A faint, grey-scale circuit diagram serves as the background. It features two NPN transistors, a 9V battery, a resistor, and a red LED. The LED is labeled 'Red LED' and has two arrows pointing away from it, indicating light emission. The text 'CATHODE' is visible near the LED's negative terminal. The main title 'HOW TRANSISTORS WORK' is overlaid in large, white, bold, sans-serif font.

HOW TRANSISTORS WORK

Joe Knows
Electronics™

TYPES OF TRANSISTORS

There are several types of transistors included in your Joe Knows Electronics Semiconductor Kit, bipolar junction transistors (BJT), junction field effect transistors (JFET), metal-oxide-semiconductor field effect transistors (MOSFET), Darlington pairs, and even the silicon controlled rectifier (SCR), which isn't a transistor, but is easiest to understand as a 2-transistor model.

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The best way to communicate with us is by email. This allows us to have a record of your correspondence and the ability to convey information like technical specifications more easily.

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(855-563-5669)

Someone is available 24/7 to take your call at our toll free number. Your contact information will be taken and a member of our management team will contact you within normal business hours, 9am – 6pm EST M-F. Please note that our phone associates don't have the necessary information to discuss products or orders but will direct your call to the appropriate company representative.

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DATASHEET ACCESS

Access more information about this product including datasheets by scanning this QR code or visiting wiki.joeknowselectronics.com

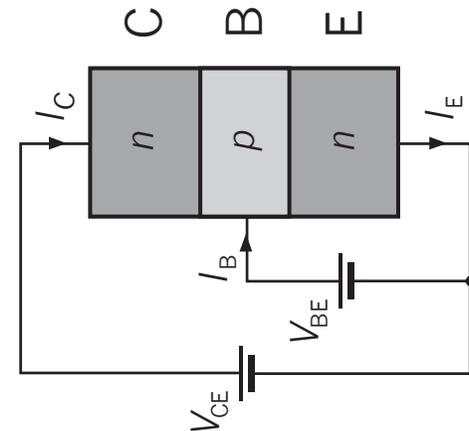
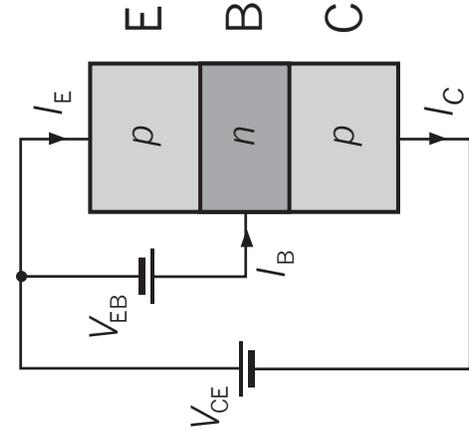


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BIPOLAR JUNCTION TRANSISTORS (BJT)

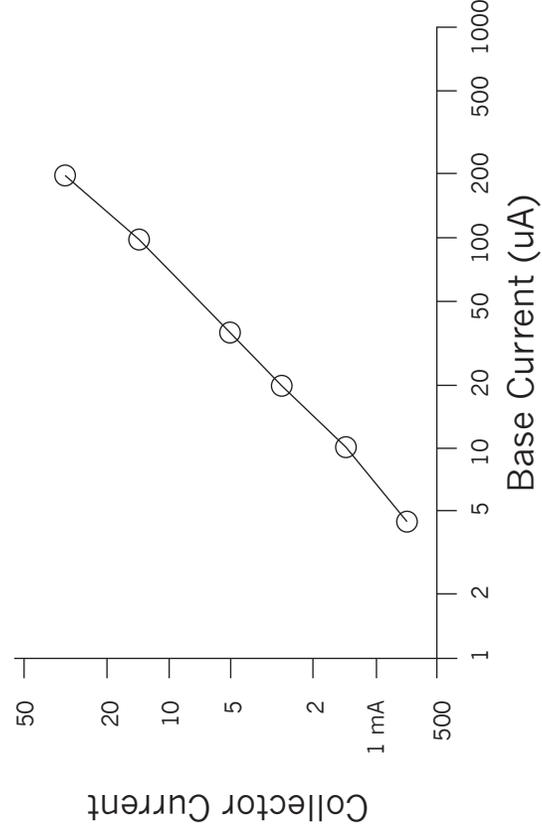
These are the workhorses of the transistor family – if you don't know what to use, try a BJT. There are two types of bipolar junction transistors, NPN and PNP.

In an NPN transistor, there are two p-n junctions separated by a region of p-type silicon, where p-type silicon is doped (often with boron) to insure there are more holes than electrons. Conversely, in a PNP transistor, the two p-n junctions are separated by a region of n-type silicon, in which there are more electrons than holes.

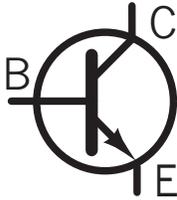


The three terminals of a transistor are called the base, emitter, and collector. The usefulness of a transistor is that small changes in the current flowing through the base can produce large changes in the current through the emitter and collector – this property is called gain – the collector current divided by the base current.

The 2N3904 BJTs from your kit are NPN transistors with a rated gain of about 140. By providing less than a mA of base current and measuring the resulting collector current, the gain of the transistor can be tested. We did this using a simulator and a fixed 3 volt collector-emitter voltage. Not surprisingly, the DC current gain of the transistor is about the expected 140, with small differences entering in when the collector current becomes large enough.



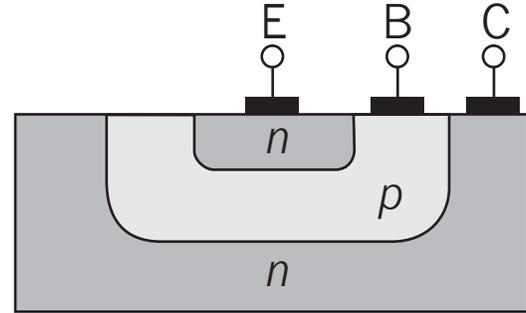
The key here is that the size of the collector-emitter voltage doesn't matter (so long as the transistor doesn't burn out.) The current through the transistor is controlled by the base current, so a BJT is a current-controlled current source.



The symbol for an NPN transistor



The symbol for a PNP transistor

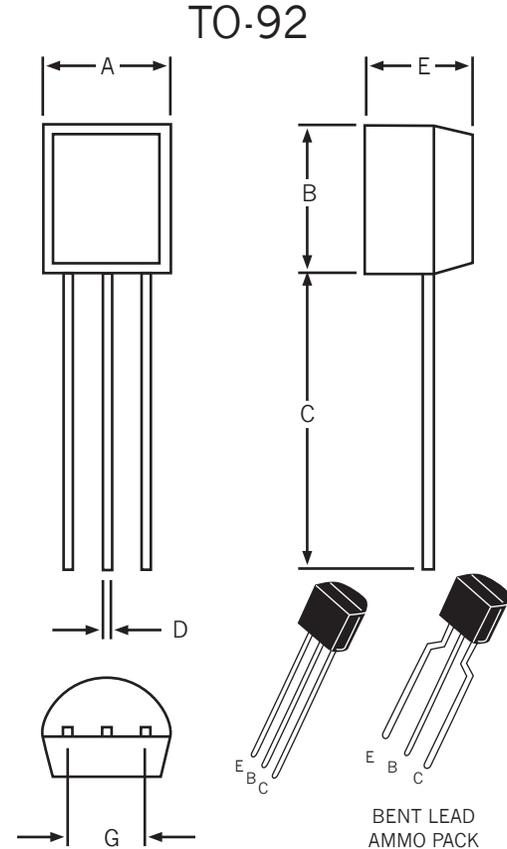


Today, more NPN transistors are used than are PNP. The main reason for this is that electrons move faster than holes, so it takes less time for the collector to make contact with all the boundaries of the base p-type material.

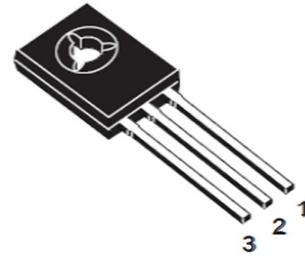
PACKAGES

The transistors in your kit come in three different packages, the TO-92 (2N3904, 2N3906, MPSA42, MPSA92, SS9018, STX616), the SOT-32 (MJE172, MJE182), and the SOT-23 (2SC5227A) .

The **TO-92** is a small plastic package as shown in the figure on the following page. Dimensions A, B, and E are all roughly 4mm. The pins are in the indicated order (EBC) for all the transistors in the kit save for the STX616, for which the order is ECB.

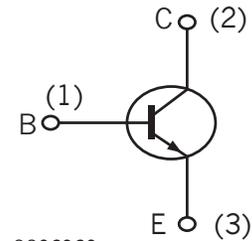


The SOT-32 is a larger package (7.5mm wide and 10.5mm tall) with a heat sink pad on the back surface. The image below is of the front side, and the ECB pins order is correct for the MJE172/82 transistors.



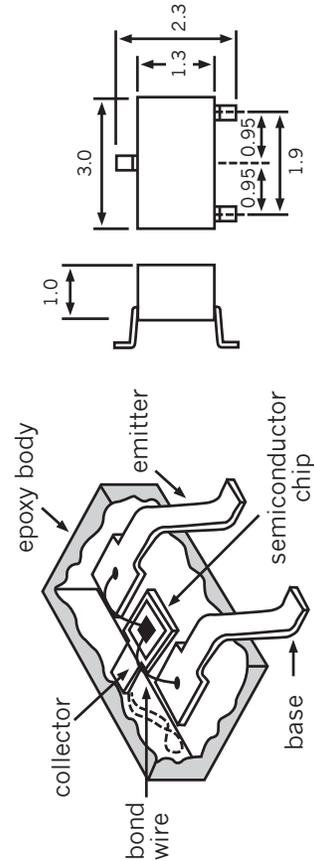
SOT-32

INTERNAL SCHEMATIC DIAGRAM



SC06960

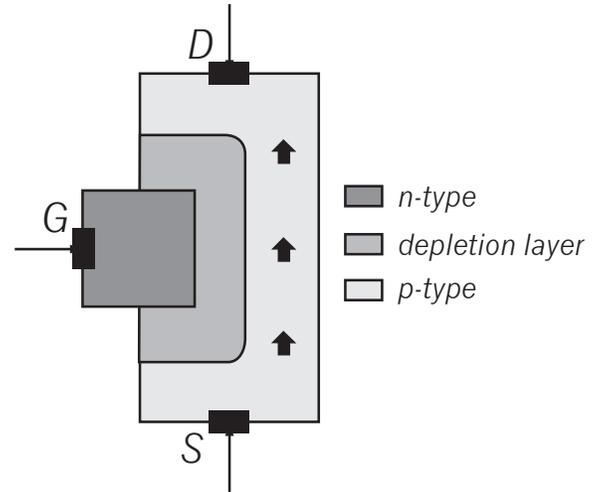
Finally, the SOT-23 is a very small package only 2 by 3 mm in size, and having only surface mount tabs rather than through-board leads. Only the 2SC5227A 7GHz epitaxial transistors come in this package, which require the small size to reduce stray capacitance to a suitable level for multi-GHz operation. A set of adapters is included to simplify the task of soldering these small devices into a circuit.



JUNCTION FIELD EFFECT TRANSISTORS (JFET)

A JFET is a long channel of highly doped semiconductor, with a gate electrode grown on it. A JFET works rather like a garden hose: There is a path for conduction (the channel), and a terminal (the gate) through which you step on the hose. Step with enough pressure (gate voltage), and the flow of water (electrons) will slow and eventually stop. Current is being controlled in a JFET with an applied voltage, making these voltage-controlled current sources.

This can be seen in the diagram opposite, where a gate voltage pushes a depletion layer (see discussion in diodes) across the p-type material connecting the drain and source terminals. The resistance



of the device increases as the depletion layer grows, until it eventually cuts off all conduction.

The common theme of transistors appears here, in that a small gate signal controls a much larger source-drain signal. There is a difference with JFETs, however, in that the control signal is a voltage, rather than the currents which control BJTs. To turn off a p-channel JFET (such as is shown above), the voltage between the gate and the source must be positive, while a negative voltage is needed to turn off an n-channel JFET. If the gate voltage oscillates around a given value, the oscillation will be superimposed and amplified on the channel current.

Because the channel pinch off is controlled by an electric field (voltage), the JFET and most of its kin exhibit a very large input impedance – there isn't any path for gate current to flow. They make excellent low-noise amplifiers and tuners for VHF through microwave applications. The length of the gate largely determines the upper frequency response, as the gate won't entirely turn off (or on) until carriers have had time to move into or out of the gate region. A one-micron wide gate corresponds to about a 5 GHz frequency cut-off.

METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR (MOSFET)

The MOSFET is the most commonly encountered three-terminal semiconductor device in both digital and analog electronics. The difference between a JFET and a MOSFET lies in the gate design. The gate of a JFET is a small region of doped semiconductor, while in the MOSFET the gate is a metal electrode (nowadays usually highly doped polysilicon) sitting atop an insulating layer (typically a silicon oxide.) Although MOSFETs can be designed to operation in depletion mode (like the JFET, in which a conducting channel is pinched off with increasing gate voltage), it is more common for these to work in enhancement mode, meaning

that increasing gate voltage pushes additional carriers into the channel. In essence a depletion mode device closes a channel, while an enhancement mode device increases the conductivity of a channel. Either effect can be used for amplification of a signal.

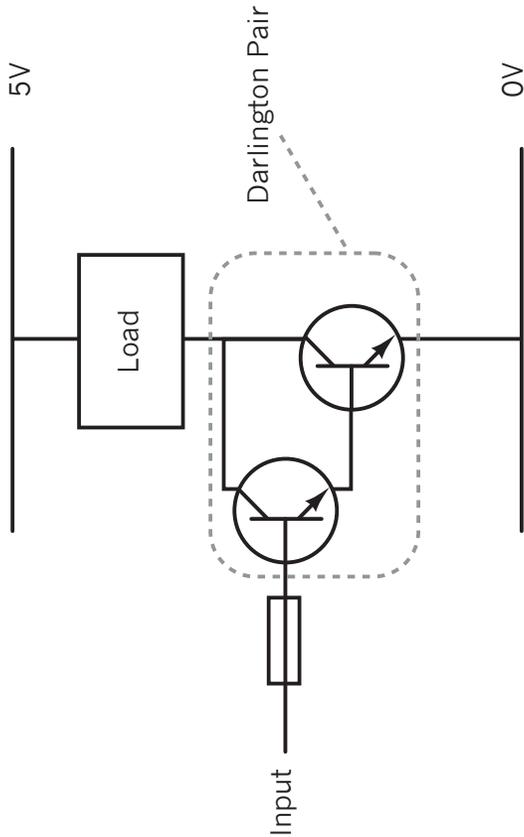
PACKAGES FOR FIELD EFFECT TRANSISTORS

The field effect transistors in your semiconductor kit come in TO-92 packages (2N7000G, J310G). However, the pin order for the 2N7000G is Source, Gate, and Drain, while for the J310G it is Drain, Source, and Gate. The best advice is to check the datasheets for the specific device you are using prior to, during, and after construction – then check again.

DARLINGTON TRANSISTOR PAIRS

Sometimes in electronics you simply need a lot of gain from your circuit. This is a relatively common situation in sensor circuitry, as well as dynamic microphone preamplifiers. A Darlington transistor (or Darlington pair) is a pair of transistors with a common collector wired so that the emitter of the first is directly connected to the base of the second.

While Darlington pairs can be assembled from two discrete transistors, in their original 1953 form the common collector was literally a single piece of germanium on which a pair of BJTs was grown.



This configuration carries with it a huge current gain. While a normal BJT will have a gain of 100-200, the KSP13BU Darlington pair included in your semiconductor device kit has a minimum gain in the 5-10000 range. If, for example, you want to amplify the signal from a dynamic microphone, quiet speech will generate only about a microvolt of signal. As such microphones usually have impedance of around 300 ohms; the current of the microphone's signal will only be a few nanoamps.

However, after passing through a Darlington pair, the current will be amplified to tens of microamps, a level large enough that additional stages in a preamplifier can concentrate on producing a quality signal, rather than simply seeking enough gain. Darlington

pairs are also commonly used in touch-sensitive sensors, where they can respond to the tiny currents associated with static discharges, as well as in photodetector electronics.

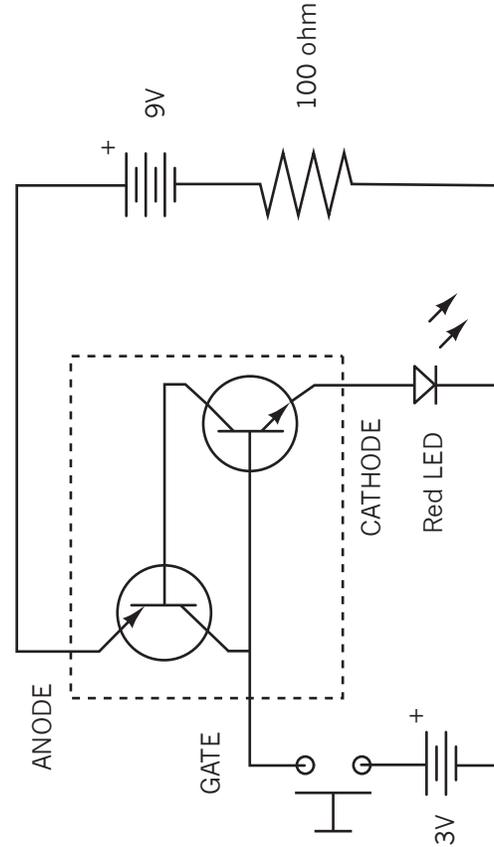
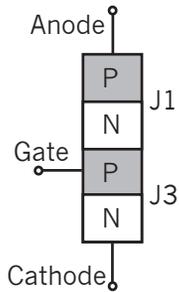
Naturally, Darlington pairs also have problems. Being two transistors in one, the “equivalent” transistor has twice the turn-on voltage (about 1.4 volts compared to the 0.7 volts typical of a silicon BJT.) An increase in saturation voltage also results in substantially larger power dissipation if used in association with digital logic circuits, a problem exacerbated by reduction in high frequency response combined with an increase in phase shift, which can lead toward feedback instability. All told, when a Darlington pair is appropriate, it is a

real boon to a circuit designer, but you must be sure it is the right choice.

The KSP13BU Darlington pair included in your semiconductor kit has a TO-92 package, with the pin order Emitter, Base, Collector.

SILICON CONTROLLED RECTIFIER (SCR)

A silicon controlled rectifier is a four-layer three-terminal semiconductor device, which functions as a triggered unidirectional switch. It is probably easiest to understand how an SCR works by treating it as a pair of back-to-back complementary BJTs (inside the dashed box opposite). (In this context, complimentary means that one of the BJTs is an NPN transistor and the other is a PNP transistor, as shown below.)



Initially, no current flows between the anode and cathode of an SCR, as both transistors are turned off.

When a small current (about 40 μA for the MCR100-6G included in the semiconductor kit) is applied to the gate of the SCR by pressing the pushbutton, the NPN transistor turns on. This causes the NPN transistor's collector voltage to fall toward that of the NPN emitter. In turn, a current now flows through the base of the PNP transistor, which turns on that transistor. A current now flows through the PNP transistor, which, as it is connected to the base of the NPN transistor, causes the NPN transistor to remain turned on. In the circuit as shown, the current passing through the SCR also passes through the LED, so it lights when the SCR is turned on.

A short pulse to the gate at a power of tens of micro watts can turn on the MCR100-6G SCR, which can carry over 300 watts of power. Even though this is an on-off switch, it is still an effective amplification of about one million.

In essence, the output of the NPN transistor is connected to the base of the PNP transistor, and the output of the PNP transistor is connected to the base of the NPN transistor. This produces a positive feedback in which each transistor causes the other to remain on. Nothing about the feedback causes it to cease if the voltage applied to the SCR gate terminal is disconnected, so the LED remains lit even when the pushbutton is released.

How do we turn off the SCR? Under normal circumstances it will remain on

as long as the current passing through the SCR remains above the holding current – about 5 mA for the MCR100-6G. The usual approach to turning off an SCR is to interrupt the supply voltage, or to turn on a voltage that opposes the supply current.

The MCR100-6G SCR in your semiconductor kit comes in a TO-92 package, with the pin order Cathode, Gate, and Anode.

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