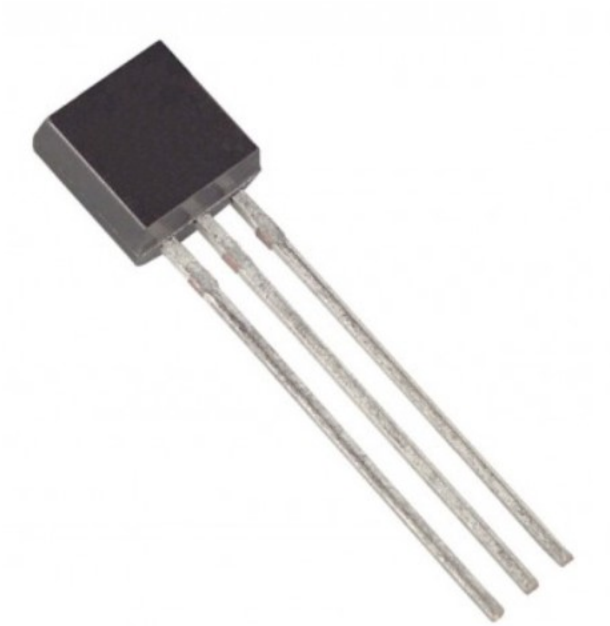
Laboratory exercise 1 – diode, BJT and MOSFET

This lab is divided into three parts, in the first part you will characterize a bipolar junction transistor (BJT), in the second part a metal-oxide-semiconductor field-effect-transistor (MOSFET) and if there is time also a Si diode in the third part. For the transistors, both the transfer and the output characteristics will be studied.

The underlined questions should be addressed before the lab session and the answers discussed with the lab supervisor.

NOTE: All underlined questions should be addressed BEFORE the lab session. In addition read 6.1.1-6.1.4 in Sedra Smith 7E



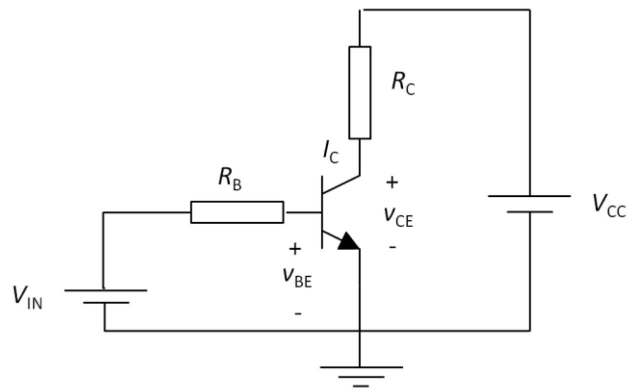
The bipolar junction transistor

Needed: BJT BC547B, 33 kΩ and 1 kΩ resistors, multimeter, power supply. The following tasks have to be solved before the lab session.

1. How can you use a multimeter to determine the terminals of the BJT (emitter, base and collector)?
2. Fill out the table below by using the data sheets for BC547. In the sheets β_F is denoted as h_{FE}.

I_C (mA)	V_{BE} (V)	β_F
0.1		
1.0		
10		

In this task you will measure the I_C characteristics for a npn BJT as a function of both V_{BE} and V_{CE} and determine the gain etc. To limit the current through the BJT, resistors are connected in series with the collector and base. Do the connections according to the figure below (R_B= 33 kΩ and R_C= 1 kΩ).



I_C - V_{BE} characteristics for BJT

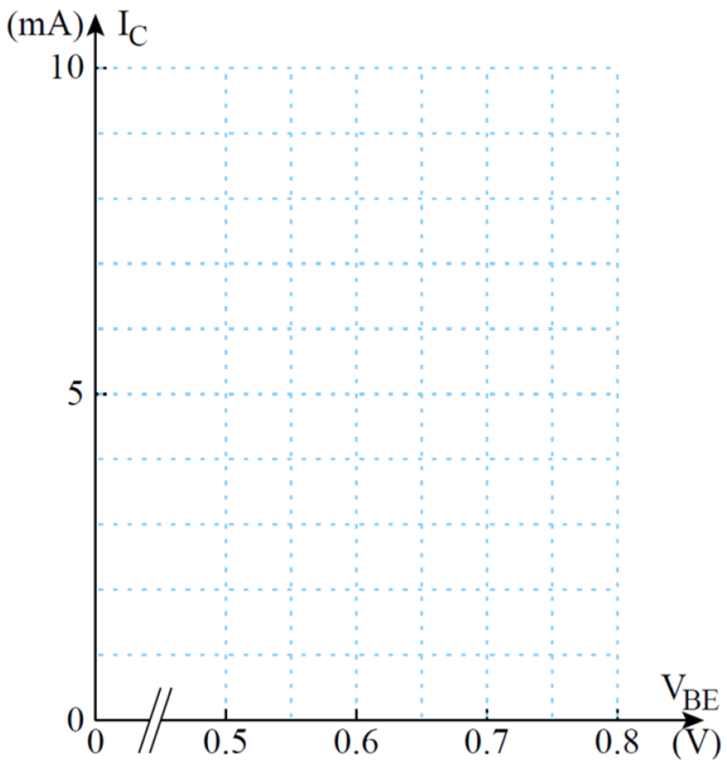
Measure the relation between the base-emitter voltage (V_{BE}) and the collector current (I_C) according to the table below. The collector current cannot be accurately measured by connecting the multimeter in series in the circuit, figure out a way to measure I_C indirectly in the circuit.

The measurements should be performed a at a constant collector-emitter voltage (V_{CE}) since we want to study the effect on I_C when varying V_{BE}. To avoid too high currents V_{BE} is measured for the indicated values of I_C instead of sweeping V_{BE}.

1) First set V_{CC} according to the first value in the table. Measure the voltage with a multimeter to get a more accurate reading than from the power supply.
2) Adjust V_{IN} (which adjusts V_{BE}) so that V_{CE} = 5 V. Measure I_C and check so that it corresponds to the values in the table.
3) Measure V_{BE} and I_B and calculate β.
4) Repeat 1)-3) for the other V_{CC} values in the table.

V_{CC} (V)	I_C (mA)	V_{BE} (V)	I_B (mA)	β
15.0	10.0			
10.0	5.0			
8.0	3.0			
6.0	1.0			
5.1	0.1			
5.0	0			

Plot the measured values in the I_C-V_{BE} diagram below.



Sketch the approximate band structure for the npn BJT (with V_{CE}=5 V) at

1) V_{CC}=5.0 V / I_C=0 mA
2) V_{CC}=10.0 V / I_C=5 mA

Indicate the energy differences between the Fermi levels.

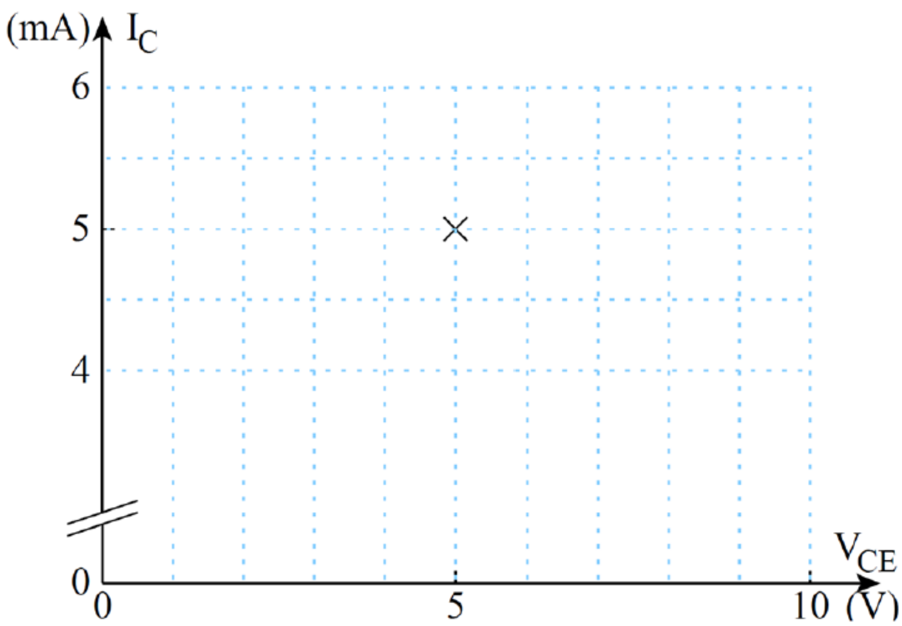
I_C – V_{CE} characteristics for BJT

In this task you will study the effect of varying V_{CE} on I_C i.e. the input voltage V_{IN} should be kept constant. Fill out the table below and plot the characteristics.

1) Set V_{CC} to 10 V.
2) Set V_{IN} so that V_{CE} = 5 V (measure V_{BE} and compare to your previous measurement). Keep this value for V_{IN} for the entire measurement series.
3) Adjust V_{CC} to set V_{CE} according to the table and measure I_C.
4) Repeat 3) for the bias points in the table.

V_{CE} (V)	**I_C (mA)**
0	
0.2	
1.0	
3.0	
5.0	5.0
10.0	

Plot the data in the diagram below.

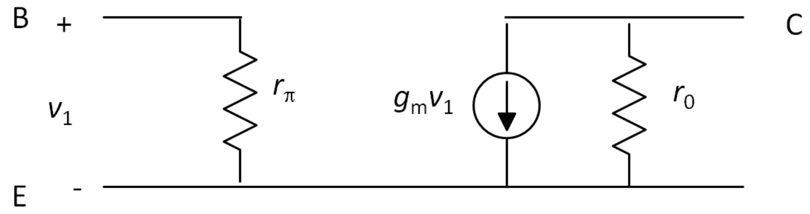


Mark the different regions of operation (cut-off, saturation, forward active…)

Sketch the expected curve if you measure a similar BJT without any Early effect.

Small-signal model for the BJT

A simple small-signal model for the BJT (ignoring capacitances, base and collector resistances etc.) is



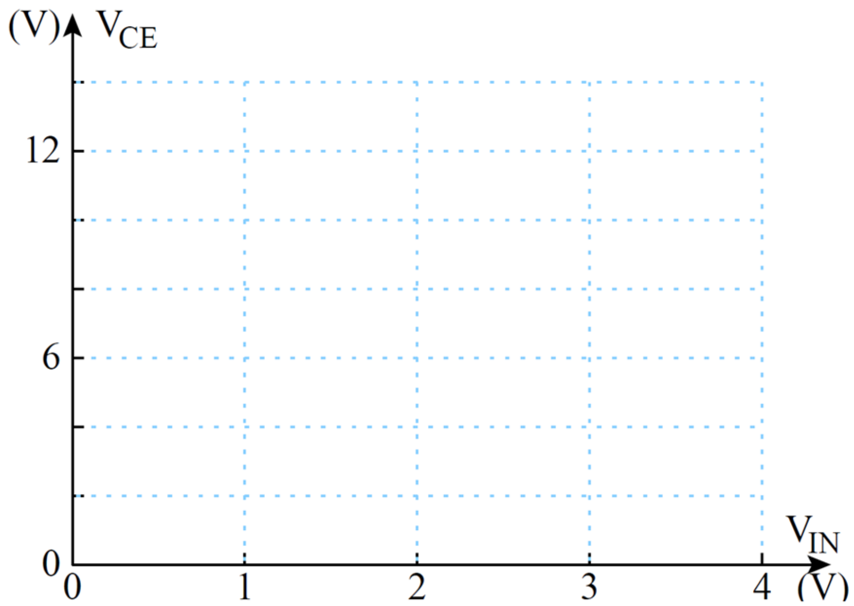
Use your measured data (both I_C-V_{BE} and I_C-V_{CE} characteristics) for the operating point V_{CE}=5.0 V, I_C= 5 mA and calculate the transconductance (g_m), input resistance (r_π) and output resistance (r_0).

$$g_m = \frac{\Delta I_C}{\Delta V_{BE}} \quad r_\pi = \frac{\Delta V_{BE}}{\Delta I_B} \quad r_o = \frac{\Delta V_{CE}}{\Delta I_C}$$

Operating modes of the BJT

In this you will study the different modes of operation of the BJT by observing how the voltage drop between collector and emitter changes as the input voltage is varied which is known as the voltage transfer characteristic (VTC). This is similar as using the BJT to amplify a small change in input voltage to obtain a large change in the output voltage. Use the same setup as previously. You should read 6.1.1-6.1.4 in Sedra Smith 7E to understand the basic function of voltage amplifiers.

1) Set V_{CC}=12 V, vary the input voltage V_{IN} (0 to 4 V), measure the collector emitter voltage V_{CE}. Plot the results in the diagram below.



2) Mark the regions of V_{IN} for the three different modes of operation (cut-off, saturation and active mode).
3) Sketch the band diagrams for the three modes. How are the base-emitter and the base-collector junctions biased (forward or reverse) for each mode.

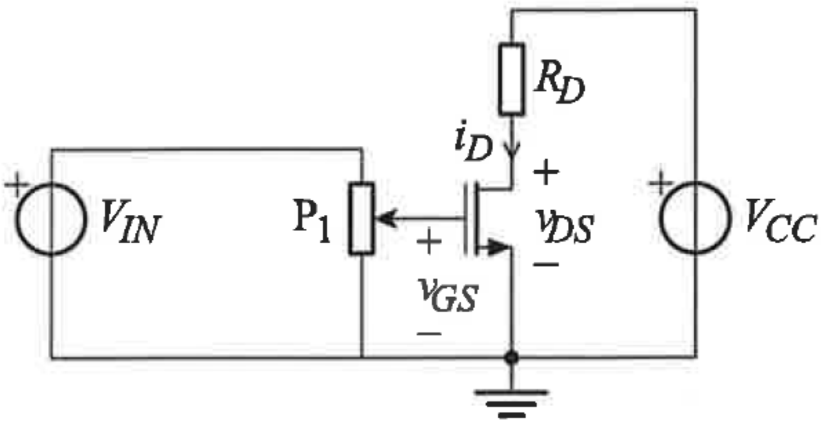
4) If we would apply a DC input signal (V_{IN}) plus a time varying signal (v_{in}), what is the best choice of V_{IN} and the maximum v_{in} that can be used without clipping (not reaching the min/max values) of the output signal V_{CE}?
5) Replace the input V_{IN} from the power supply with a time varying signal (v_{IN}=V_{IN}+v_{in}) from the function generator. Set the frequency to 1 kHz and the use the amplitude found in 4). Use the DC offset found in 4). Use the oscilloscope to study both the input (v_{in}) and output voltages (v_{ce}) and calculate the voltage gain (v_{ce}/v_{in}).
6) Reduce the AC amplitude to 50% and adjust the DC offset (V_{IN}) so that the BJT reaches saturation. Sketch the output signal and explain the shape. How could you obtain a “nice” amplification at these voltages by replacing components in the circuit?
7) Adjust the DC offset (V_{IN}) so that the BJT reaches cut-off. You may also need to increase the amplitude. Sketch the output signal and explain the shape. How could you obtain a “nice” amplification at these voltages by replacing components in the circuit?

The MOSFET

In this task you will study the n-type MOSFET BS170. The following tasks have to be solved before the lab session.

1. Write down the expression for the drain current for the long-channel MOSFET in saturation and the bias conditions that are required.
2. How can you use a multimeter to determine the terminals of the MOSFET (source, drain, gate)?

In the circuit you will use a potentiometer (P1) to vary the gate voltage. Use the following circuit with R_D=1 kΩ and the power boxes as a DC voltage supplies.

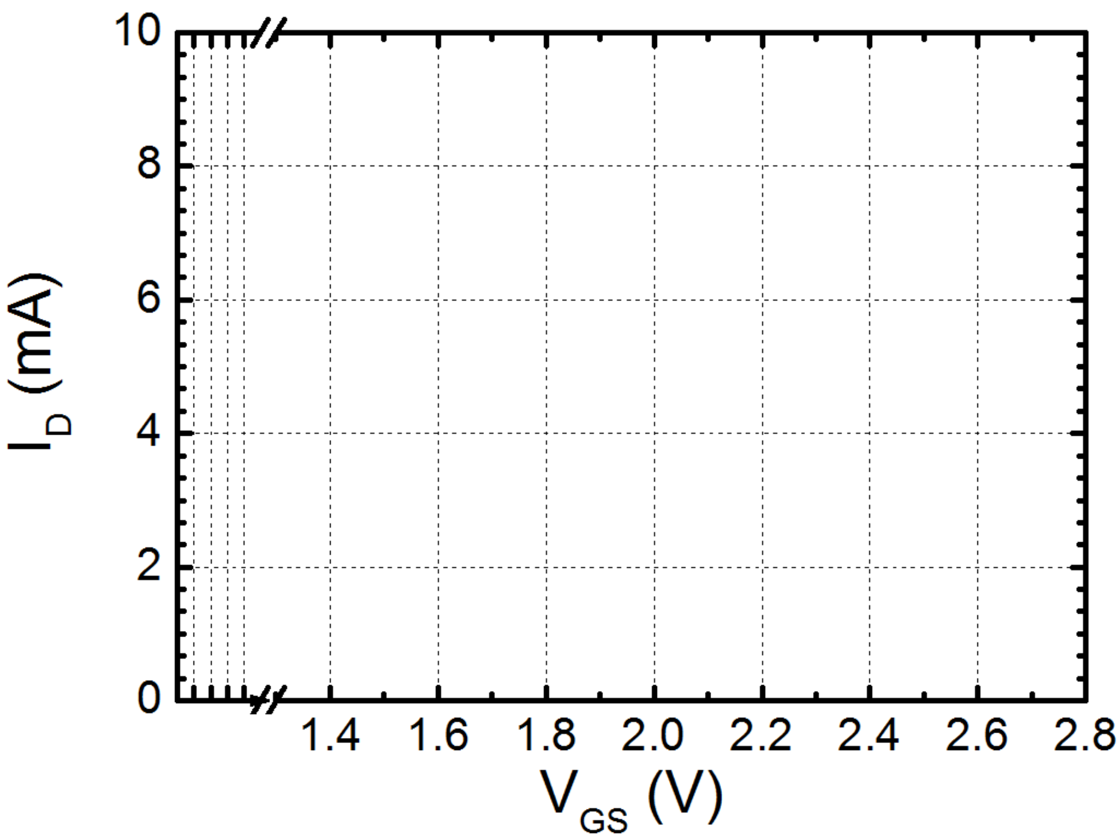


I_D- V_{GS} characteristics for MOSFET

First, the transfer characteristics, i.e. the dependence of the drain current (I_D) on the input voltage (V_{GS}), will be measured at a fixed drain bias V_{DS} = 5.0 V. Since the resistivity of the MOSFET changes as V_{GS} is changed, V_{CC} have to be adjusted for each point to keep V_{DS}=5.0 V. It is suitable to have V_{IN}=5 V to be able to vary V_{GS} with the potentiometer. Measure the points in the table below and plot the data in the diagram. In this task V_{GS} is measured as a function of set I_D values instead of the other way around to avoid too high currents through the MOSFET.

1) Set V_{CC} according to the table.
2) Adjust the potentiometer until the indicated I_D is reached and measure V_{GS}.

V_{CC} (V)	I_D (mA)	V_{GS} (V)
15.0	10.0	
10.0	5.0	
8.0	3.0	
6.0	1.0	
5.1	0.1	
5.0	0	

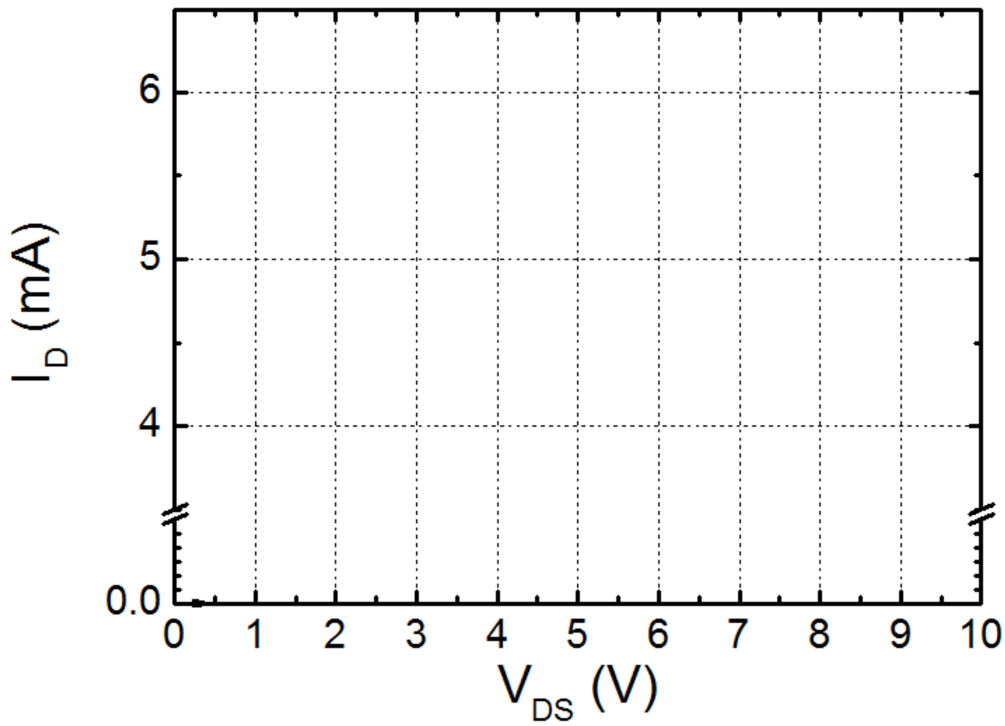


Does I_D follow the expected long or short (velocity saturated) channel behaviour? Remember that I_D is proportional to V_{GS} for a velocity saturated MOSFET.

I_D- V_{DS} characteristics for MOSFET

In this task the output characteristics, i.e. the dependence of the drain current (I_D) on the drain voltage (V_{DS}), will be measured at a fixed gate bias. Adjust V_{CC} to 10 V and adjust the potentiometer so that you obtain I_{DS}= 5 mA with V_{DS}= 5 V. Keep this setting of the potentiometer (controlling V_{GS}) throughout the measurement while varying V_{CC} to obtain the V_{DS} values in the table. Fill out I_D in the table and plot the data in the diagram below.

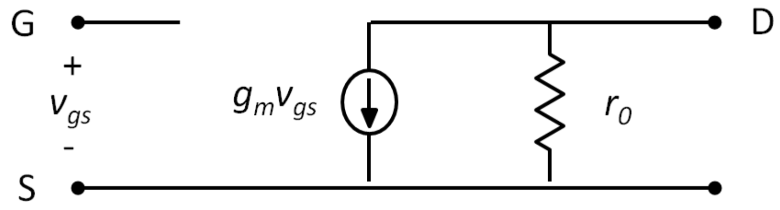
V_{DS} (V)	**I_D (mA)**
0	0
0.2	
1.0	
3.0	
5.0	5.0
10.0	



Does I_D saturate? If not, what is the reason?

Small-signal model for the MOSFET

A simple small-signal model for the MOSFET (ignoring capacitances, drain and source resistances etc.) is

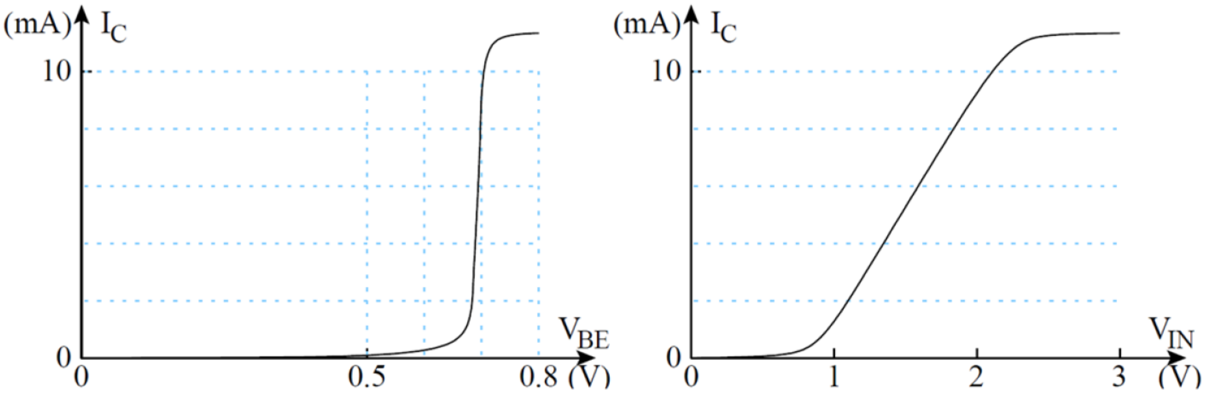


Use the operating point V_{DS} = 5.0 V , I_D= 5 mA and calculate the transconductance (g_m) and the output resistance (r_0) using your measured data.

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}} \qquad r_0 = \frac{\Delta V_{DS}}{\Delta I_D}$$

Final Questions

1. Using your measured characteristics describe some differences and similarities between BJTs and MOSFETs.
2. What are the requirements for the BJT to be in active mode?
3. For the BJT, I_C as a function of V_{BE} is different compared to I_C as a function of V_{IN} as seen below. Explain the difference.



The diode (if there is time)

Needed: Si diode 1N4148, 1 kΩ resistor, two multimeters, power supply. The following tasks have to be solved before the lab session.

1. List a few of the differences in the current-voltage characteristics of Ge and Si diodes?
2. How can you determine the polarity of a diode using a multimeter?
3. Draw the layout of the circuit needed for the measurement tasks below.

In this task you will determine the current-voltage characteristics of a Si pn-diode. You need a power supply and two multimeters to measure the voltage drop (voltmeter) and current (ammeter) through the diode. In addition you need a 1kΩ resistor (connected in series with the power supply) to limit the current through the diode. Note that the voltmeter (in parallel with the diode) has to be connected differently (test if the voltmeter gives a different result for different connections) depending on if the diode is reverse or forward biased to get an accurate result.

1. Plot the IV- characteristics for voltages (measured over the diode) between - 5V and 0.6 V. To avoid tripping the fuse in the multimeter it is better to use it as a voltmeter in parallel to the resistor and calculate the current than to use it in series in the circuit.

2. Calculate the dynamic resistance at -0.5 V, +0.15 V and +0.2 V.

3. Why does the voltmeter have to be connected differently for forward and reverse bias?