University of Nottingham

Electromechanical devices MM2EMD

Lecture 7 – Transistors - Switching high voltage things on with a low voltage

Dr. Roderick MacKenzie
roderick.mackenzie@nottingham.ac.uk
Summer 2015

@rcimackenzie

Outline of the lecture

- **No recap of last lecture :)**

- Transistor basics
  - Relays (Mechanical transistor)
  - NPN Bipolar Junction Transistors
  - PNP Bipolar Junction Transistors
  - MOSFETs

  - Push pull pairs to drive MOSFETs

- One last thing

- Summary

Outline of the lecture

- No recap of last lecture :)

- **Transistor basics**
  - Relays (Mechanical transistor)
  - NPN Bipolar Junction Transistors
  - PNP Bipolar Junction Transistors
  - MOSFETs

  - Push pull pairs to drive MOSFETs

- One last thing

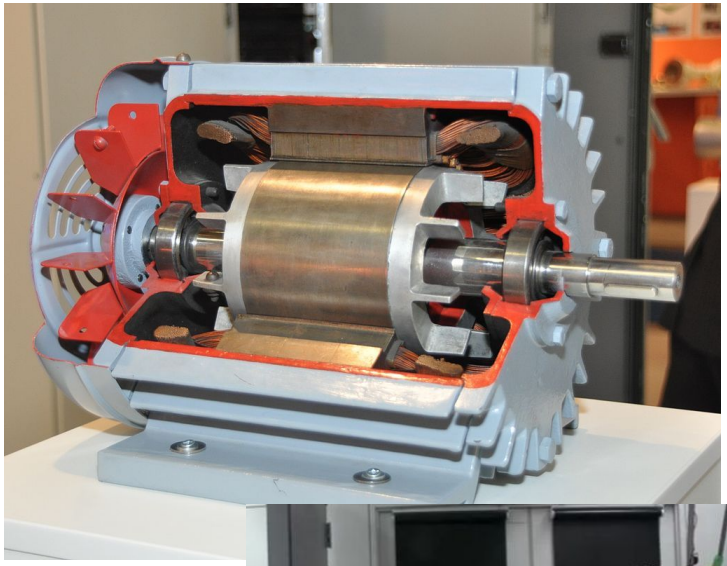
- Summary

Think back to lecture 1.

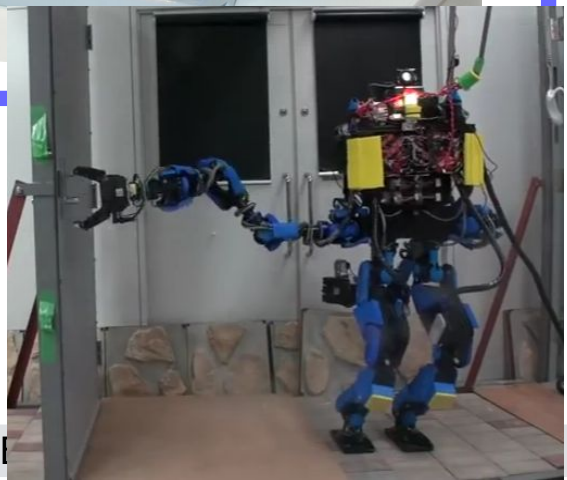
Smart Electronic Circuits (low voltage)

Dave Jones

Simple Electrical Circuits (high voltage)

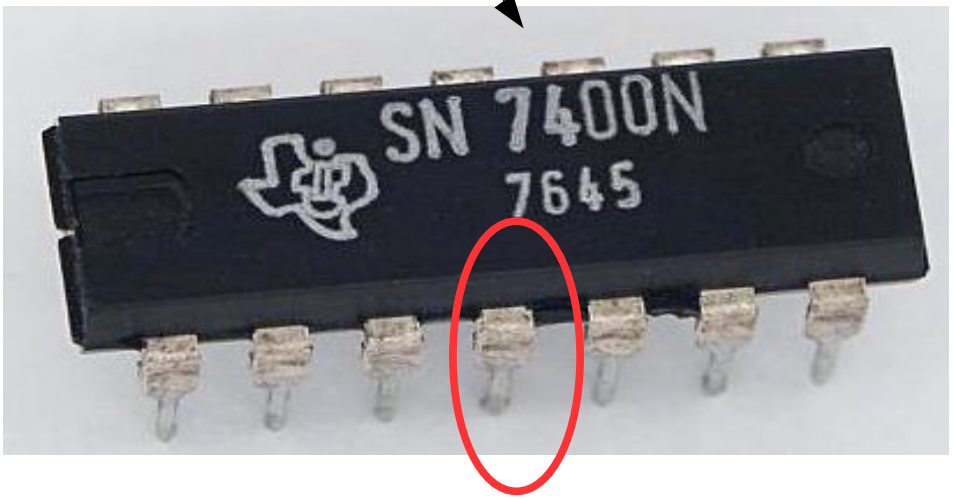


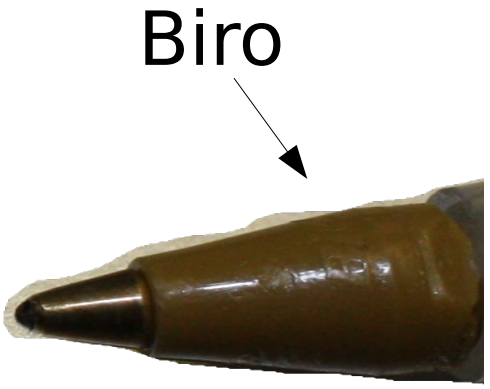
S.J. de Waard



- This lecture is making low voltage electronics control high voltage electrical devices such as motors.

Think about an AND gate chip

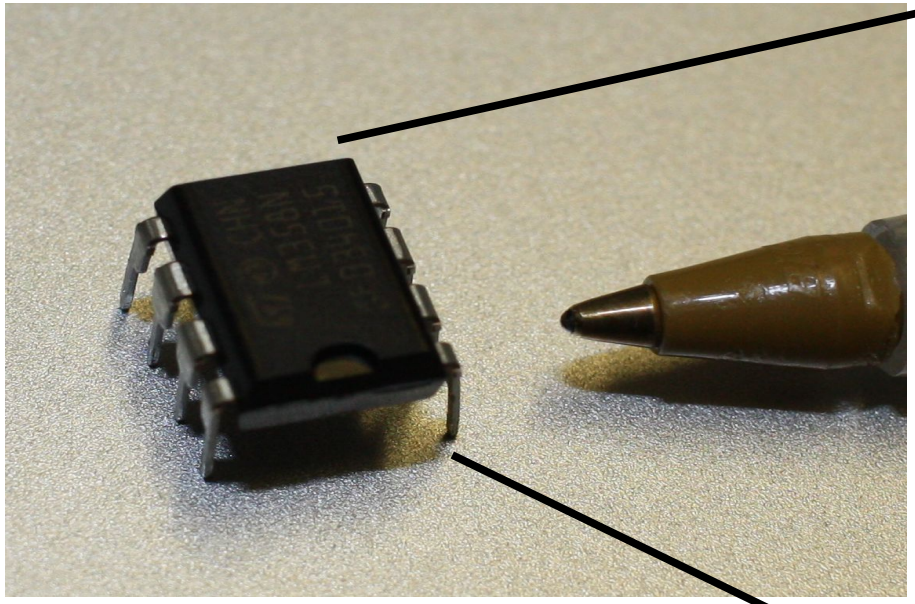


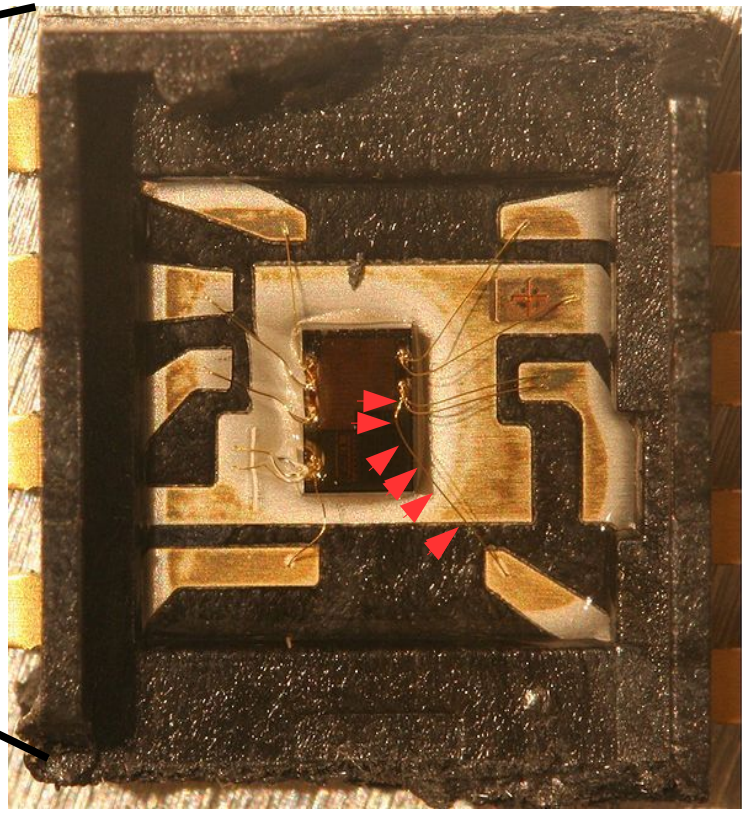


- Look at the tiny thin pins which are used to carry current in and out of the chip.

- These pins can supply **25 mA** @ **5V** at the most.

But why is this?





Gophi

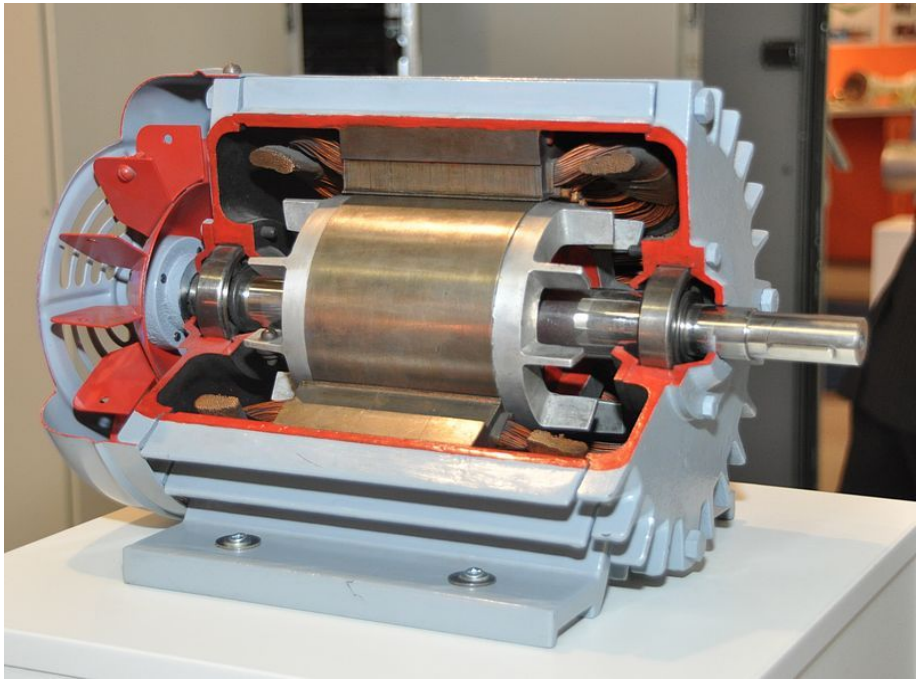
•If we take the top off the chip with acid.

- Look how much small the actual chip is and look at the tiny bond wires (**25 mA @ 5V max!!!**)

Now think about this motor.

- It needs **10 Amps** at **500 V** to run.

CMBJ

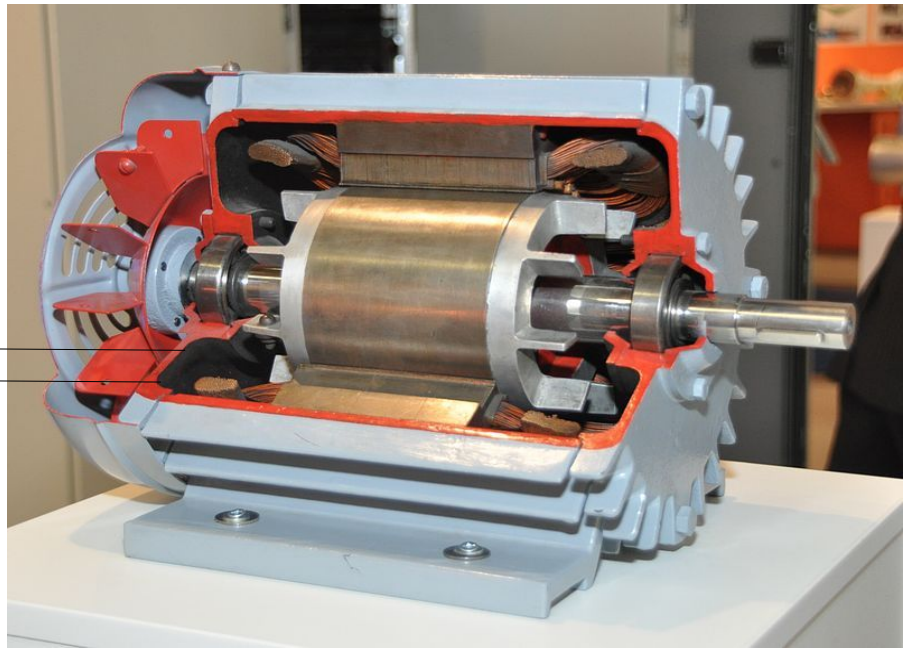


S.J. de Waard

- It will also need cable as thick as my finger to carry the current.

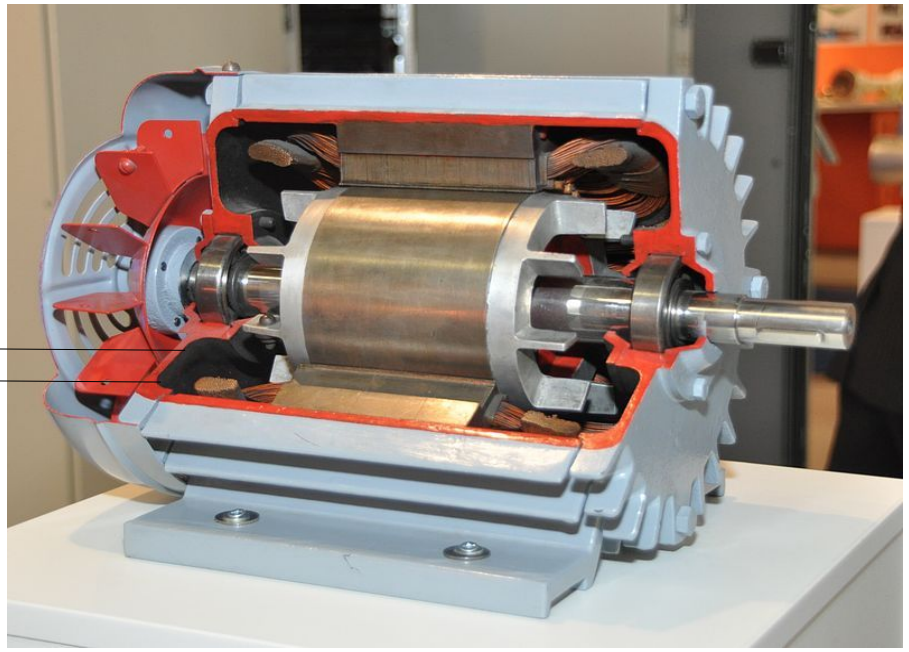
Using chips to run large voltage/current loads.

- Now imagine trying to run this motor which needs **500V @ 10 Amps** from this tiny chip chat can only deliver **5V @ 25 mA**.



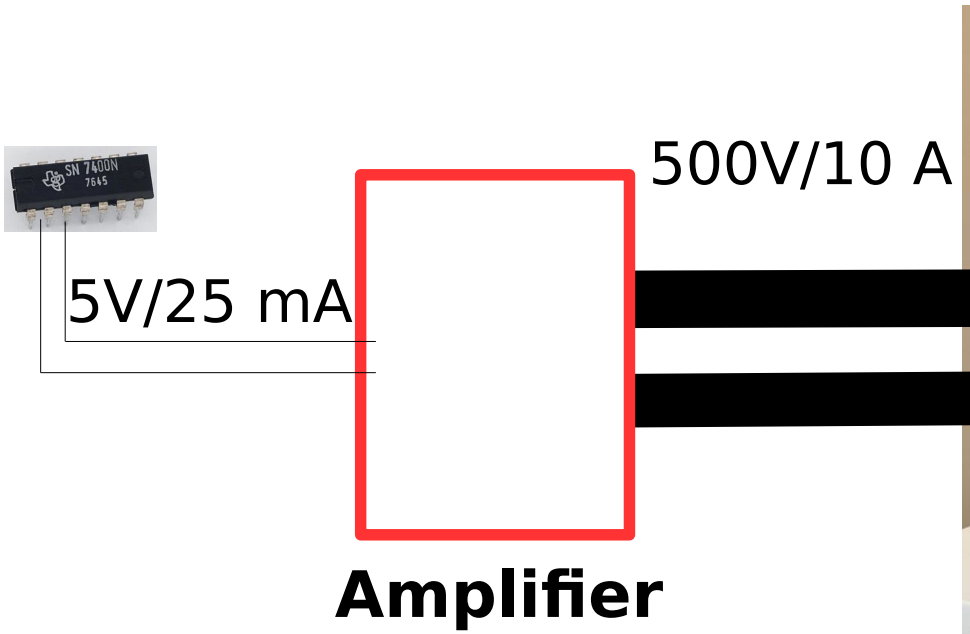
Using chips to run large voltage/current loads.

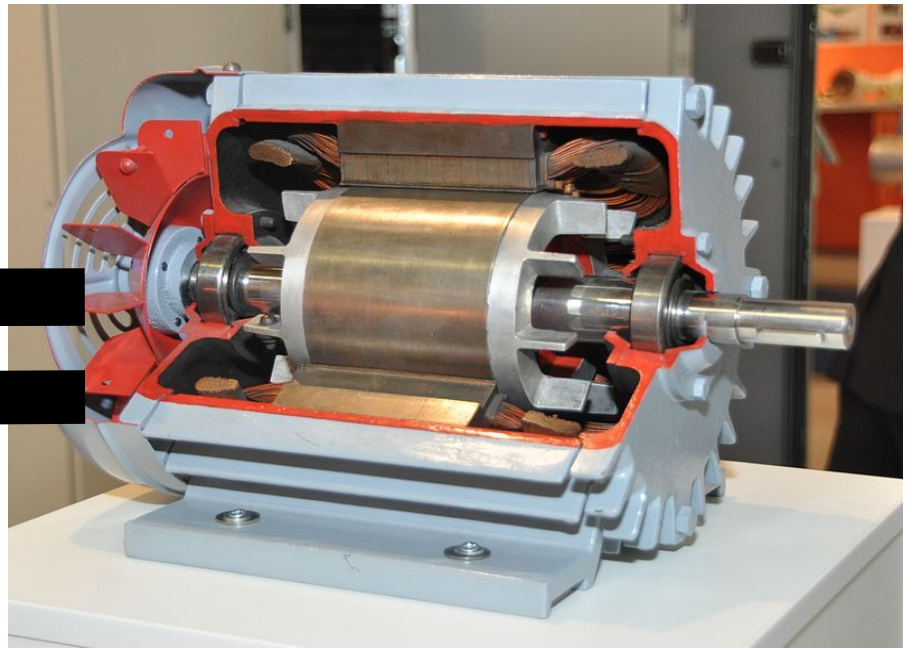
- It would not work – the chip would just get hot and melt because it can not deliver enough voltage/current.



Voltage/current amplifier

- So if we want to use our chip to run a motor, we need some type of voltage/current **amplifier component**.





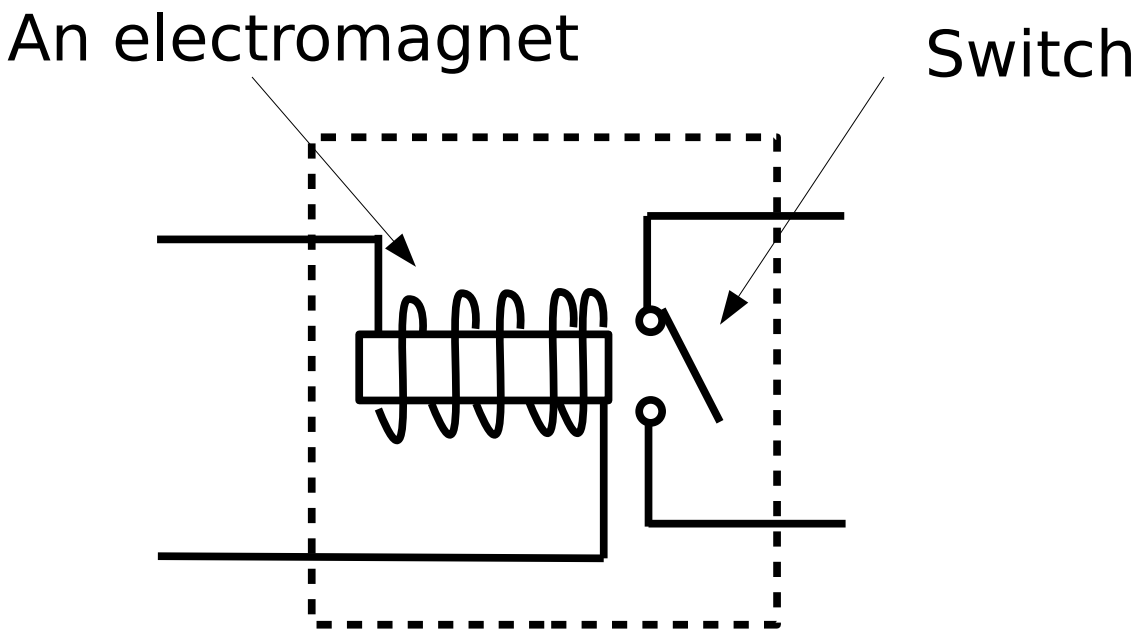
(Notice this is different from a transformer)

Outline of the lecture

- No recap of last lecture :)
- Transistor basics
  - **Relays (Mechanical transistor)**
  - NPN Bipolar Junction Transistors
  - PNP Bipolar Junction Transistors
  - MOSFETs
- Push pull pairs to drive MOSFETs
- One last thing
- Summary

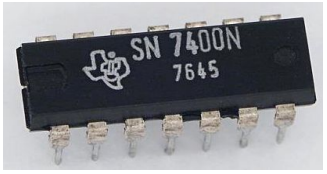
One such component is the ***relay***

- A relay is a an ***electromechanical switch***



- And this is how it works.....

Relay example



5 V/25 mA

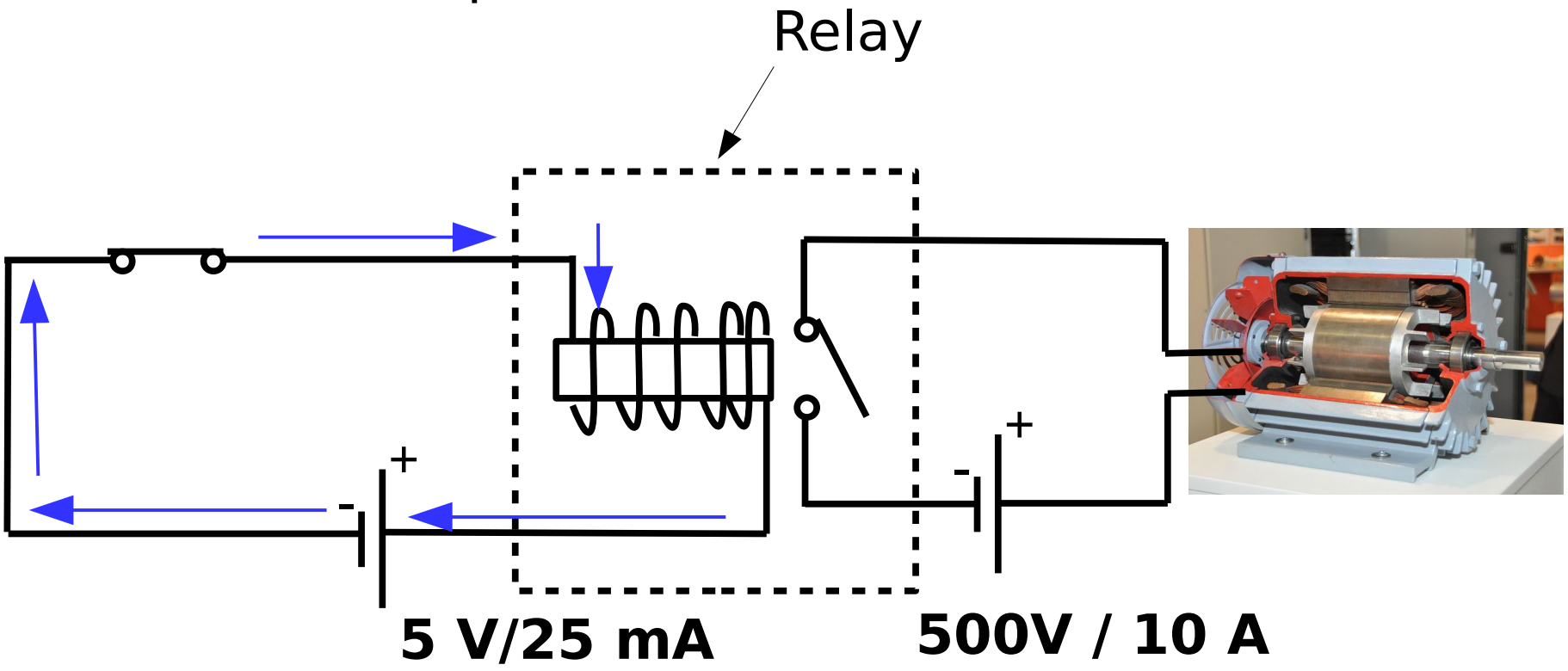
- Low voltage side

500V / 10 A

- High voltage side

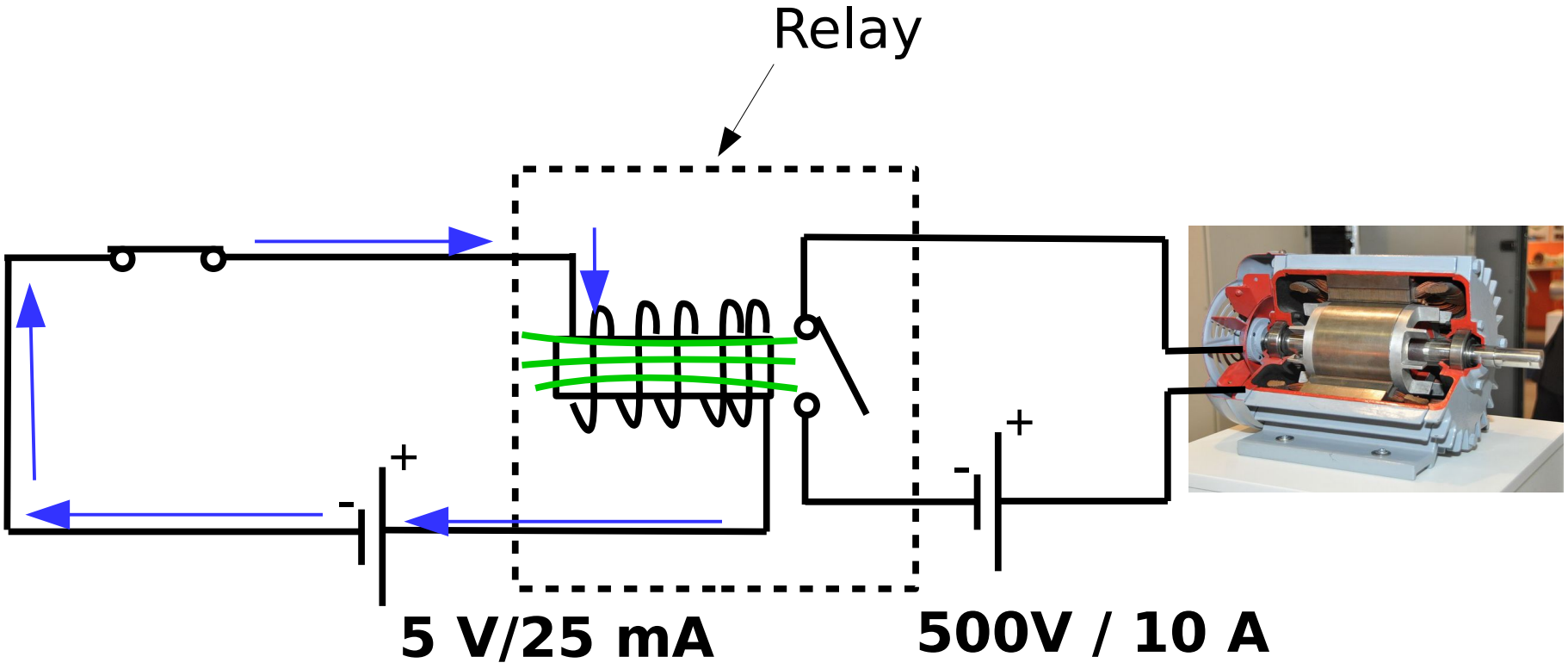
Relay example

•When the **5 V** supply is turned on current flows in the low voltage side of the relay. This current *could* come from a chip.



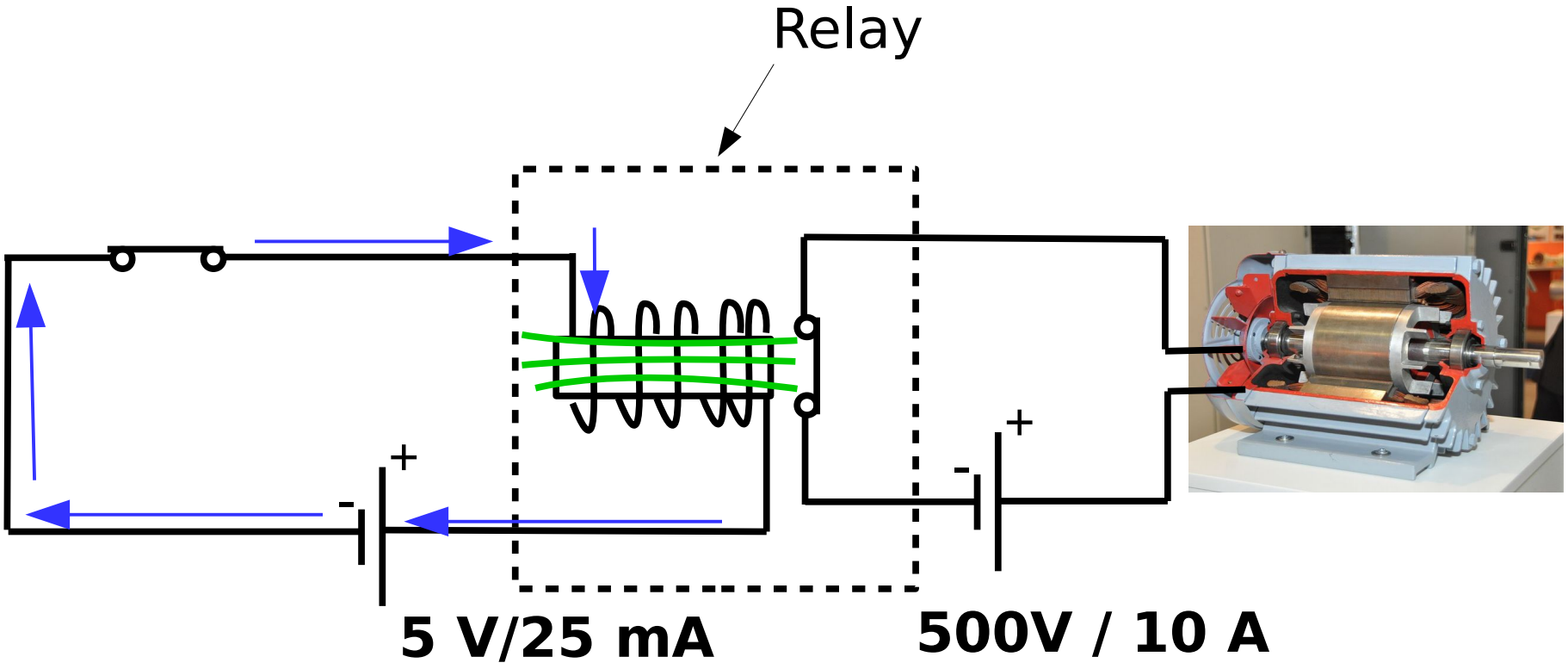
Relay example

- The electromagnet becomes energized



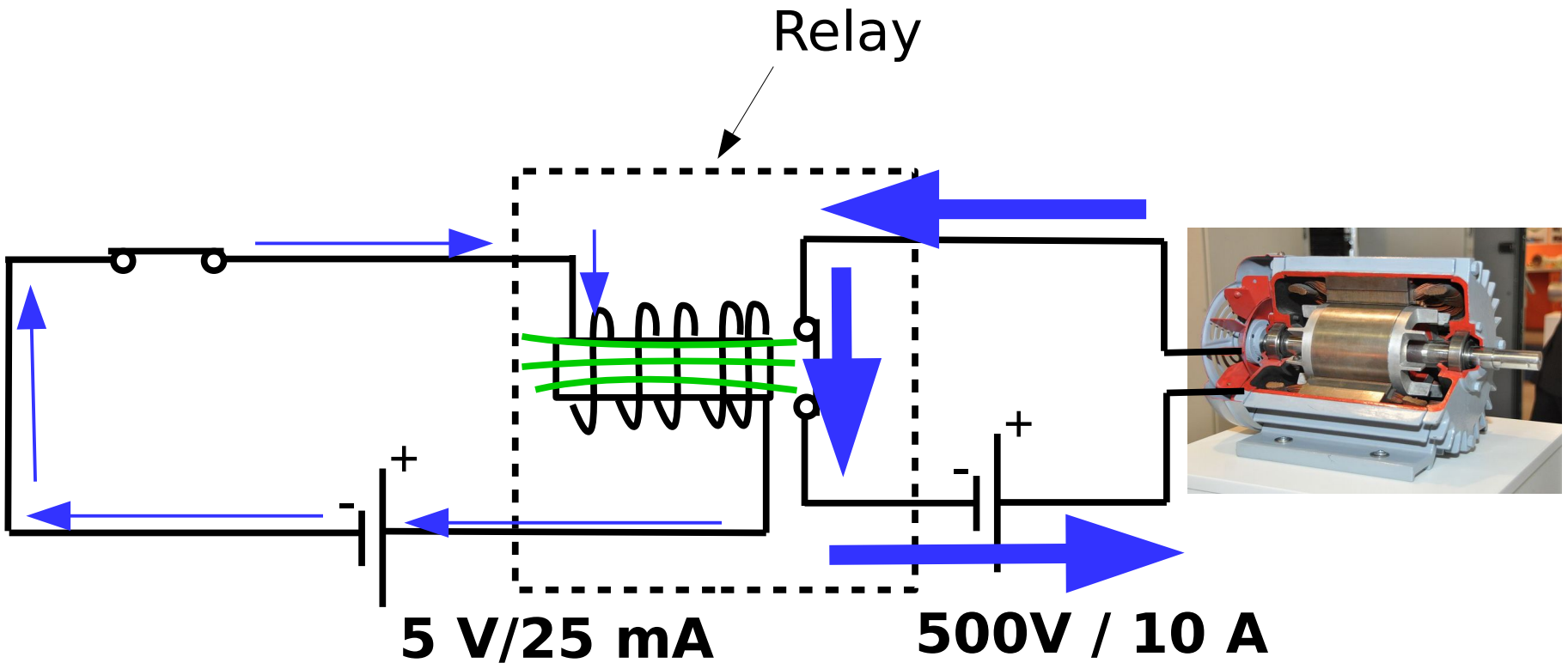
Relay example

- The magnetic field pulls the switch shut.



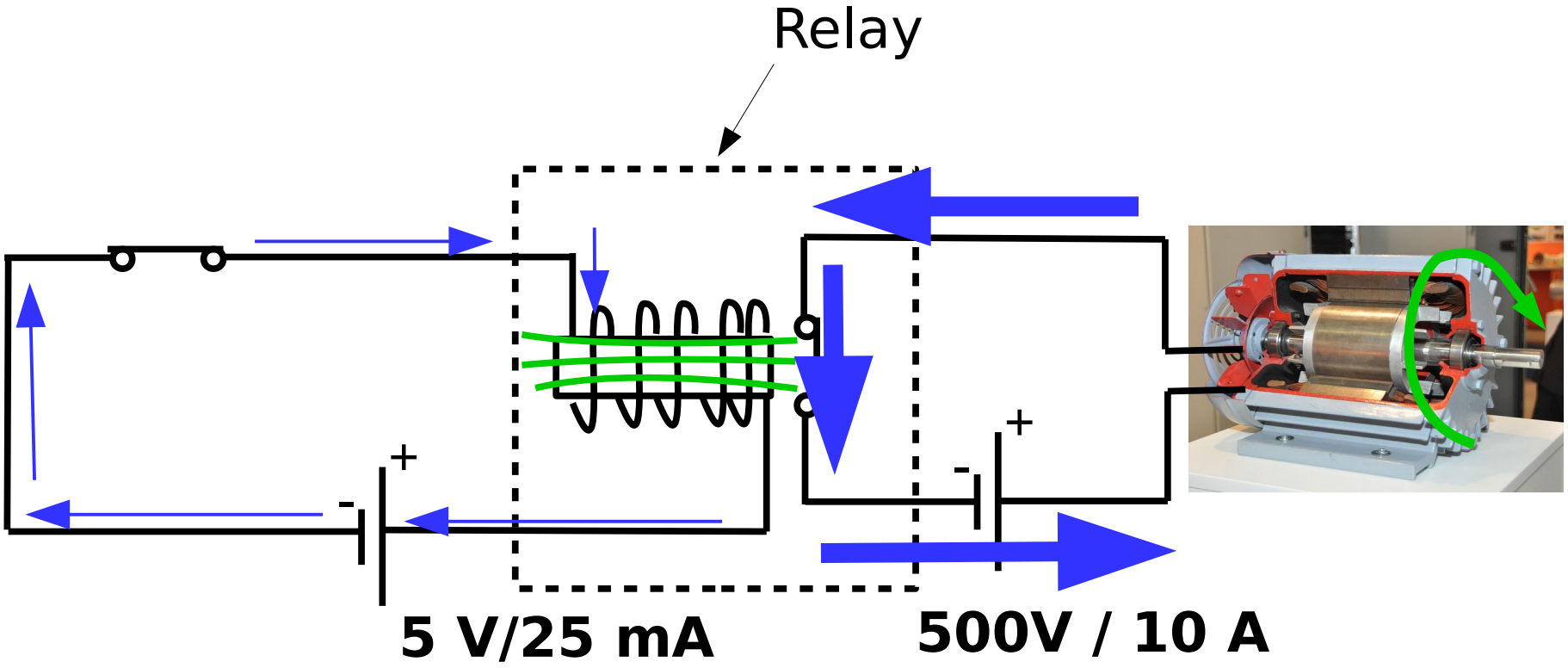
Relay example

- Current flows in the high voltage circuit.



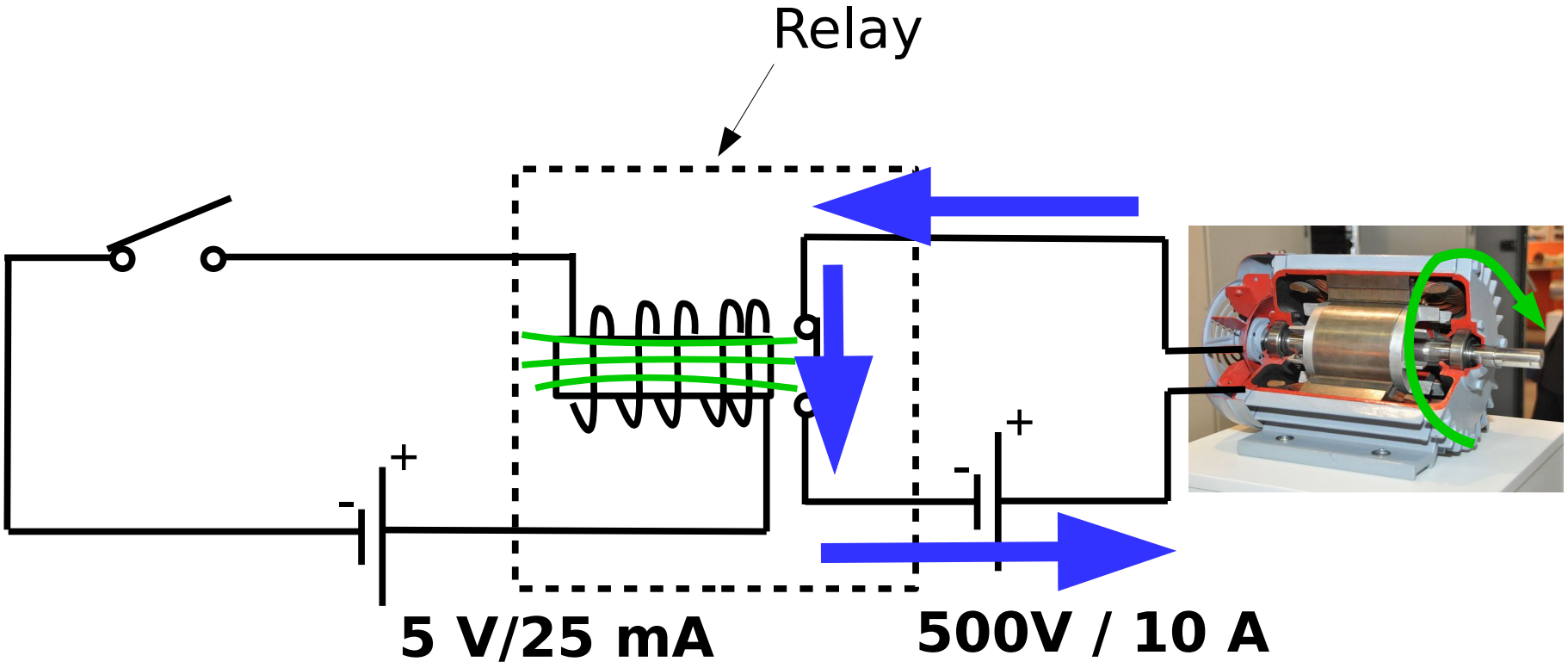
Relay example

- And the motor turns



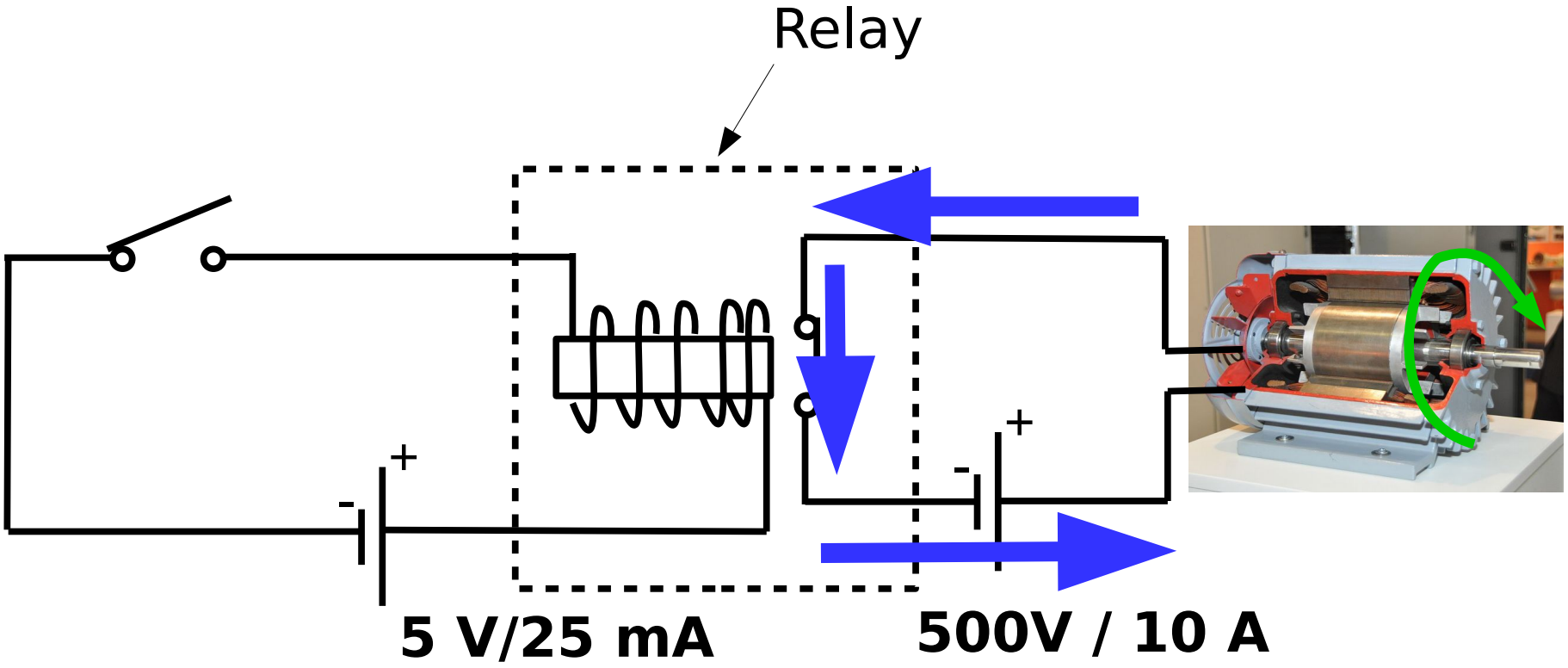
Relay example

- When the 5V supply is turned off...



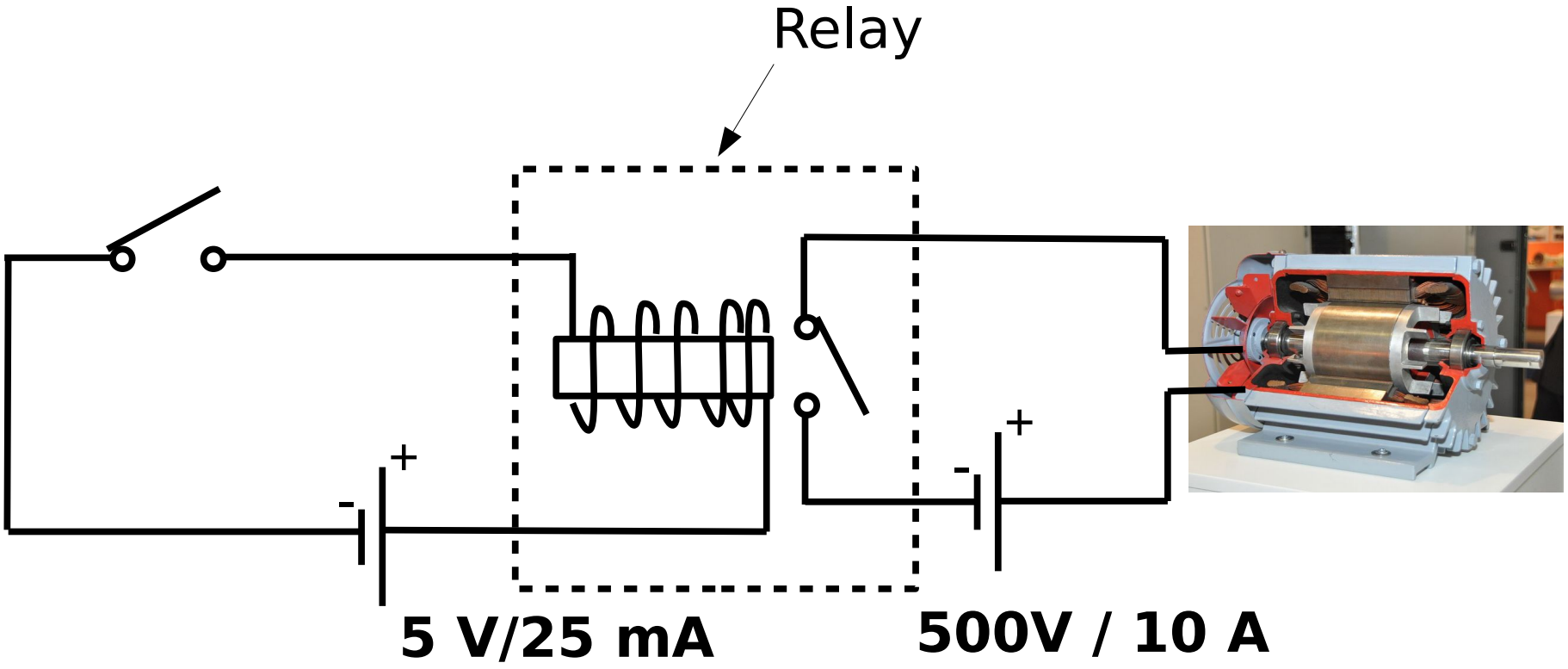
Relay example

- When the 5V supply is turned off...



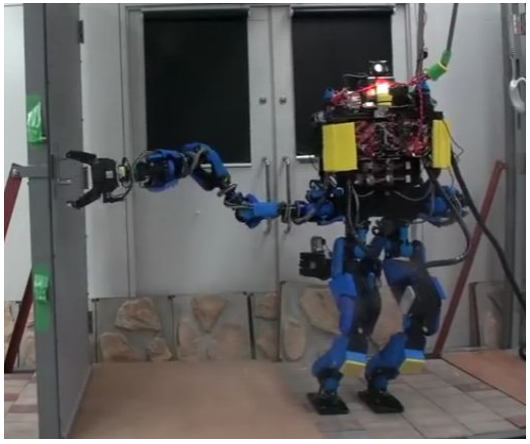
Relay example

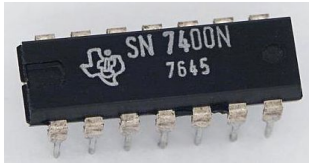
- The magnetic field disappears and the motor turns off.

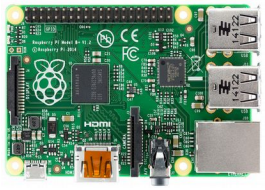


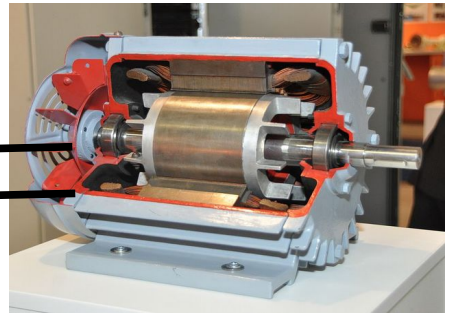
Relay example

- The magnetic field disappears and the motor turns off.

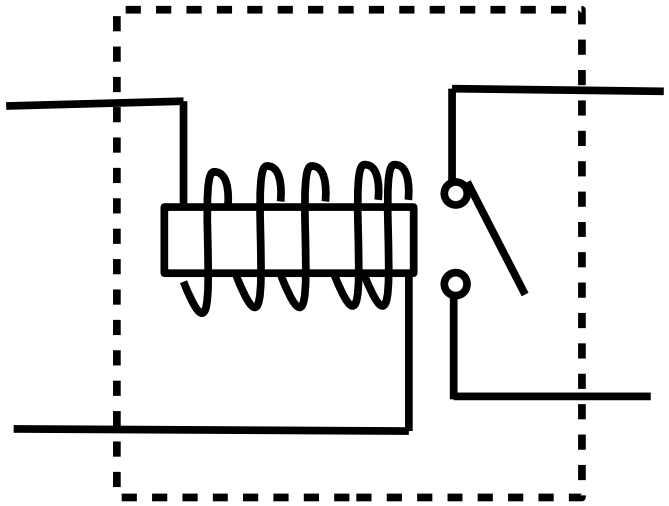


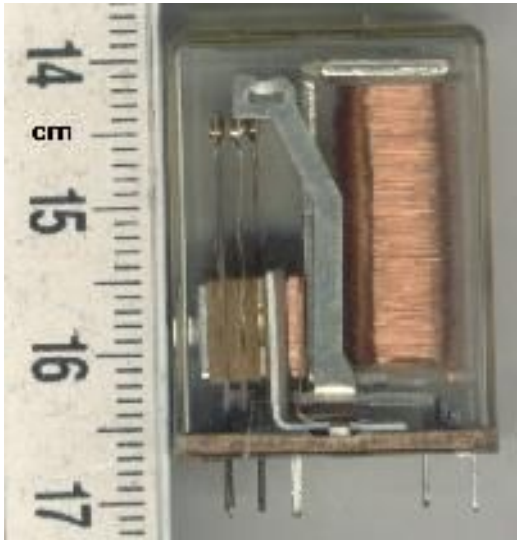


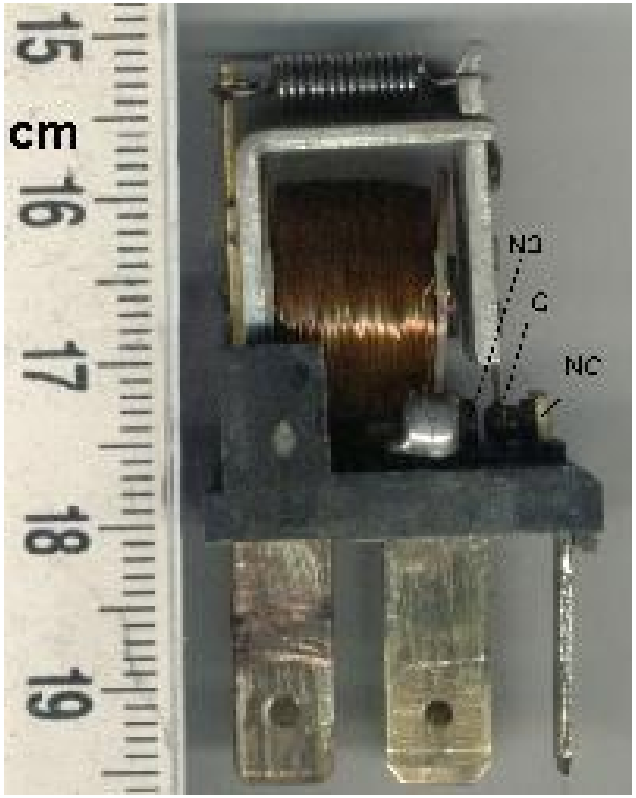




A real relay looks like this:



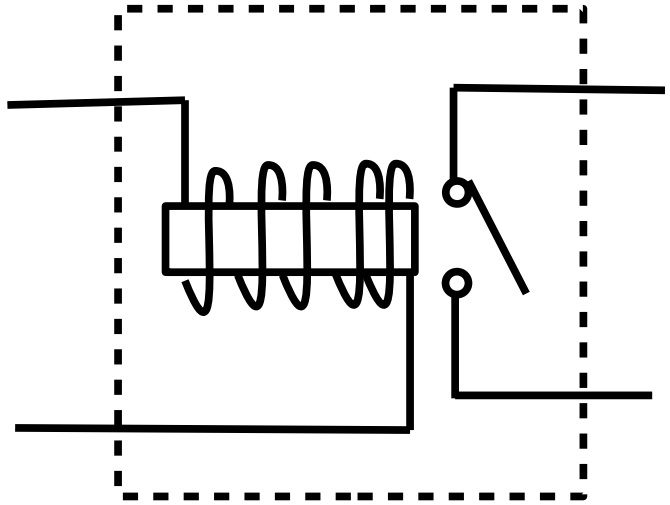




Advantages of using relays for switching things on and off

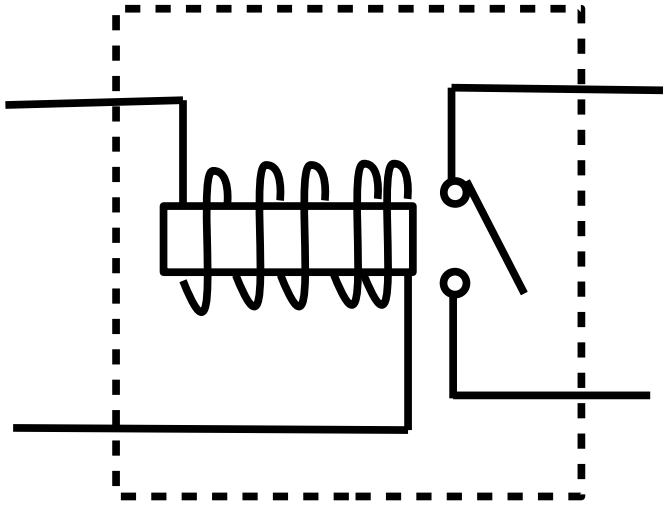
The University of Nottingham

•You get physical isolation of both circuits. Important when you are dealing with very high voltages.



•Relays were the primary way to turn high voltages on/off before the advent of the transistor in the 1960s – they not so bad at this.

The drawbacks of using relays for switching



- You have to keep that coil **energized if you want to keep your device on**.
- **This uses a lot of power**.
- They are **mechanical devices** and therefore slow.
- They are **full of copper and cost a lot (a few pounds.)**
- **They are big.**

Outline of the lecture

- **No recap of last lecture :)**

- Transistor basics
  - Relays (Mechanical transistor)
  - **NPN Bipolar Junction Transistors**
  - PNP Bipolar Junction Transistors
  - MOSFETs

- Push pull pairs to drive MOSFETs

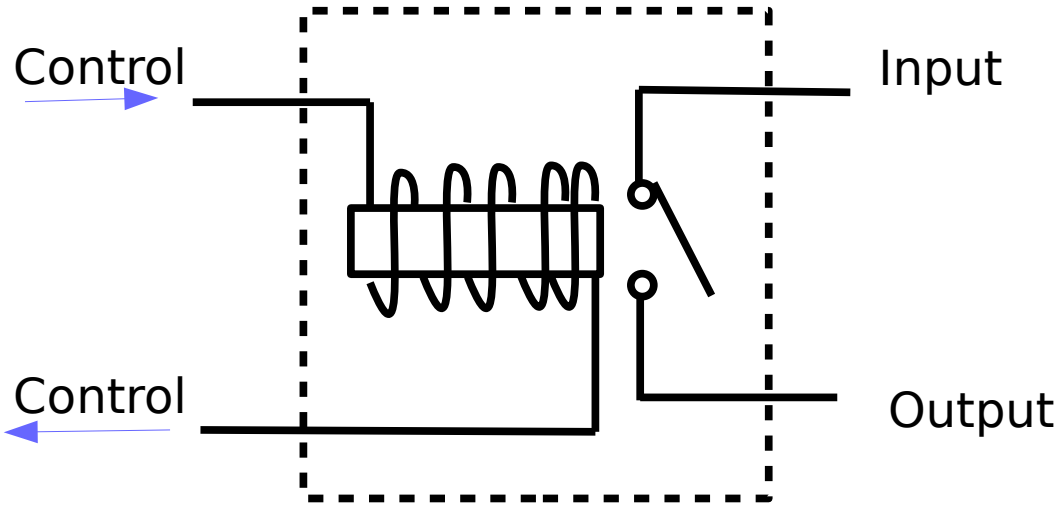
- One last thing

- Summary

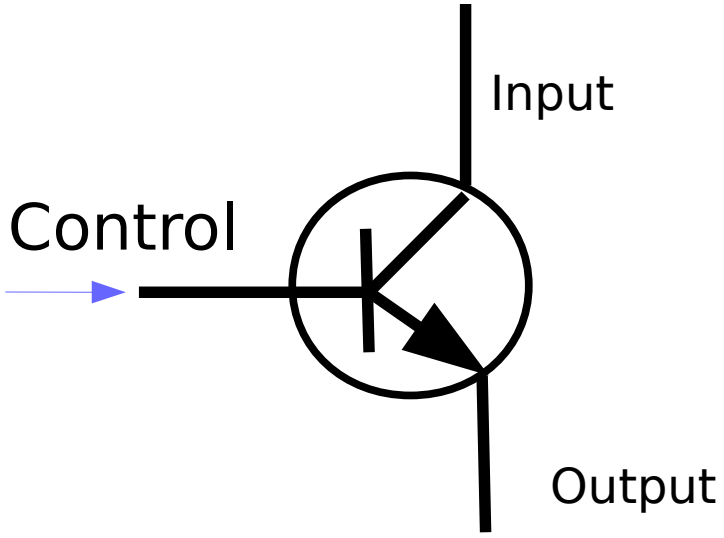
Transistors

- You can think of a transistor as being just like a relay except they have only one control wire.

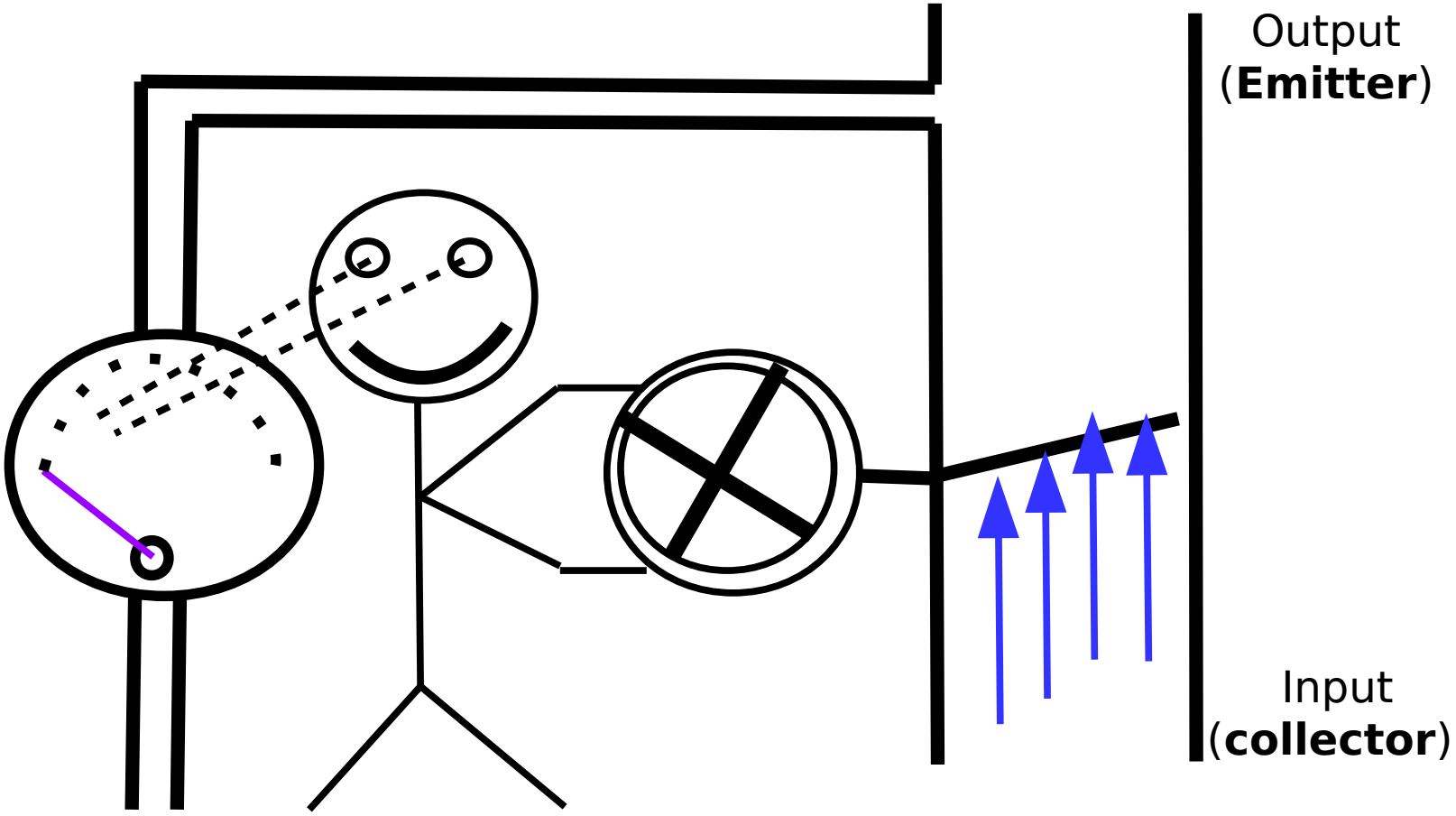
Relay



Transistor

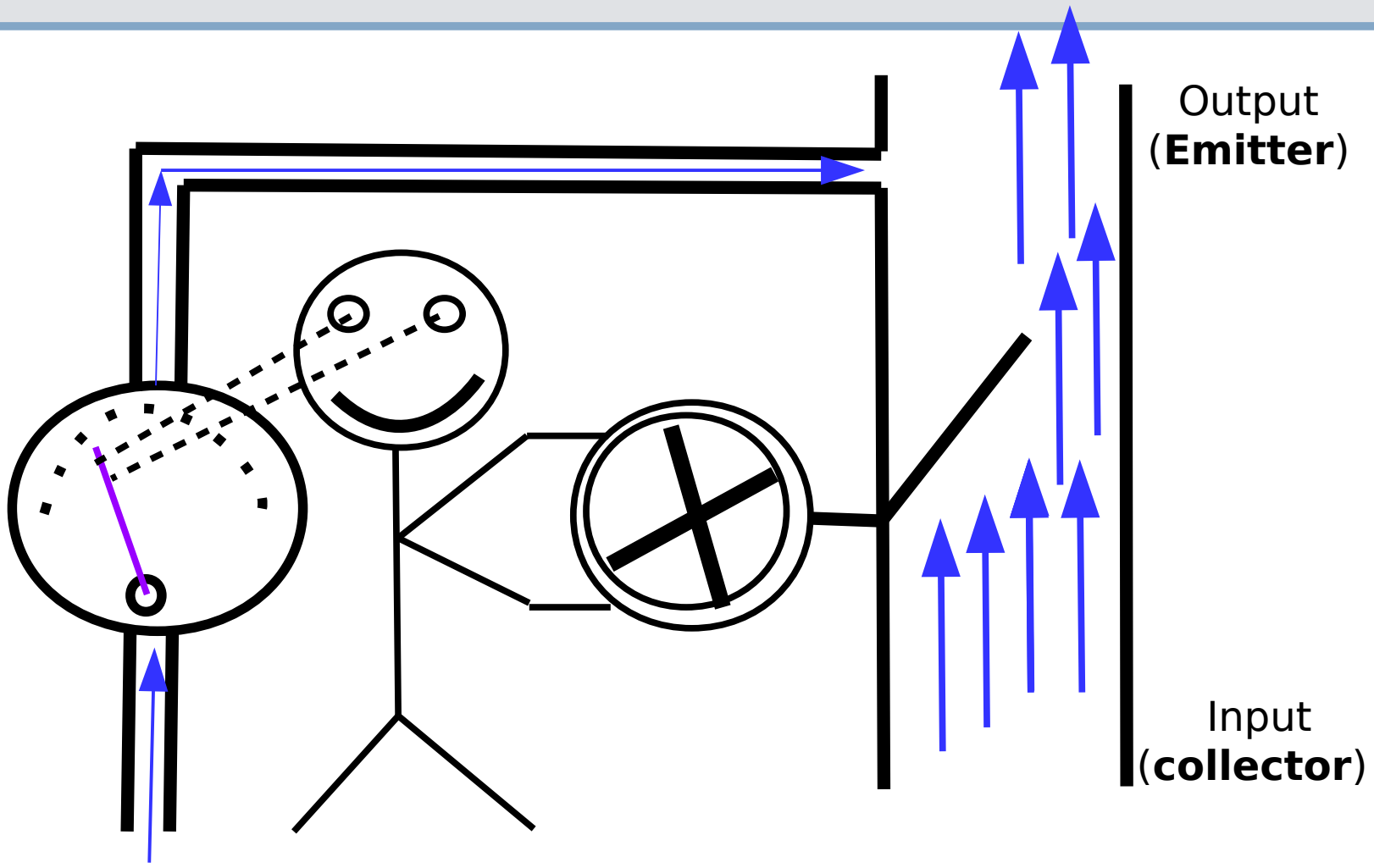


You can think of a transistor like this.... The Transistor Man



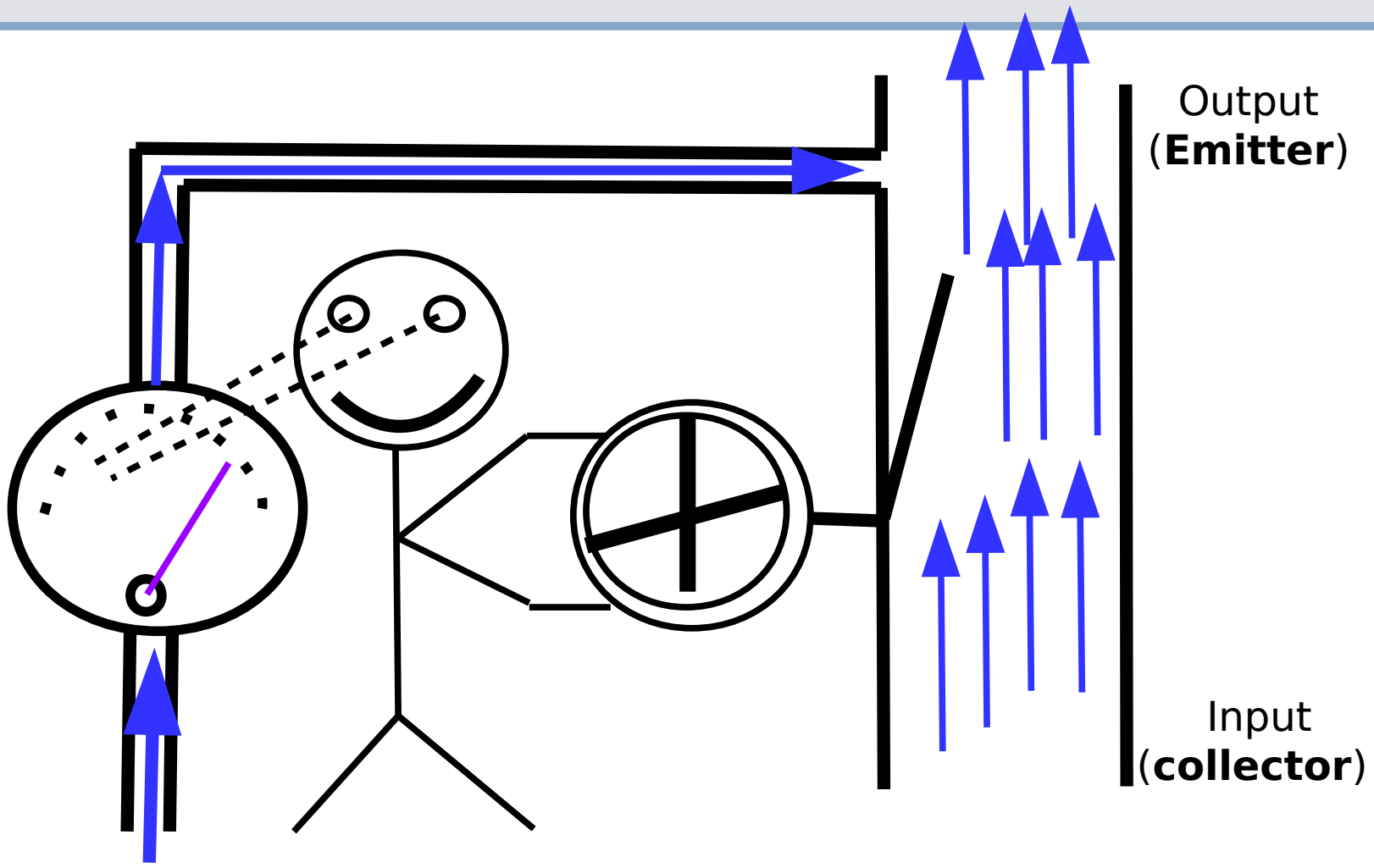
After Horowitz and Hill

Transistors – The Transistor Man



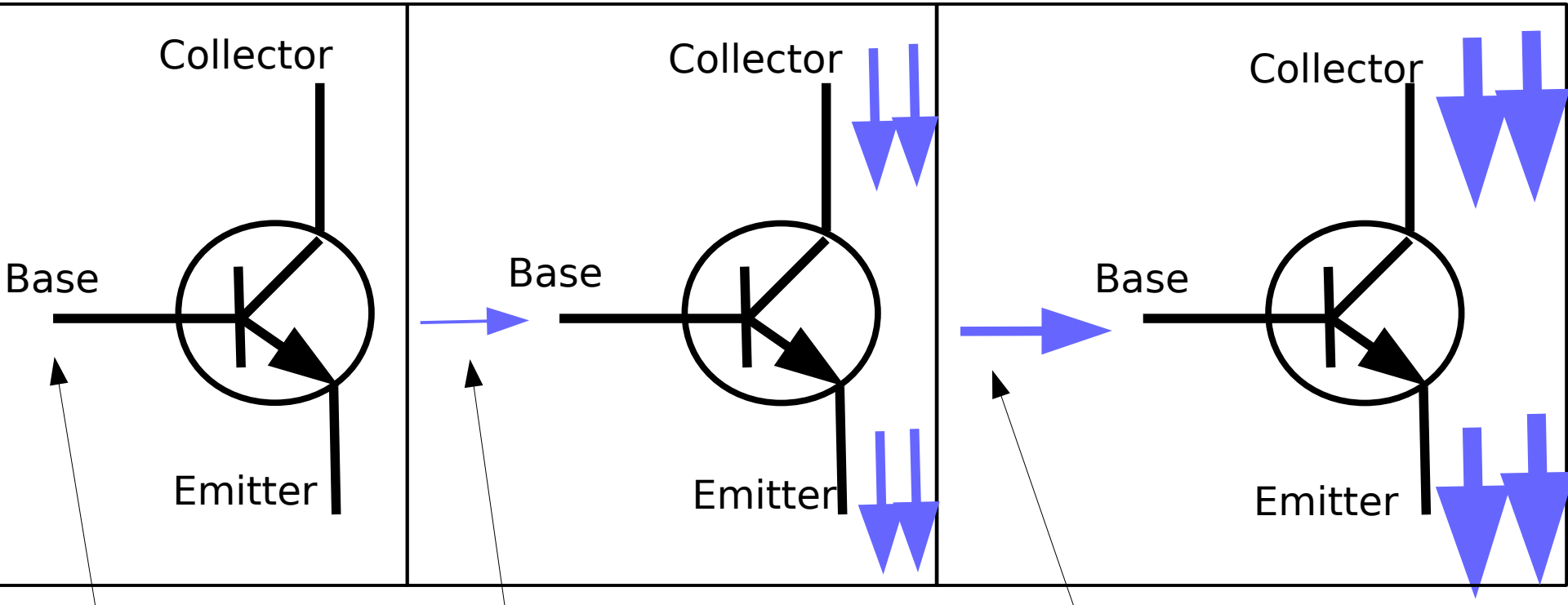
After Horowitz and Hill

Transistors – The Transistor Man



After Horowitz and Hill[30]

Transistors



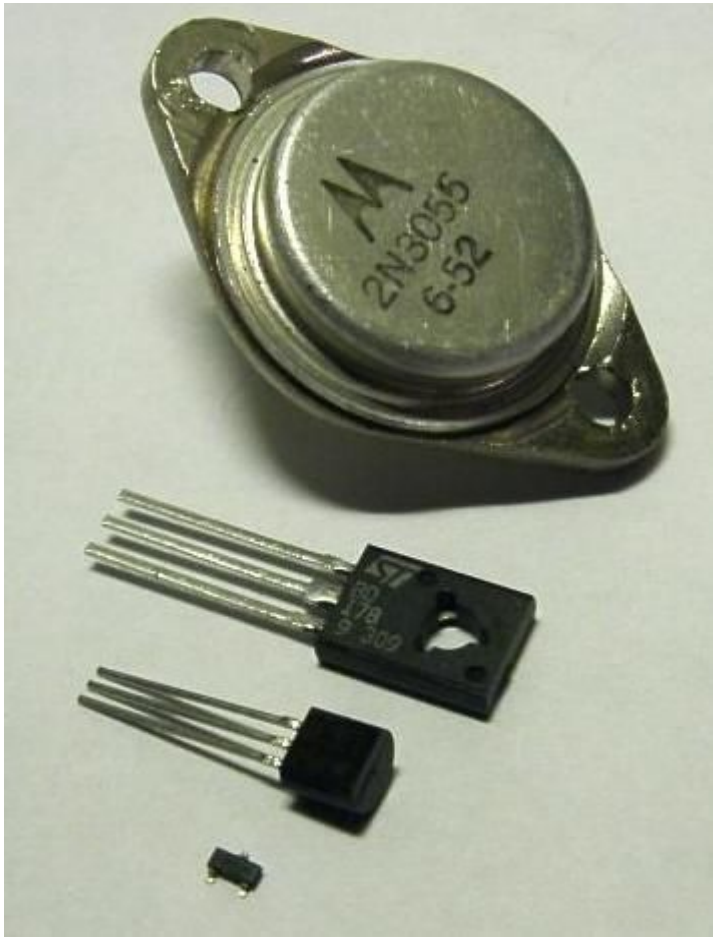
1. No base current – **no output current**

2. Small base current – **small output current**

3. Big base current – **big output current**

Transistors

- Transistors look like this →
- Little black beads (although sometimes silver boxes)
- They always have three legs.
- Invented in June 30th 1948

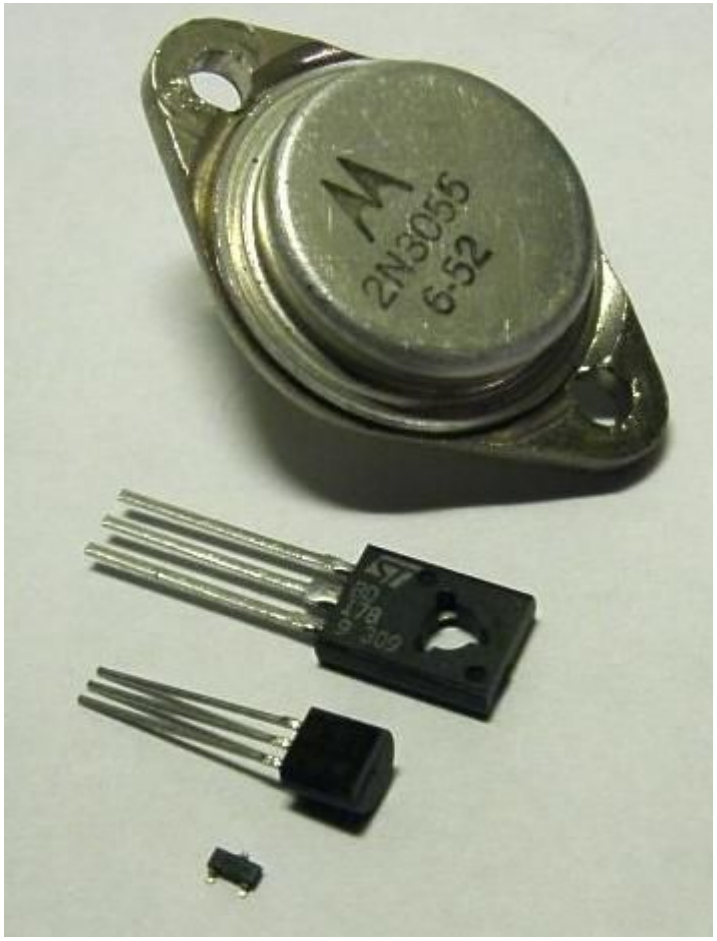


Transisto

John Bardeen, William Shockley and Walter Brattain

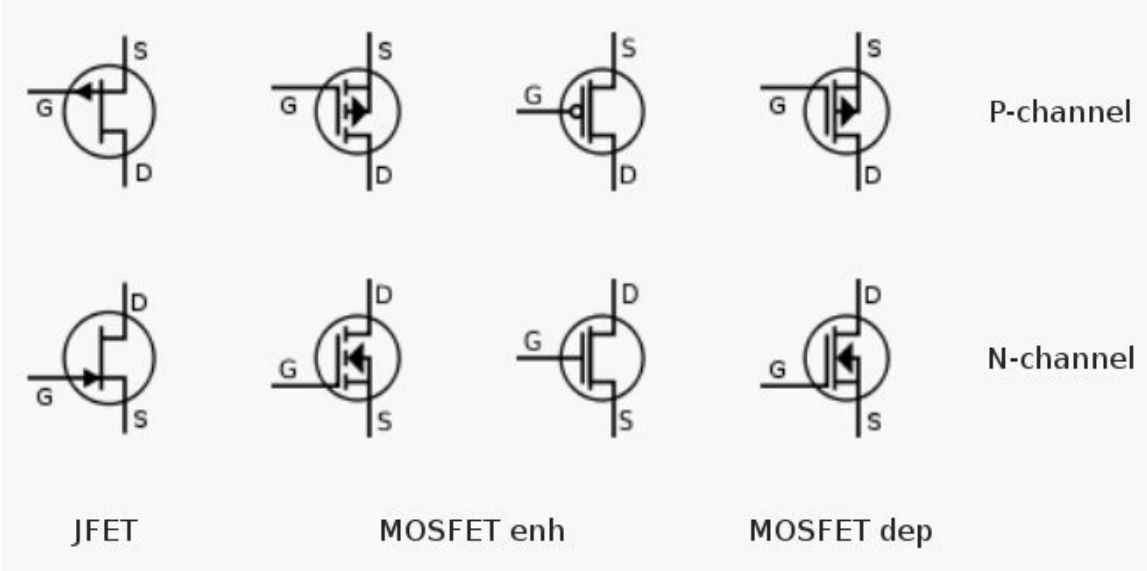
Advantages of Transistors

- No moving parts so they won't break – very long lifetime. ✓
- Don't need as much control current to operate as a relay. ✓
- Cheep as chips! ✓

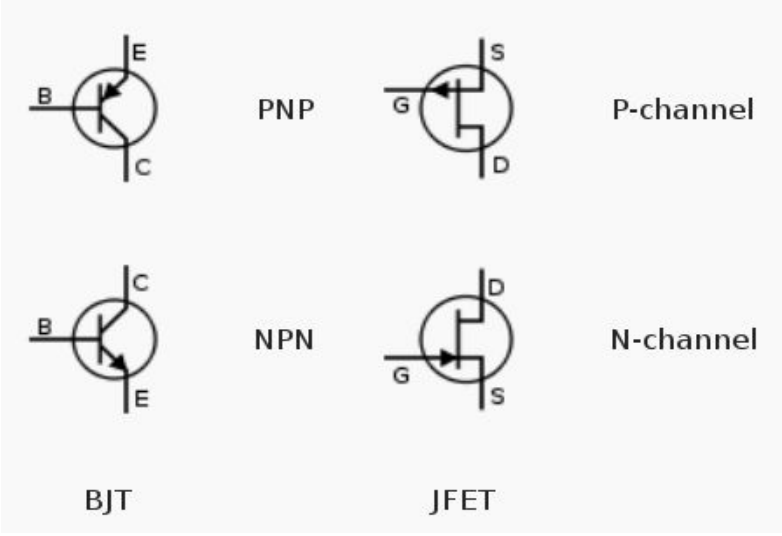


Transisto

Transistors – Different types of transistors

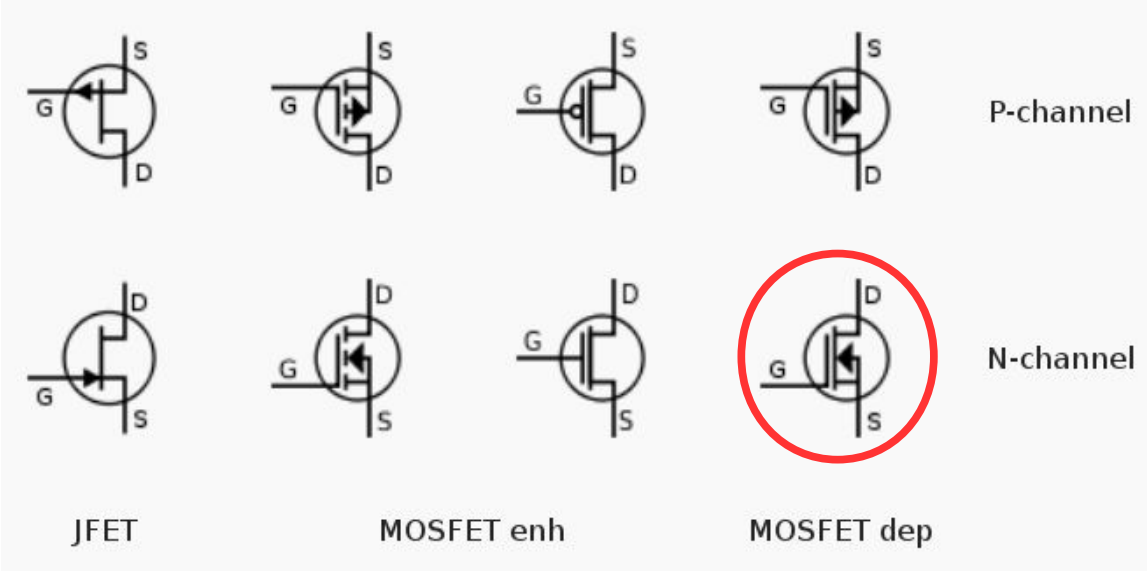


- There are lots of different types of transistors – too many to learn about in this course.

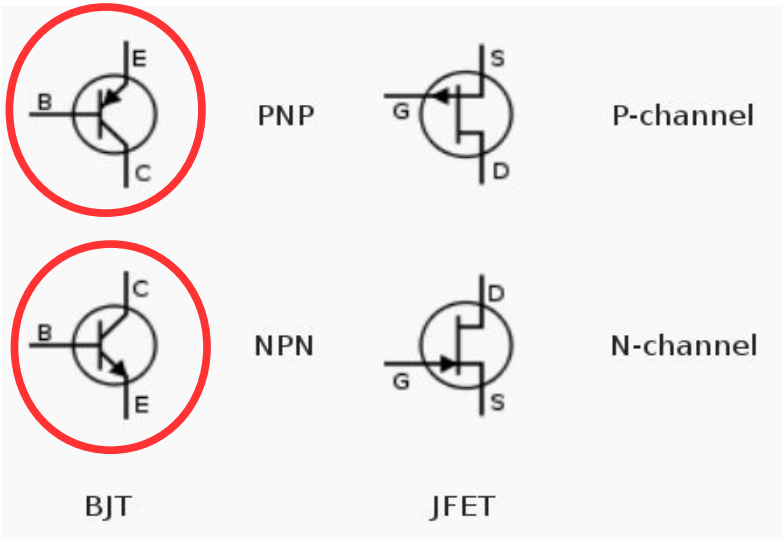


- I have decided to teach you about the three of the most useful ones.

Transistors – Different types of transistors



- There are lots of different types of transistors – too many to learn about in this course.



- I have decided to teach you about the three of the most useful ones.

Outline of the lecture

- **No recap of last lecture :)**

- Transistor basics
  - Relays (Mechanical transistor)
  - **NPN Bipolar Junction Transistors**
  - PNP Bipolar Junction Transistors
  - MOSFETs

- Push pull pairs to drive MOSFETs

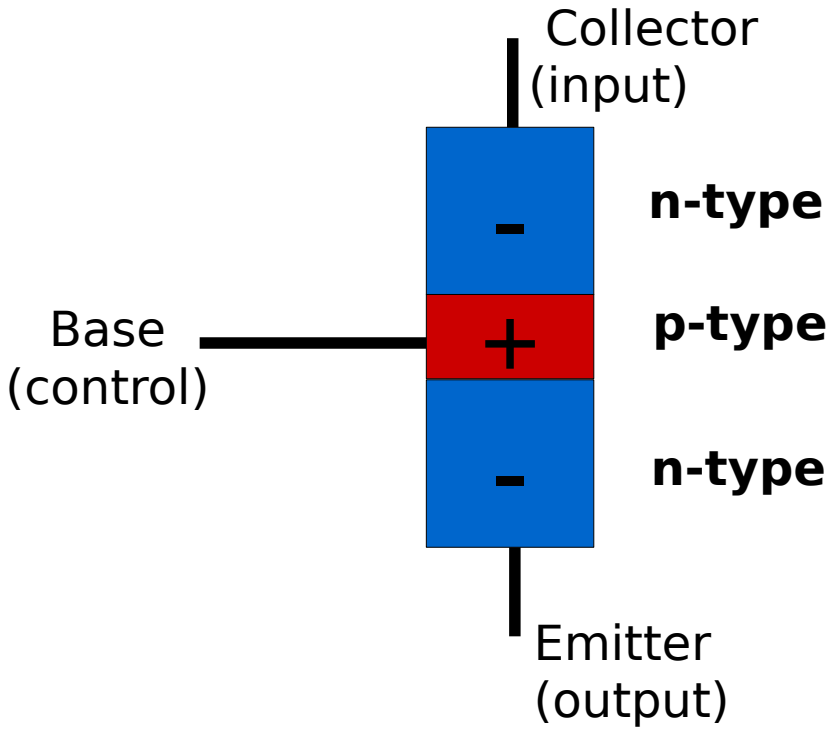
- One last thing

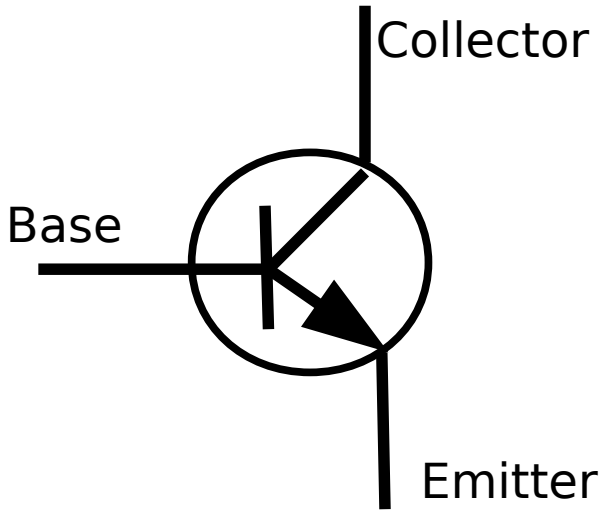
- Summary

Transistors – The NPN Bipolar Junction Transistor (**BJT**)

The University of Nottingham

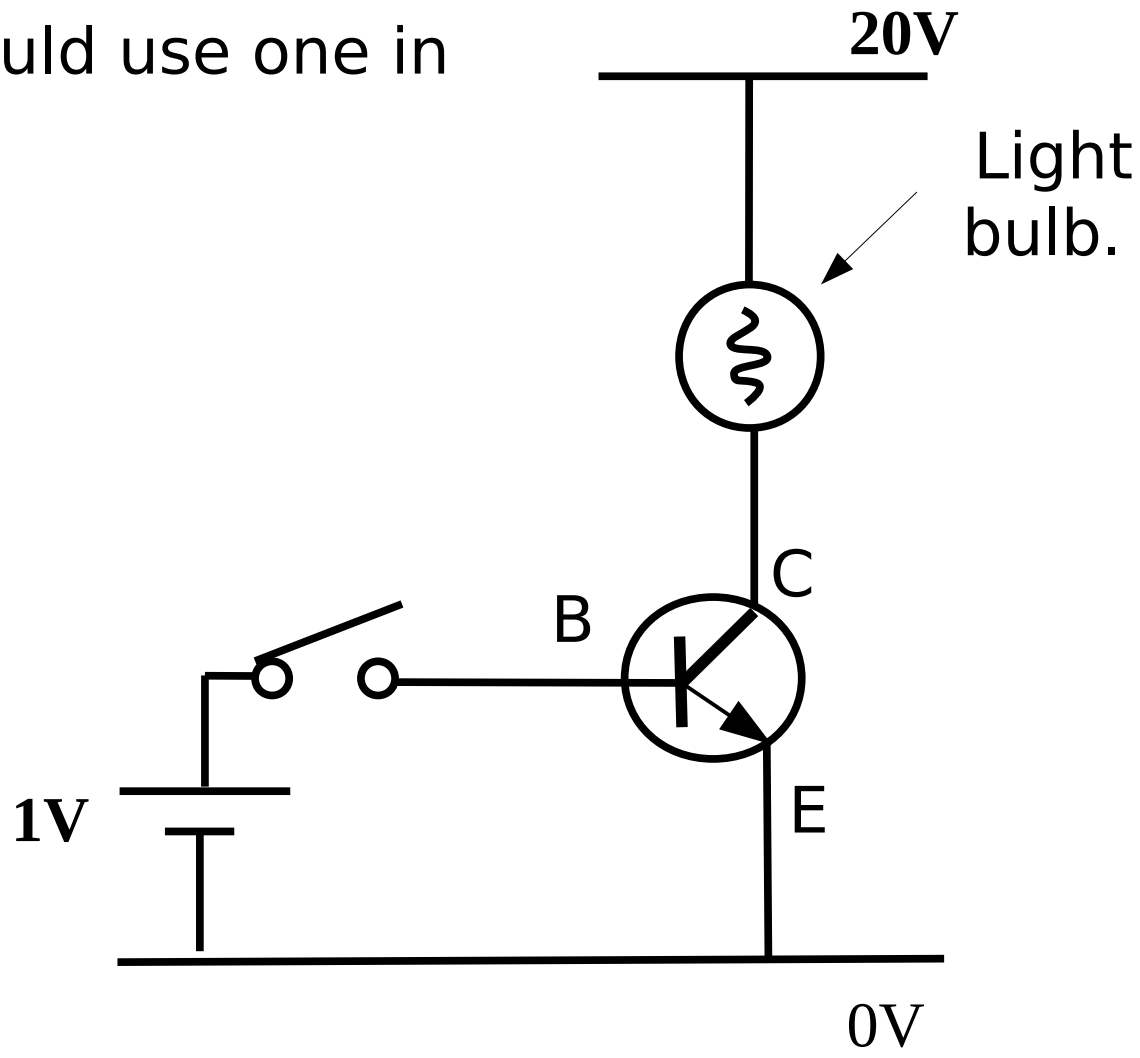
- It's called an **NPN** transistor because it's made of three layers of material, one with **n**egative charge, one with **p**ositive charge and one with **n**egative charge.





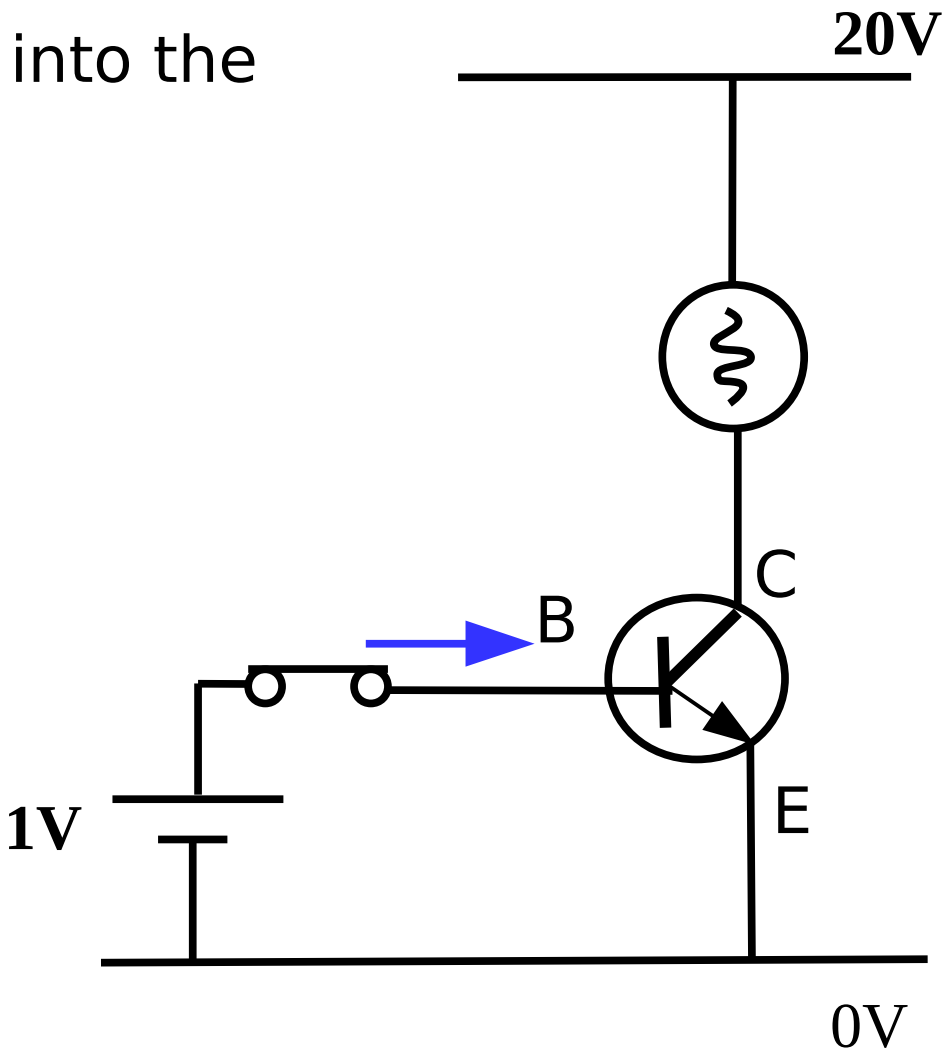
Transistors – The NPN Bipolar Junction Transistor (**BJT**)

- This is how you would use one in a circuit.....



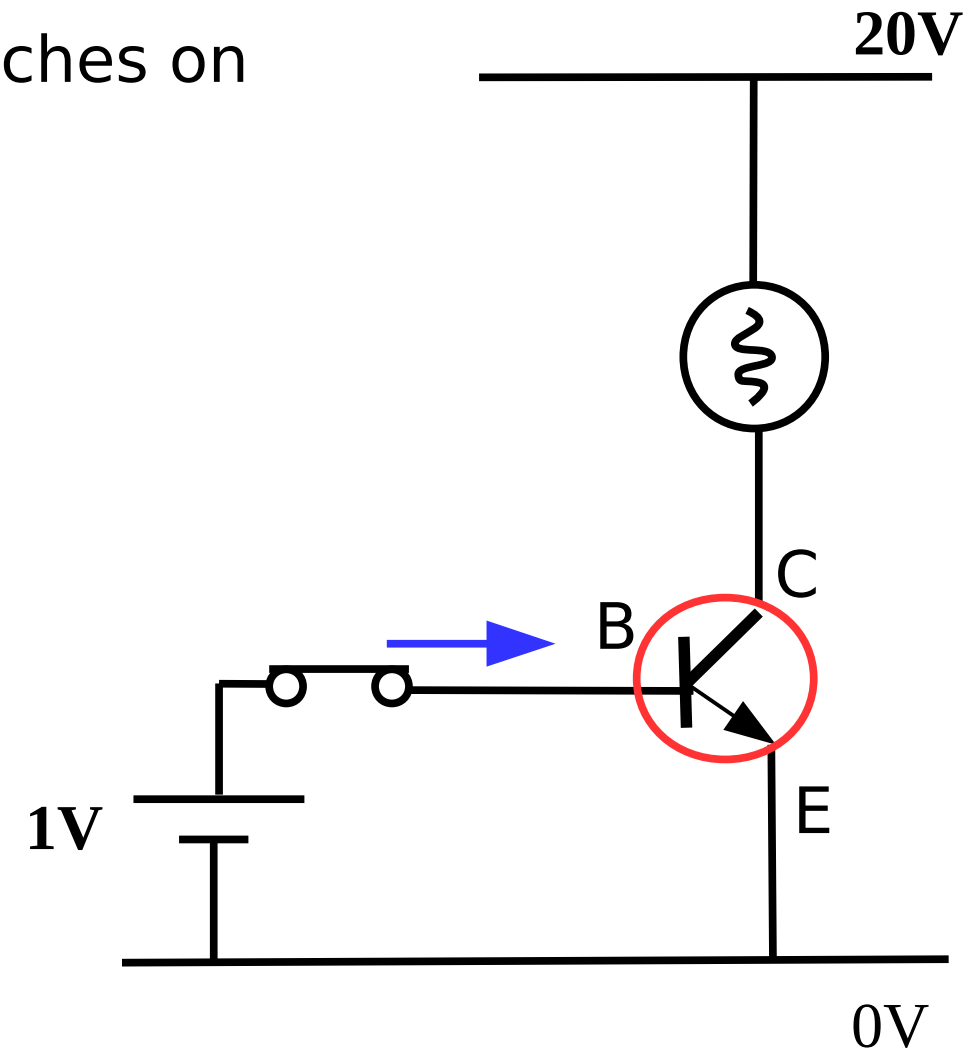
Transistors – The NPN Bipolar Junction Transistor (BJT)

- Put a small current into the **B**ase.



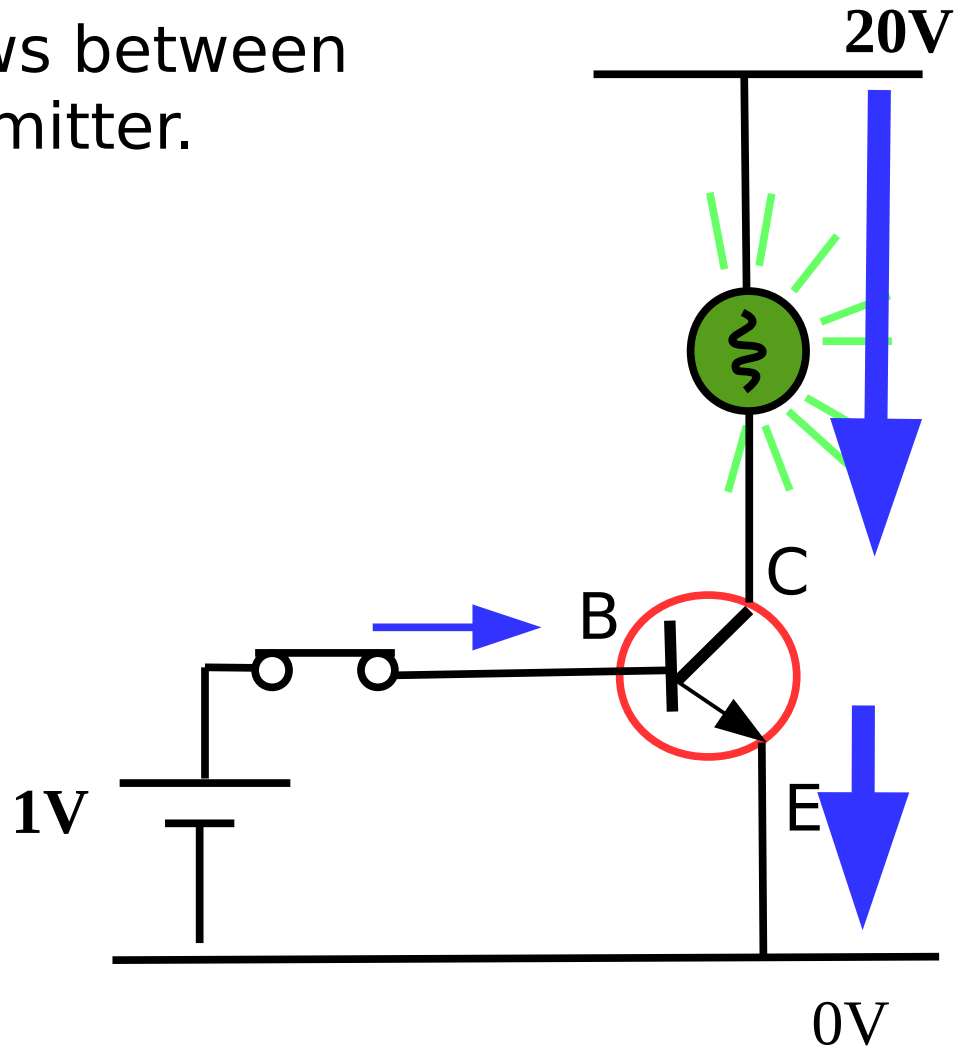
Transistors – The NPN Bipolar Junction Transistor (BJT)

- The transistor switches on



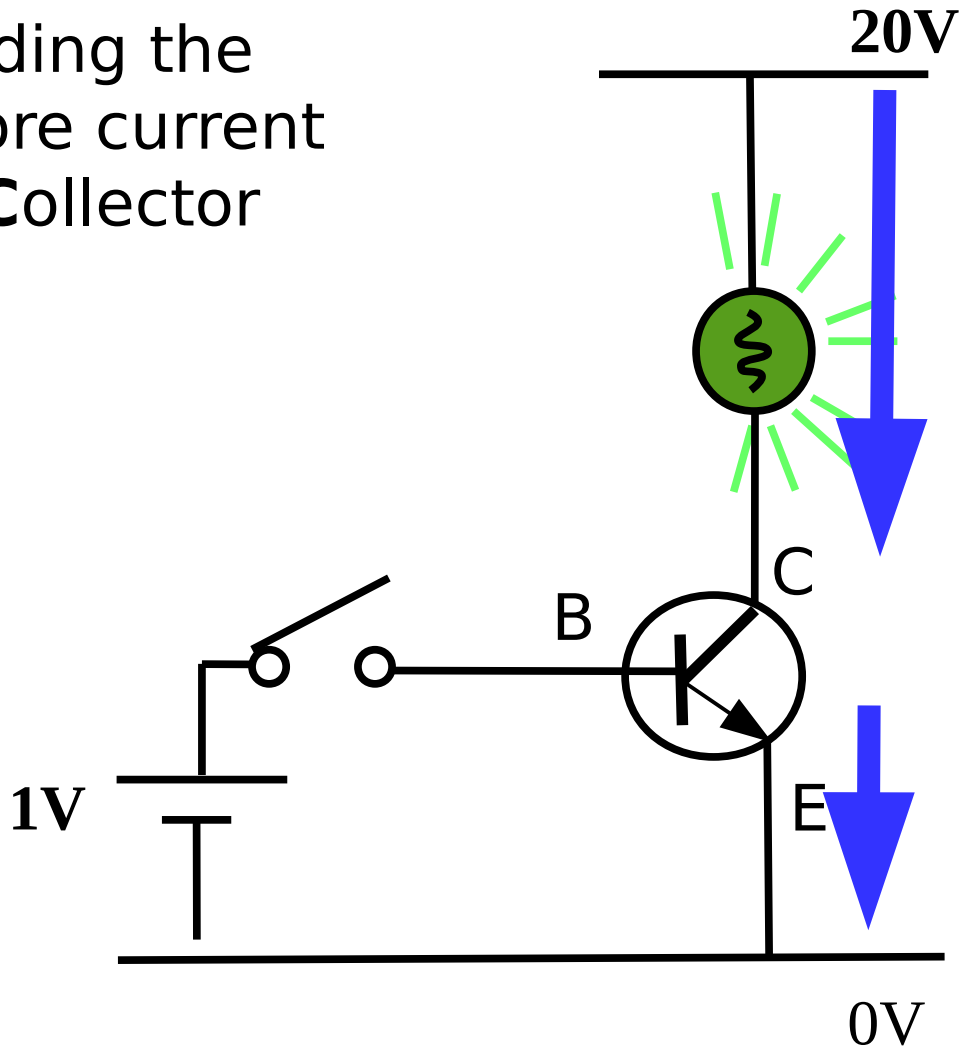
Transistors – The NPN Bipolar Junction Transistor (BJT)

- A large current flows between the **C**ollector and **E**mitter.



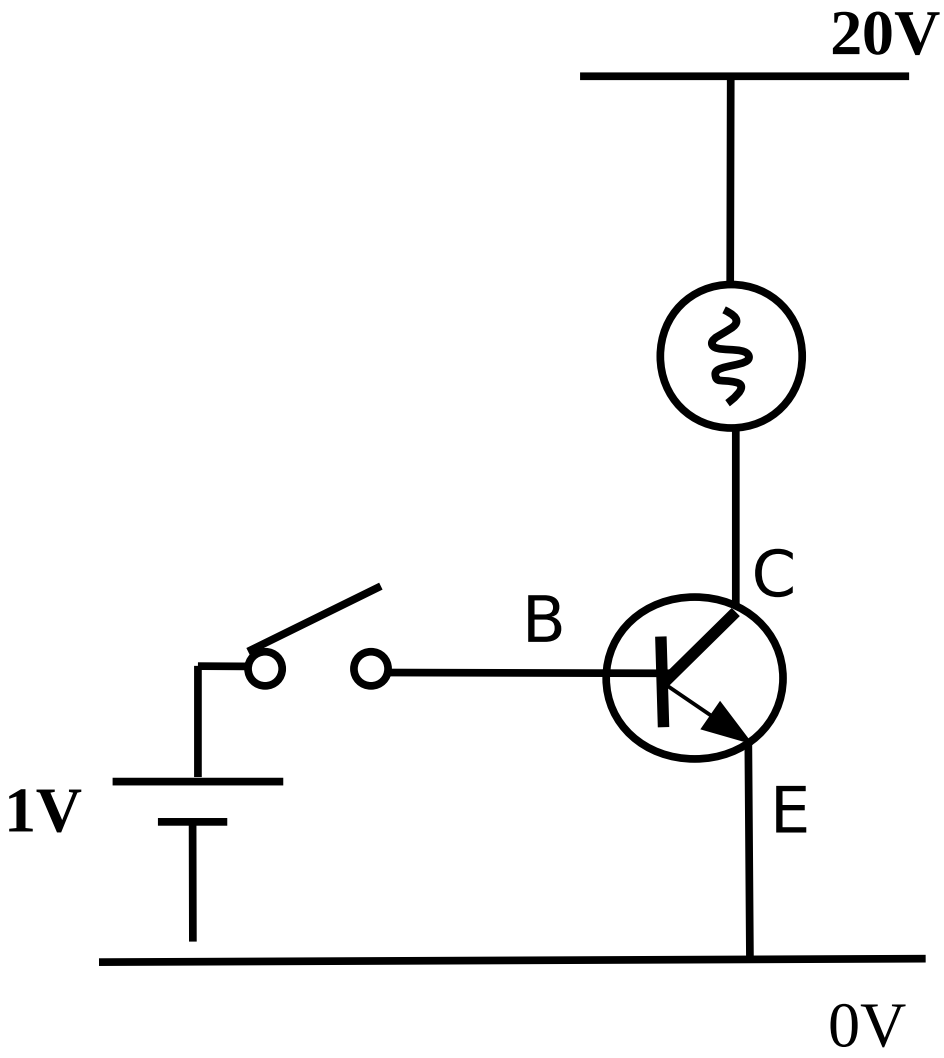
Transistors – The NPN Bipolar Junction Transistor (BJT)

- When you stop feeding the base current, no more current flows between the **C**ollector and the **E**mitter.



Transistors – The NPN Bipolar Junction Transistor (BJT)

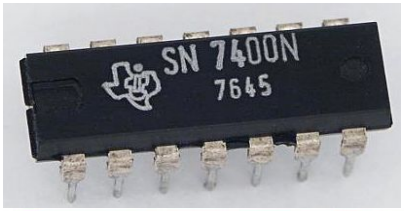
- And the light bulb will turn off.

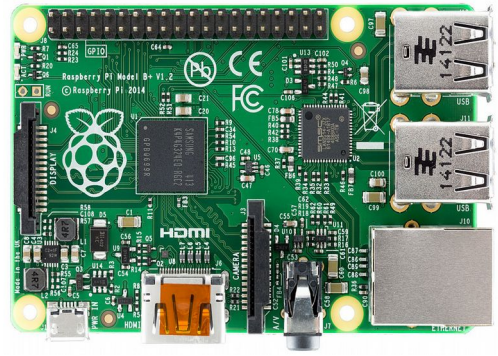


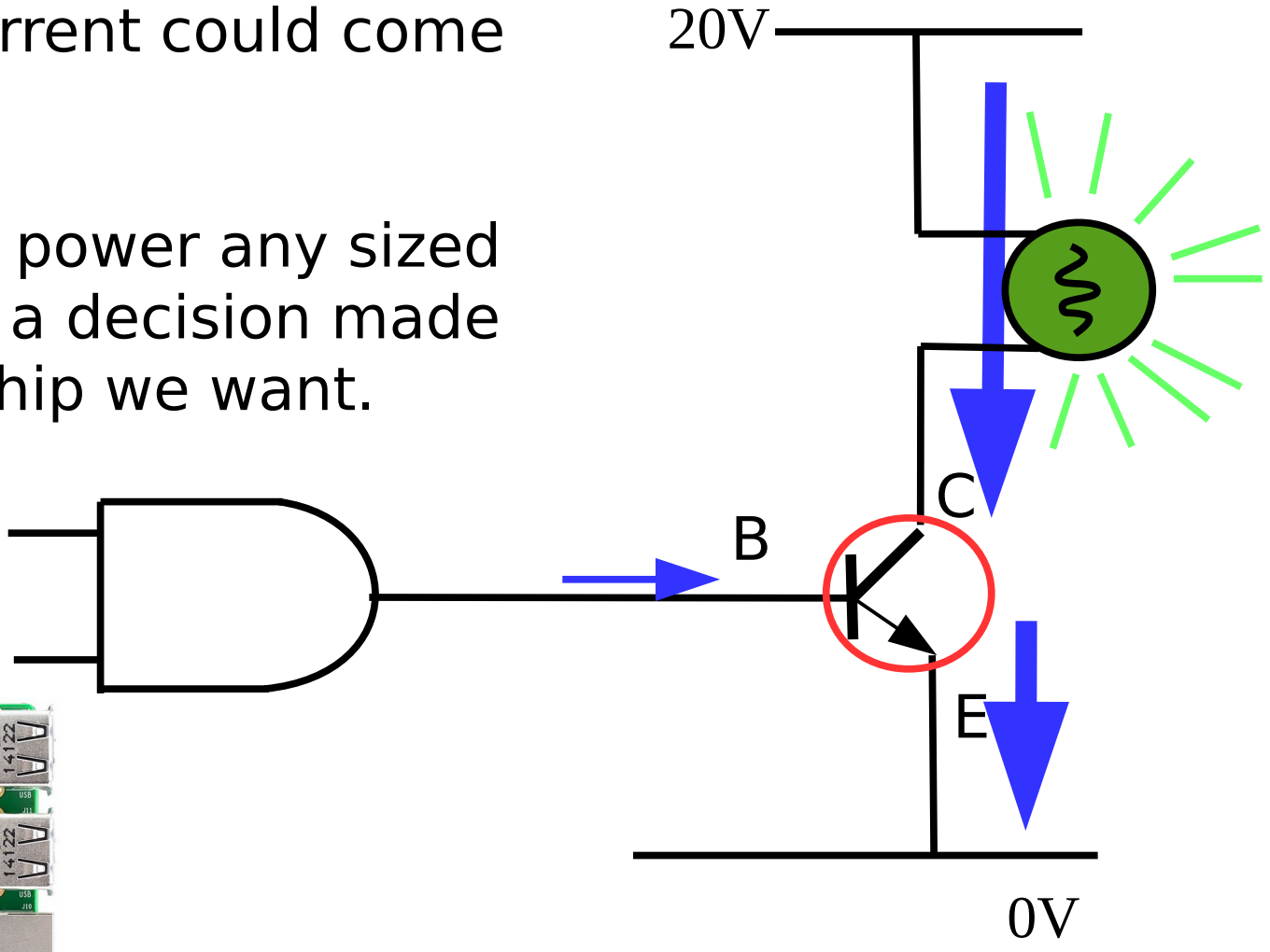
Transistors – The NPN Bipolar Junction Transistor (BJT)

- The base current could come from a chip!

- Now we can power any sized device using a decision made form a tiny chip we want.





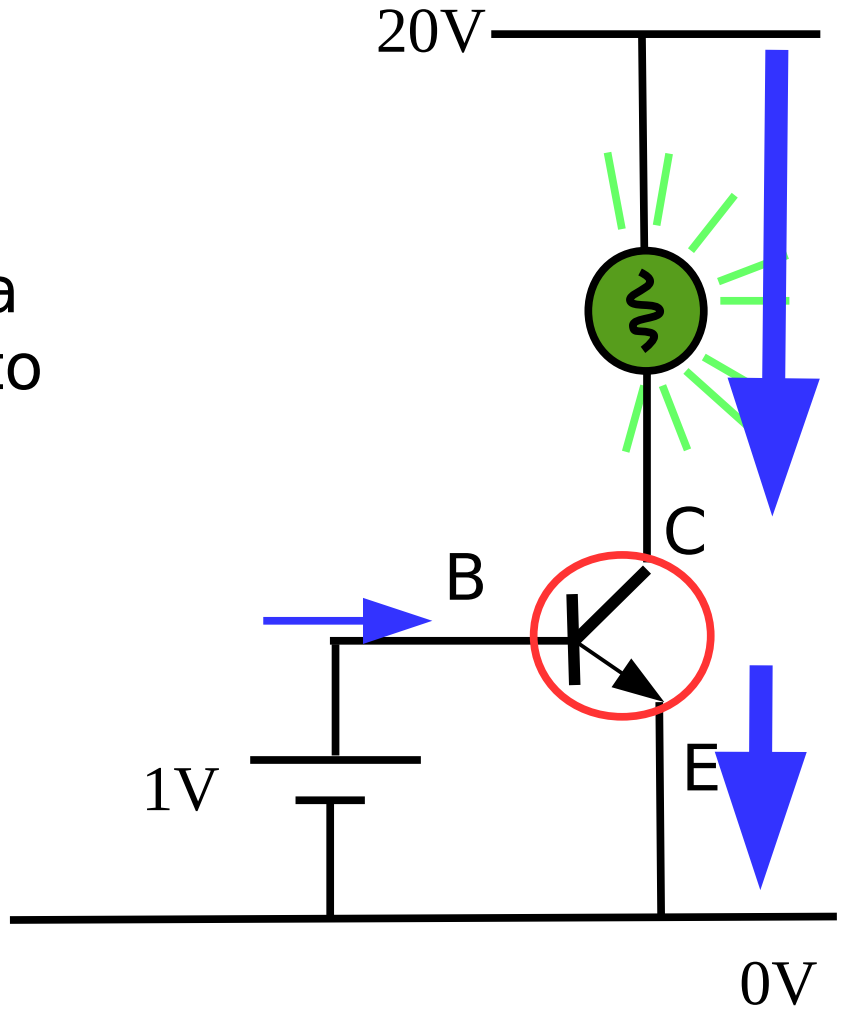


Transistors – The NPN Bipolar Junction Transistor (BJT)

The University of Nottingham

- In summary:

The **NPN** Bipolar Junction Transistor will turn **ON** when a **positive** voltage is supplied to the **Base**.



Outline of the lecture

- **No recap of last lecture :)**

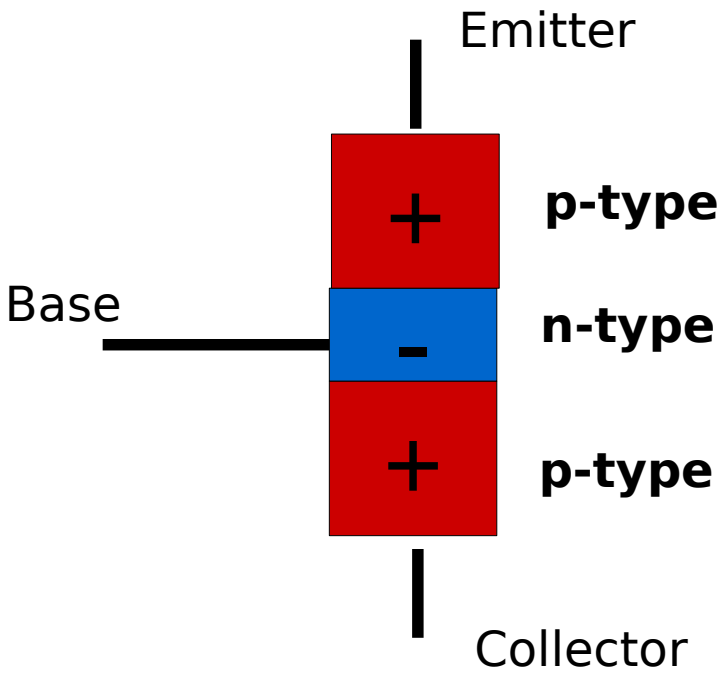
- Transistor basics
  - Relays (Mechanical transistor)
  - NPN Bipolar Junction Transistors
  - **PNP Bipolar Junction Transistors**
  - MOSFETs

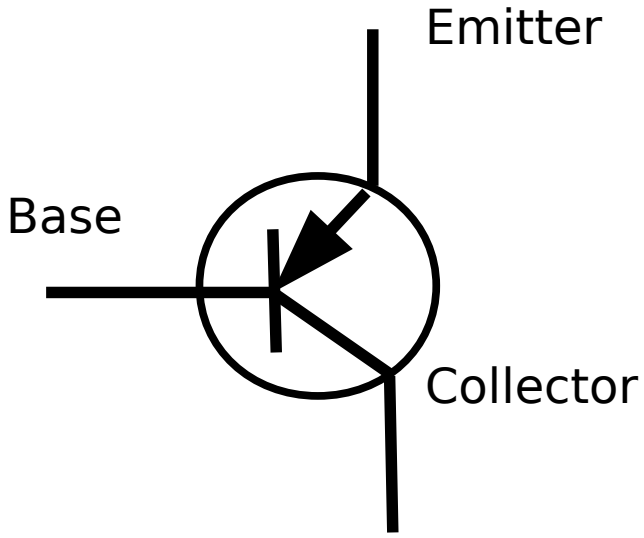
- Push pull pairs to drive MOSFETs

- One last thing

- Summary

Transistors – The PNP Bipolar Junction Transistor (BJT)



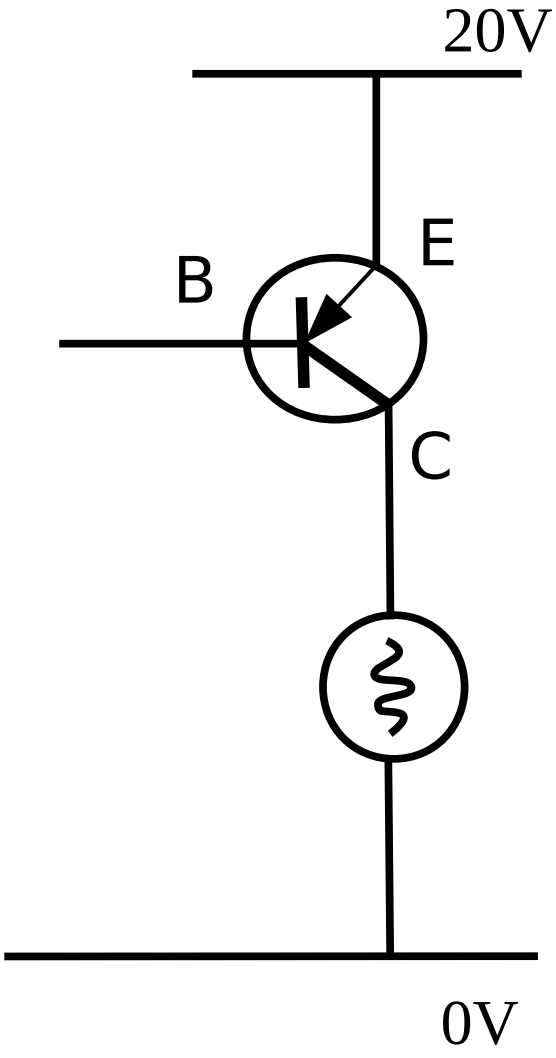


Transistors – The PNP Bipolar Junction Transistor (BJT)

- The **PNP** transistor is just like the **NPN** transistor.

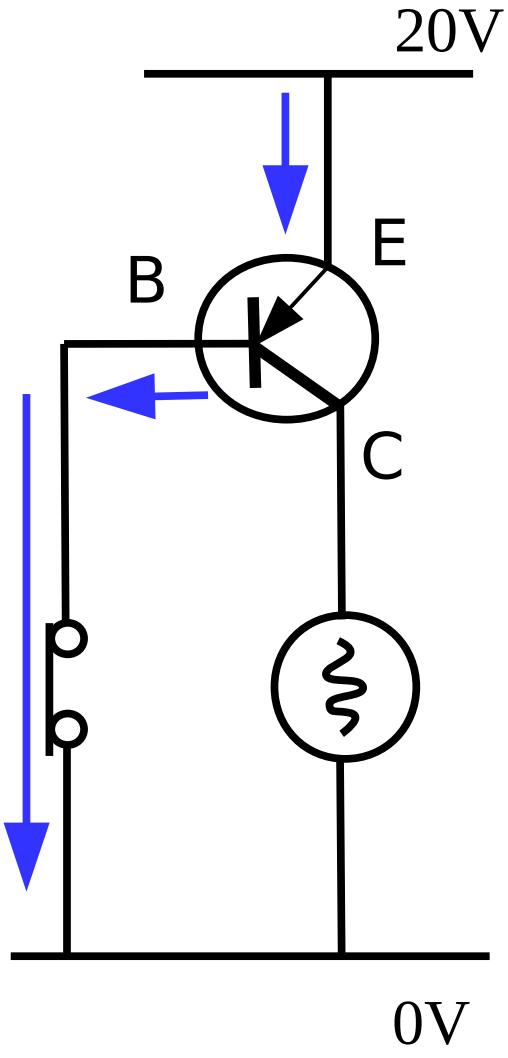
- **Except it turns ON when the input is switched OFF by connecting it to 0V.**

- **And switched OFF when the input is connected to a positive voltage.**



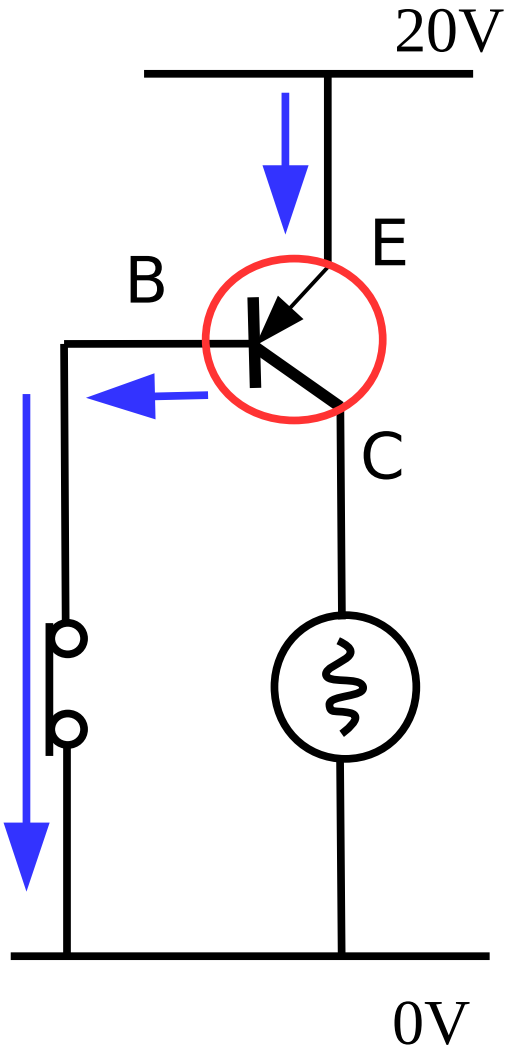
Transistors – The PNP Bipolar Junction Transistor (BJT)

- If you connect the base to 0V allowing a small current to flow out of the transitor.



Transistors – The PNP Bipolar Junction Transistor (BJT)

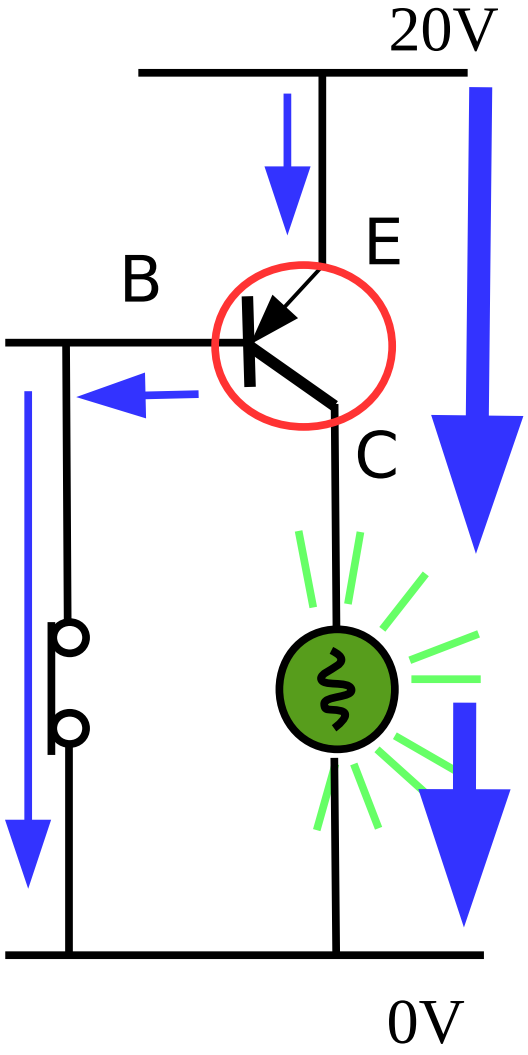
- This turns the transistor on



Transistors – The PNP Bipolar Junction Transistor (BJT)

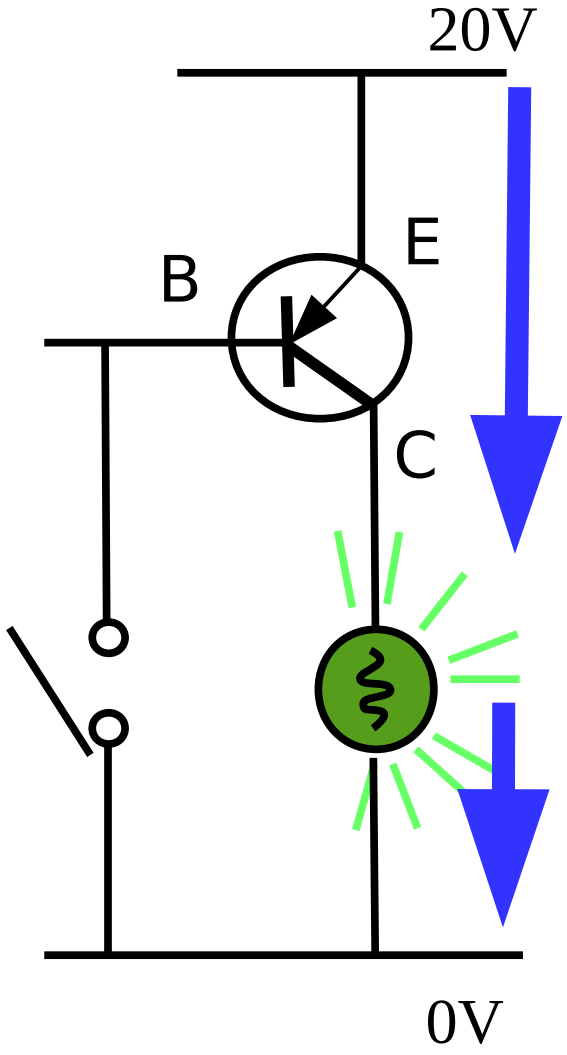
- Then a large current is turned on between the emitter and collector.

- Thus your light bulb will turn on.



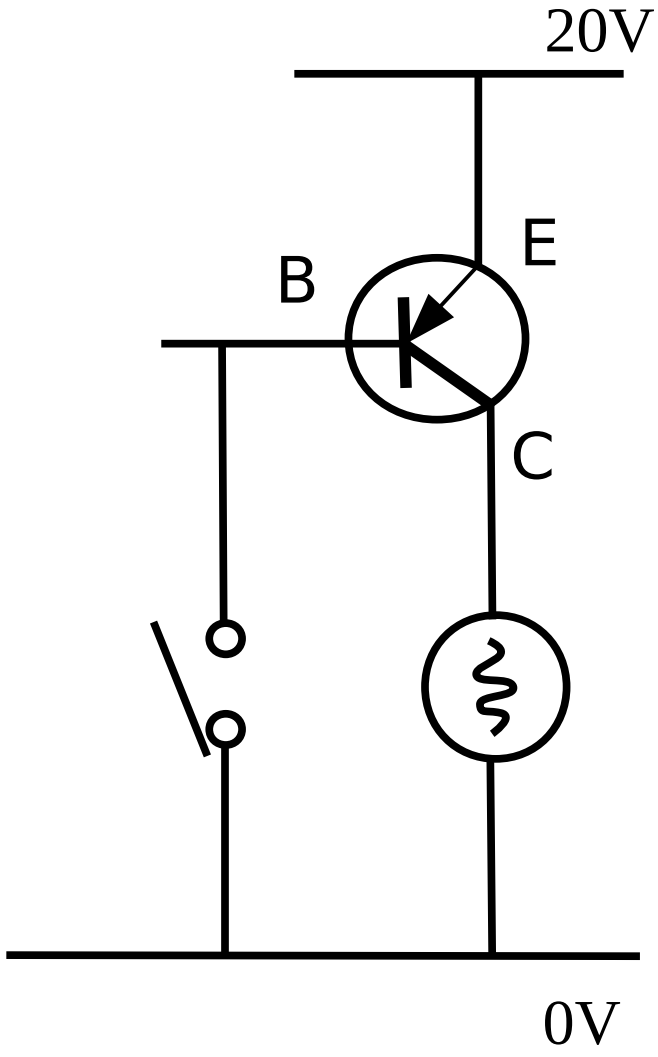
Transistors – The PNP Bipolar Junction Transistor (BJT)

- When the switch is opened...



Transistors – The PNP Bipolar Junction Transistor (BJT)

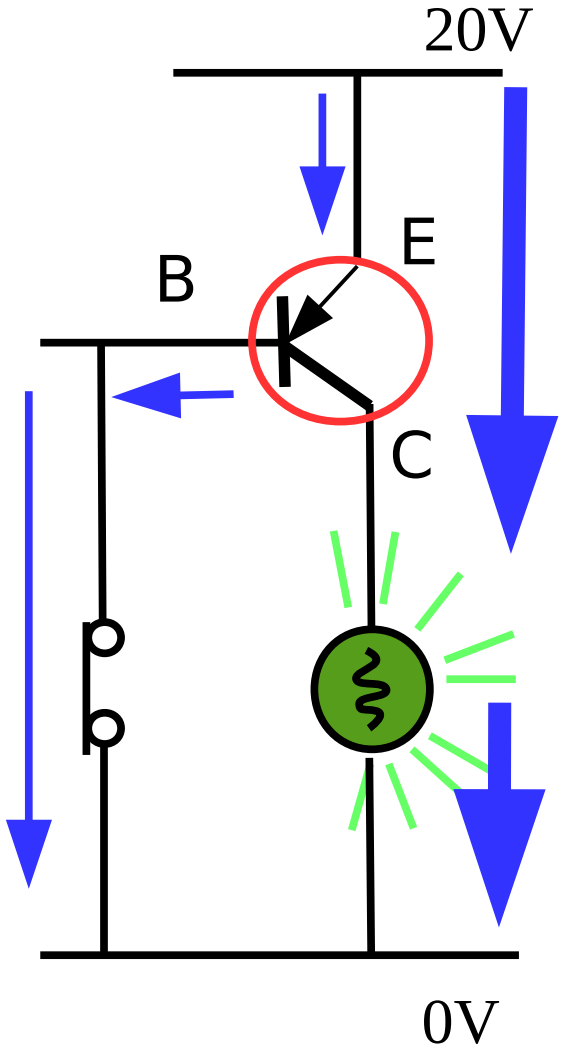
- Remove the base current and the transistor will turn off.



Transistors – The PNP Bipolar Junction Transistor (BJT)

- In summary the the **PNP** transistor will turn **ON** when 0V is applied to the input.

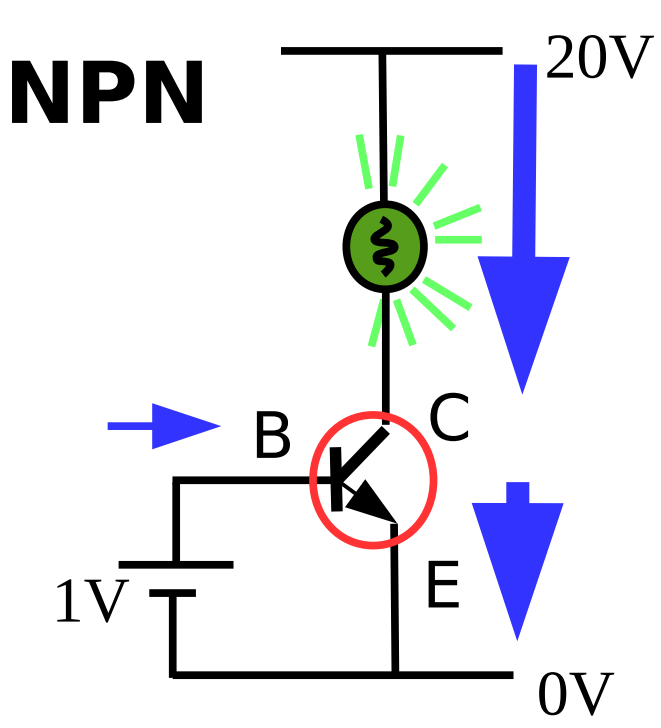
- Which is the **opposite** of how the **NPN** transistor works.

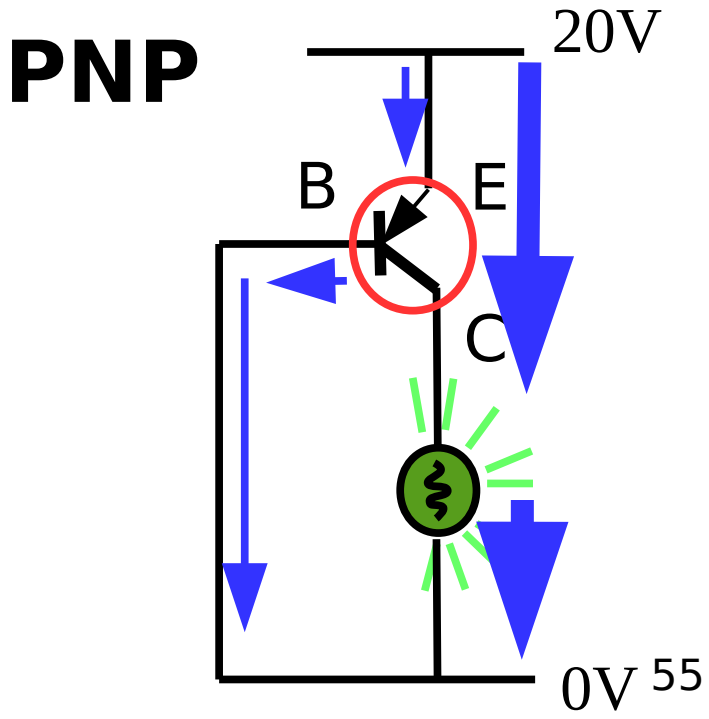


NPN/PNP Bipolar Junction Transistors summary

- We have two transistors the **NPN** that turns **ON** when a positive voltage is applied

- And then **PNP** which turns **ON** when 0V is applied.





Advantages and disadvantages of BJT transitors

- Advantages
  - **They can turn on and off very quickly** – good for audio amplifiers and (Radio Frequency) RF. ✓
  - Low cost. ✓
- Disadvantages
  - They continually need a **base** current to keep them turned on. ✗
  - **Not** so good for switching high currents i.e. running motors. ✗

Outline of the lecture

- **No recap of last lecture :)**

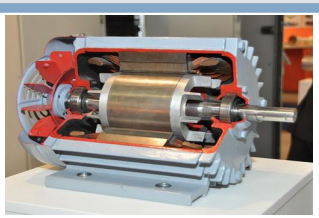
- Transistor basics
  - Relays (Mechanical transistor)
  - NPN Bipolar Junction Transistors
  - PNP Bipolar Junction Transistors
  - **MOSFETs**

  - Push pull pairs to drive MOSFETs

- One last thing

- Summary

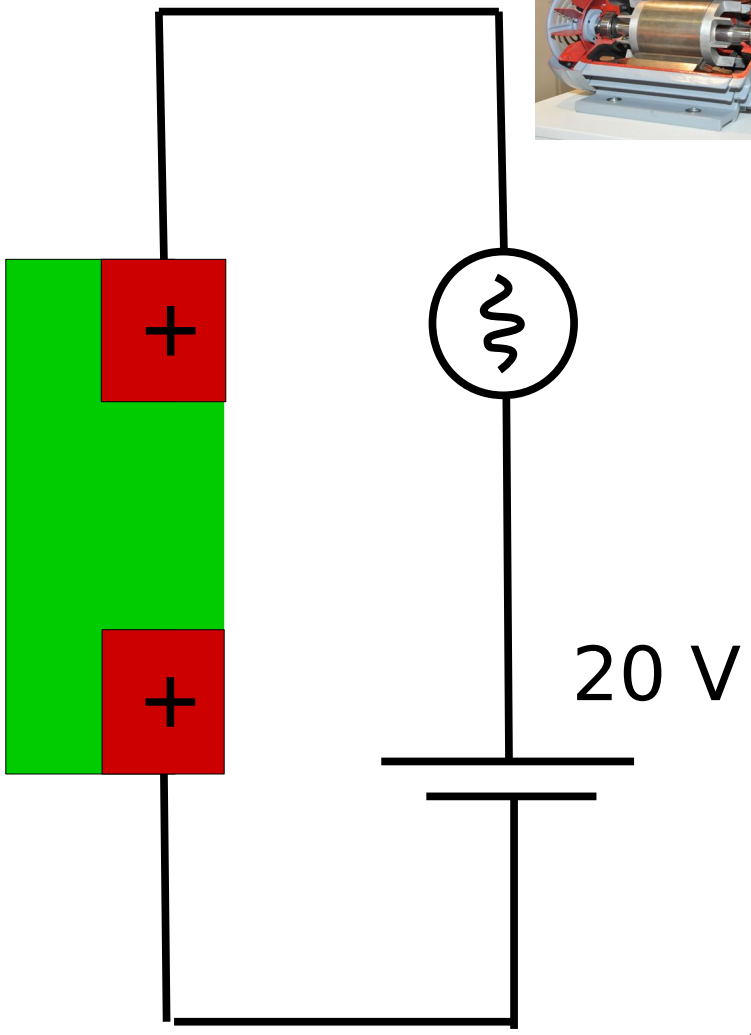
MOSFET (Mattel Oxide Semiconductor Field Effect Transistor)



- Good for **high currents** i.e. running motors.

- MOSFETs consists of two contacts which are made of a material with a positive charge.

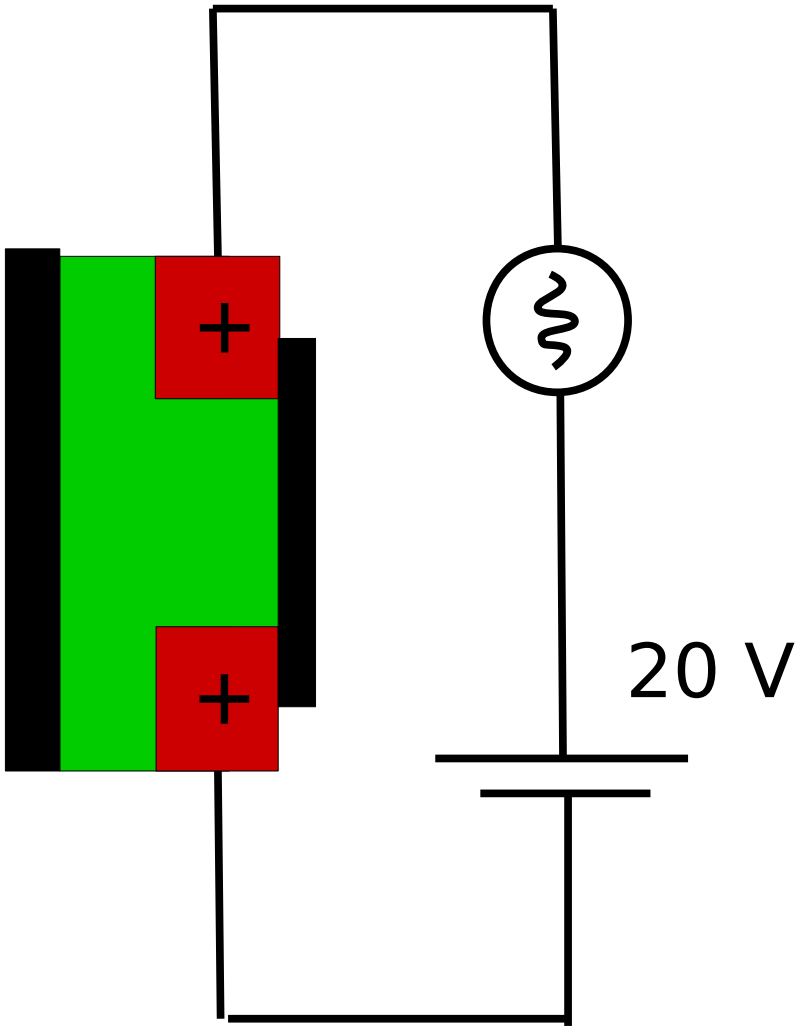
- Between these to contacts is an insulator – **no charge can flow through this layer.**



MOSFET (Mattel Oxide Semiconductor Field Effect Transistor)

- On the edge of our MOSFET we attach two metal plates.

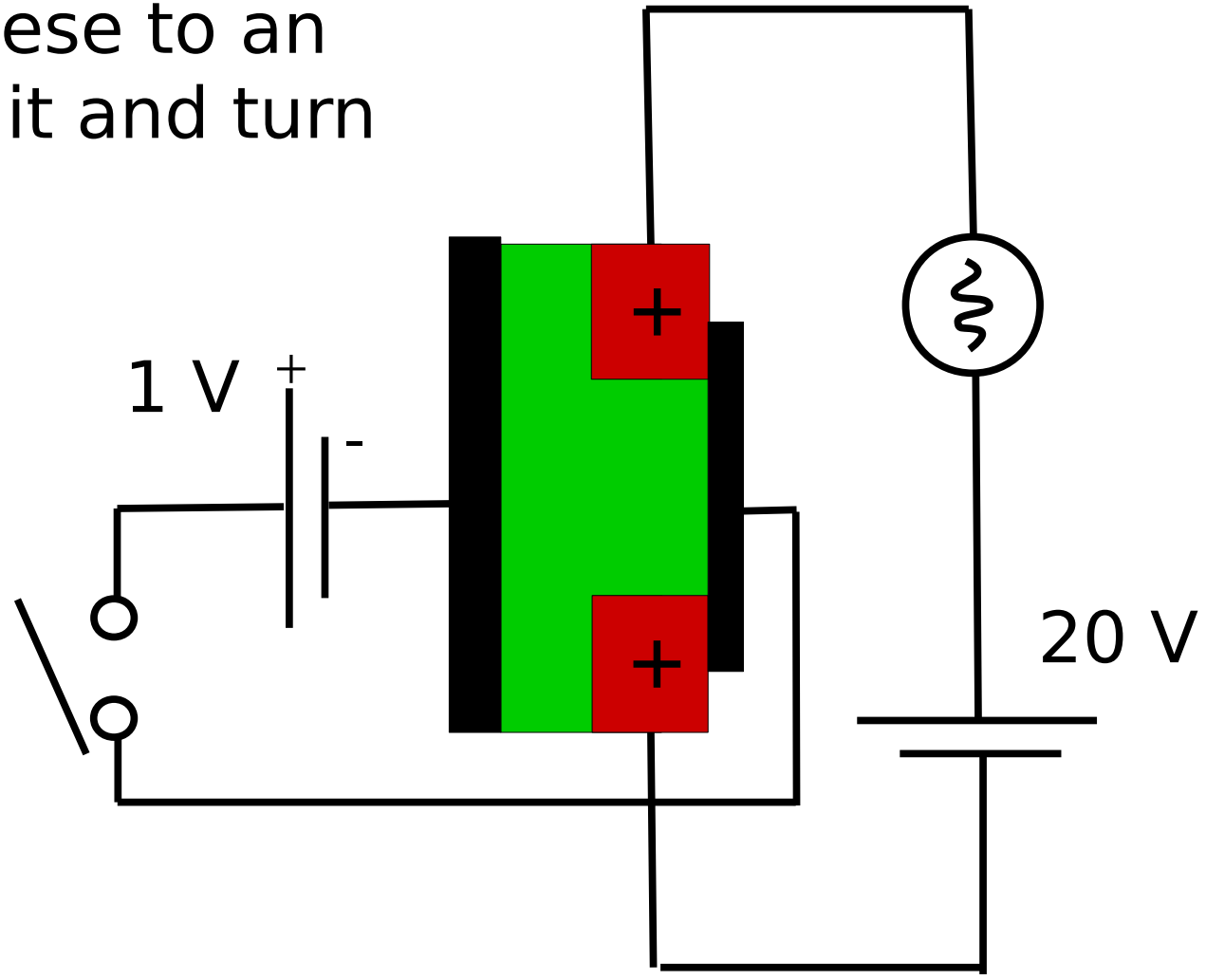
- These act like a capacitor.



MOSFET (Mattel Oxide Semiconductor Field Effect Transistor)

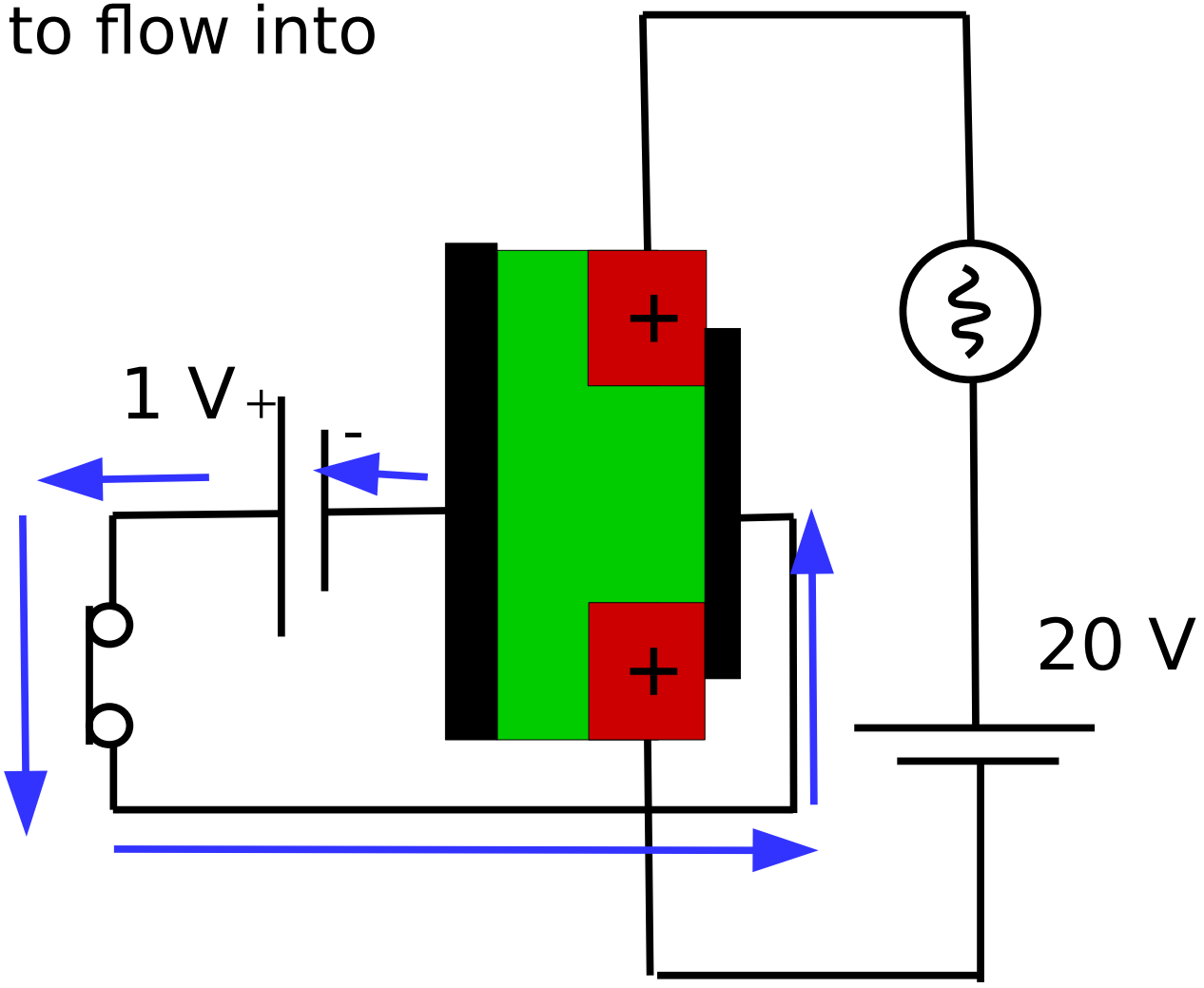
The University of Nottingham

- We attach these to an external circuit and turn it on....



MOSFET (Mattel Oxide Semiconductor Field Effect Transistor)

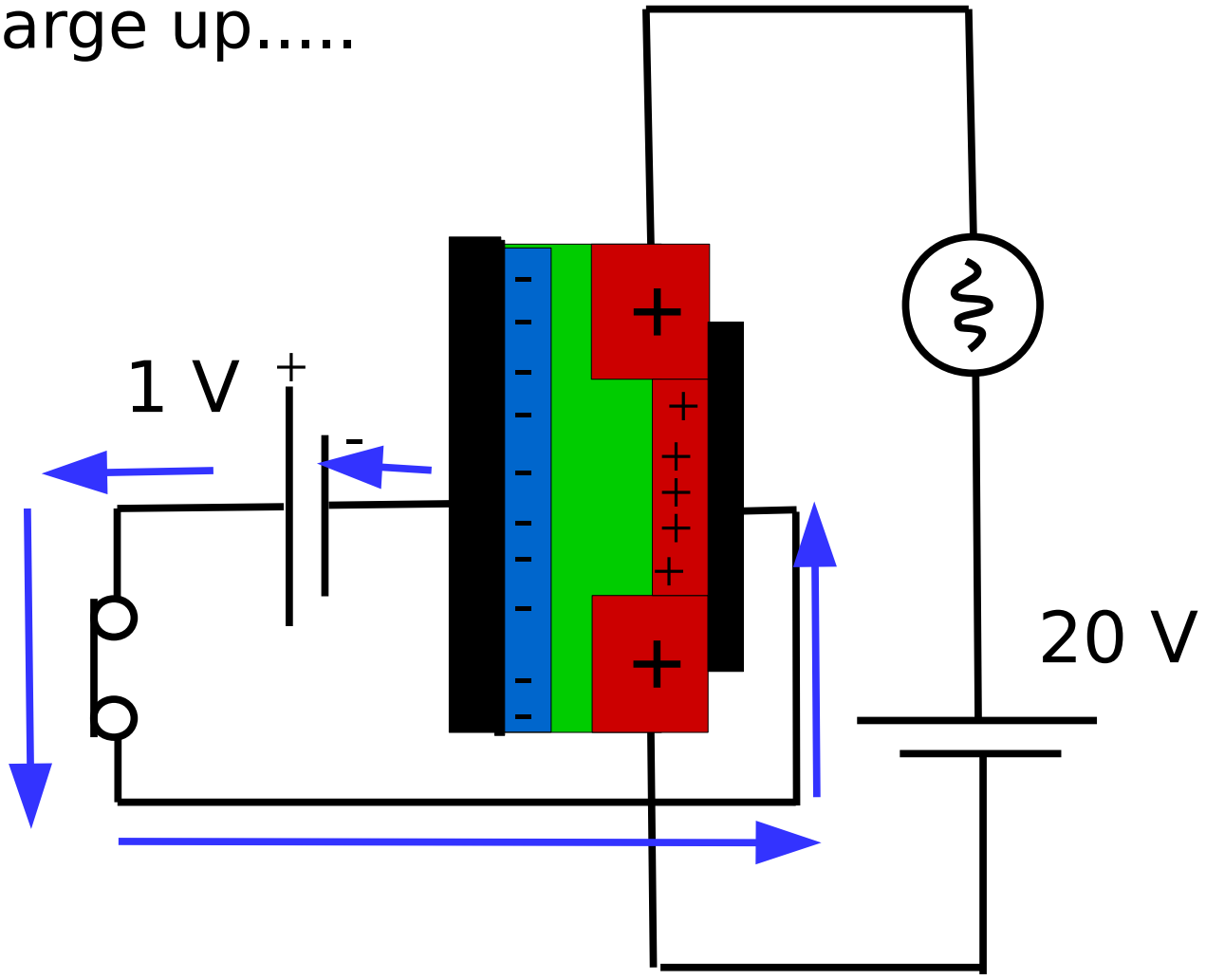
- Charge starts to flow into the capacitor.



MOSFET (Mattel Oxide Semiconductor Field Effect Transistor)

The University of Nottingham

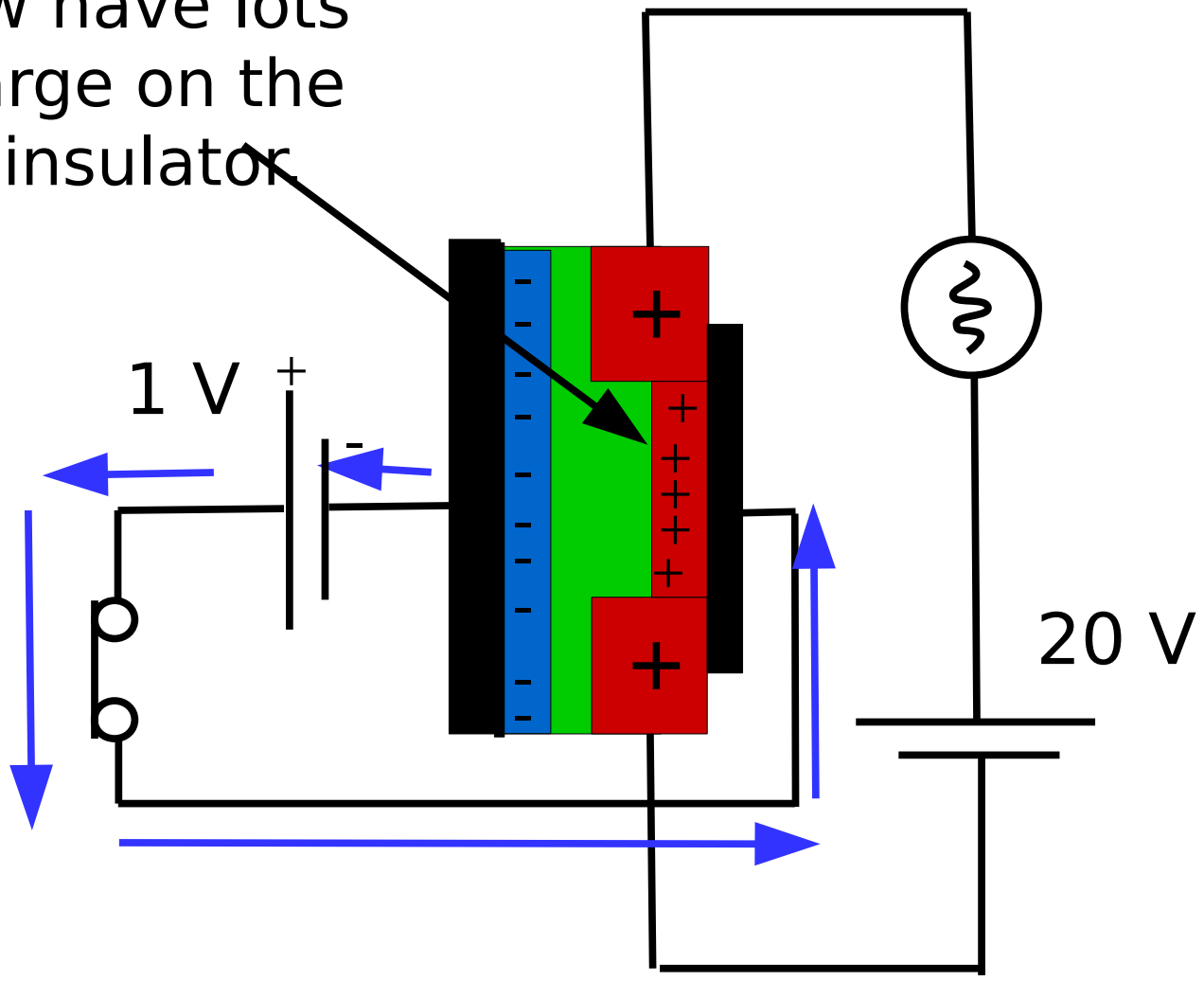
- The plates charge up.....



MOSFET (Mattel Oxide Semiconductor Field Effect Transistor)

The University of Nottingham

- Notice we now have lots of positive charge on the surface of the insulator.

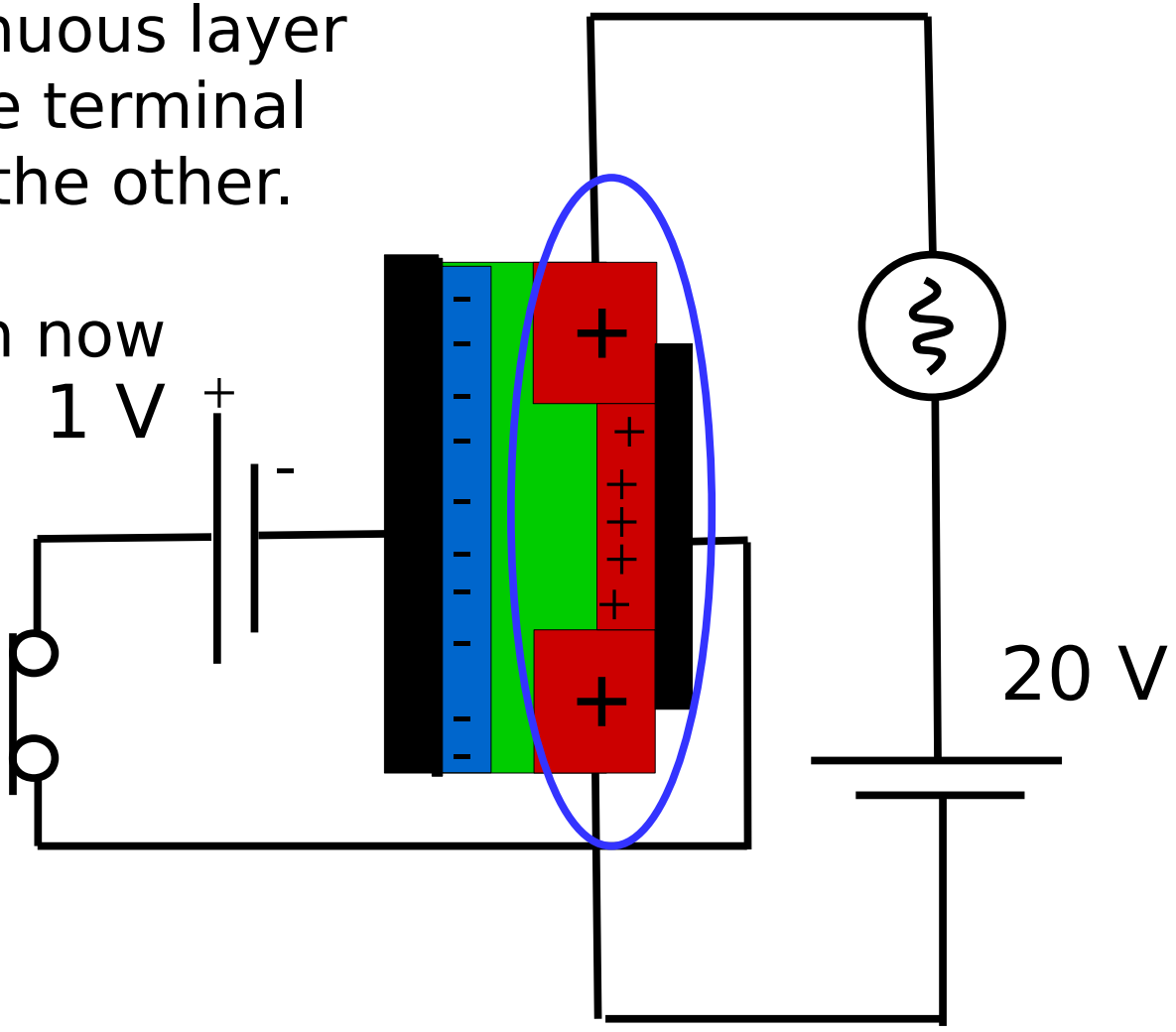


MOSFET (Mattel Oxide Semiconductor Field Effect Transistor)

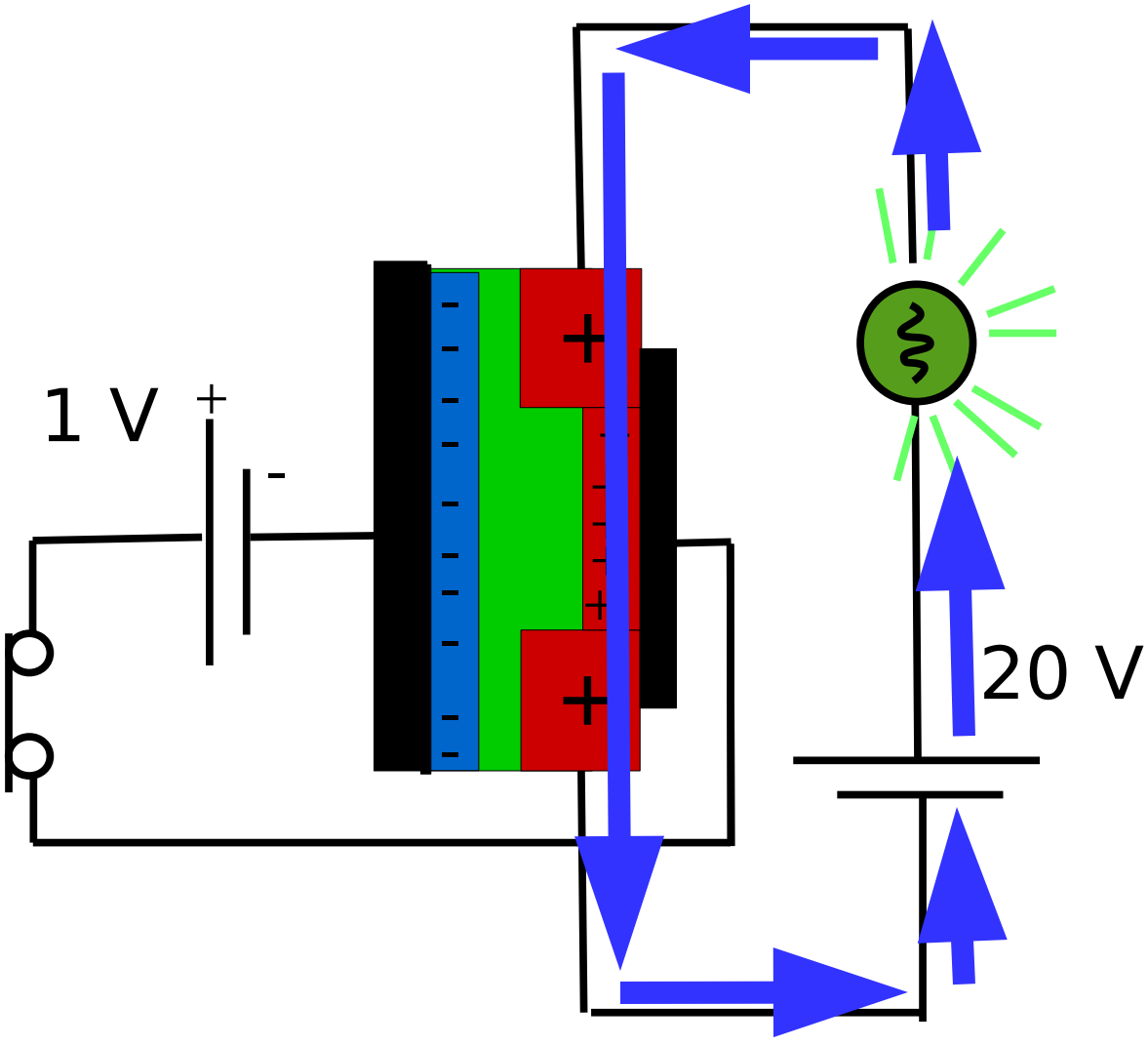
The University of Nottingham

- And have a continuous layer of charge from one terminal of the MOSFET to the other.

- The transistor can now conduct current.



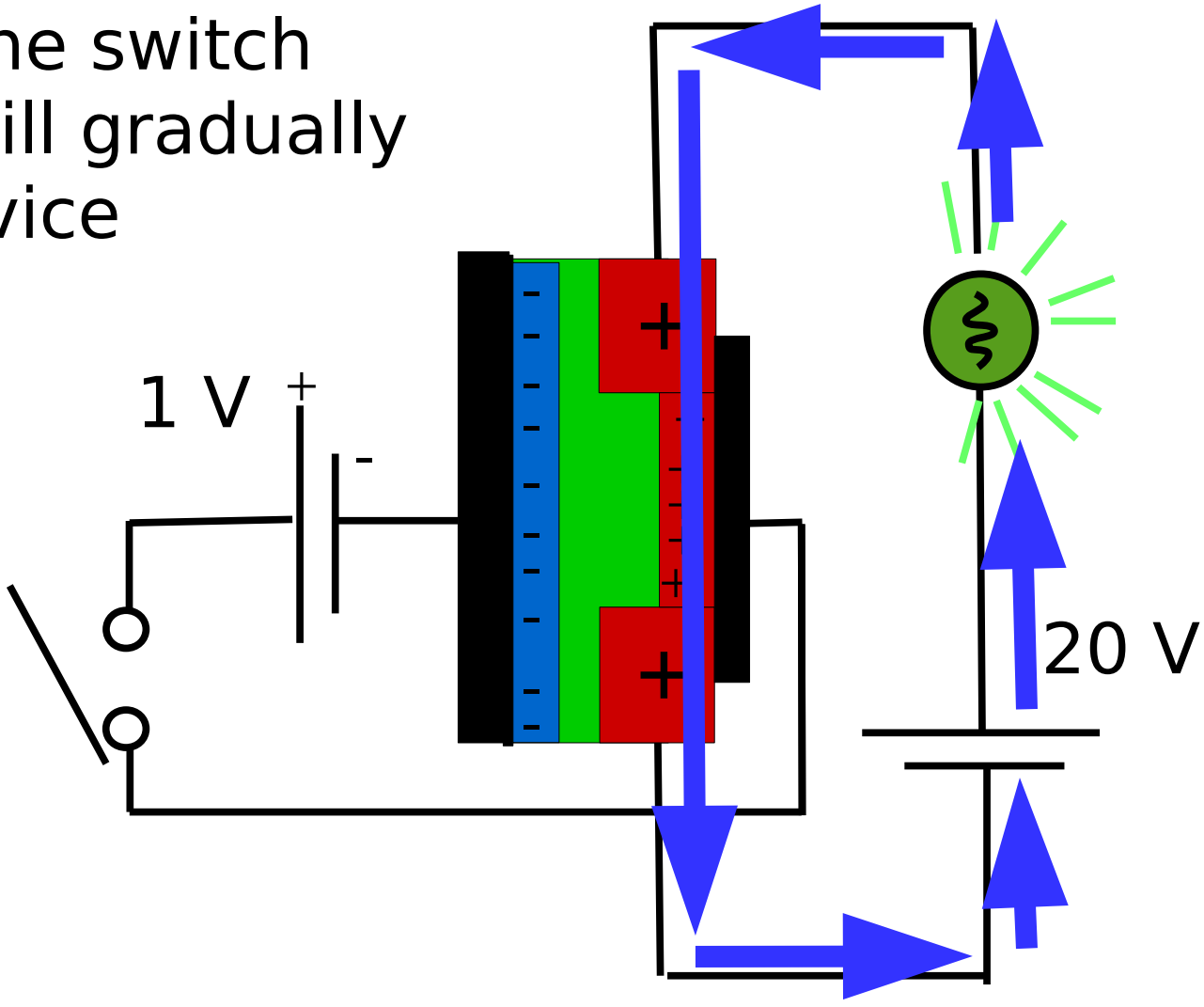
MOSFET (Mattel Oxide Semiconductor Field Effect Transistor)



MOSFET (Mattel Oxide Semiconductor Field Effect Transistor)

The University of Nottingham

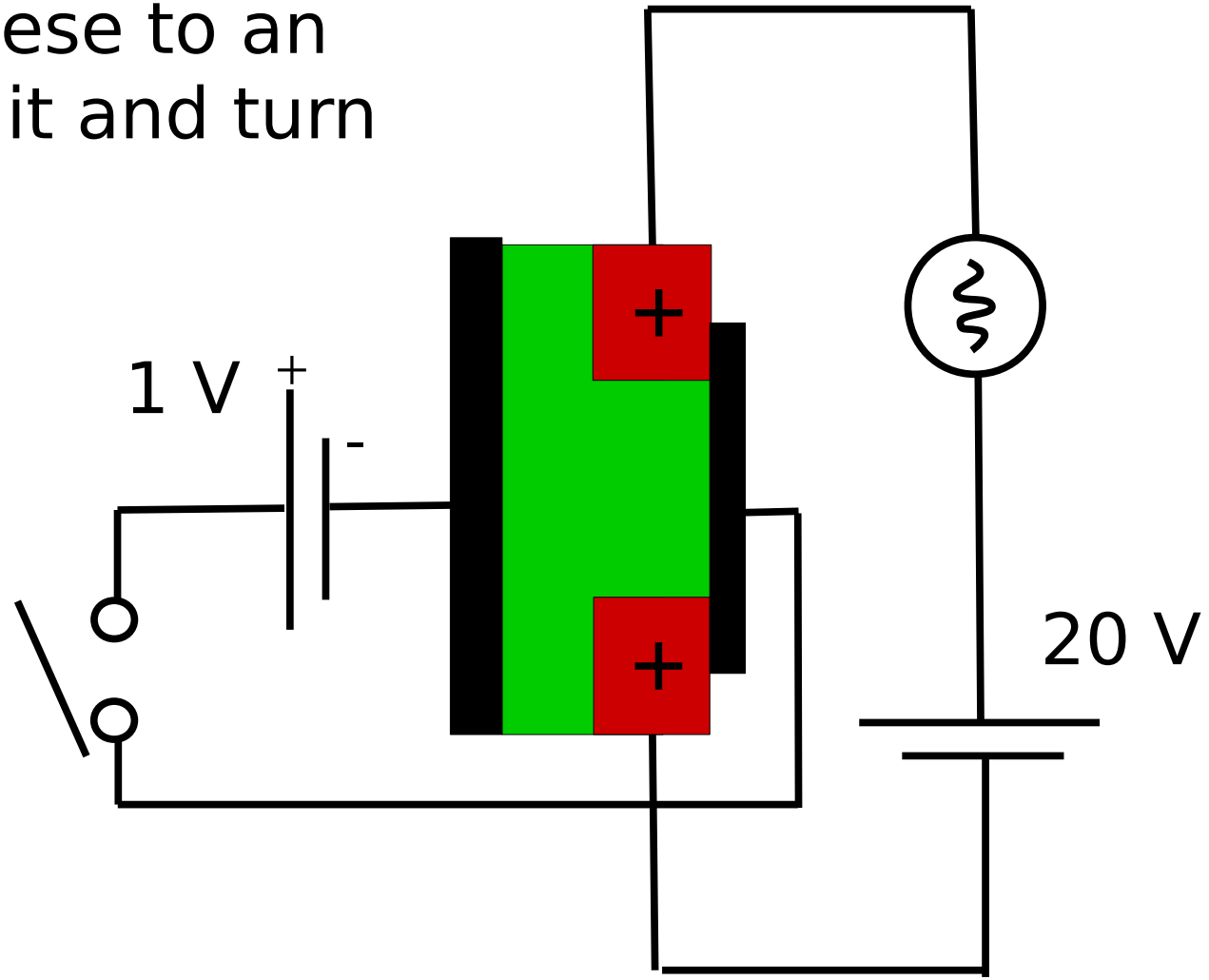
- If we open the switch the charge will gradually leave the device (eventually).



MOSFET (Mattel Oxide Semiconductor Field Effect Transistor)

The University of Nottingham

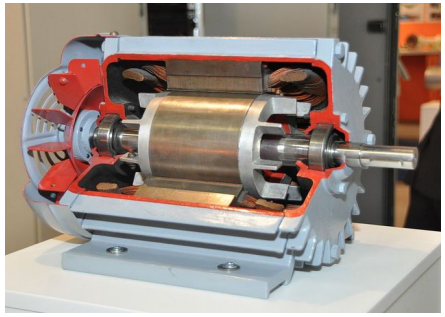
- We attach these to an external circuit and turn it on....

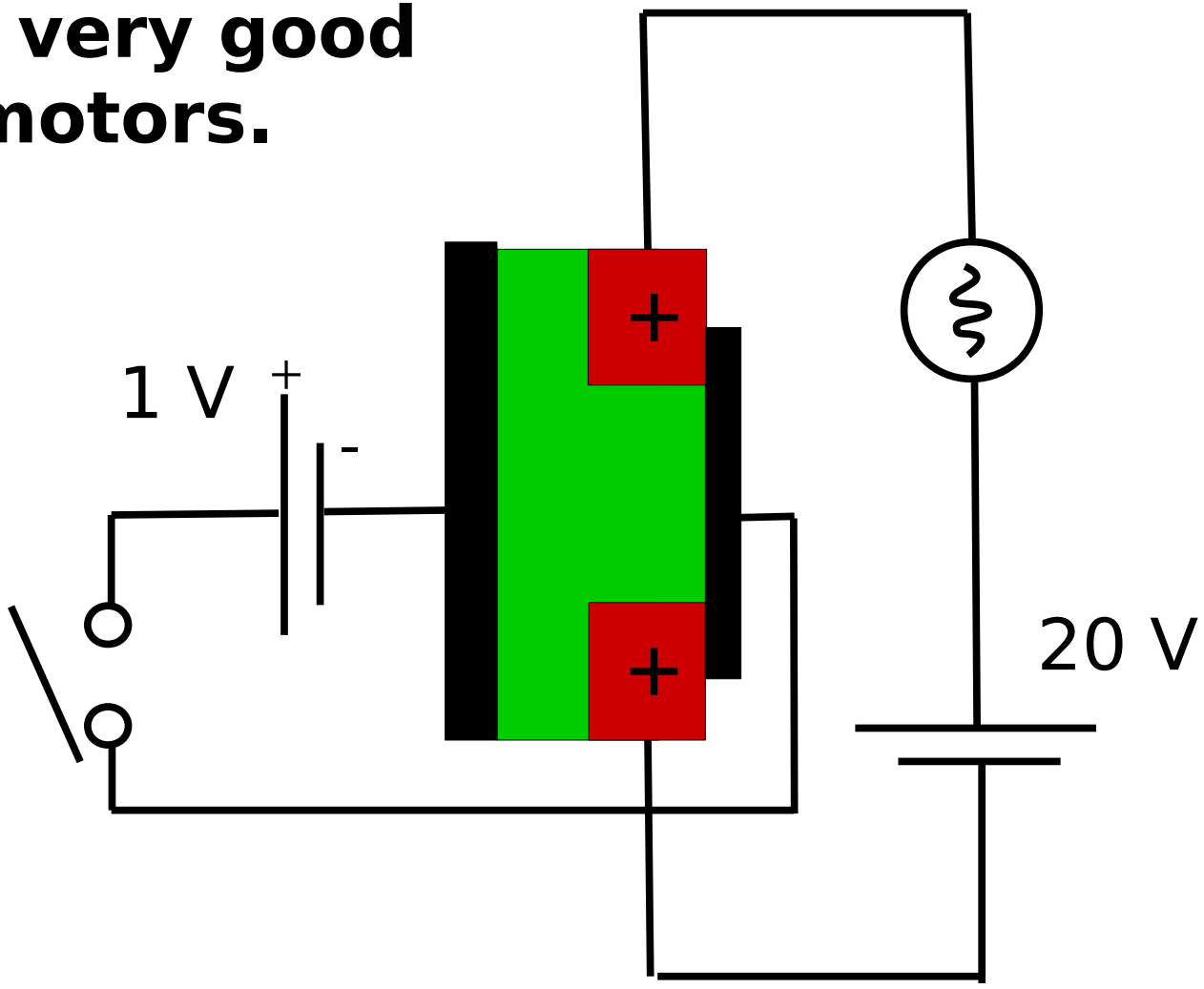


MOSFET (Mattel Oxide Semiconductor Field Effect Transistor)

The University of Nottingham

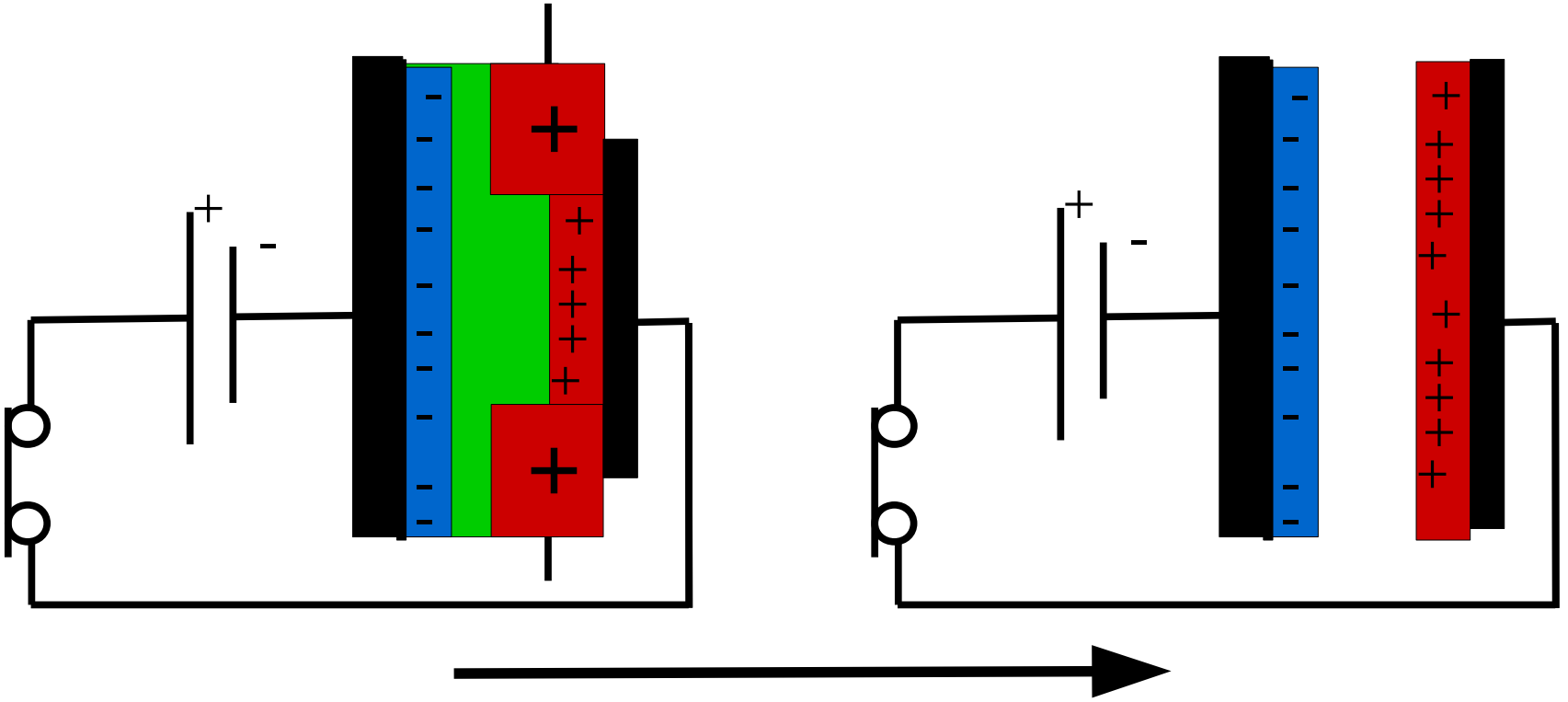
- MOSFETs are **very good for driving motors.**





The problem with MOSFETs

- The problem with MOSFETs is that they are in effect a capacitor

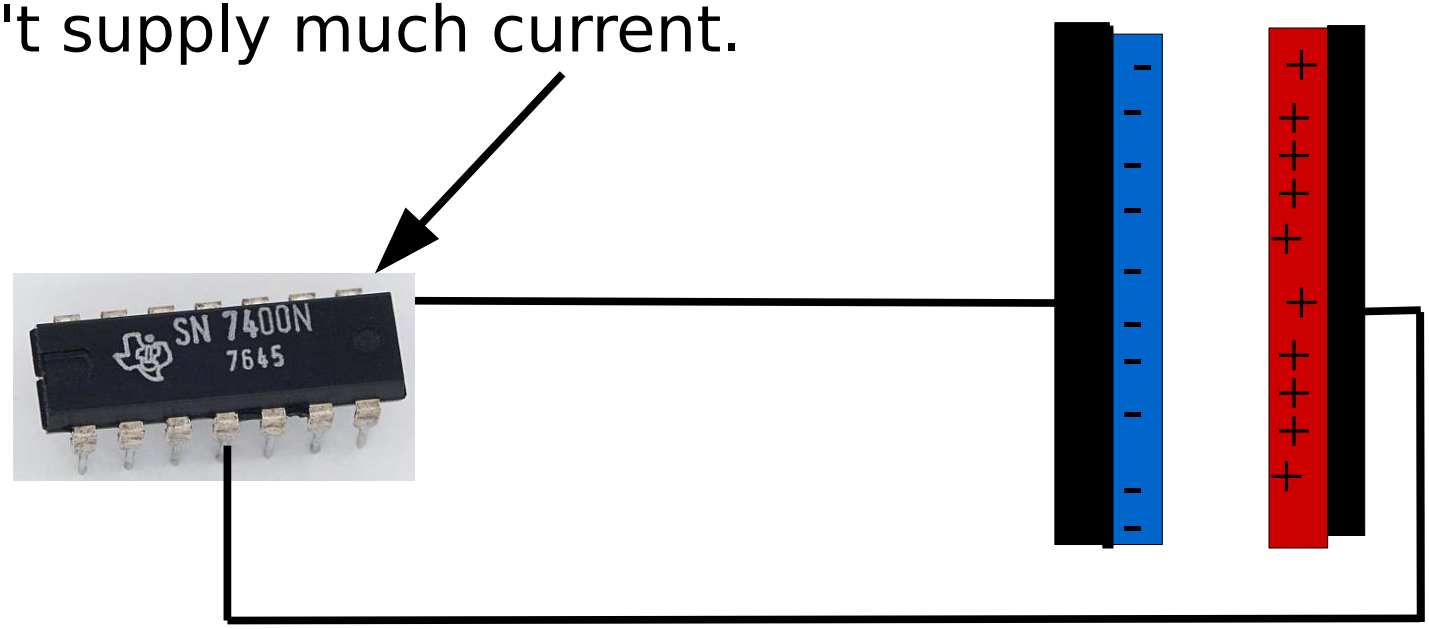


The problem with MOSFETs

The University of Nottingham

- And capacitors take a long time to charge up.

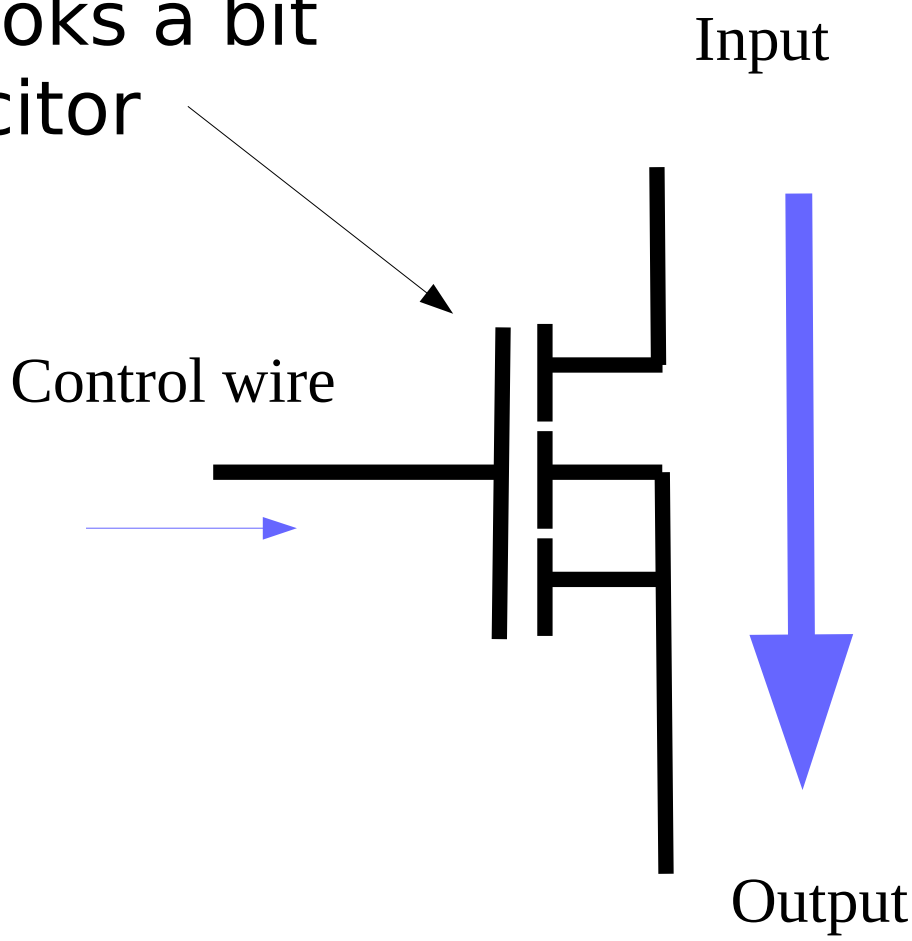
- Especially if you are driving it from a tiny chip that can't supply much current.



- This means they will **turn off and on really really slowly in fact too slowly to do anything useful.....**

Circuit symbol for a MOSFET

- Notice it looks a bit like a capacitor



Outline of the lecture

- No recap of last lecture :)
- Turning things on and off
  - Relays
  - NPN Bipolar Junction Transistors
  - PNP Bipolar Junction Transistors
  - MOSFETs
- **Push pull pairs to drive MOSFETs**
- One last thing
- Summary

Question:

- Q: What type of transistors turn on and off very quickly??

Question:

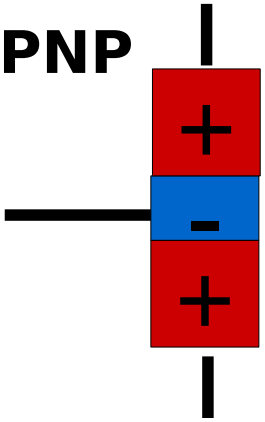
- Q: What type of transistors turn on and off very quickly??

- A: Bipolar Junction transistor

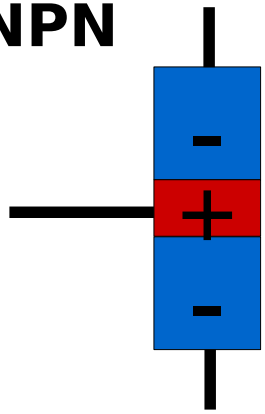
Two types of transistor

Bipolar Junction transistors: Fast / not very good for high currents

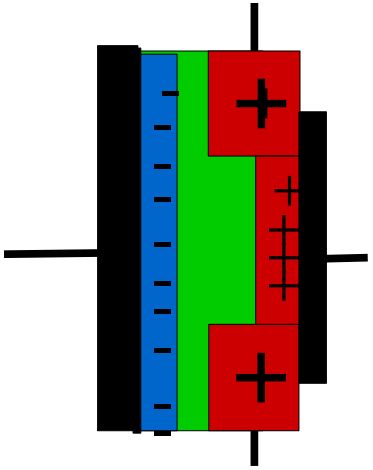
PNP



NPN

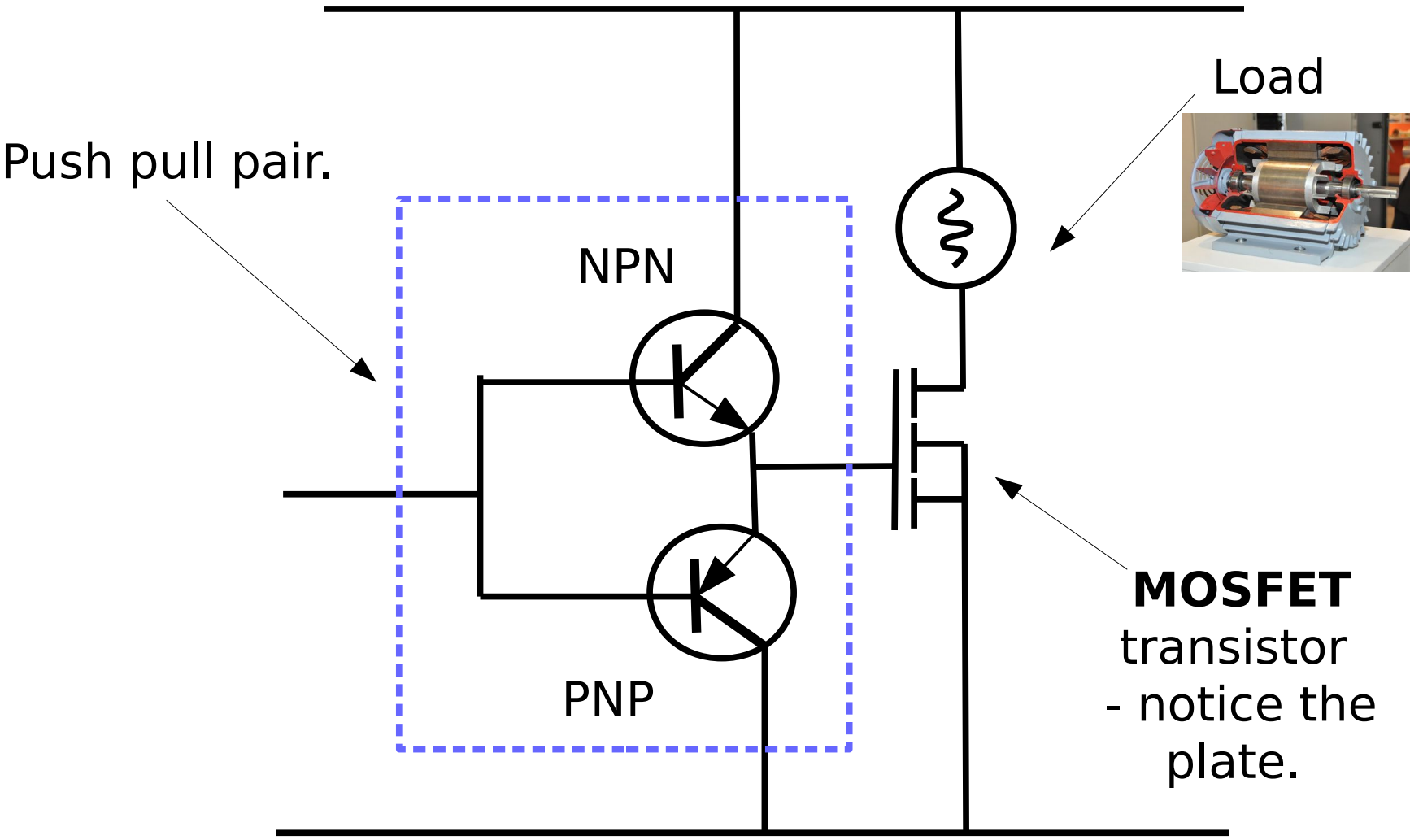


MOSFET: Slow to turn on and off/ But good for motors.



•May be we can combine these transistors to make an optimum circuit to switch high current devices on and off.....

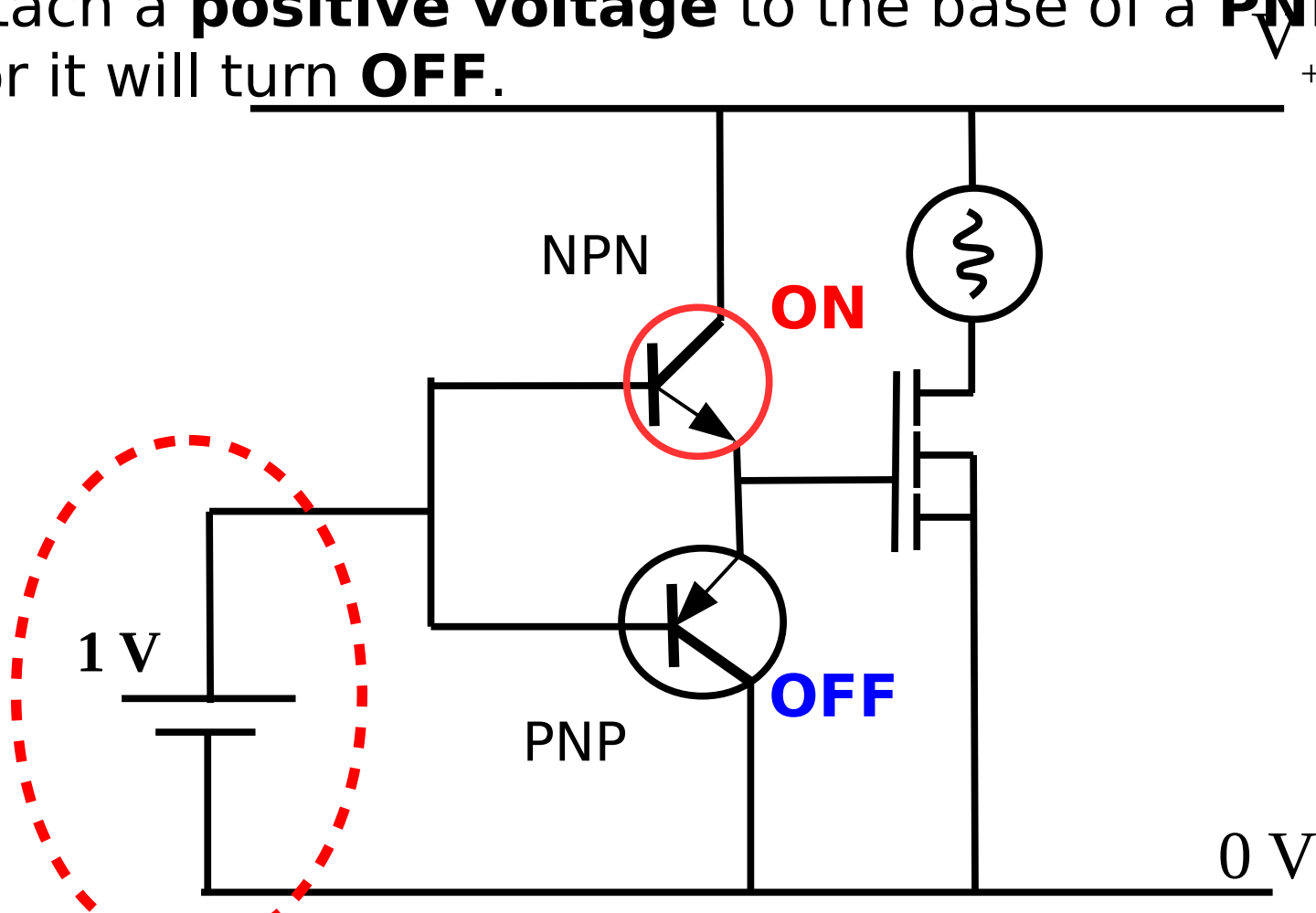
Yes, we can and the circuit looks like this.... a push pull pair circuit...



Push pull pair – turning the MOSFET ON

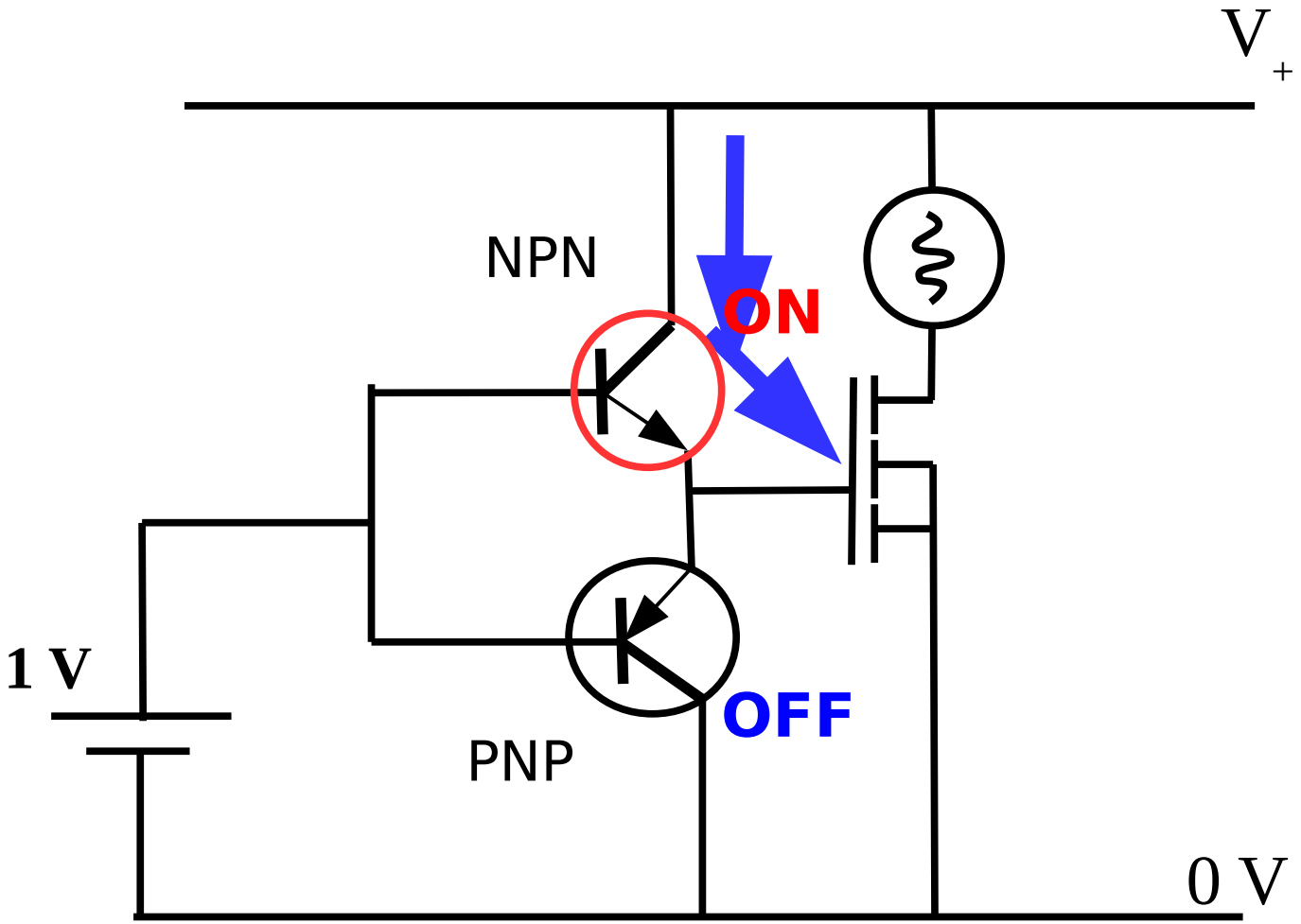
- If we attach a **positive voltage** to the base of an **NPN** transistor it will turn **ON**.

- If we attach a **positive voltage** to the base of a **PNP** transistor it will turn **OFF**.



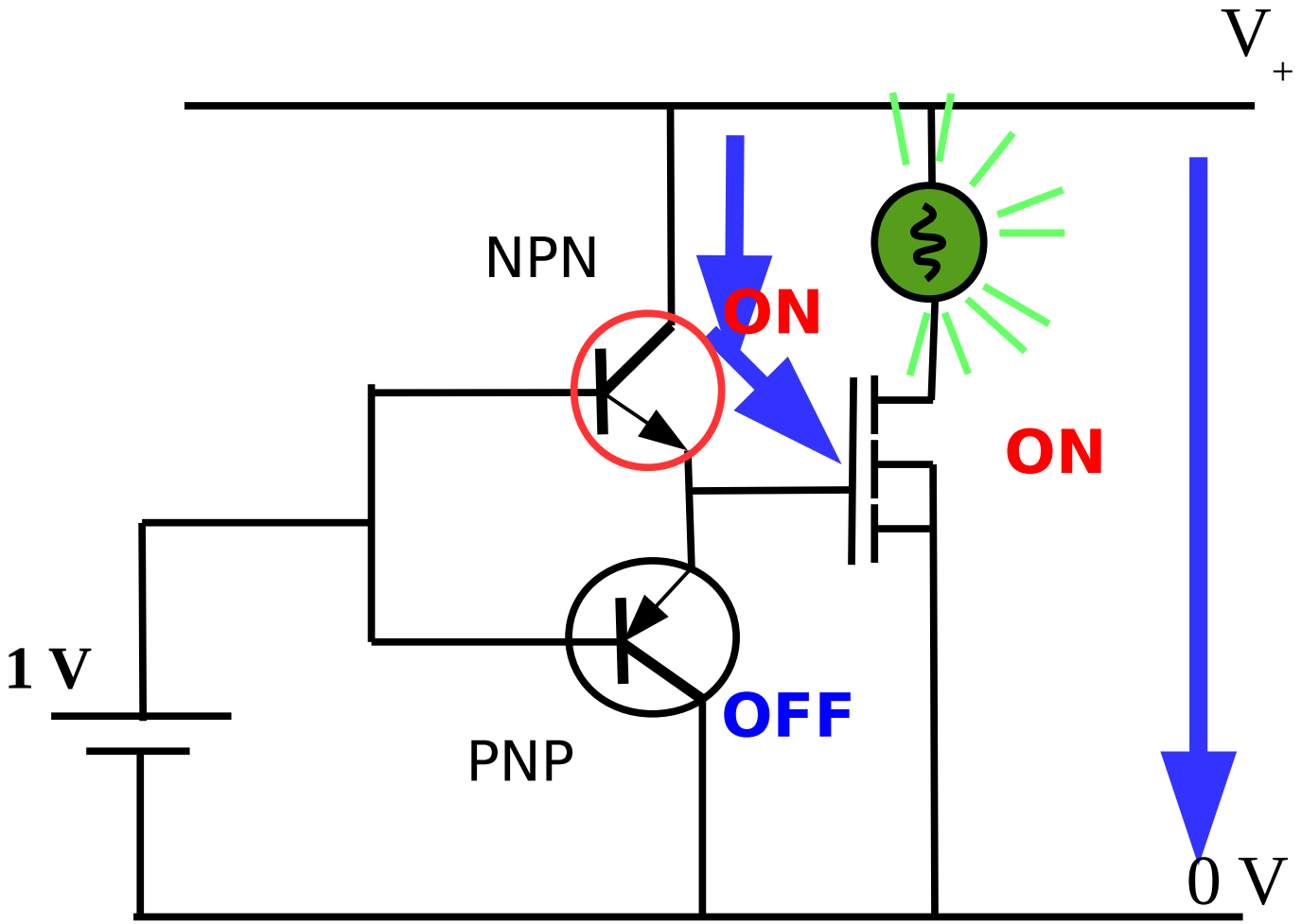
Push pull pair – turning the MOSFET ON

•This will allow charge to flow through the NPN transistor, to the gate of the MOSFET



Push pull pair – turning the MOSFET ON

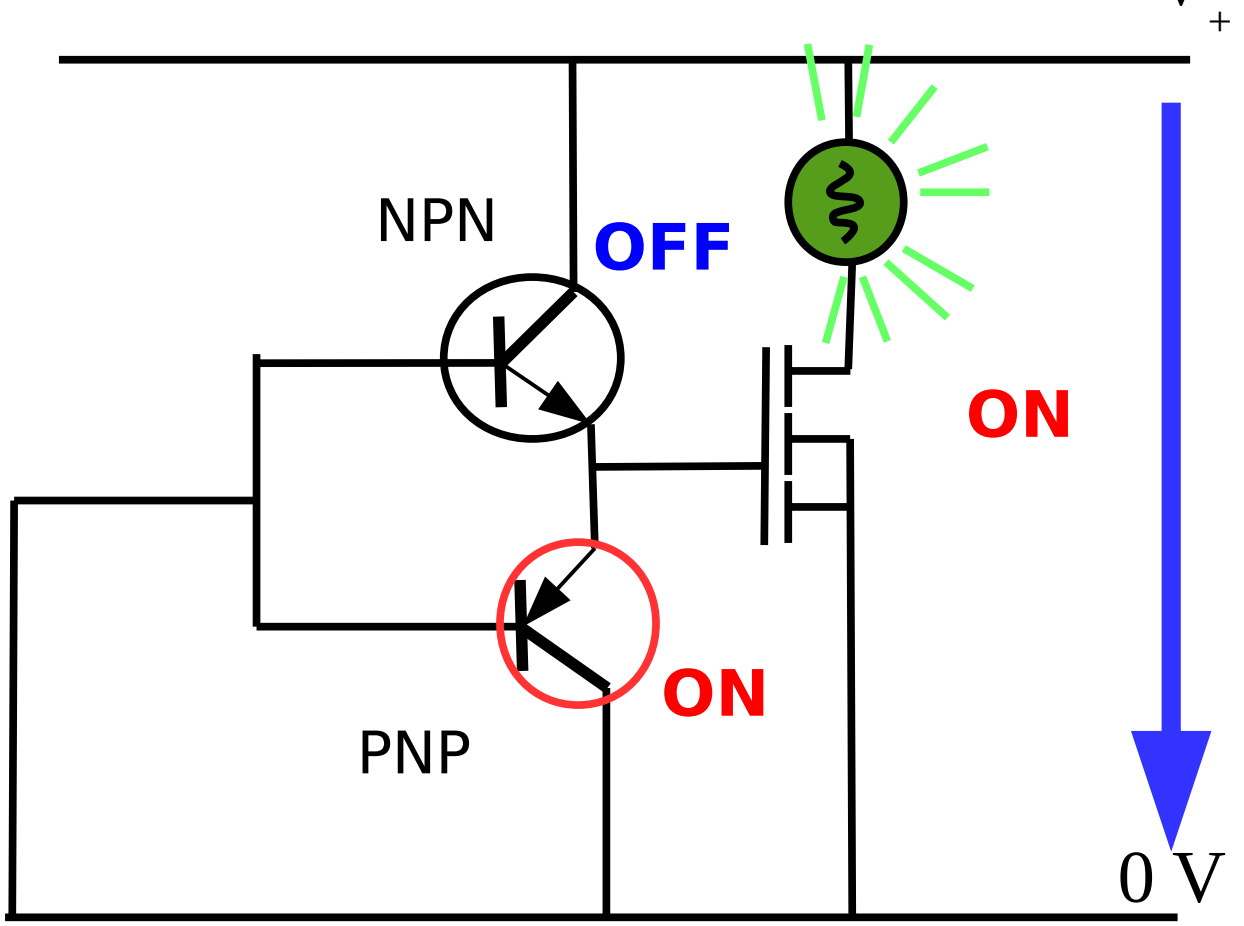
- And the MOSFET will turn ON!



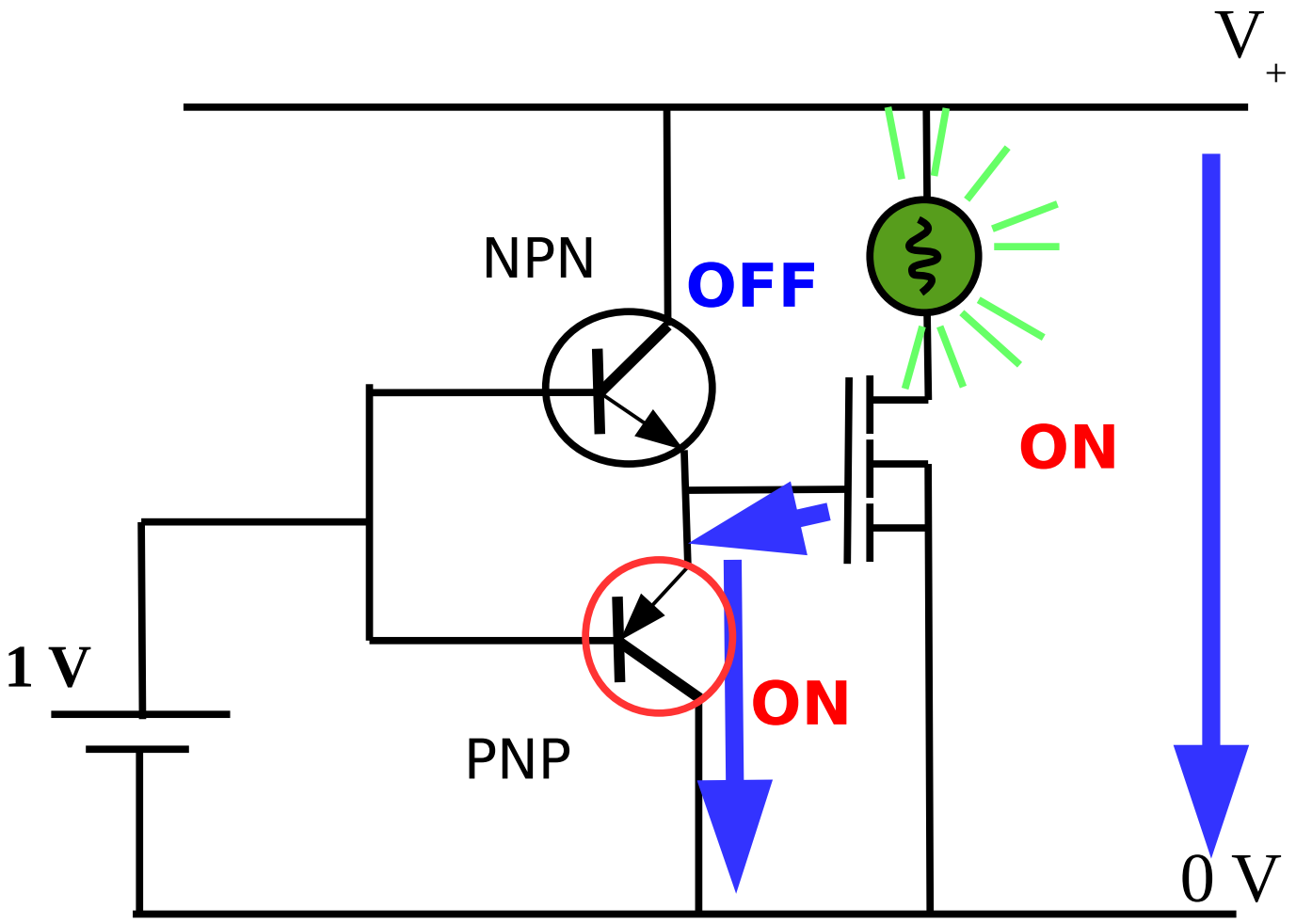
Push pull pair – turning the MOSFET OFF

- If we attach a **0 Volts** to an **NPN** transistor it will turn **OFF**.

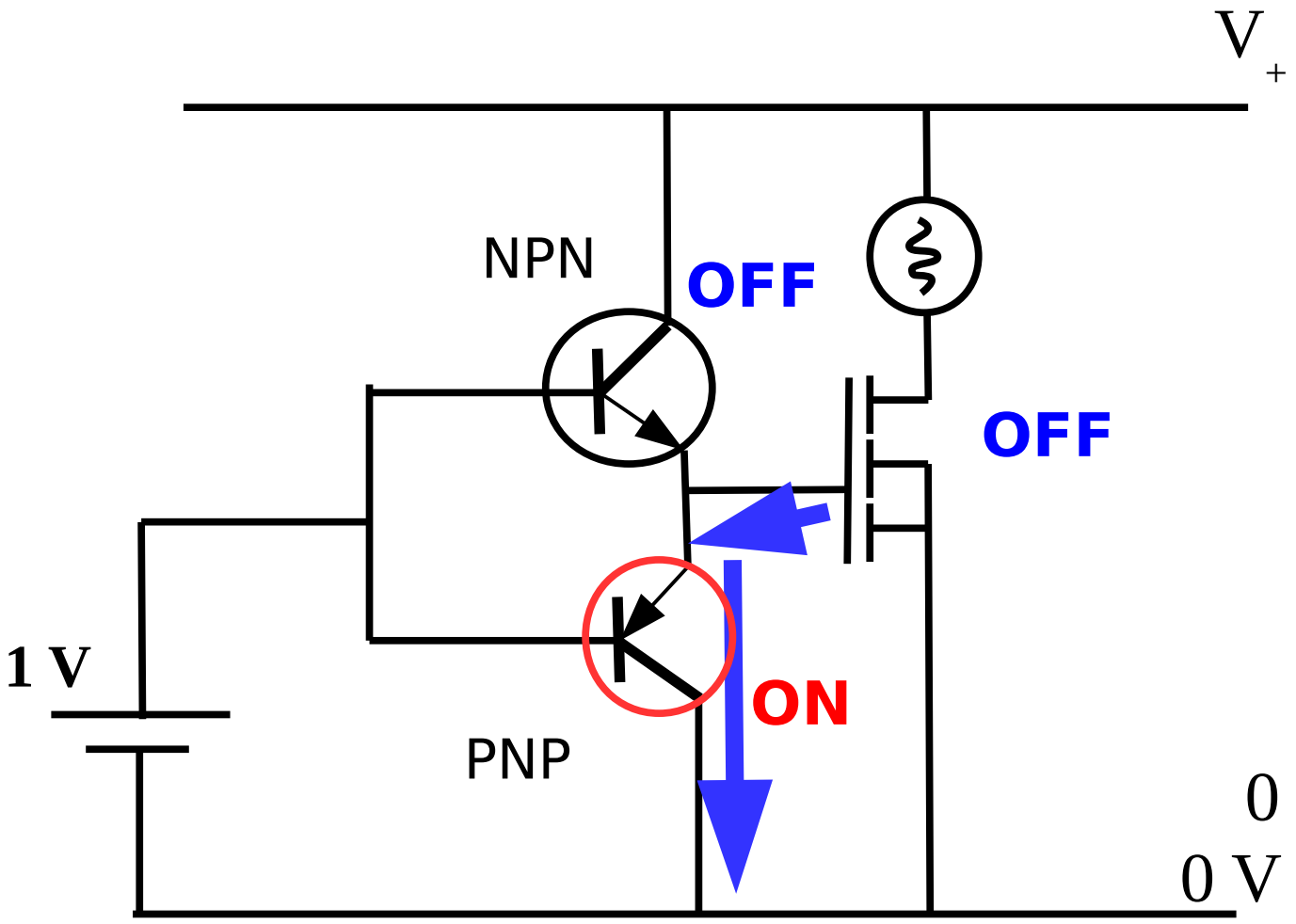
- If we attach **0 Volts** to a **PNP** transistor it will turn **ON**.



Push pull pair – turning the MOSFET OFF



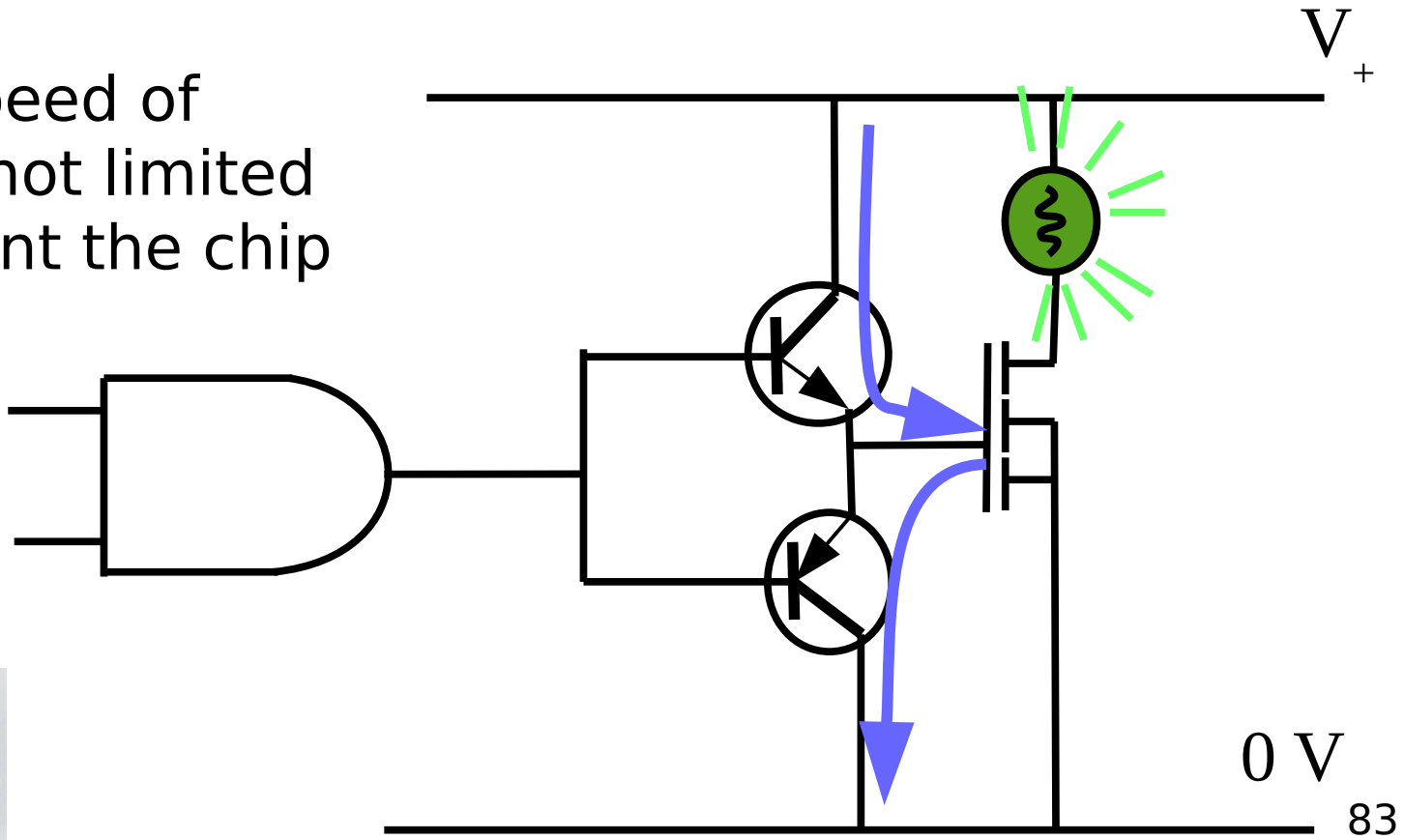
Push pull pair – turning the MOSFET OFF

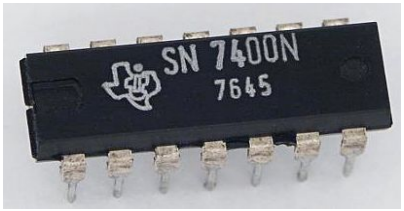


Notice...

- The current to charge and discharge our MOSFET does not come from the chip it comes directly from the power supply.

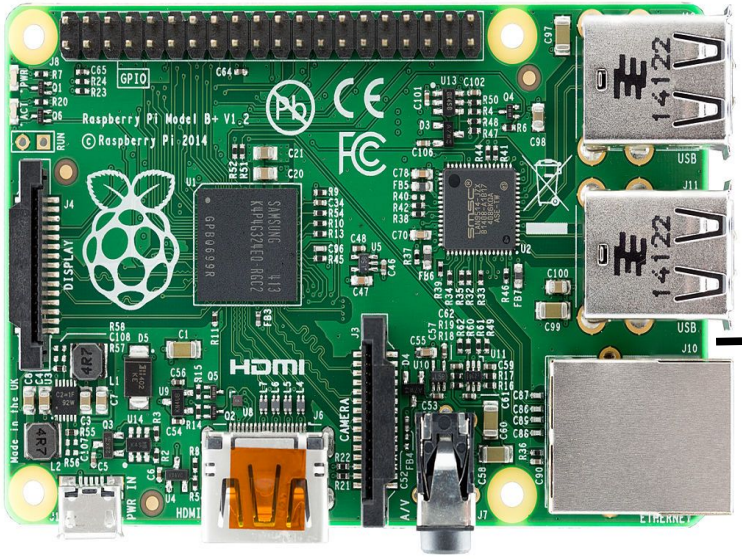
- Thus the speed of charging is not limited by the current the chip can supply.

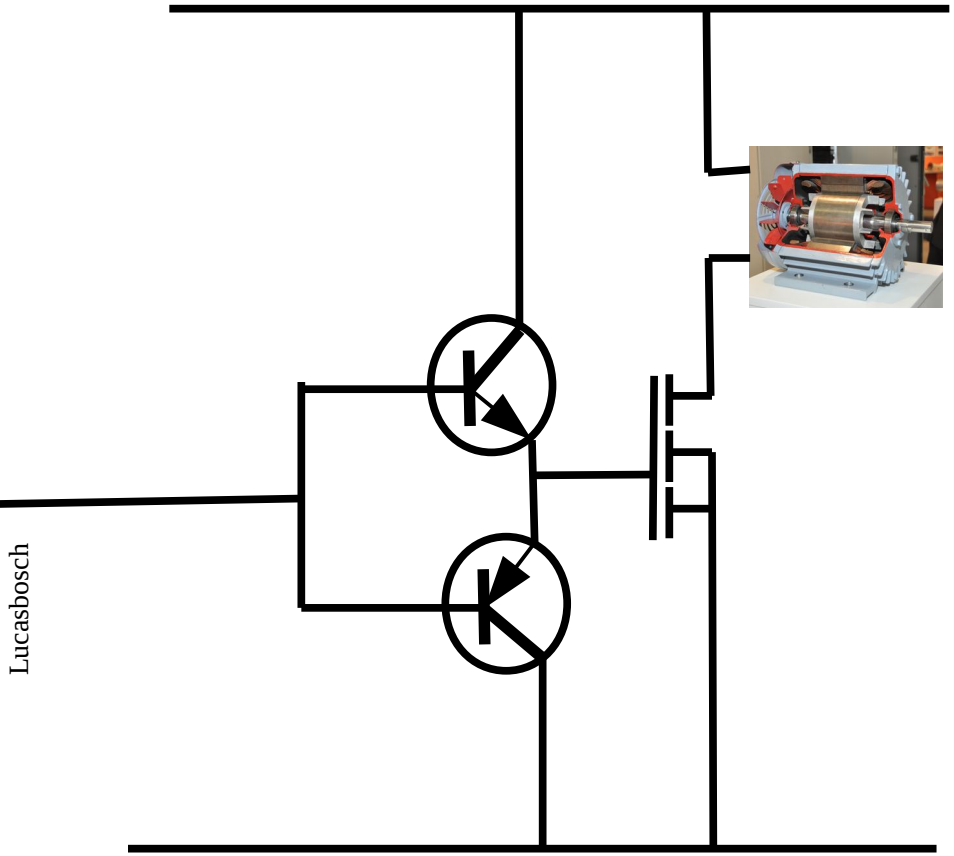




Push-pull pair

- This now means that we can now use any digital circuit such as a microcomputer to turn of big loads such as a motor **FAST**.





Outline of the lecture

- No recap of last lecture :)

- Transistor basics
  - Relays (Mechanical transistor)
  - NPN Bipolar Junction Transistors
  - PNP Bipolar Junction Transistors
  - MOSFETs

  - Push pull pairs to drive MOSFETs

- **One last thing**

- Summary

Outline of the lecture

- No recap of last lecture :)

- Transistor basics
  - Relays (Mechanical transistor)
  - NPN Bipolar Junction Transistors
  - PNP Bipolar Junction Transistors
  - MOSFETs

- Push pull pairs to drive MOSFETs

- **One last thing**

- **Summary**