor into saturation.
- $I_{c,limited}$ is the current that flows through the load (and collector) when the transistor is switched on and is determined by the Ohmic characteristics of the load.
- When switched in saturation, the amount of power dissipated in the transistor is usually very small, since the potential difference between collector and emitter (V_{ce}) will be very small (around 0.2 V). $P_{transistor} = I_c \cdot V_{ce}$.

BJTs and Switching

$$I_{b,sat} \approx 10.\frac{I_{c,limited}}{\beta}. \qquad (9.2)$$

Lamp current = 50 mA; subcircuit X can only supply 2V at a maximum current of 1mA; β = 500

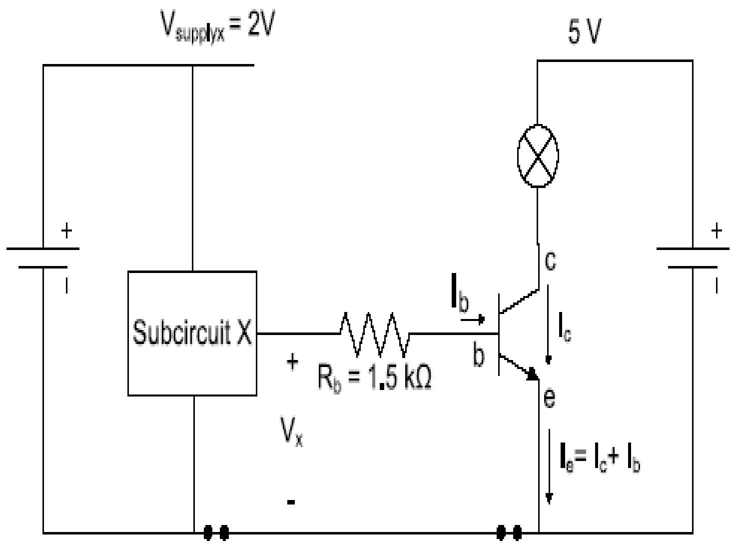


Figure 9.4: *Switching of a lamp by subcircuit X using an NPN-transistor.*

First: calculate I_b

$I_b = \frac{I_{c,limited}}{\beta} = \frac{50.10^{-3}}{500} = 0.1mA$

Second: multiply I_b by a factor 10 for forcing saturation.

$I_b, saturation = 10.I_b = 1\text{mA}$

Third: calculate R_b. This is simple since V*over* R_b and I*through* R_b (I_b) are known.

$V_{be} = 0.6\text{ V} \rightarrow \frac{V_X - 0.6}{R_b} = I_b \rightarrow \frac{2-0.6}{R_b} = 0.001A \rightarrow R_b = \frac{1.4}{0.001} = 1400\ \Omega.$

from E12 series, choose 1.5 kΩ

BJTs and Switching

! **Note**

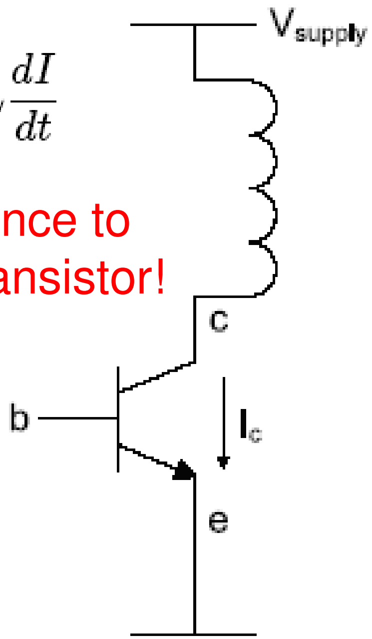
Whenever you use a BJT for switching, think of the following important issues:

1. **Always connect a resistor R_b to the base of the transistor;** never connect the (controlling) subcircuit to the transistor directly.
2. When using an **NPN** transistor, you always need to connect the load between the positive supply contact and the **collector** of the transistor.
3. When using a **PNP** transistor, you always need to connect the load between the **collector** and the negative supply contact.
4. Since the current through a transistor can only flow in one direction (from collector to emitter in case of a NPN type and vice versa for a PNP type) a single transistor can not switch AC currents.
5. The (controlling) subcircuit can be everything! (output of a computer port, a digital circuit, a circuit designed by yourself, a functiongenerator, etc. . .)

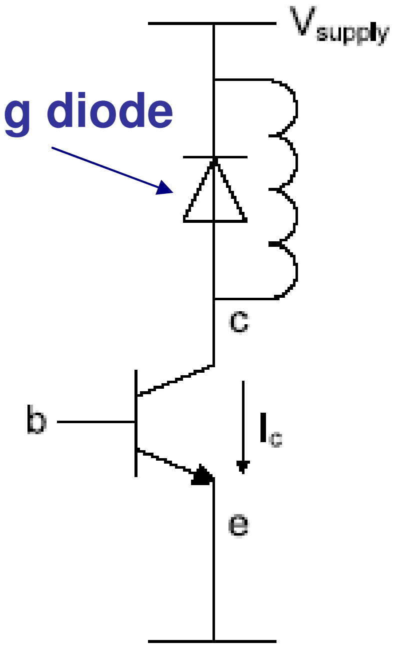
BJTs and Switching Inductors as Load

$$V = \frac{d\Phi}{dt} = L\frac{dI}{dt}$$

Significant chance to damage the transistor!



Bleeding diode



BJTs and Darlington Pairs

Darlington pairs are used to amplify weak signals.

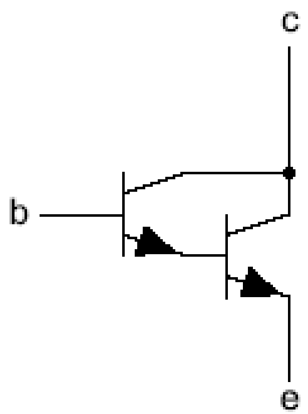


Figure 9.8: *NPN Darlington pair transistor.*

www.technologystudent.com/elec1/transis2.htm

Field Effect Transistor (FET)

- BJT - Current controlled device
- FET - Voltage controlled device

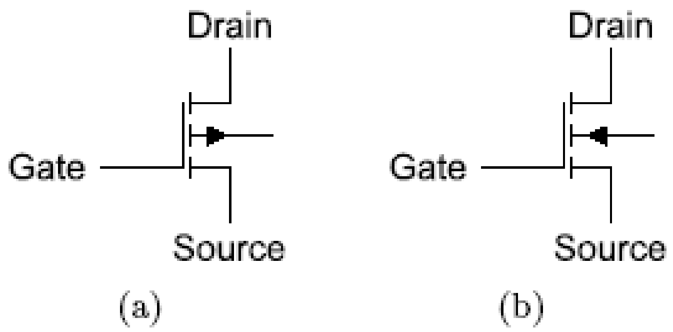


Figure 9.9: *Schematic symbols for (a) P-type and (b) N-type FETs.*

- A voltage applied between the gate and source controls the current flowing between the drain and source.
- I_{ds} is proportional to V_{gs}^2