

## **Conventional transistor overview and special transistors**

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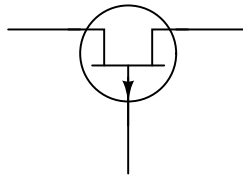
Resources and methods for learning about these subjects (list a few here, in preparation for your research):

## Questions

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### Question 1

Examine the following transistor symbol:



Identify the following:

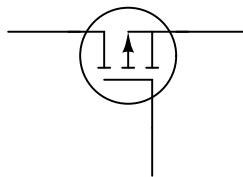
- Type of transistor (*BJT, JFET, or MOSFET*)
- Semiconductor doping (*NPN, PNP ; N-channel, P-channel*)
- Identification of all 3 terminals (*Base, Collector, Emitter ; Gate, Drain, Source*)
- Direction of each terminal's current for proper transistor operation (*be sure to note whether you are using conventional flow or electron flow notation. If current direction is unimportant, or if there is no current at all, be sure to say so!*)

file 02331

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### Question 2

Examine the following transistor symbol:



Identify the following:

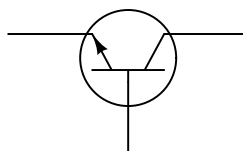
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### Question 3

Examine the following transistor symbol:



Identify the following:

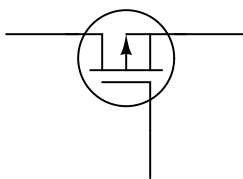
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- Semiconductor doping (*NPN, PNP ; N-channel, P-channel*)
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- Direction of each terminal's current for proper transistor operation (*be sure to note whether you are using conventional flow or electron flow notation. If current direction is unimportant, or if there is no current at all, be sure to say so!*)

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Question 4

Examine the following transistor symbol:



Identify the following:

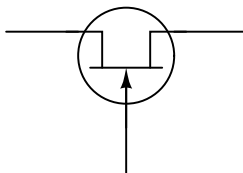
- Type of transistor (*BJT, JFET, or MOSFET*)
- Semiconductor doping (*NPN, PNP ; N-channel, P-channel*)
- Identification of all 3 terminals (*Base, Collector, Emitter ; Gate, Drain, Source*)
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Question 5

Examine the following transistor symbol:



Identify the following:

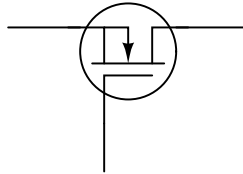
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- Semiconductor doping (*NPN, PNP ; N-channel, P-channel*)
- Identification of all 3 terminals (*Base, Collector, Emitter ; Gate, Drain, Source*)
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Question 6

Examine the following transistor symbol:



Identify the following:

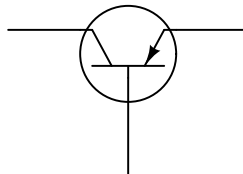
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Question 7

Examine the following transistor symbol:



Identify the following:

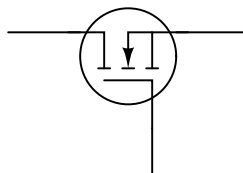
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- Semiconductor doping (*NPN, PNP ; N-channel, P-channel*)
- Identification of all 3 terminals (*Base, Collector, Emitter ; Gate, Drain, Source*)
- Direction of each terminal's current for proper transistor operation (*be sure to note whether you are using conventional flow or electron flow notation. If current direction is unimportant, or if there is no current at all, be sure to say so!*)

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Question 8

Examine the following transistor symbol:



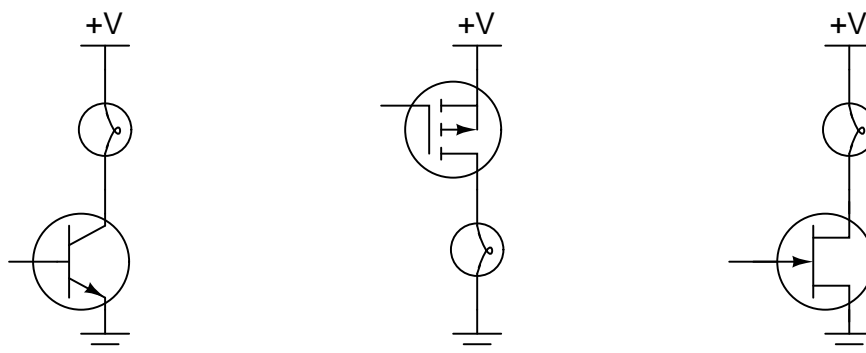
Identify the following:

- Type of transistor (*BJT, JFET, or MOSFET*)
- Semiconductor doping (*NPN, PNP ; N-channel, P-channel*)
- Identification of all 3 terminals (*Base, Collector, Emitter ; Gate, Drain, Source*)
- Direction of each terminal's current for proper transistor operation (*be sure to note whether you are using conventional flow or electron flow notation. If current direction is unimportant, or if there is no current at all, be sure to say so!*)

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#### Question 9

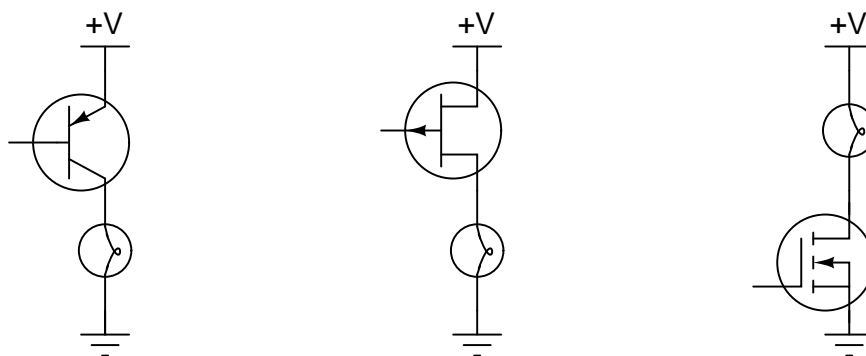
Identify what each type of transistor is (MOSFET, JFET, or BJT; N-channel, P-channel, NPN, or PNP, E-type or D-type), and what must be connected to the controlling terminal of each transistor (base or gate) to turn each one *on* so that the light bulb energizes:



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#### Question 10

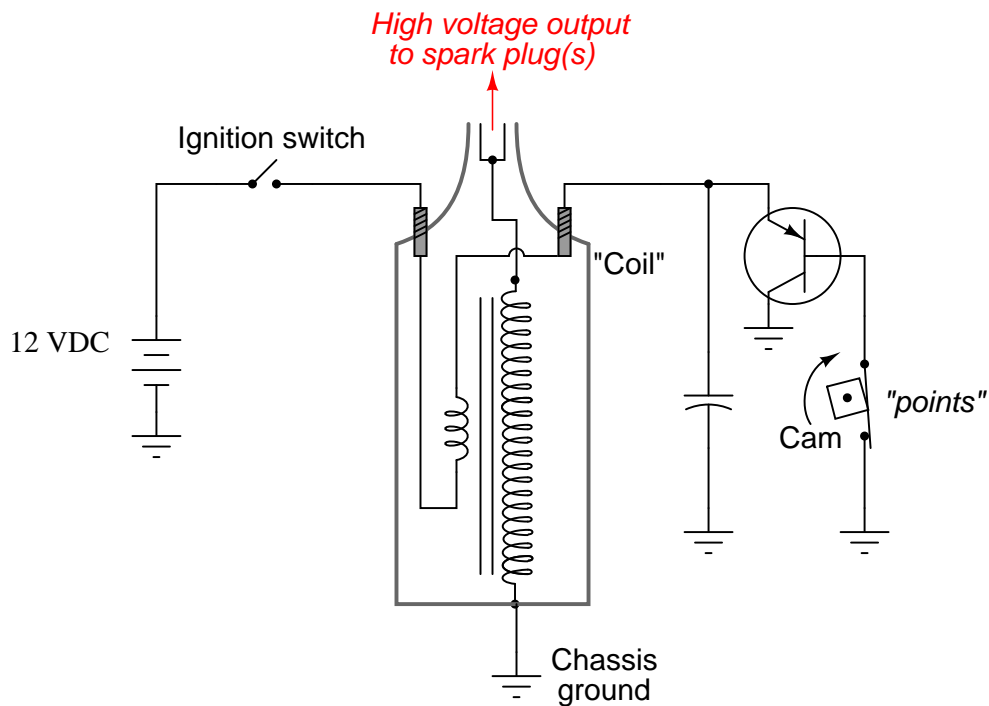
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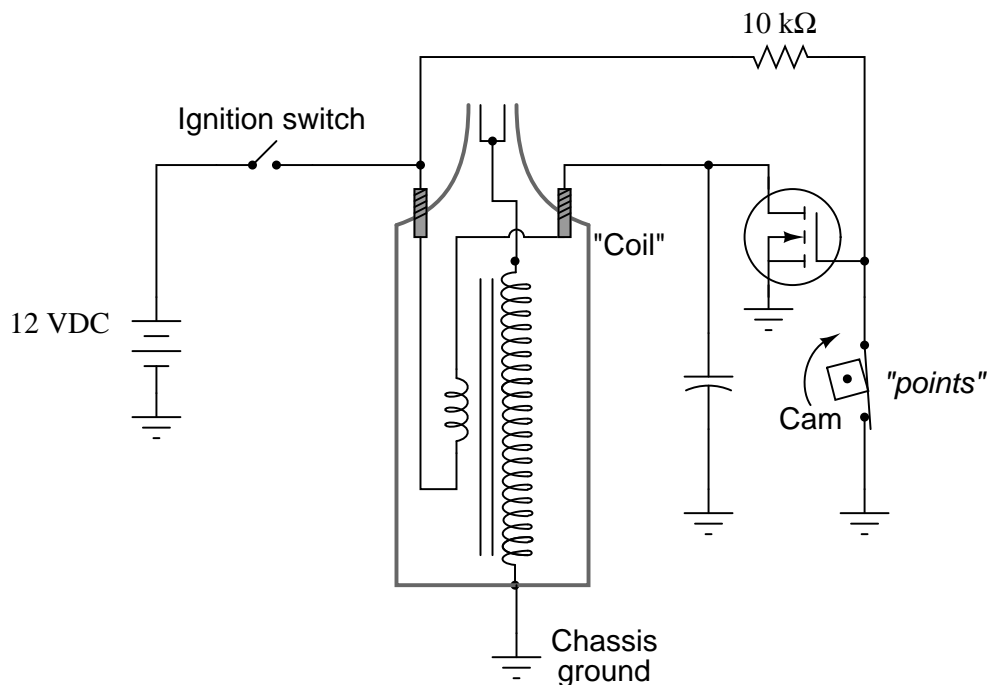
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Question 11

Shown here is the schematic diagram for a simple automotive ignition system, to produce pulses of high voltage sufficient to energize spark plugs in an engine:



An engineer decides to replace the BJT with a MOSFET, and arrives at the following circuit design:



Explain how this revised circuit works. When does the MOSFET conduct current, when the point

contacts are open or closed? How does this compare to the working of the previous (BJT) circuit? What purpose does the  $10\text{ k}\Omega$  resistor serve?

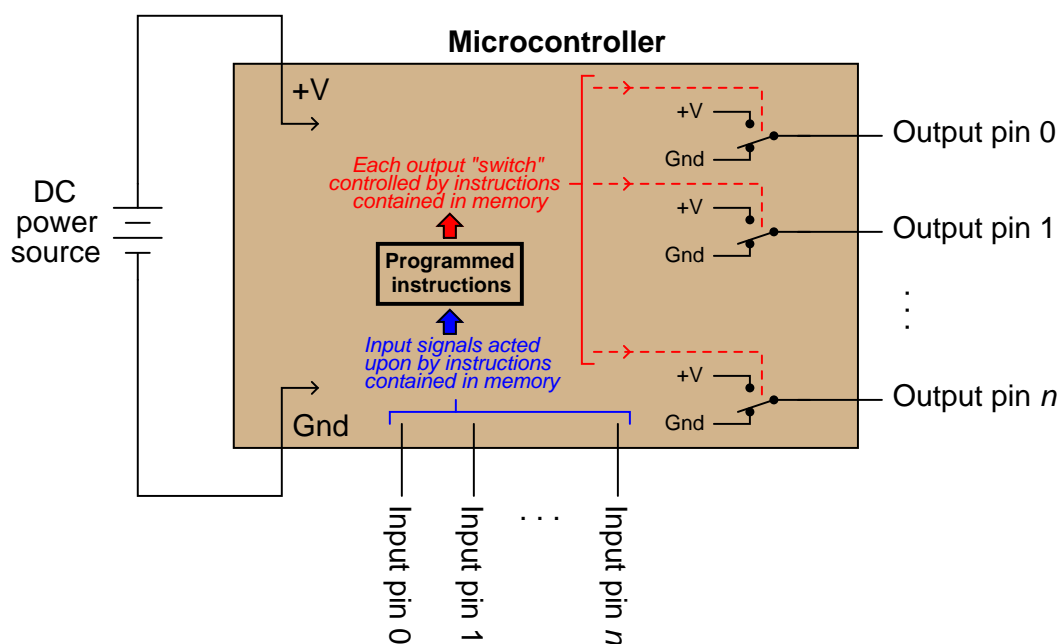
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## Question 12

A *microcontroller* is a specialized type of digital computer used to provide automatic sequencing or control of a system. Microcontrollers differ from ordinary digital computers in being very small (typically a single integrated circuit chip), with several dedicated pins for input and/or output of digital signals, and limited memory. Instructions programmed into the microcontroller's memory tell it how to react to input conditions, and what types of signals to send to the outputs.

The simplest type of signal "understood" by a microcontroller is a discrete voltage level: either "high" (approximately +V) or "low" (approximately ground potential) measured at a specified pin on the chip. Transistors internal to the microcontroller produce these "high" and "low" signals at the output pins, their actions being modeled by SPDT switches for simplicity's sake:

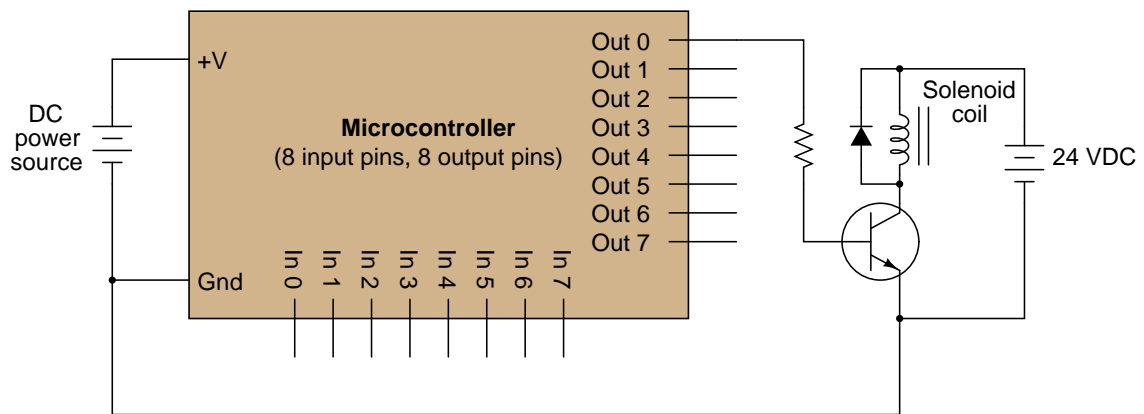


It does not require much imagination to visualize how microcontrollers may be used in practical systems: turning external devices on and off according to input pin and/or time conditions. Examples include appliance control (oven timers, temperature controllers), automotive engine control (fuel injectors, ignition timing, self-diagnostic systems), and robotics (servo actuation, sensory processing, navigation logic). In fact, if you live in an industrialized nation, you probably own several dozen microcontrollers (embedded in various devices) and don't even realize it!

One of the practical limitations of microcontrollers, though, is their low output drive current limit: typically less than 50 mA. The miniaturization of the microcontroller's internal circuitry prohibits the inclusion of output transistors having any significant power rating, and so we must connect transistors to the output pins in order to drive any significant load(s).

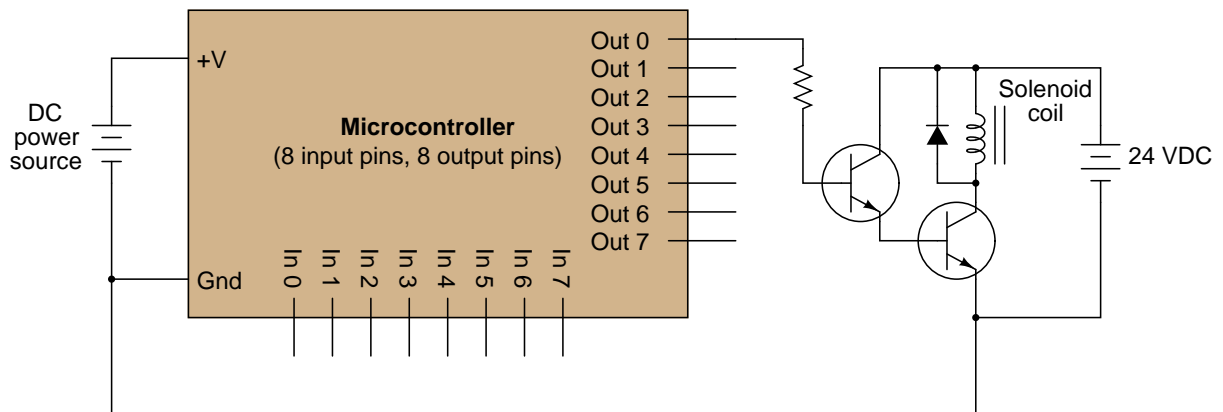
Suppose we wished to have a microcontroller drive a DC-actuated solenoid valve requiring 2 amps of current at 24 volts. A simple solution would be to use an NPN transistor as an "interposing" device between the microcontroller and the solenoid valve like this:



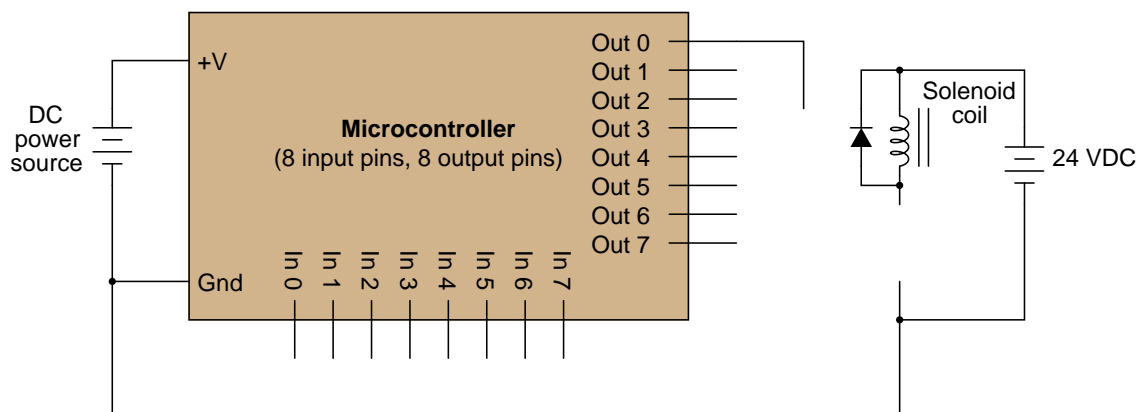


Unfortunately, a single BJT does not provide enough current gain to actuate the solenoid. With 20 mA of output current from the microcontroller pin and a  $\beta$  of only 25 (typical for a power transistor), this only provides about 500 mA to the solenoid coil.

A solution to this problem involves two bipolar transistors in a *Darlington pair* arrangement:



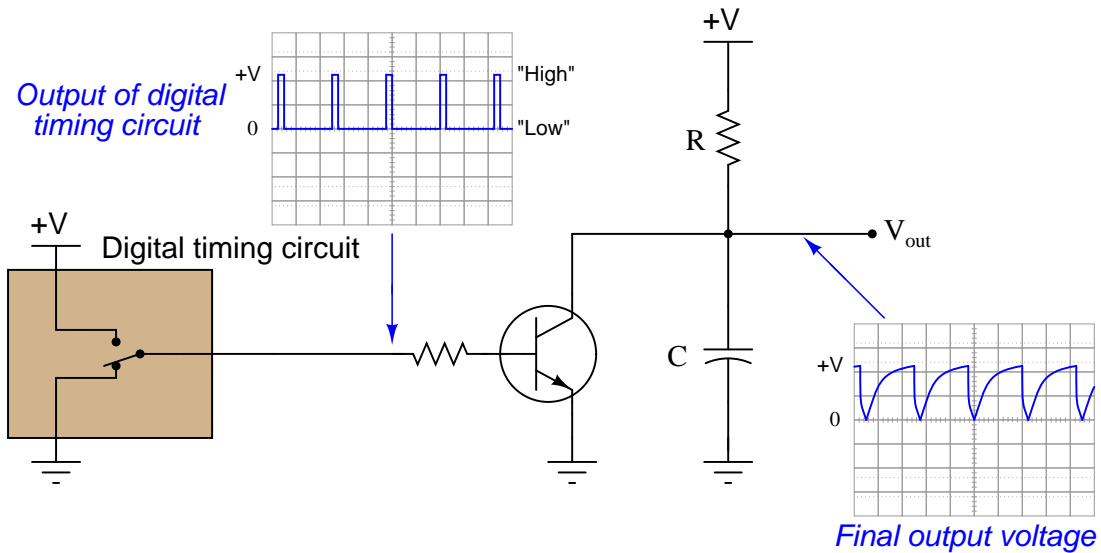
However, there is another solution yet – replace the single BJT with a single MOSFET, which requires no drive current at all. Show how this may be done:



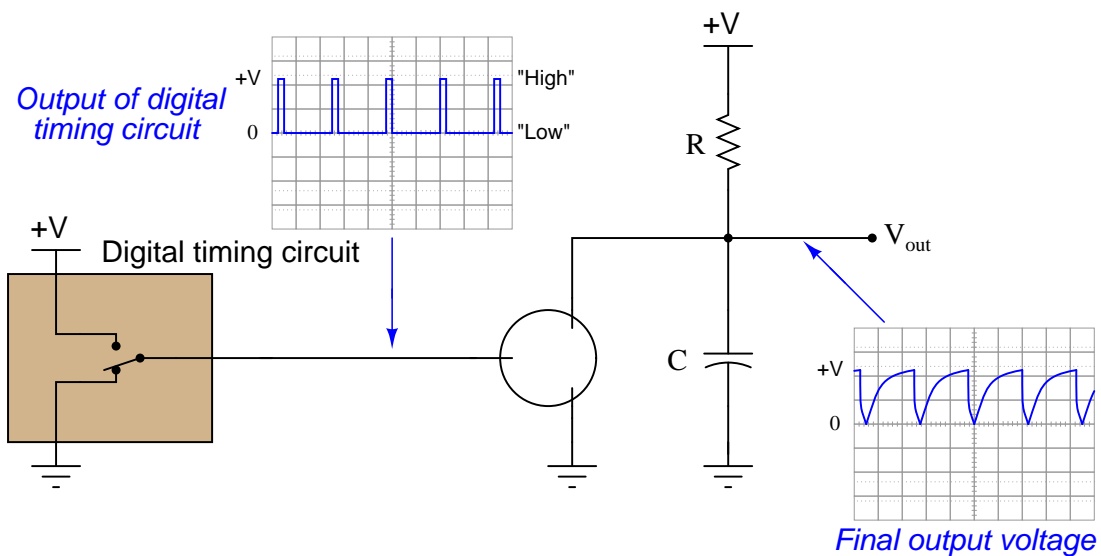
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### Question 13

In this system, the voltage output of a digital timing circuit controls the charging and discharging of a resistor-capacitor network. The inner workings of the digital timing circuit are hidden for simplicity's sake, but we may model it as a two-position switch, outputting either a "high" voltage signal (full supply voltage) or a "low" voltage signal (ground potential) at regular intervals:



First, identify what signal level from the digital circuit ("high" or "low") causes the capacitor to charge, and what level causes it to discharge. Then, replace the BJT with a suitable MOSFET to accomplish the exact same timing function:

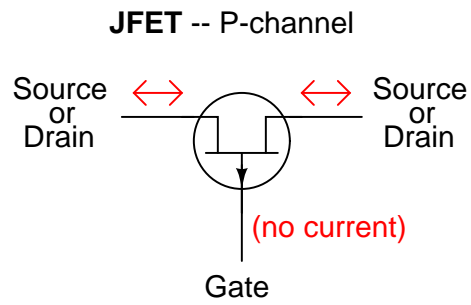


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## Answers

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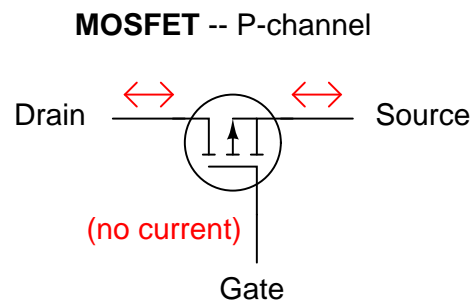
Answer 1



*This type of transistor can handle source/drain currents of either direction*

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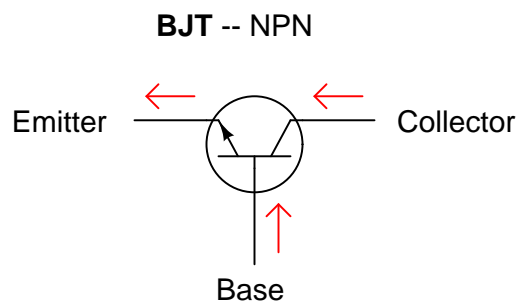
Answer 2



*This type of transistor can handle source/drain currents of either direction*

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Answer 3

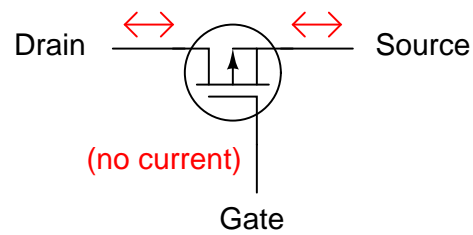


*Current arrows drawn in the direction of conventional flow notation*

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Answer 4

**MOSFET -- P-channel**

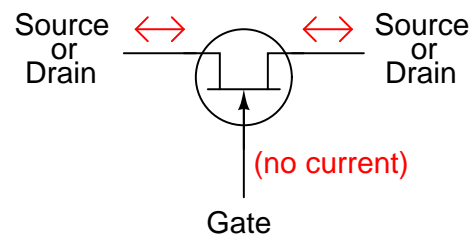


*This type of transistor can handle source/drain currents of either direction*

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Answer 5

**JFET -- N-channel**

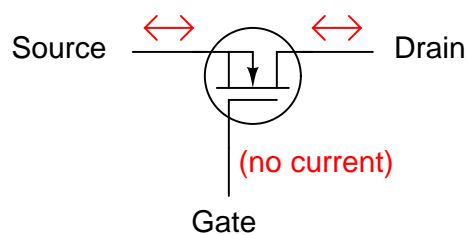


*This type of transistor can handle source/drain currents of either direction*

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Answer 6

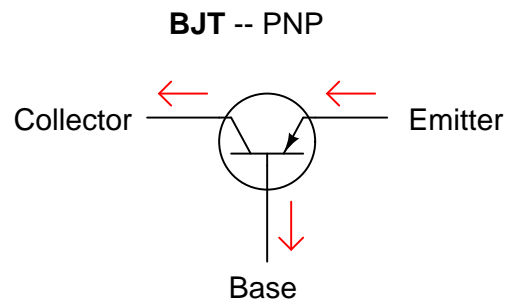
**MOSFET -- N-channel**



*This type of transistor can handle source/drain currents of either direction*

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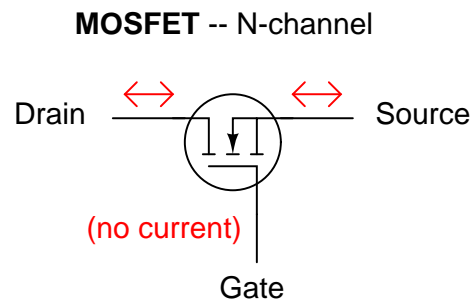
Answer 7



*Current arrows drawn in the direction  
of conventional flow notation*

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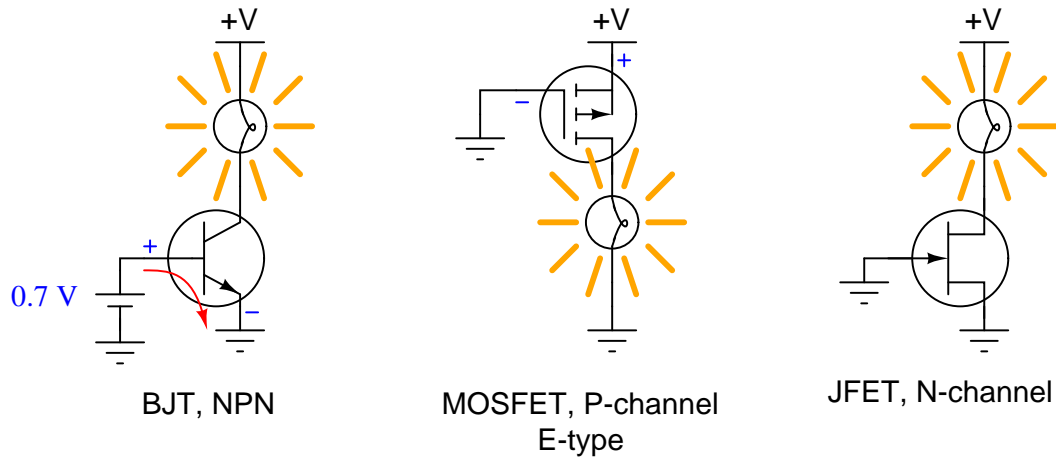
Answer 8



*This type of transistor can handle  
source/drain currents of either direction*

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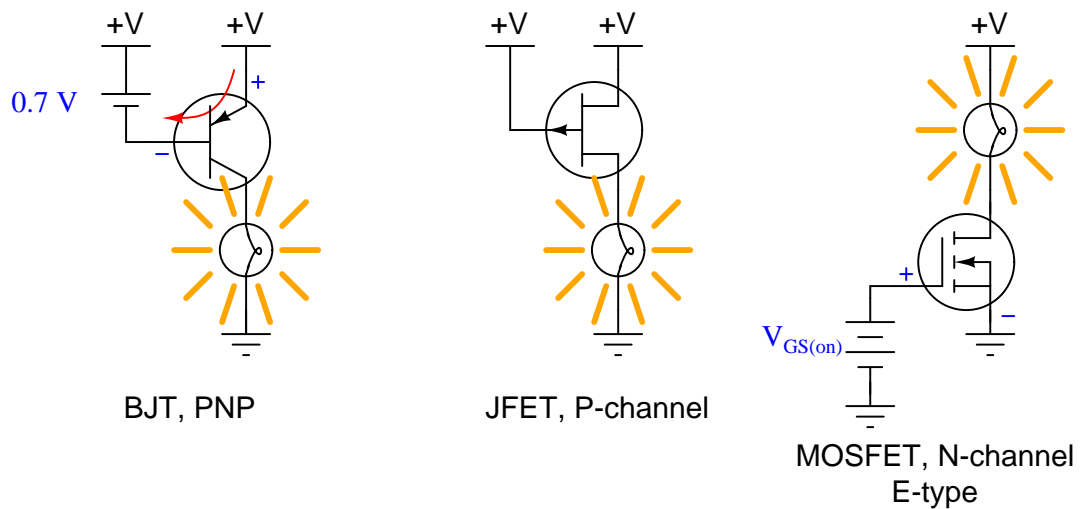
Answer 9



Follow-up question: for the JFET, which is already "on" with zero voltage applied to the gate, describe what would be necessary to force it into the "off" state.

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Answer 10



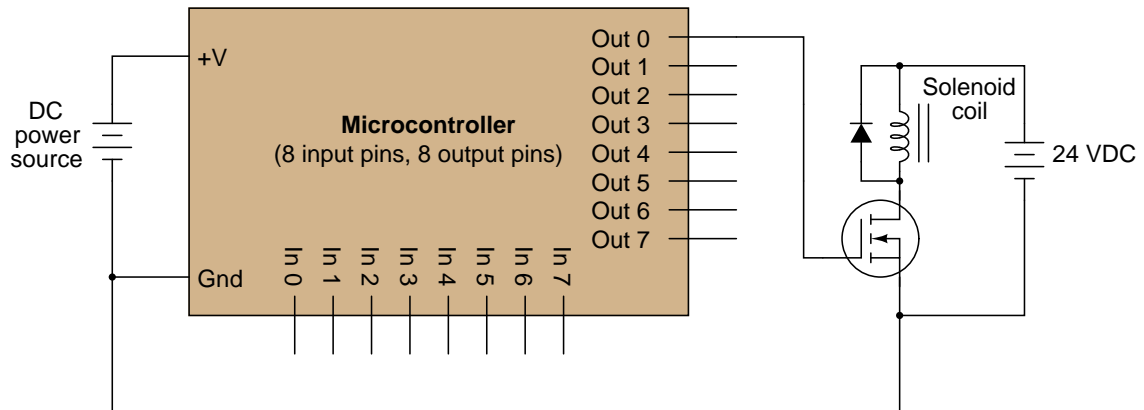
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Answer 11

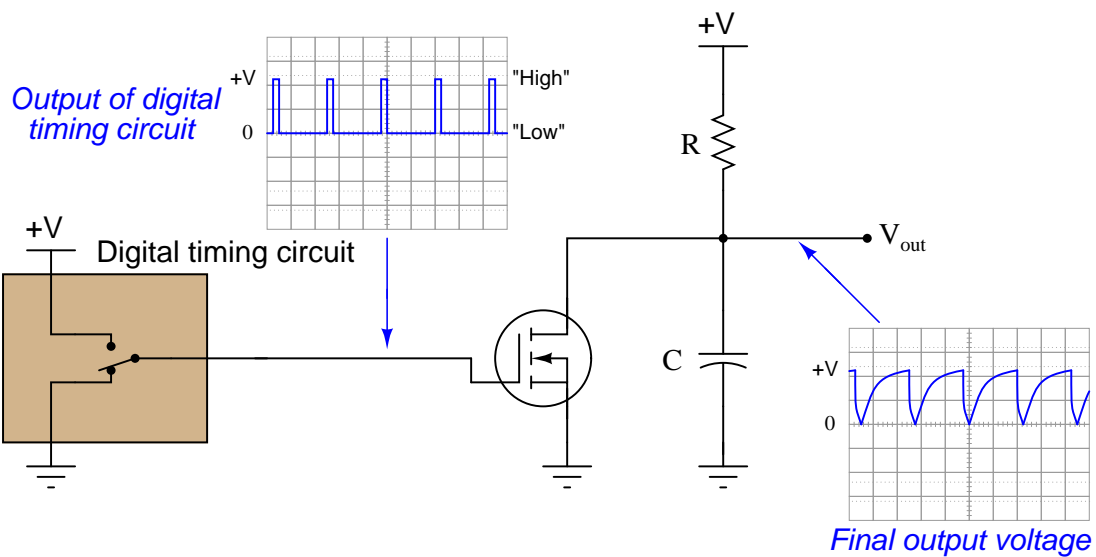
The MOSFET conducts current when the point contacts are open, which is opposite that of the BJT. I'll let you figure out what the purpose of the resistor is!

Answer 12



Answer 13

In the BJT version of the circuit, a "low" signal output by the digital circuit causes the capacitor to charge. The same thing happens in this MOSFET version of the circuit:



Follow-up question: explain why no resistor is required in series with the MOSFET gate as there was with the BJT base in the original circuit version.

## Notes

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### Notes 1

This question probes some basic yet important knowledge about transistor identify and operation. If students have difficulty identifying all the parameters asked for in this question, you need to spend more time on transistor fundamentals before proceeding with any other aspects of transistor circuitry!

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### Notes 8

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### Notes 9

It is very important for students to understand what conditions are necessary to drive any of these transistor types into their "on" states, as a precursor to understanding their function in linear (analog) circuitry.

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### Notes 10

It is very important for students to understand what conditions are necessary to drive any of these transistor types into their "on" states, as a precursor to understanding their function in linear (analog) circuitry.



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Notes 11

If this were a real ignition system, the timing would have to be adjusted, as the spark will now be produced every time the points *close* rather than every time the points *open* as it did before (with the BJT). Discuss the operation of this circuit with your students, asking them to explain how they know the MOSFET's status (and the BJT's status, for that matter).

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Notes 12

The purpose of this long-winded question is not just to have students figure out how to replace a BJT with a MOSFET, but also to introduce them to the concept of the microcontroller, which is a device of increasing importance in modern electronic systems.

Some students may inquire as to the purpose of the diode in this circuit. Explain to them that this is a *commutating diode*, sometimes called a *free-wheeling diode*, necessary to prevent the transistor from being overstressed by high-voltage transients produced by the solenoid coil when de-energized ("inductive kickback").

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Notes 13

This circuit could be used as an introduction to the 555 timer, since that IC uses the same scheme for capacitor discharge.