MOSFET AS A SWITCH AND BASICS OF PNEUMATIC SOLENOIDS.

SET-4

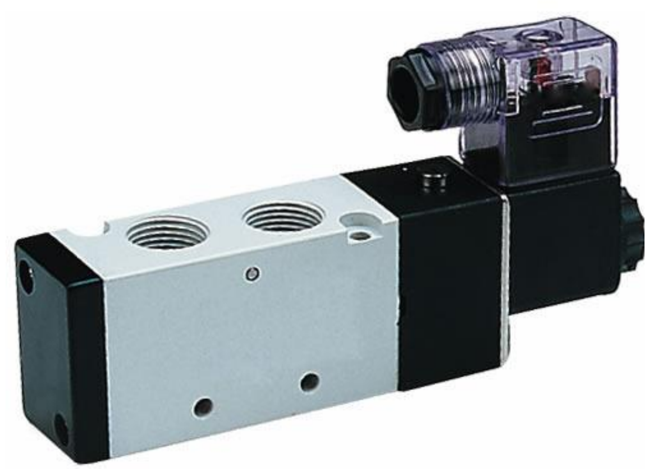

Figure 1. A Pneumatic Solenoid

By

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MOSFET as a Switch

MOSFETs exhibit three regions of operation viz., Cut-off, Linear or Ohmic and Saturation. Among these, when MOSFETs are to be used as amplifiers, they are required to be operated in their ohmic region wherein the current through the device increases with an increase in the applied voltage. On the other hand, when the MOSFETs are required to function as switches, they should be biased in such a way that they alter between cut-off and saturation states. This is because, in cut-off region, there is no current flow through the device while in saturation region there will be a constant amount of current flowing through the device, just mimicking the behaviour of an open and closed switch, respectively. This functionality of MOSFETs is exploited in many electronic circuits as they offer higher switching rates when compared to BJTs (bipolar junction transistors).

Figure 1 shows a simple circuit which uses an n-channel enhancement **MOSFET as a switch**. Here the drain terminal (D) of the **MOSFET** is connected to the supply voltage V_S via the drain resistor R_D while its source terminal (S) is grounded. Further, it has an input voltage V_i applied at its gate terminal (G) while the output V_o is drawn from its drain.

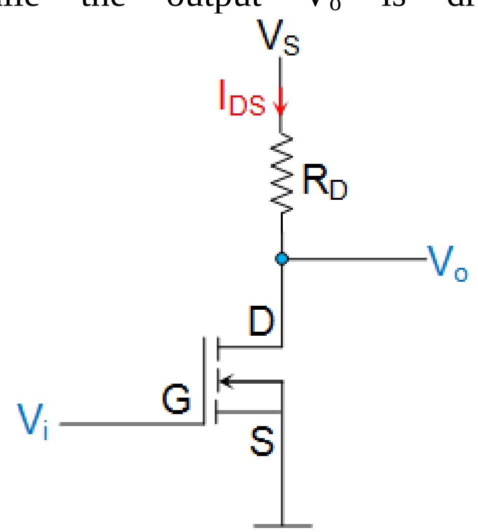

Figure 2. n-Channel Enhancement type MOSFET functioning as a switch

Now consider the case where V_i applied is 0V, which means the gate terminal of the MOSFET is left unbiased. As a result, the MOSFET will be OFF and operates in its cutoff region wherein it offers a high impedance path to the flow of current which makes the I_{DS} almost equivalent to zero. As a result, even the voltage drop across R_D will become zero due to which the output voltage V_o will become almost equal to V_S. Next, consider the case where the input voltage V_i applied is greater than the threshold voltage V_T of the device. Under this condition, the MOSFET will start to conduct and if the V_S provided is greater than the pinch-off voltage V_P of the device (usually it will be so), then the MOSFET starts to operate in its saturation region. This further means that the device will offer low resistance path for the flow of constant I_{DS}, almost acting like a short circuit. As a result, the output voltage will be pulled towards low voltage level, which will be ideally zero.

From the discussion presented, it is evident that the output voltage alters between V_S and zero depending on whether the input provided is less than or greater than V_T, respectively. Thus, it can be concluded that MOSFETs can be made to function as electronic switches when made to operate between cut-off and saturation operating regions. Similar to the case of n-channel enhancement type MOSFET, even n-channel depletion type MOSFETs can be used to perform switching action as shown by Figure 2. The behaviour of such a circuit is seen to be almost identical to that explained above except the fact that for cut-off, the gate voltage V_G needs to be made negative and should be lesser than $-V_T$.

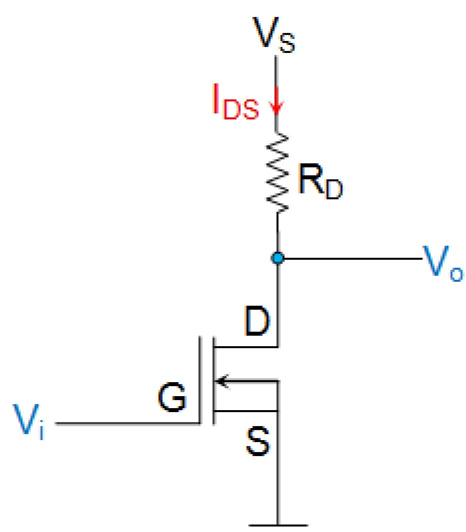

Figure 3. n-Channel Depletion type MOSFET functioning as a switch

Next, Figure 3 shows the case wherein the p-channel enhancement **MOSFET is used as a switch**. Here it is seen that the supply voltage V_S is applied at its source terminal (S) and the gate terminal is provided with the input voltage V_i

while the drain terminal is grounded via the resistor R_D. Further the output of the circuit V_o is obtained across R_D, from the drain terminal of the MOSFET. In the case of p-type devices the conduction current will be due to holes and will thus flow from source to drain I_{SD}, and not from drain to source (I_{DS}) as in the case of n-type devices. Now, let us assume that the input voltage which is nothing but the gate voltage V_G of the MOSFET goes low. This causes the MOSFET to switch ON and to offer a low (almost negligible) resistance path to the current flow. As a result heavy current flows through the device which results in a large voltage drop across the resistor R_D. This inturn results in the output which is almost equal to the supply voltage V_S.

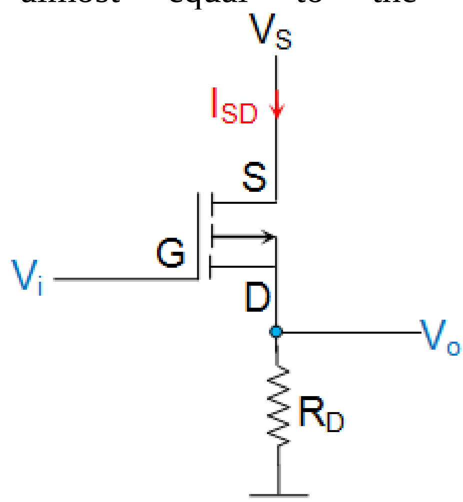

Figure 4. p-Channel Enhancement type MOSFET functioning as a switch

Next, consider the case where V_i goes high i.e. when Vi will be greater than the threshold voltage of the device (V_T will be negative for these devices). Under this condition, the **MOSFET** will be OFF and offers a high impedance path for the current flow. This results in almost zero current leading to almost zero voltage at the output terminal.

Similar to this, even p-channel depletion-type **MOSFETs** can be used to perform switching action as shown by Figure 4. The working of this circuit is almost similar to the one explained above except for the fact that here the cut-off region is experienced only if $V_i = V_G$ is made positive such that it exceeds the threshold voltage of the device.

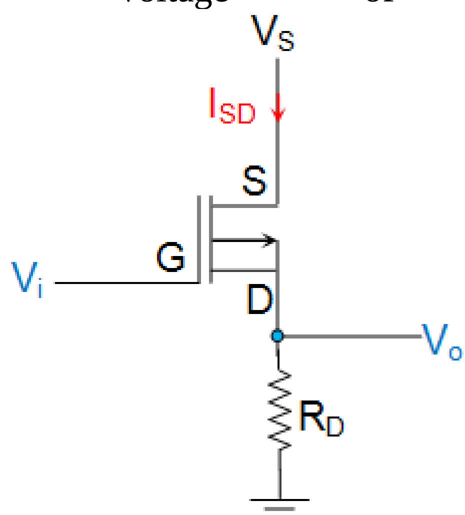

Figure 5. p-Channel Depletion type MOSFET functioning as a switch

The table presented below summarizes the discussion presented above.

MOSFET type	State of the device	
	ON	OFF
***n*-Channel Enhancement-type**	$V_i > V_T$	$V_i < V_T$
***n*-Channel Depletion-type**	$V_i > -V_T$	$V_i < -V_T$
***p*-Channel Enhancement-type**	$V_i < -V_T$	$V_i > -V_T$
***p*-Channel Depletion-type**	$V_i < V_T$	$V_i > V_T$

Parts of the Solenoid Valve and their Working

Here are the various parts of the solenoid valve and their working.

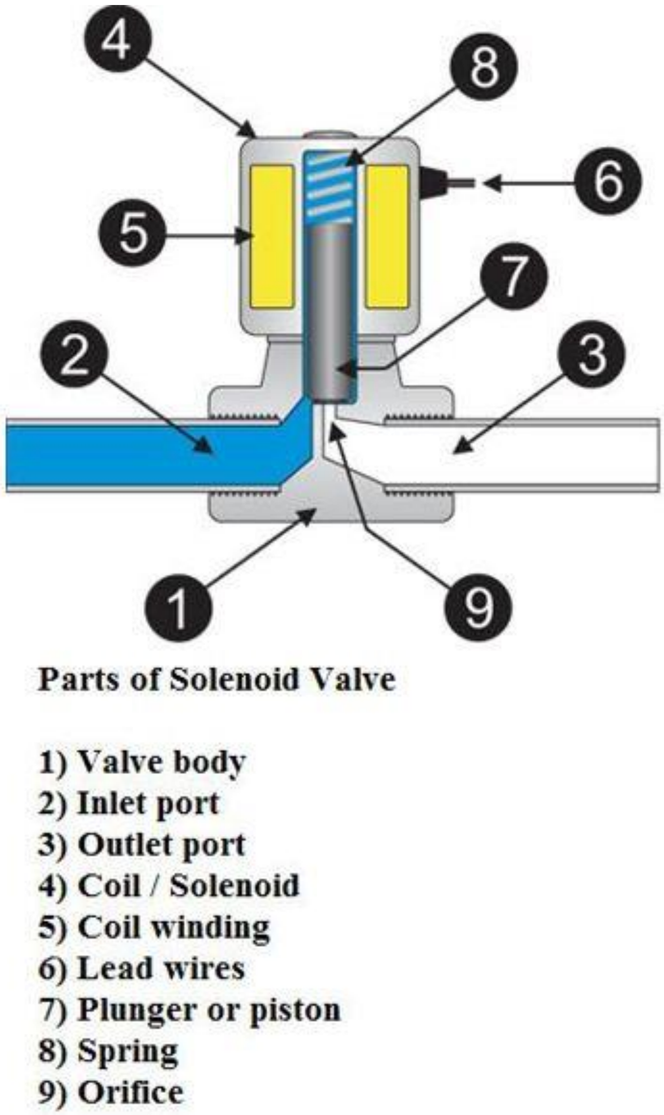

Figure 6. Solenoid Valve Parts

1) Valve body: This is the body of the valve to which the solenoid valve is connected. The valve is usually connected in the process flow pipeline to control the flow of certain fluid like liquid or air. Ordinarily the flow from the valve is controlled by the handle, but in case of the automatic valve the solenoid valve is connected to the valve.

2) Inlet port of the valve: This is the port through which the fluid enters inside the automatic valve and from here it can enter into the final process.

3) Outlet port: The fluid that is allowed to pass through the automatic valve leaves the valve through the outlet port. The solenoid valve controls the flow of the fluid from inlet port to the outlet port. The outlet port is eventually connected to the process where the fluid is required.

4) Coil/ Solenoid: This is body of the solenoid coil. The body of the solenoid coil is cylindrical in shape, and it is hollow from inside. The body is covered with steel covering and it has metallic finish. Inside the solenoid valve there is solenoid coil.

5) Coil windings: The solenoid consists of several turns of the enameled wire wound around the ferromagnetic material like steel or iron. The coil forms the shape of the hollow cylinder. Externally this coil is covered with the steel covering and inside the hollow part there is a plunger or the piston, whose motion inside the hollow space is controlled by the spring.

6) Lead wires: These are external connections of the solenoid valve that are connected to the electrical supply. The current is supplied to the solenoid valve from these wires. When the solenoid valve is energized, the current flows through these wires to the solenoid valve and when the solenoid valve is de-energized the flow of current stops.

7) Plunger or piston: This is the solid round metallic part cylindrical in shape and placed in the hollow portion the solenoid valve. When the electrical current is passed through the solenoid valve, the magnetic field is generated inside the hollow space. Due to this the plunger tends to move vertically in the hollow space. When the electrical current is stopped to the solenoid valve, the magnetic field is stopped and the plunger is remains the existing place due to the force of the spring.

8) Spring: The plunger moves inside the hollow space due to the action of the magnetic field against the action of the spring. The magnetic field generated inside the solenoid valve tends to move the plunger, but the spring tends to stop the motion of the plunger in which ever the position it is. This action of the spring against the magnetic field helps keeping the plunger in the position where the flow of current to the solenoid valve is stopped. The spring performs very crucial action inside the hollow space. For one, the plunger is in the vertical position, so the spring helps keeping it at the desired position instead of allowing the plunger to fall to the bottom due to gravity when the current to the solenoid valve is stopped. Secondly, the spring also prevents the movement of the plunger due to force of the fluid flowing through the valve body. If the spring was not there the plunger would have moved up when the fluid is present and moved down when the fluid is not there. Thus the spring actually forces the plunger to carry out the control of the fluid. It allows the movement of the plunger only to the extent when the electric current is flowing through the solenoid valve.

9) Orifice: The orifice is an important part of the valve though which the fluid is flowing. It is the connection between the inlet and the outlet port. The flow of fluid from the inlet port to the outlet port takes place from this port. In the ordinary valves, this port is covered with the valve disc at the bottom of the stem of the valve to which the handle is connected. Thus in ordinary valves, the opening of the orifice are controlled by the handle, but in case of the solenoid valves, the opening of the orifice is controlled by the plunger. The movement of the plunger is in turn controlled by the spring and the current flowing through the solenoid valve.

- If the current passing through the solenoid valve is constant, the position of the plunger and hence opening of the orifice remains constant. If the sensor senses that more flow of the fluid is required, it allows the increase in current passing through the solenoid valve, which creates more magnetic field and more upwards motion of the plunger. This leads to further opening of the orifice and more flow of the fluid from the inlet port to the outlet. If the required flow of fluid is less, the sensor allows passage of the lesser current to the solenoid valve. When the sensor senses that the fluid is no more required in the process, it stops the flow of the current to the solenoid valve completely. Due to this the solenoid valve gets de-energized and the plunger reaches the bottom most position and closes the orifice completely thus stopping the flow of fluid from the inlet port to the outlet port.

Working of the Solenoid Valve

- Initially the sensor senses the process towards the outlet side of the solenoid valve. When it senses that certain quantity of the flow of the fluid is required, it allows the current to pass through the solenoid valve. Due to this the valve gets energized and the magnetic field is generated which triggers the movement of the plunger against the action of the spring. Due to this the plunger moves in upwards direction, which allows the opening of the orifice. At this instant the flow of the fluid is allowed from the inlet port to the outlet port.

- If the current passing through the solenoid valve is constant, the position of the plunger and hence opening of the orifice remains constant. If the sensor senses that more flow of the fluid is required, it allows the increase in current passing through the solenoid valve, which creates more magnetic field and more upwards motion of the plunger. This leads to further opening of the orifice and more flow of the fluid from the inlet port to the outlet. If the required flow of fluid is less, the sensor allows passage of the lesser current to the solenoid valve.
- When the sensor senses that the fluid is no more required in the process, it stops the flow of the current to the solenoid valve completely. Due to this the solenoid valve gets de-energized and the plunger reaches the bottom most position and closes the orifice completely thus stopping the flow of fluid from the inlet port to the outlet port.
- In this way the solenoid coil operates the valve as if it is being operated by the human being. When the flow of certain quantity of fluid is required it opens the valve to required extent and when the flow is not required it shuts the valve entirely.
- The whole working animation of this solenoid valve is shown at LABAUTOPEDIA. Another type of solenoid valve used to control the flow of the process is shown in the figure below. Yet another figure shows how the flow of fluid is allowed when the solenoid valve is energized and stopped when the solenoid valve is de-energized.

Solenoid valves operational principle

A-Input side
B-Diaphragm
C-Pressure chamber
D-Pressure relief conduit
E-Solenoid
F-Output side

Solenoid valve Working principle

- A solenoid valve has two main parts: the solenoid and the valve. The s olenoid converts electrical energy into mechanical energy which, in tu rn, opens or closes the valve mechanically. A Direct Acting valve has only a small flow circuit, shown within section E of this diagram (this section is mentioned below as a pilot valve). This Diaphragm Piloted V alve multiplies this small flow by using it to control the flow through a much larger orifice.

- Solenoid valve may use metal seals or rubber seals, and may also have electrical interfaces to allow for easy control. A spring may be used to hold the valve opened or closed while the valve is not activated.
- The diagram to the right shows the design of a basic valve. If we look at the top figure we can see the valve in its closed state. The water und er pressure enters at A. B is an elastic diaphragm and above it is a wea k spring pushing it down. The function of this spring is irrelevant for n ow as the valve would stay closed even without it. The diaphragm has a pinhole through its center which allows a very small amount of wate r to flow through it. This water fills the cavity C on the other side of th e diaphragm so that pressure is equal on both sides of the diaphragm. While the pressure is the same on both sides of the diaphragm, the forc e is greater on the upper side which forces the valve shut against the in coming pressure. By looking at the figure we can see the surface being acted upon is greater on the upper side which results in greater force. O n the upper side the pressure is acting on the entire surface of the diaph ragm while on the lower side it is only acting on the incoming pipe. Th is results in the valve being securely shut to any flow and, the greater t he input pressure, the greater the shutting force will be.
- Now let us turn our attention to the small conduit D. Until now it was blocked by a pin which is the armature of the solenoid E and which is pushed down by a spring. If we now activate the solenoid drawing the pin upwards via magnetic force from the solenoid current, the water in chamber C will flow through this conduit D to the output side of the v alve. The pressure in chamber C will drop and the incoming pressure w ill lift the diaphragm thus opening the main valve. Water now flows di rectly from A to F.
- When the solenoid is again deactivated and the conduit D is closed aga in, the spring needs very little force to push the diaphragm down again and the main valve closes. In practice there is often no separate spring, the elastomer diaphragm is moulded so that it functions as its own spri ng, preferring to be in the closed shape.
- From this explanation it can be seen that this type of valve relies on a d ifferential of pressure between input and output as the pressure at the i

nput must always be greater than the pressure at the output for it to wo rk. Should the pressure at the output, for any reason, rise above that of the input then the valve would open regardless of the state of the solen oid and pilot valve.

- In some solenoid valves the solenoid acts directly on the main valve. O thers use a small, complete solenoid valve, known as a pilot, to actuate a larger valve. While the second type is actually a solenoid valve comb ined with a pneumatically actuated valve, they are sold and packaged a s a single unit referred to as a solenoid valve. Piloted valves require m uch less power to control, but they are noticeably slower. Piloted solen oids usually need full power at all times to open and stay open, where a direct acting solenoid may only need full power for a short period of time to open it, and only low power to hold it.

Controlling A Solenoid Valve With Arduino

In this tutorial we will be controlling a solenoid with an Arduino and a transistor. The solenoid we have picked for this tutorial is our Plastic Water Solenoid Valve (perfect for controlling flow to a drip irrigation system) but this tutorial can be applied to most inductive loads including relays, solenoids, and basic DC motors.

A Few Considerations:
Before choosing this solenoid valve for a project there are a few things that should be considered:

• Water can only flow in one direction through this valve.
• There is a 3 PSI minimum pressure requirement on the inlet otherwise the valve will not shut off.
• This solenoid valve is not rated for food safety or use with anything but water.

How It Works:
This valve is very similar to those found in a lawn irrigation system – the only real difference being the size. The inlet water pressure actually holds the valve closed so if you do not have any inlet water pressure (3psi minimum) the valve will never close!

The Parts Needed:

This tutorial will be requiring a few common parts:

- 1 x Solenoid Valve
- 1 x Arduino Uno or compatible microcontroller
- 1 x Solderless Breadboard
- 1 x TIP120 Darlington Transistor
- 1 x 1K Ohm Resistor
- 1 x 1N4001 Diode
- Hookup Wires – We recommend Premium Male/Male Jumper Wire

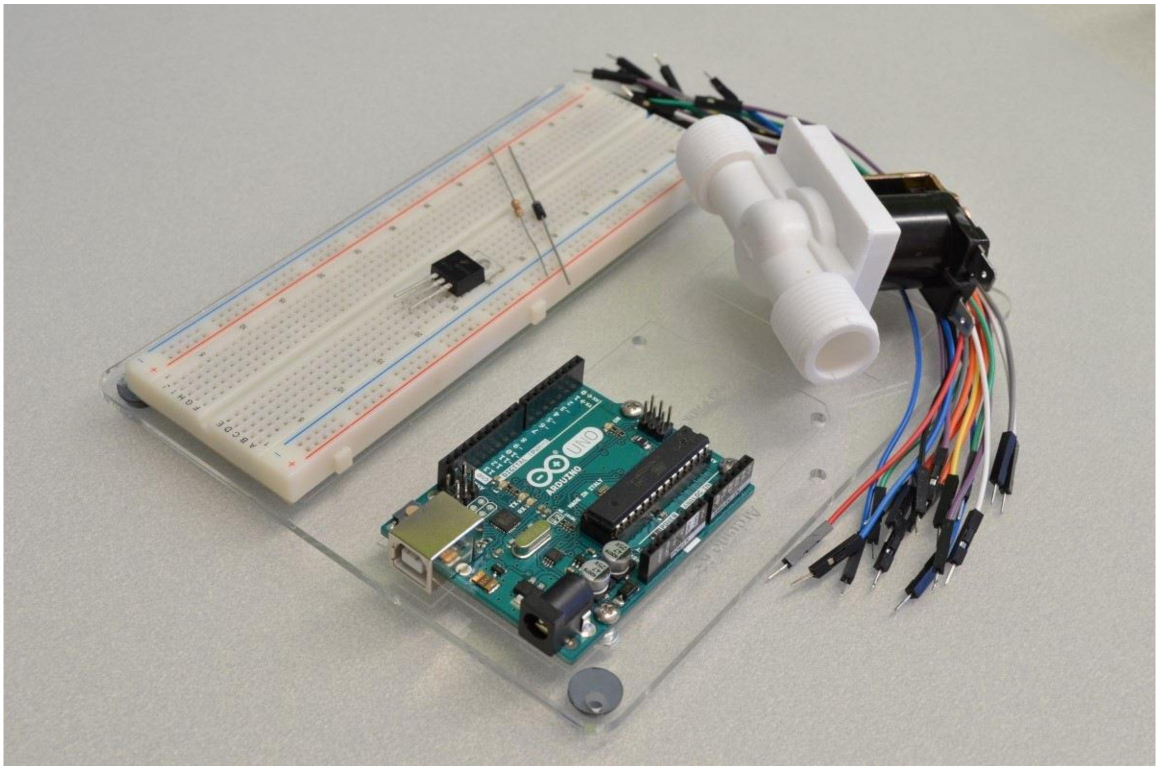

Figure 7. Components

The Schematic

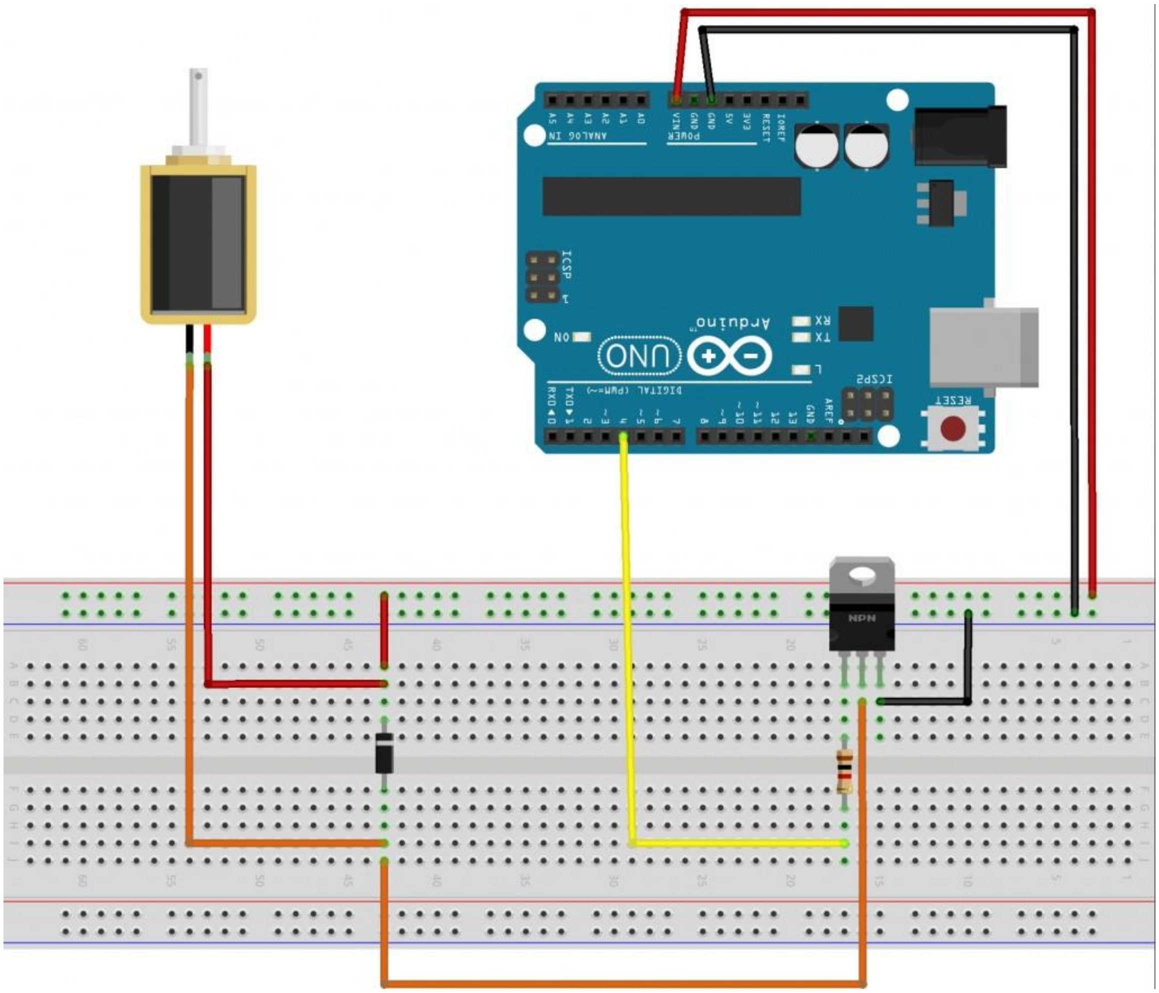

Figure 8. Schematic

Step 1 – Powering The Breadboard

Let's go ahead and set up the Arduino Uno and the breadboard right next to one another. The solenoid works with anywhere between 6-12V which is too high to use with the standard Arduino 5V. To get around this problem we will be using a 9V power supply – the solenoid will operate at 9V while the Arduino's built in voltage regulator will turn that 9V into the 5V that it needs to operate. To gain access to the raw voltage going into the DC barrel jack on the Arduino Uno we will use the "Vin" pin located next to the ground pin on the Arduino.

Start by connecting one of the jumper wires to the "Vin" pin on the Arduino and running it over to the positive rail on the side of the solderless breadboard. Next, run a wire from the Ground pin on the Arduino over to the negative rail on the solderless breadboard.

We now have 9VDC power on the breadboard! With the exception of the "Vin" pin, 9V is more than enough to damage your Arduino so do not plug ANY other pins from the Arduino into the positive rail on the breadboard.

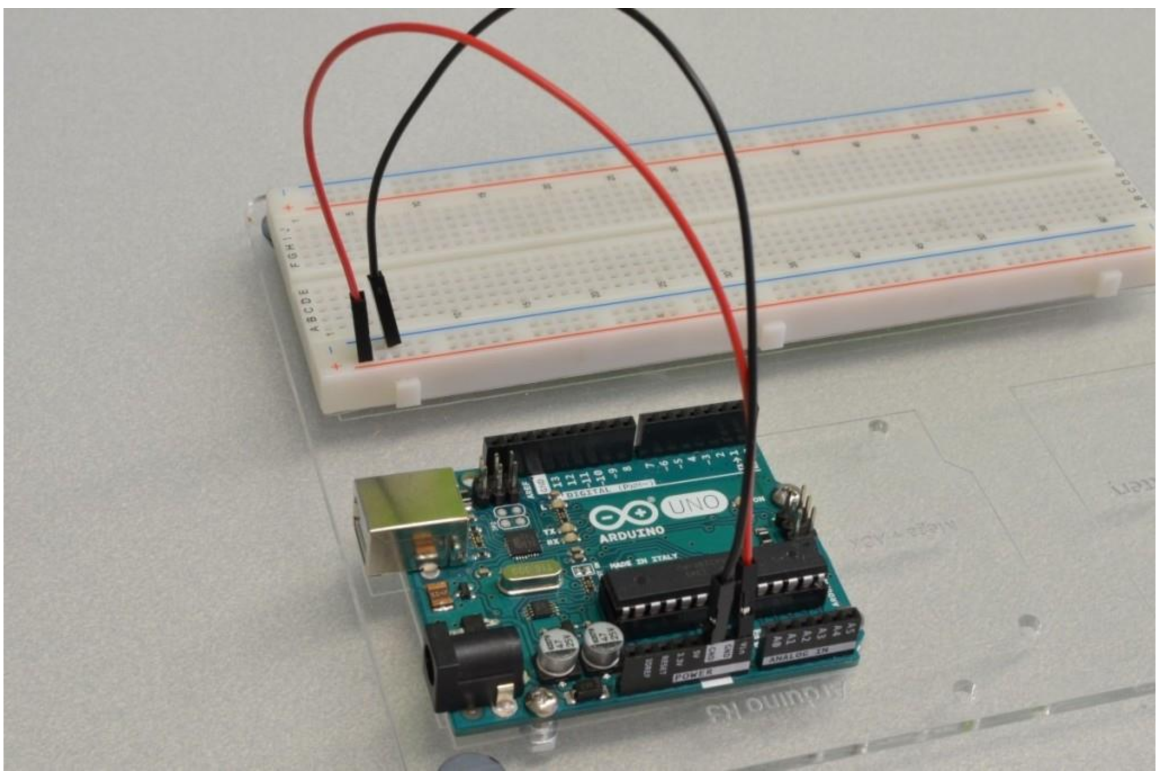

Figure 9. powering the Arduino

Step 2 – The Solenoid's Wire Harness

This solenoid does not have a wire harness and instead relies on 0.250″ Quick Connects. These are the best way to connect the solenoid. If you do not have Quick Connects laying around, Alligator Clips or even soldering wires to the tabs will work!

The connections on the solenoid do not matter, the coil does not care which side is positive or negative.

Step 3 – Solenoid To Breadboard

Connect the solenoid to the breadboard – we will need to add a diode between the two contacts so we will leave some space for that.

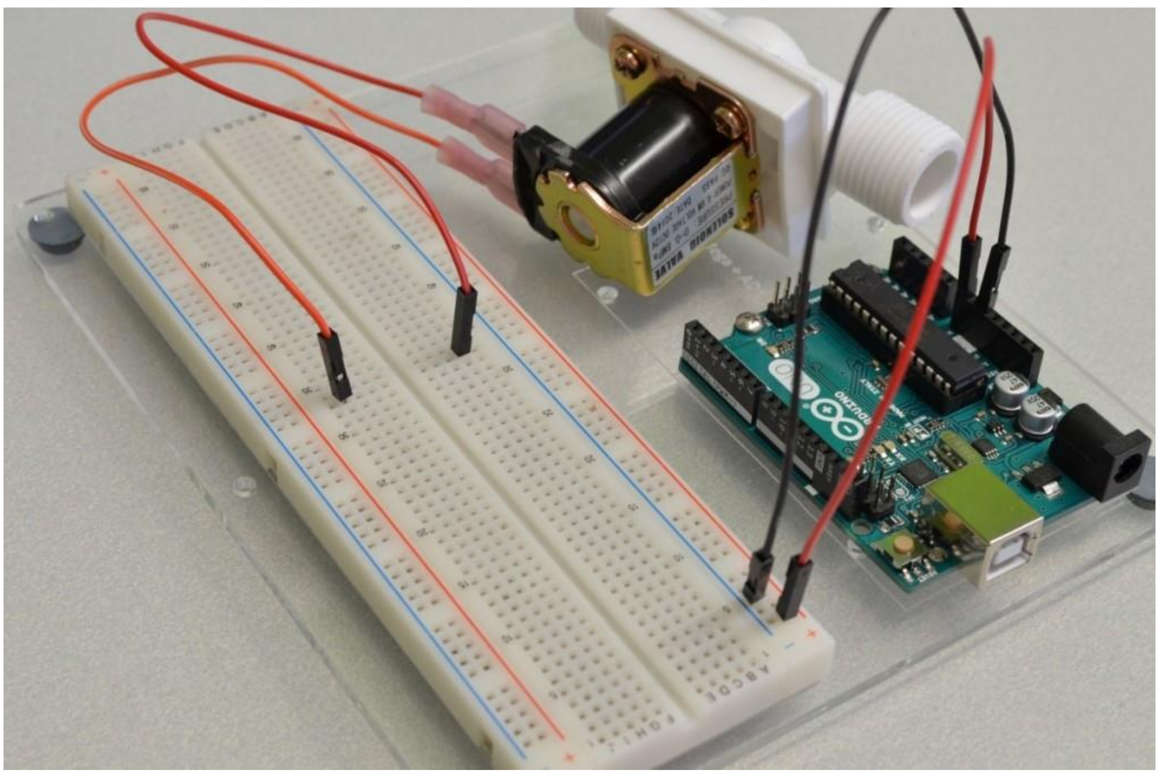

Figure 10. Connection from Solenoid to Breadaboard

Step 4 – Snubber Diode

Since a solenoid is an inductive load we need to include a snubber diode across the contacts. Snubber diodes help eliminate transient voltages caused when a magnetic coil (such as those found in a motor, relay, or solenoid) suddenly loses power. Without this diode in place the transient voltage spikes can damage other elements of the circuit.

The snubber is placed from the negative side of the coil to the positive side. Since diodes only allow current to flow in one direction we need to make sure we get this right, otherwise it will be a dead short between power and ground. Ensure the side with the White stripe is connected to power/positive side of the solenoid! In our circuit the Red wire is the positive 9V so we will connect it to this side.

Step 5 – Power To The Solenoid

Now that we are sure the diode is facing the correct direction the solenoid can be attached to the 9V Power on the breadboard. The solenoid gets constant power because we will using low side switching to turn on and off this solenoid. Low side switching means we will be interrupting the circuit between the negative side of the solenoid and the ground rather than between the power and the solenoid. This seems a little counter intuitive, but we do this because switching the high side is a lot more difficult with a transistor when the voltage being switched is higher than the Arduino’s 5V logic. Don’t worry, in later tutorials we will go into high side switching!

Step 6 – The Transistor

The current draw of this solenoid is higher than a standard transistor can handle so we will be using a TIP120 Darlington Transistor. A Darlington transistor is actually a pair of transistors that act as a single transistor with a high current gain. The pin output is still the same as a standard transistor so (for now) just think of this as a transistor with a higher current rating.

We will start by placing this transistor in the breadboard

Step 7 – Base Resistor

A base resistor is exactly what it sounds like – it is a resistor placed on the base pin of the transistor. This resistor limits the current going to the base (control line) of the transistor; no resistor would result in no current limit, and could result in a transistor blowing up! We will be using a 1K ohm resistor in this case; it can be placed from the base of the transistor as shown.

Step 8 – Connecting To The Arduino

Now that the current limiting resistor is in place we can go ahead and connect this up to one of the Arduino digital pins. Take a wire and run it from Arduino pin 4 to the current limiting resistor we just placed in the last step.

Step 9 – Connect The Solenoid

Next we are going to connect the solenoid's negative terminal to the collector on the transistor. The collector is one side of the "switch" in a transistor, this is connected to the emitter (other side of the "switch") when the base pin is has a voltage applied. An easy way to remember what goes where on a transistor is:

"The Collector collects whatever the Emitter will emit when the Base commands it to"

So in this case we are going to "collect" the negative from the solenoid and "emit" it to the ground of the circuit. So let's run a wire from the solenoid negative to the middle pin (collector) of the transistor.

Step 10 – Connecting To Ground

Now we will connect the transistor's emitter to the ground rail on the breadboard. The circuit is complete!

Step 11 – Double Check And Plug It In!

Before we give the Arduino power it is always a good idea to go over all of the connections to make sure there are no wires in the wrong spot – sometimes that can make for a very expensive mistake!

One way to avoid this problem is good wire color discipline. In other words, decide on a purpose for each color of wire and stick to them! In this example all 9V power are red wires, all grounds are black wires, orange is the negative output of the solenoid, and yellow is the signal wire. This way, if you ever see a red wire going to a black wire you will know right away that something isn't quite right!

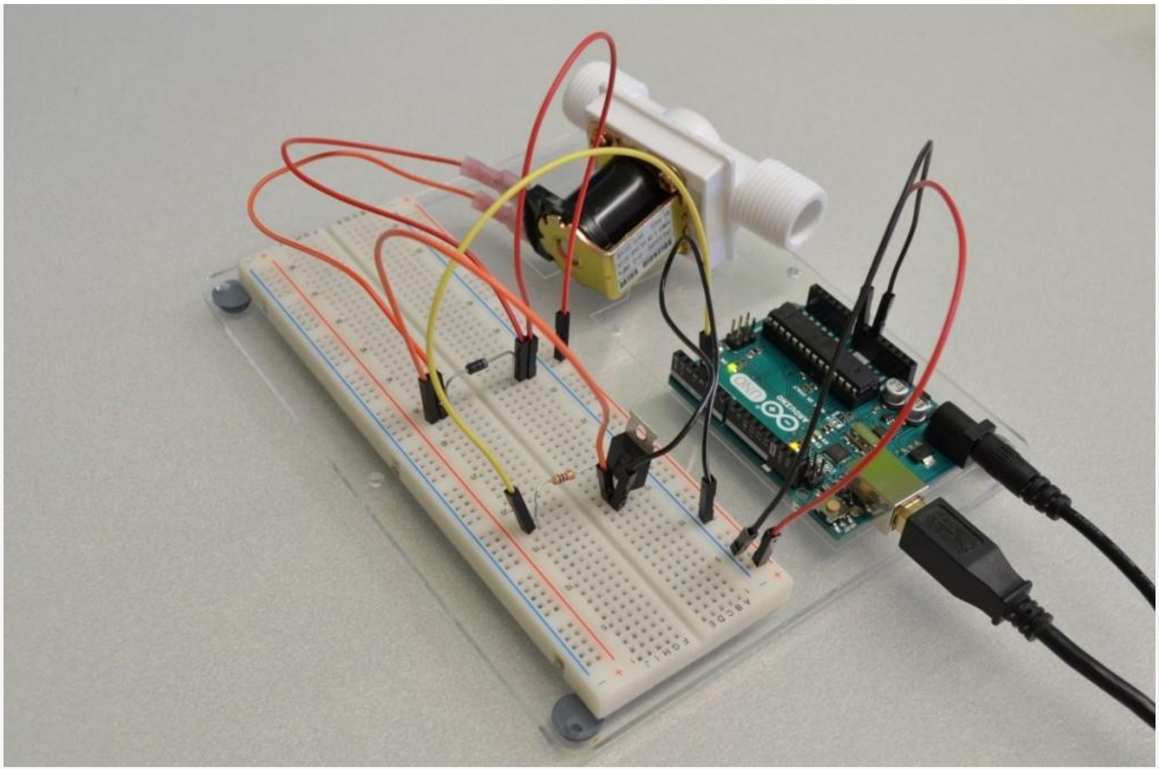

Figure 11. Final Connections

Step 12 – Writing The Code

We are starting with the BareMinimum Sketch found in the IDE, it should look something like this:

```
void setup() {
  // put your setup code here, to run once:
}

void loop() {
  // put your main code here, to run repeatedly:
}
```

So first we will need a variable for the Arduino pin:

```
int solenoidPin = 4;    //This is the output pin on the Arduino we are using

void setup() {
```

```
  // put your setup code here, to run once:
}

void loop() {
  // put your main code here, to run repeatedly:
}
```

Next we need to set the Arduino pin to act as an output:

```
int solenoidPin = 4;    //This is the output pin on the Arduino we are using

void setup() {
  // put your setup code here, to run once:
  pinMode(solenoidPin, OUTPUT);           //Sets the pin as an output
}

void loop() {
  // put your main code here, to run repeatedly:
}
```

Now that it is set as an output we can tell it what to do:

```
int solenoidPin = 4;    //This is the output pin on the Arduino we are using

void setup() {
  // put your setup code here, to run once:
  pinMode(solenoidPin, OUTPUT);           //Sets the pin as an output
}

void loop() {
  // put your main code here, to run repeatedly:
  digitalWrite(solenoidPin, HIGH);    //Switch Solenoid ON
  delay(1000);                      //Wait 1 Second
  digitalWrite(solenoidPin, LOW);     //Switch Solenoid OFF
  delay(1000);                      //Wait 1 Second
}
```

So if we want the solenoid to allow water to flow, set the pin high. When you want the water to stop flowing, set the pin low. In this case it will turn the water on for 1 second and then off for 1 second, looping forever (or at least until it is unplugged!)