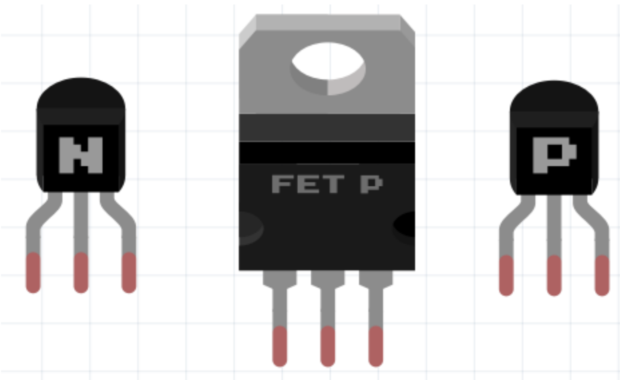
Curtin University

Transistor as a Switch

Transistors are a vital component in nearly all electronic circuits. They fit into the semiconductor category with diodes, in that they cannot be seen as true conductors or insulators but somewhere between. They come as a variety of different physical forms, including large, high power transistors in metal heat-sink packages and very small ones integrated into the substrate of a microchip. Different transistors also vary in their electrical properties so must be chosen based on the purpose and specifications they are intended for. Two main uses of transistors in circuits are to switch and to amplify.



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In this activity we will use Tinkercad's® circuits feature to simulate a transistor acting as a switch. The transistor will be used to switch an electric motor on and off. If you are not familiar with how to use Tinkercad® then watch the **"Introduction to Tinkercad®"** video before following these steps:

1. Log in to your account on the **Tinkercad®** website and create a new circuit. **Tinkercad®** runs best using Google Chrome as the browser.

2. Open the **components** menu, find the part named **"Breadboard Small"** and drag it into the workspace.

3. Rotate the breadboard clockwise by 90 degrees so that you see "**+ - a b c d e f g h i j + -**" at the top of the board.

4. In the components menu, change the category from **"Basic Components"** to **"All Components"** and scroll down to the **"Power Control"** section.

5. This section has a number of different transistors and other components. Click and drag an **"nMOS Transistor (MOSFET)"** into your workspace.

6. If you zoom in to the transistor, you will see the legs are **labeled "G", "D" and "S".** By hovering your mouse cursor over the legs of the transistor you will also see that these stand for **"Gate", "Drain"** and **"Source".** These are the names of the

connections to a **Metal-Oxide Semiconductor Field-Effect Transistor (MOSFET).**

7. Rotate the transistor clockwise by 90 degrees and place it on the breadboard so that the gate, drain and source pins are in holes **j24, j25 and j26,** respectively.

The reason these transistors can be used as an electronic switch is because when a certain voltage is applied between the gate and source pins, current can flow between the drain and the source pins (switching the transistor on). Below a certain gate-source voltage, no current can flow between the drain and source (switching the transistor off).

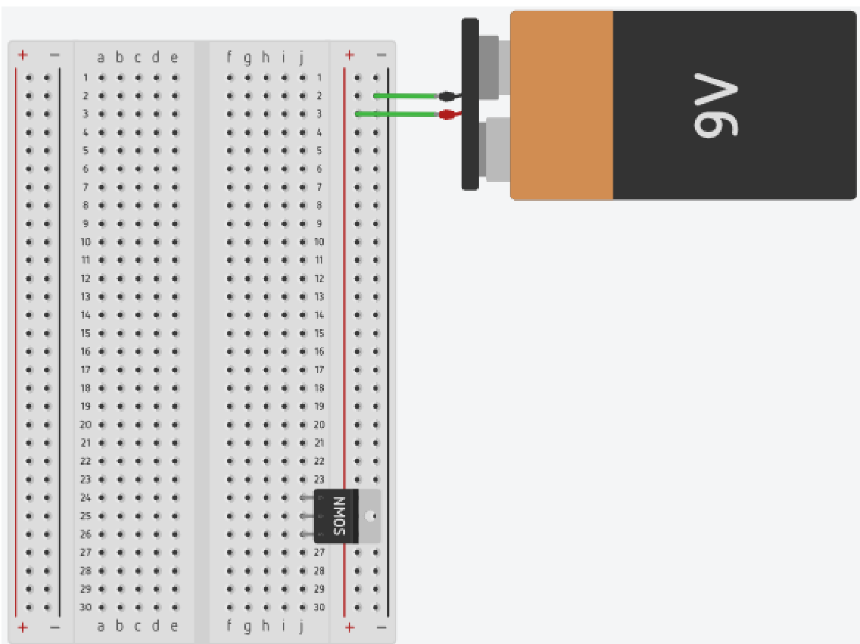
We will start by connecting a circuit from a 9V battery, through an electric motor to ground. The only point at which this circuit will be broken is between the drain and source of the transistor, which means the motor can't run until these pins are allowed to connect.

8. From the components menu, drag a **9V battery** into the workspace.

9. Place the 9V battery near the top, right-hand corner of the breadboard.

10. Drag a wire from the **positive (red) terminal** of the battery to a **hole in the right-hand positive rail**. Now all holes in that column will connect to positive 9V.

11. Drag another wire from the **negative (black) terminal** of the battery to a hole in the **right-hand negative rail**. Now all holes in that column will connect to ground. See the picture below for reference.



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12. Connect a wire from another pin on the positive rail across to **hole j6.**

13. Find the **DC motor** in the components menu and drag that into the workspace.

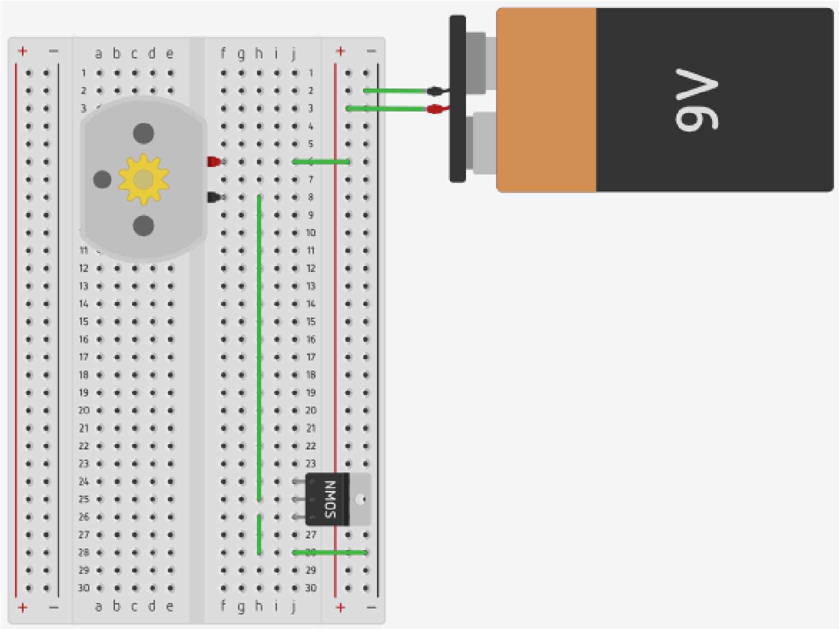
14. Rotate the **DC motor** so its terminals are facing to the right and connect it so its **red terminal is in f6 and its black terminal is in f8.**

15. Run a wire from **h8 down to h25,** so that it connects the DC motor to the drain (middle pin) of the transistor.

16. Connect a wire from **h26 (transistor source pin) to h28.**

17. Connect another wire from **j28 to the ground rail (negative) pin two holes** to the right. This has effectively connected the source of the transistor to the black terminal of the 9V battery, or ground.

Your circuit should look similar to the picture below.



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18. Try clicking **"Start Simulation".**

You should see no movement on the electric motor. There will be a reading on the motor showing "0 rpm". This indicates the speed that the motor is turning in revolutions per minute. A reading of zero indicates it is not moving at all.

19. **Stop** the simulation.

The motor did not move because the circuit from the positive 9 volt terminal of the battery to ground was broken (not connected) at the point between the drain and source of the transistor.

20. For testing purposes, temporarily short these two pins out to complete the circuit. Do this by connecting a wire between holes **f25 and f26.**

21. Start the simulation.

Does the DC motor appear to rotate? What speed is indicated?

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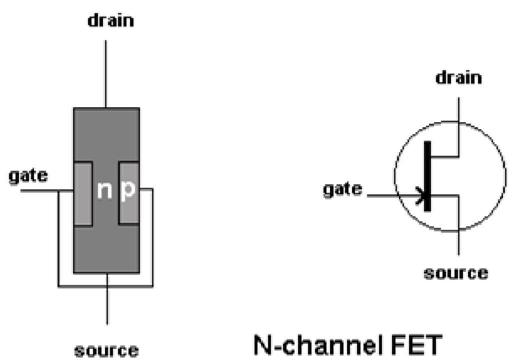
If the motor didn't start then check your wiring before continuing.

22. Stop the simulation and delete the temporary wire which connected the drain and source together.

To switch the motor on electronically we need to apply a voltage at the gate of the transistor, which will switch the transistor on and complete the circuit between the drain and source. The minimum voltage to apply before a field-effect transistor switches on correctly varies depending on the particular model and specifications. It is usually around 2-3V.



N-channel FET

The picture to the left shows the internal structure and the picture on the right shows the electrical symbol for a FET.

You can think of the gate as an electrically controlled on/off switch which starts or stops current flow between the drain and source.

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Switching a MOSFET requires a relatively low voltage and low current. This situation makes it ideal for being switched on and off through software control by using the relatively low powered outputs of a microcontroller.

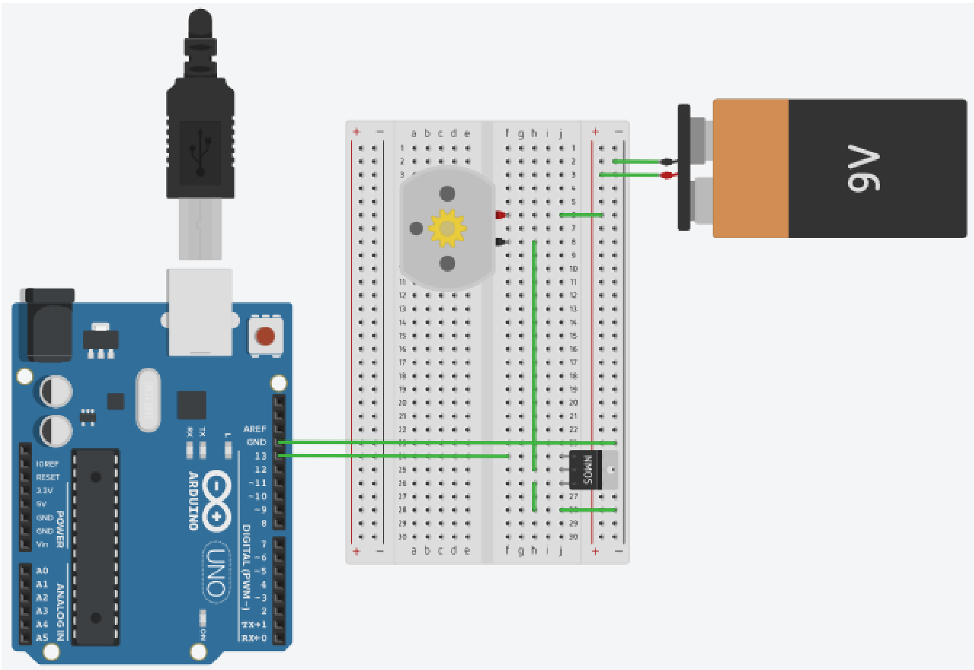
Tinkercad® simulates an Arduino Uno microcontroller board which we can connect to the gate of the transistor. The programming in the Arduino can change the voltage at the gate to switch the transistor, and subsequently the motor, on and off.

23. In the components menu you will find an **"Arduino Uno R3".** Place this in your workspace to the left of the breadboard and rotate it clockwise 90 degrees so that you see its red reset button in its top-right corner.

24. You will see a socket on the Arduino labelled **"GND",** which is the ground point. Connect a wire from this across to any of the holes on the far right column of the breadboard. It will now be effectively connected to the black terminal of the battery and the source of the transistor.

25. Connect another wire from **socket 13 of the Arduino to hole f24** of the breadboard, which means it also connects to the gate of the transistor.

Your circuit should now look similar to the picture below.



Don't worry if you don't completely understand the purpose or how to use the Arduino at this stage. All you need to know is that Tinkercad® has it pre-loaded with a program that means it will output around 4.5V to pin 13 for 1 second, then turn it off for 1 second (0V) before continuing this on/off cycle continuously until the simulation is manually stopped.

There are two precautionary measures to be taken in this circuit before turning it on to ensure that it operates as intended and reduces the risk of damage to any components:

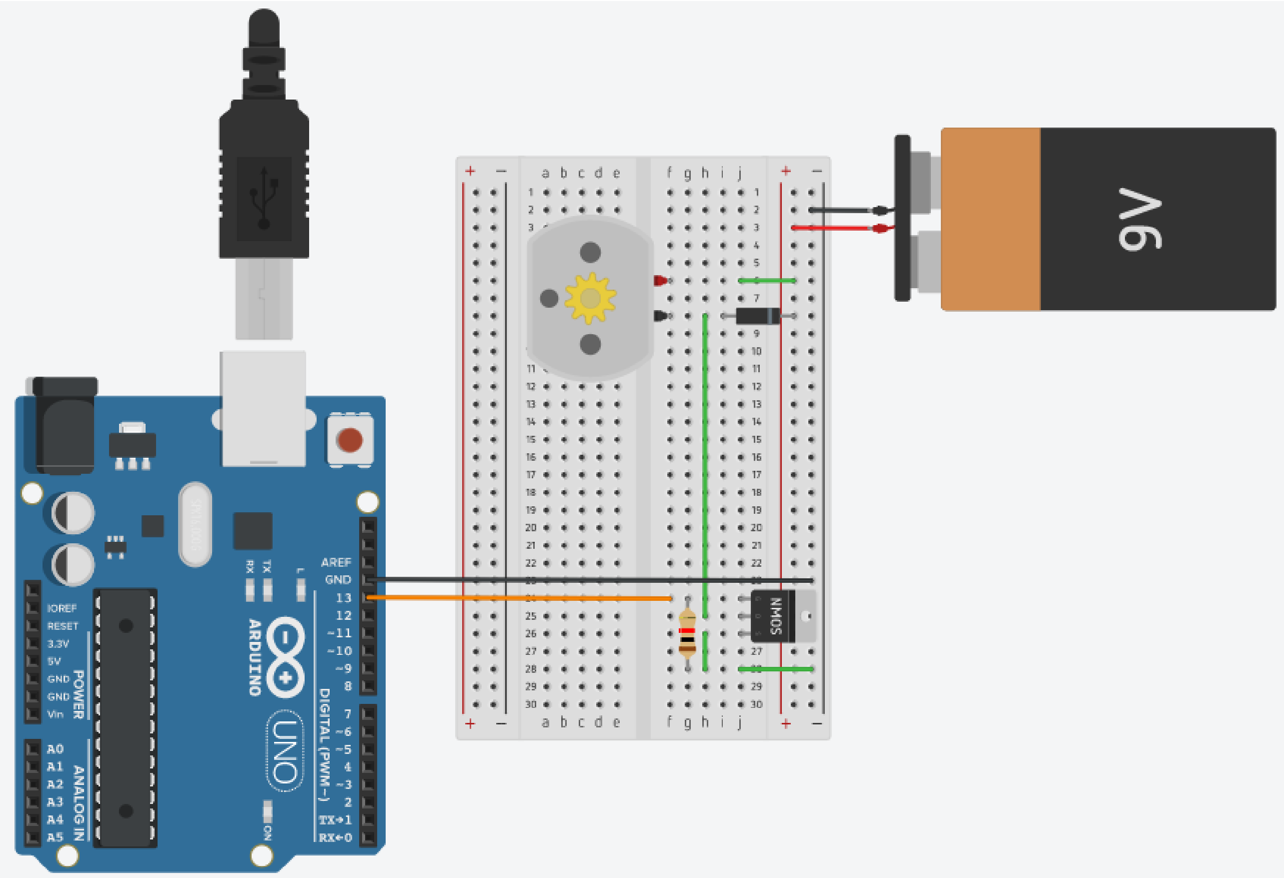
26. Find **a resistor** in the components menu. Place it on the breadboard so that one end connects to **g24** and the other end connects to **g28**. It doesn't matter which way around a resistor goes (unlike a diode) and you can leave it at the default value **(1kΩ).**

27. Find a **diode** in the components menu. Rotate it and place it on the breadboard so that the end with the **grey band (cathode)** is connected to the **positive rail** and the other end is connected to **hole i8.**

The resistor ensures the voltage at the transistor's gate is pulled down to 0V when we are not trying to switch it on. Otherwise there is a chance that small voltages are induced which allow the motor to move when it shouldn't.

The diode across the DC motor is designed to protect the circuit from any negative voltages (often called "back EMF") generated by the load (motor) in the brief period of time after *power is cut to it but before it slows to a stop. It is often referred to as a "flyback" or "flywheel" diode. While this may not be as important in a simulation as a real circuit, it is good practise to recognise the problem and the solution.*

Your circuit should now look similar to the picture below. Some wire colours have been changed from the default green colour to help illustrate their different purposes.



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28. Start the simulation.

You will see the USB lead plug into the Arduino to power it up then the motor will spin for a second. It will turn off for a second before being switched on again for a second. This cycle will continue until the simulation is stopped.

Note: if you notice that the simulation timing is not accurate then it is possible your web browser or its settings are not ideal. Tinkercad® simulations appear to run best when opened in Google Chrome browser.

What speed does the motor run at when it is on?

You may wonder why the need to run the motor from an external power supply (the battery) and not directly drive it from the Arduino without needing the transistor and associated circuit. With the help of the simulator, we can try connecting the motor directly to the Arduino's output for comparison.

29. Drag the DC motor off and away from the breadboard and place it next to the Arduino.

30. Delete the wires that connect to pin 13 and GND of the Arduino.

31. Connect new wires directly from the Arduino to the DC motor. Connect pin 13 to the red terminal and GND to the black terminal. It doesn't matter if they cross over or run above other components.

32. Start the simulation.

What speed does the motor now run at when it is on?

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You can see that the lower voltage won't let the motor run with correct speed and power. In addition to this, the current that devices like this DC motor would draw from the Arduino is above the recommended maximum rating. At the very least this will cause the Arduino to function incorrectly but in the worst case it may become damaged.

This activity has demonstrated one example of using a transistor as a switch, so that a small signal may allow a higher powered device to switch on and off. Aside from this advantage, transistor switching is often preferable to using a physical switch that can't be operated remotely. Removing the need for moving parts in switching can also increase reliability, can save physical space and allows switching signals on and off to create very high speed pulses. These properties are just some of the reasons transistors are a necessary part of most electronics.