

## Bipolar Transistors

### MEASURE THE CHARACTERISTIC CURVES RELEVANT TO AN NPN TRANSISTOR

- Measure the input characteristic, i.e. the base current  $I_B$  as a function of the base emitter voltage  $U_{BE}$ .
- Measure the transfer characteristic, i.e. the collector current  $I_C$  as a function of the base current  $I_B$  for a fixed collector-emitter voltage  $U_{CE}$ .
- Measure the transfer characteristic, i.e. the collector current  $I_C$  as a function of the collector-emitter voltage for a fixed base current  $I_B$ .

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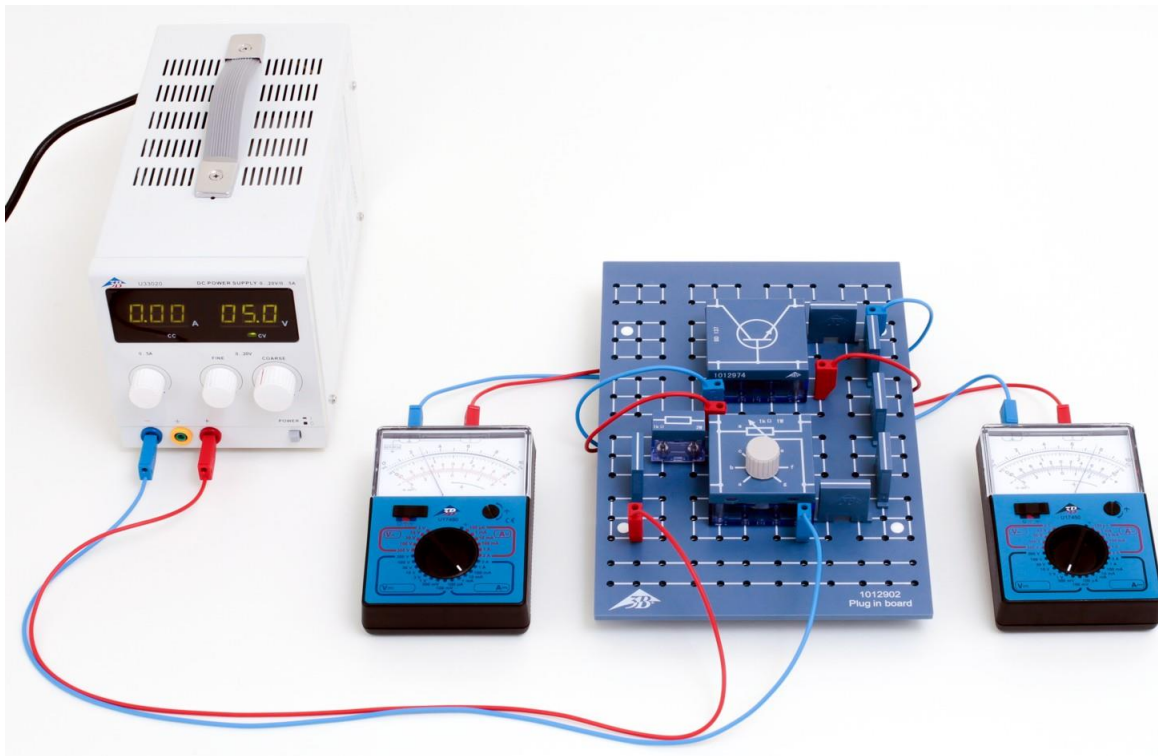


Fig. 1: Experiment set-up (Example: input characteristic).

### GENERAL PRINCIPLES

A bipolar transistor is an electronic component composed of three alternating p-doped and n-doped semiconductor layers called the base B, the collector C and the emitter E. The base is between the collector and emitter and is used to control the transistor. In principle a bipolar transistor resembles two diodes facing opposite

directions and sharing an anode or cathode. Bipolarity arises from the fact that the two varieties of doping allow for both electrons and holes to contribute to the transport of charge.

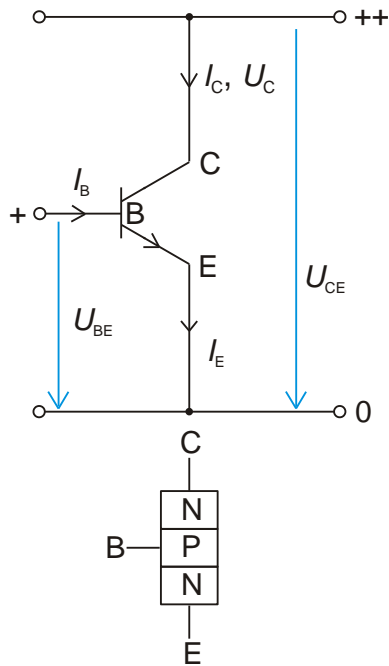


Fig. 2: Design of an npn transistor in principle, including accompanying circuit symbol plus indications of voltage and current

Depending on the sequence of the layers, the transistor may either be termed npn or pnp (Fig. 2). Bipolar transistors are operated as quadripoles in three basic circuits, distinguished by the arrangement of the terminals and called common emitter, common collector and common base. The names indicate which of the terminals is common to both the input and the output.

Only npn transistors are considered in the following treatment.

There are four operating modes for an npn transistor, depending on whether the base-emitter or base-collector junctions are aligned in a conducting or forward-bias direction ( $U_{BE}, U_{BC} > 0$ ) or a non-conducting or reverse bias ( $U_{BE}, U_{BC} < 0$ ) direction (see Table 1). In forward-bias mode, electrons from the emitter migrate into the base across the transistor's forward-biased base-emitter junction ( $U_{BE} > 0$ ) while holes from the base move into the emitter. Since the emitter has much higher doping than the base, more electrons will migrate than holes, which minimises recombination between the two. Because the width of the base is shorter than the diffusion length of the electrons, which count as minority carriers within the base itself, the electrons diffuse through the base into the depletion layer between the base and the collector before drifting further towards the collector itself. This is because the depletion layer only forms a barrier for majority carriers. This results in a transfer current  $I_T$  from the emitter into the collector, which is the major contributor to the collector current  $I_C$  in forward-bias mode. The transistor can therefore be regarded as a voltage controlled current source whereby the  $I_C$  at the output can be controlled by the voltage  $U_{BE}$  at the input. Electrons which recombine in the base emerge from there in a base current  $I_B$  which guarantees a constant transfer current  $I_T$ , thereby ensuring that the transistor remains stable. A small input current  $I_B$  can therefore control a much greater output current  $I_C$  ( $I_C \approx I_T$ ), which gives rise to current amplification.

Table 1: Four operating modes of an npn transistor

$U_{BE}$	$U_{BC}$	Operating mode
$> 0$	$< 0$	Normal mode
$> 0$	$> 0$	Saturation
$< 0$	$> 0$	Inverse mode
$< 0$	$< 0$	Off state

Table 2: Four characteristics of an npn transistor in normal mode.

Name	Depend- cy	Parameter
Input characteristic	$I_B(U_{BE})$	
Transfer characteristic	$I_C(I_B)$	$U_{CE} = \text{const.}$
Output characteristic	$I_C(U_{CE})$	$I_B = \text{const.}$
Feedback characteristic	$U_{BE}(U_{CE})$	$I_B = \text{const.}$

The response of a bipolar transistor is described by four characteristics, the input characteristic, the transfer or base characteristic, the output characteristic and the feedback characteristic (see Table 2). This experiment involves measuring, by way of example, input, transfer and output characteristics for an npn transistor and plotting them as a graph.

### LIST OF EQUIPMENT

1	Plug-In Board for Components	1012902 (U33250)
1	Set of 10 Jumpers, P2W19	1012985 (U333093)
1	Resistor, 1 kΩ, 2 W, P2W19	1012916 (U333024)
1	Resistor, 47 kΩ, 0.5 W, P2W19	1012926 (U333034)
1	Potentiometer, 220 Ω, 3 W, P4W50	1012934 (U333042)
1	Potentiometer, 1 kΩ, 1 W, P4W50	1012936 (U333044)
1	NPN Transistor, BD 137, P4W50	1012974 (U333082)
1	AC/DC Power Supply, 0...12 V / 3 A @230V	1002776 (U117601-230)
or		
1	AC/DC Power Supply, 0...12 V / 3 A @115V	1002775 (U117601-115)
3	Escola 30 Analogue Multimeter	1013526 (U8557330)
1	Set of 15 Experiment Leads, 75 cm, 1 mm <sup>2</sup>	1002840 (U13800)

## SET-UP AND EXPERIMENT PROCEDURE

### Notes:

In all of these circuits, a 1 kΩ resistor acts as a protective resistor and must be plugged in at all times.

Only turn on the power supply and turn up the voltage once the circuits have been fully assembled.

For all experiments, set the voltage on the power supply to 5 V.

Select the variables which need to be measured on the analogue multimeters (voltage, current) and choose suitable measuring ranges for them. Be careful to get the polarities the right way round.

### Input characteristic

- Set up the circuit as shown in Fig. 3. The two analogue multimeters in the circuit are for the purpose of measuring the base-emitter voltage  $U_{BE}$  and the base current  $I_B$ .
- Adjust the 1 kΩ potentiometer in such a way that the base-emitter voltage is 0 V.
- Use the potentiometer to slowly increase the base-emitter voltage in suitable steps. For each of these steps, measure the base current and enter the values into Table 3.

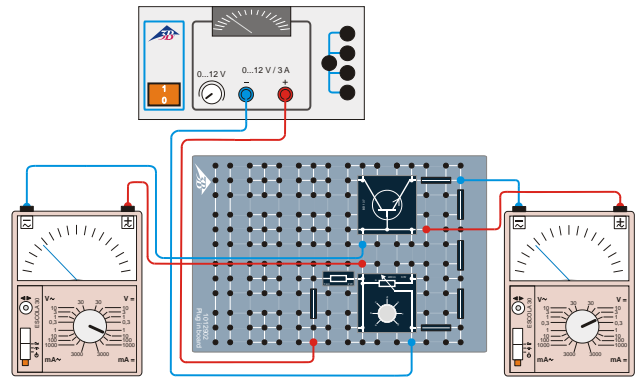


Fig. 3: Sketch of circuit for recording input characteristic.

### Transfer characteristic

- Set up the circuit as shown in Fig. 4. The three analogue multimeters in the circuit are for the purpose of checking the collector-emitter voltage  $U_{CE}$  while measuring the base current  $I_B$  and collector current  $I_C$ .
- Read off the collector-emitter voltage and make a note of it.
- Adjust the 1 kΩ potentiometer in such a way that the base current is as low as possible.
- Use the potentiometer to slowly increase the base current in suitable steps. For each of these steps, measure the collector current and enter the values into Table 4.

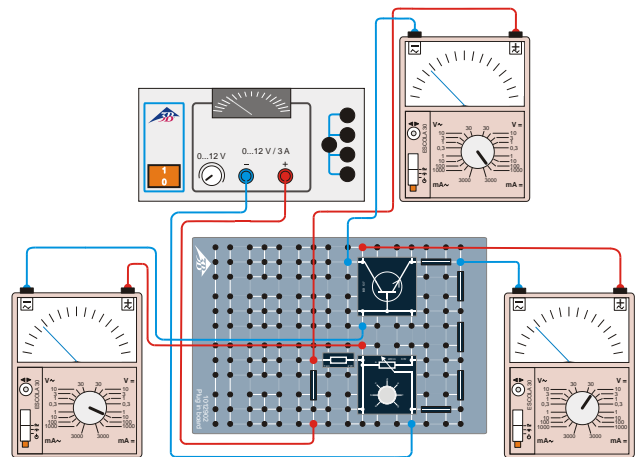


Fig. 4: Sketch of circuit for recording transfer characteristic.

### Output characteristic

- Set up the circuit as shown in Fig. 5. Replace the 1 kΩ potentiometer with a 47 kΩ resistor. Also insert a 220 Ω potentiometer just before the collector. The three analogue multimeters in the circuit are for the purpose of checking the base current  $I_B$  while measuring the collector-emitter voltage  $U_{CE}$  and collector current  $I_C$ .
- Read off the base current and make a note of it.
- Adjust the 220 Ω potentiometer in such a way that the collector-emitter voltage is as low as possible.
- Use the potentiometer to slowly increase the collector-emitter voltage in suitable steps. For each of these steps, measure the collector current  $I_C$  and enter the values into Table 5.

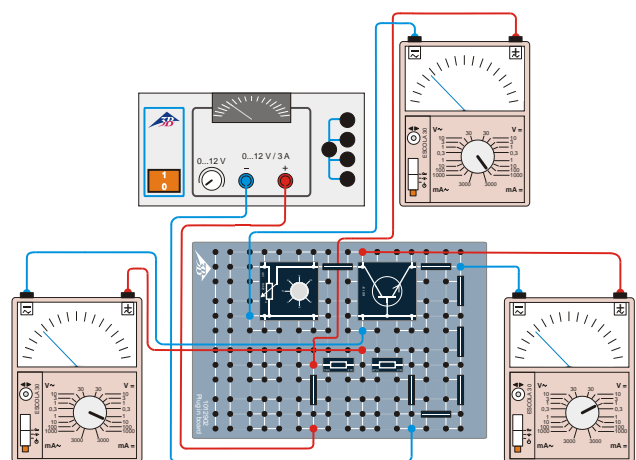


Fig. 5: Sketch of circuit for recording output characteristic.

## SAMPLE MEASUREMENT

Table 3: Input characteristic – measurements of  $U_{BE}$  and  $I_B$ .

$U_{BE} / \text{mV}$	$I_B / \text{mA}$
0	0.0
100	0.0
200	0.0
300	0.0
400	0.0
500	0.0
600	0.0
660	0.1
690	0.3
720	0.6
740	1.0
750	1.5
760	2.0
770	2.6
780	3.4

Table 4: Transfer characteristic – measurements of  $I_B$  and  $I_C$ ,  
 $U_{CE} = 5.2 \text{ V}$ .

$I_B / \text{mA}$	$I_C / \text{mA}$
0.0	0
0.1	20
0.2	40
0.3	80
0.4	100
0.5	130
0.6	150
0.7	180
0.8	200
0.9	230
1.0	260
1.1	280
1.2	300
1.3	320
1.4	340
1.5	360
1.6	380
1.7	400
1.8	410
1.9	425
2.0	440

Table 5: Output characteristic – measurements of  $U_{CE}$  and  $I_C$ ,  
 $I_B = 4.2 \text{ mA}$ .

$U_{CE} / \text{mV}$	$I_C / \text{mA}$
0	0
30	50
50	100
70	160
90	210
110	260
130	310
150	430
170	380
190	410
220	440
260	480
350	520
430	540
560	560
700	580
890	600

### EVALUATION

The input characteristic (Fig. 6), as expected, is the same as the forward-bias characteristic of a silicon diode. A semiconductor diode starts to conduct in the forward-bias direction once a voltage threshold has been reached. To determine what this threshold is from our measurements, the sharply rising part of the input characteristic is extrapolated back to the x-axis and then the voltage  $U_S$  where it crosses the axis is read off:

$$(1) \quad U_S = 720 \text{ mV} = 0.72 \text{ V} .$$

This value is well in agreement with the typical value for silicon, 0.7 V.

The transfer characteristic (Fig. 7) is almost linear, although the gradient decreases slightly once the collector current is greater than  $I_C \approx 300 \text{ mA}$ . The current gain is calculated using the following formula:

$$(2) \quad B = \frac{I_C}{I_B}$$

Its average value is about 240. The maximum value for it under defined test conditions is specified to be 250.

The output characteristic (Fig. 8) rises sharply as  $U_{CE}$  increases until the voltage is about 200 mV but then gradually flattens out until it is nearly horizontal. The power dissipation is calculated as follows:

$$(3) \quad P = U_{CE} \cdot I_C$$

Where the curve is roughly horizontal, this corresponds to about 0.5 W. The absolute maximum value specified is 8 W.

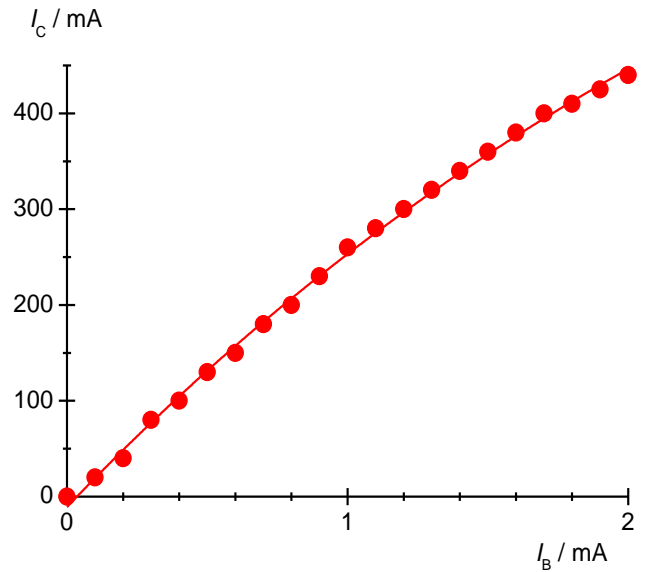


Fig. 7: Transfer characteristic for  $U_{CE} = 5.2 \text{ V}$

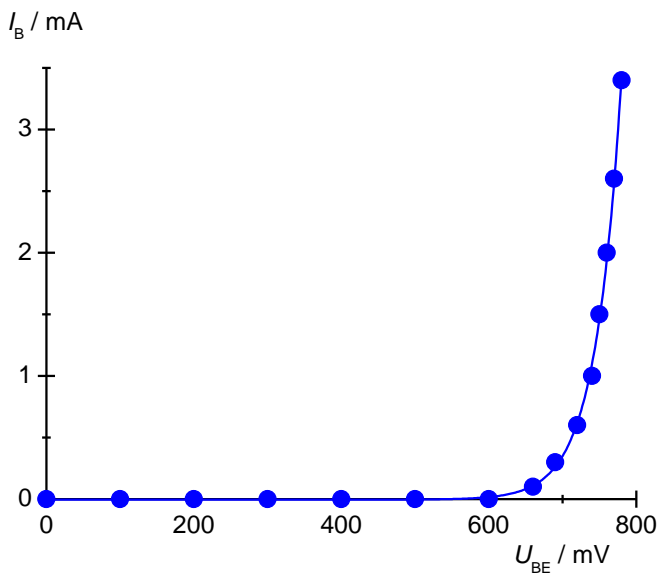


Fig. 6: Input characteristic

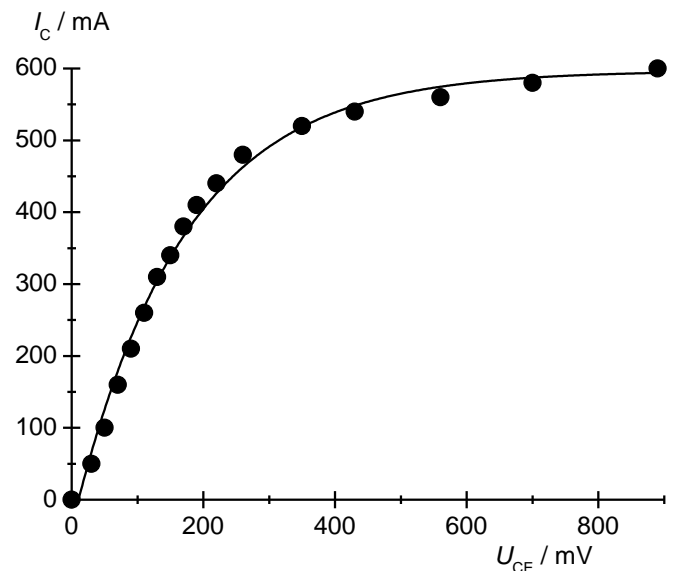


Fig. 8: Output characteristic for  $I_B = 4.2 \text{ mA}$

