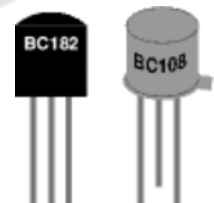




## Function

Transistors **amplify current**, for example they can be used to amplify the small output current from a logic IC so that it can operate a lamp, relay or other high current device. In many circuits a resistor is used to convert the changing current to a changing voltage, so the transistor is being used to **amplify voltage**.

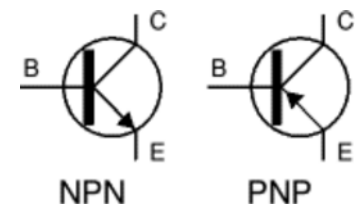


A transistor may be used as a **switch** (either fully on with maximum current, or fully off with no current) and as an **amplifier** (always partly on).

The amount of current amplification is called the **current gain**, symbol  $h_{FE}$ . For further information please see the [Transistor Circuits](#) page.

## Types of transistor

There are two types of standard transistors, **NPN** and **PNP**, with different circuit symbols. The letters refer to the layers of semiconductor material used to make the transistor. Most transistors used today are NPN because this is the easiest type to make from silicon. If you are new to electronics it is best to start by learning how to use NPN transistors.



Transistor circuit symbols

The leads are labelled **base (B)**, **collector (C)** and **emitter (E)**.

These terms refer to the internal operation of a transistor but they are not much help in understanding how a transistor is used, so just treat them as labels!

A [Darlington pair](#) is two transistors connected together to give a very high current gain.

In addition to standard (bipolar junction) transistors, there are **field-effect transistors** which are usually referred to as **FETs**. They have different circuit symbols and properties and they are not (yet) covered by this page.

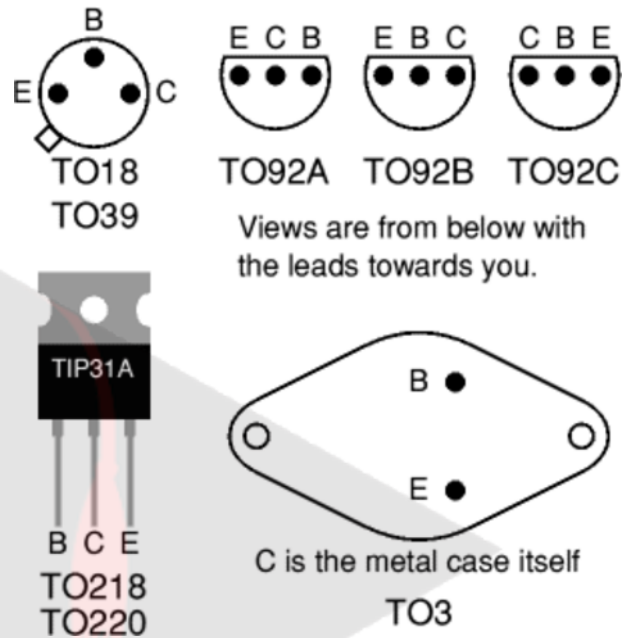
## Connecting

Transistors have three leads which must be connected the correct way round. Please take care with this because a wrongly connected transistor may be damaged instantly when you switch on.

If you are lucky the orientation of the transistor will be clear from the PCB or stripboard layout diagram, otherwise you will need to refer to a supplier's catalogue to identify the leads.

The drawings on the right show the leads for some of the most common case styles.

Please note that transistor lead diagrams show the view from **below** with the leads towards you. This is the opposite of IC (chip) pin diagrams which show the view from above.



Views are from below with the leads towards you.

Transistor leads for some common case styles.

Please see below for a [table](#) showing the case styles of some common transistors.

## Soldering

Transistors can be damaged by heat when soldering so if you are not an expert it is wise to use a heat sink clipped to the lead between the joint and the transistor body. A standard crocodile clip can be used as a heat sink.

Do not confuse this temporary heat sink with the permanent heat sink (described below) which may be required for a power transistor to prevent it overheating during operation.



Crocodile clip  
Photograph © [Rapid Electronics](#).

## Heat sinks

Waste heat is produced in transistors due to the current flowing through them. Heat sinks are needed for power transistors because they pass large currents. If you find that a transistor is becoming too hot to touch it certainly needs a heat sink! The heat sink helps to dissipate (remove) the heat by transferring it to the surrounding air.



Heat sink  
Photograph © [Rapid Electronics](#)

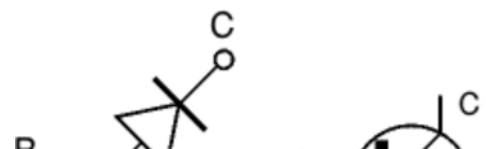
For further information please see the [Heat sinks](#) page.

## Testing a transistor

Transistors can be damaged by heat when soldering or by misuse in a circuit. If you suspect that a transistor may be damaged there are two easy ways to test it:

### 1. Testing with a multimeter

Use a [multimeter](#) or a [simple tester](#) (battery, resistor and



LED) to check each pair of leads for conduction. Set a digital multimeter to diode test and an analogue multimeter to a low resistance range.

**Test each pair of leads both ways** (six tests in total):

- The **base-emitter (BE)** junction should behave like a diode and **conduct one way only**.
- The **base-collector (BC)** junction should behave like a diode and **conduct one way only**.
- The **collector-emitter (CE)** should **not conduct either way**.

The diagram shows how the junctions behave in an NPN transistor. The diodes are reversed in a PNP transistor but the same test procedure can be used.

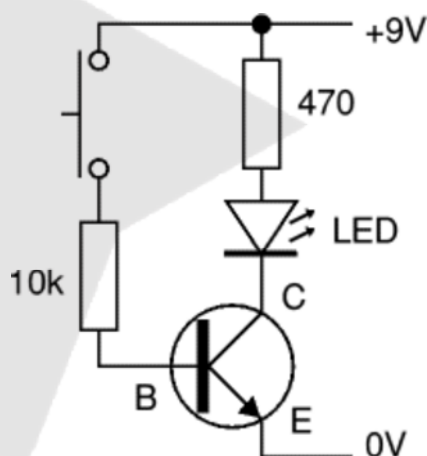
## 2. Testing in a simple switching circuit

Connect the transistor into the circuit shown on the right which uses the transistor as a switch. The supply voltage is not critical, anything between 5 and 12V is suitable. This circuit can be quickly built on [breadboard](#) for example. Take care to include the 10k $\Omega$  resistor in the base connection or you will destroy the transistor as you test it!

If the transistor is OK the LED should light when the switch is pressed and not light when the switch is released.

To test a PNP transistor use the same circuit but reverse the LED and the supply voltage.

Some [multimeters](#) have a 'transistor test' function which provides a known base current and measures the collector current so as to display the transistor's DC current gain  $h_{FE}$ .



A simple switching circuit to test an NPN transistor

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## Transistor codes

There are three main series of transistor codes used in the UK:

- **Codes beginning with B (or A), for example BC108, BC478**

The first letter B is for silicon, A is for germanium (rarely used now). The second letter indicates the type; for example C means low power audio frequency; D means high power audio frequency; F means low power high frequency. The rest of the code identifies the particular transistor. There is no obvious logic to the numbering system. Sometimes a letter is added to the end (eg BC108C) to identify a special version of the main type, for example a higher current gain or a different case style. If a project specifies a higher gain version (BC108C) it must be used, but if the general code is given (BC108) any transistor with that code is suitable.

- **Codes beginning with TIP, for example TIP31A**

TIP refers to the manufacturer: Texas Instruments Power transistor. The letter at the end identifies versions with different voltage ratings.

- **Codes beginning with 2N, for example 2N3053**

The initial '2N' identifies the part as a transistor and the rest of the code identifies the particular transistor. There is no obvious logic to the numbering system.

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## Choosing a transistor

Most projects will specify a particular transistor, but if necessary you can usually substitute an equivalent transistor from the wide range available. The most important properties to look for

are the maximum collector current  $I_C$  and the current gain  $h_{FE}$ . To make selection easier most suppliers group their transistors in categories determined either by their **typical use** or **maximum power** rating.

To make a final choice you will need to consult the tables of technical data which are normally provided in catalogues. They contain a great deal of useful information but they can be difficult to understand if you are not familiar with the abbreviations used. The table below shows the most important technical data for some popular transistors, tables in catalogues and reference books will usually show additional information but this is unlikely to be useful unless you are experienced. The quantities shown in the table are explained [below](#).

| NPN transistors |           |            |            |               |               |                |                               |                      |
|-----------------|-----------|------------|------------|---------------|---------------|----------------|-------------------------------|----------------------|
| Code            | Structure | Case style | $I_C$ max. | $V_{CE}$ max. | $h_{FE}$ min. | $P_{tot}$ max. | Category (typical use)        | Possible substitutes |
| BC107           | NPN       | TO18       | 100mA      | 45V           | 110           | 300mW          | Audio, low power              | BC182 BC547          |
| BC108           | NPN       | TO18       | 100mA      | 20V           | 110           | 300mW          | General purpose, low power    | BC108C BC183 BC548   |
| BC108C          | NPN       | TO18       | 100mA      | 20V           | 420           | 600mW          | General purpose, low power    |                      |
| BC109           | NPN       | TO18       | 200mA      | 20V           | 200           | 300mW          | Audio (low noise), low power  | BC184 BC549          |
| BC182           | NPN       | TO92C      | 100mA      | 50V           | 100           | 350mW          | General purpose, low power    | BC107 BC182L         |
| BC182L          | NPN       | TO92A      | 100mA      | 50V           | 100           | 350mW          | General purpose, low power    | BC107 BC182          |
| BC547B          | NPN       | TO92C      | 100mA      | 45V           | 200           | 500mW          | Audio, low power              | BC107B               |
| BC548B          | NPN       | TO92C      | 100mA      | 30V           | 220           | 500mW          | General purpose, low power    | BC108B               |
| BC549B          | NPN       | TO92C      | 100mA      | 30V           | 240           | 625mW          | Audio (low noise), low power  | BC109                |
| 2N3053          | NPN       | TO39       | 700mA      | 40V           | 50            | 500mW          | General purpose, low power    | BFY51                |
| BFY51           | NPN       | TO39       | 1A         | 30V           | 40            | 800mW          | General purpose, medium power | BC639                |
| BC639           | NPN       | TO92A      | 1A         | 80V           | 40            | 800mW          | General purpose, medium power | BFY51                |
| TIP29A          | NPN       | TO220      | 1A         | 60V           | 40            | 30W            | General purpose, high power   |                      |
| TIP31A          | NPN       | TO220      | 3A         | 60V           | 10            | 40W            | General purpose, high power   | TIP31C TIP41A        |
| TIP31C          | NPN       | TO220      | 3A         | 100V          | 10            | 40W            | General purpose, high power   | TIP31A TIP41A        |
| TIP41A          | NPN       | TO220      | 6A         | 60V           | 15            | 65W            | General purpose, high power   |                      |
| 2N3055          | NPN       | TO3        | 15A        | 60V           | 20            | 117W           | General purpose, high power   |                      |

**Please note:** the data in this table was compiled from several sources which are not entirely consistent! Most of the discrepancies are minor, but please consult information from your supplier if you require precise data.

### PNP transistors

| Code  | Structure | Case style | $I_C$ max. | $V_{CE}$ max. | $h_{FE}$ min. | $P_{tot}$ max. | Category (typical use) | Possible substitutes |
|-------|-----------|------------|------------|---------------|---------------|----------------|------------------------|----------------------|
| BC177 | PNP       | TO18       | 100mA      | 45V           | 125           | 300mW          | Audio, low power       | BC477                |

|        |     |       |       |      |     |       |                              |        |
|--------|-----|-------|-------|------|-----|-------|------------------------------|--------|
| BC178  | PNP | TO18  | 200mA | 25V  | 120 | 600mW | General purpose, low power   | BC478  |
| BC179  | PNP | TO18  | 200mA | 20V  | 180 | 600mW | Audio (low noise), low power |        |
| BC477  | PNP | TO18  | 150mA | 80V  | 125 | 360mW | Audio, low power             | BC177  |
| BC478  | PNP | TO18  | 150mA | 40V  | 125 | 360mW | General purpose, low power   | BC178  |
| TIP32A | PNP | TO220 | 3A    | 60V  | 25  | 40W   | General purpose, high power  | TIP32C |
| TIP32C | PNP | TO220 | 3A    | 100V | 10  | 40W   | General purpose, high power  | TIP32A |

**Please note:** the data in this table was compiled from several sources which are not entirely consistent! Most of the discrepancies are minor, but please consult information from your supplier if you require precise data.

**Structure** This shows the type of transistor, NPN or PNP. The polarities of the two types are different, so if you are looking for a substitute it must be the same type.

**Case style** There is a diagram showing the leads for some of the most common case styles in the [Connecting](#) section above. This information is also available in suppliers' catalogues.

**I<sub>C</sub> max.** Maximum collector current.

**V<sub>CE</sub> max.** Maximum voltage across the collector-emitter junction.  
You can ignore this rating in low voltage circuits.

**h<sub>FE</sub>** This is the **current gain** (strictly the DC current gain). The guaranteed minimum value is given because the actual value varies from transistor to transistor - even for those of the same type! Note that current gain is just a number so it has no units.  
The gain is often quoted at a particular collector current I<sub>C</sub> which is usually in the middle of the transistor's range, for example '100@20mA' means the gain is at least 100 at 20mA. Sometimes minimum and maximum values are given. Since the gain is roughly constant for various currents but it varies from transistor to transistor this detail is only really of interest to experts.  
**Why h<sub>FE</sub>?** It is one of a whole series of parameters for transistors, each with their own symbol. There are too many to explain here.

**P<sub>tot</sub> max.** Maximum total power which can be developed in the transistor, note that a [heat sink](#) will be required to achieve the maximum rating. This rating is important for transistors operating as amplifiers, the power is roughly I<sub>C</sub> × V<sub>CE</sub>. For transistors operating as switches the maximum collector current (I<sub>C</sub> max.) is more important.

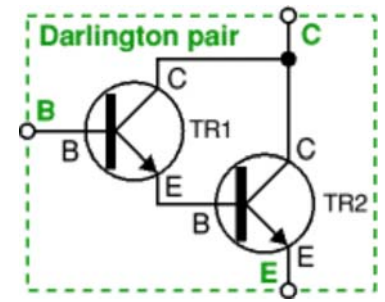
**Category** This shows the typical use for the transistor, it is a good starting point when looking for a substitute. Catalogues may have separate tables for different categories.

**Possible substitutes** These are transistors with similar electrical properties which will be suitable substitutes in most circuits. However, they may have a different case style so you will need to take care when placing them on the circuit board.

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Darlington pair

This is two transistors connected together so that the amplified current from the first is amplified further by the second transistor. This gives the Darlington pair a very high current gain such as 10000. Darlington pairs are sold as complete packages containing the two transistors. They have three leads (**B**, **C** and **E**) which are equivalent to the leads of a standard individual transistor.



You can make up your own Darlington pair from two transistors. For example:

- For TR1 use BC548B with  $h_{FE1} = 220$ .
- For TR2 use BC639 with  $h_{FE2} = 40$ .

The overall gain of this pair is  $h_{FE1} \times h_{FE2} = 220 \times 40 = 8800$ . The pair's maximum collector current  $I_C(\text{max})$  is the same as TR2.

