University of Nottingham

Electromechanical devices MM2EMD

Lecture 6 – Diodes (How to power my device I have just designed).

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@rcimackenzie

Outline of the lecture

- **Recap of last lecture**
- Introduction to diodes
- Power diodes – the basics.
- Designing a power supply
  - Diodes the bridge between AC and DC
- The less ideal diode
- Other kinds of diodes including Solar cells
- Summary

Recap: Being able to measure acceleration is important

$$\int acceleration\, dt = velocity$$

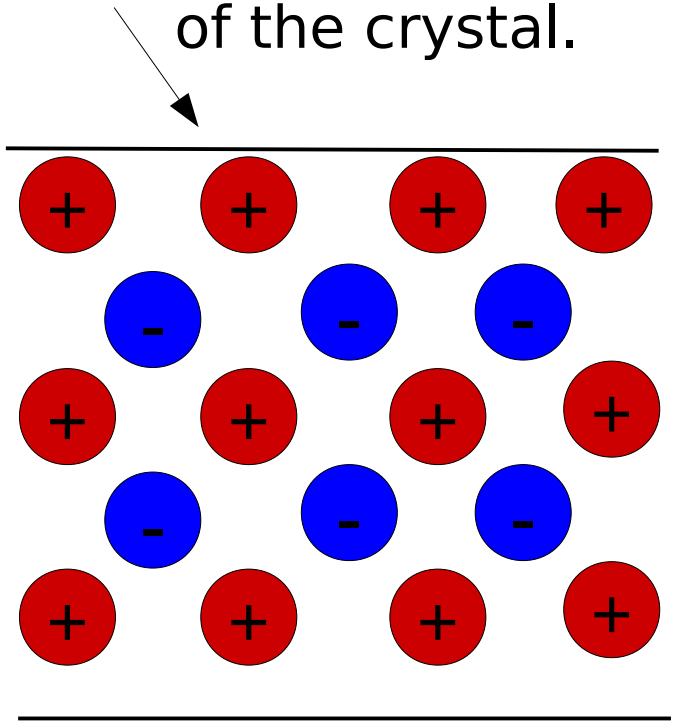
$$\int velocity\, dt = position$$

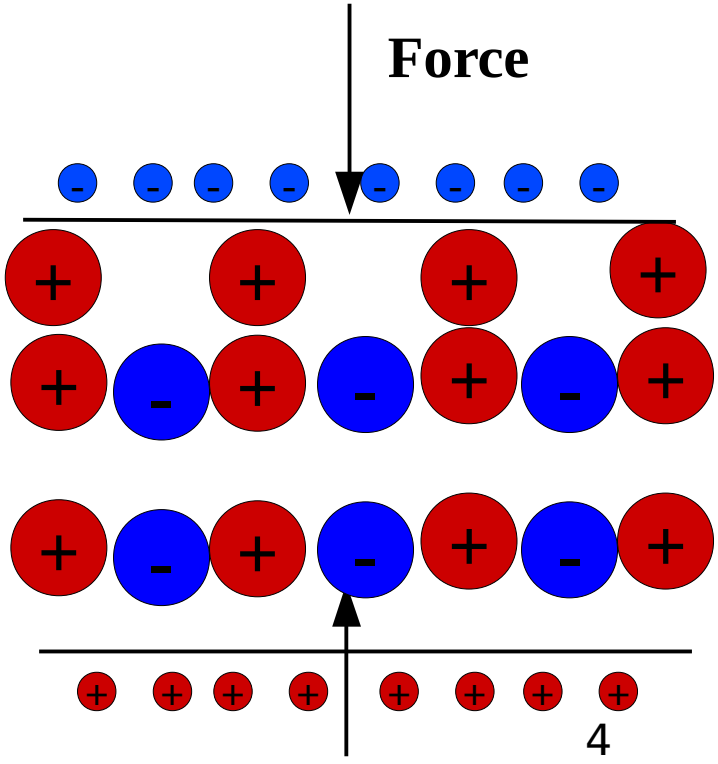
Recap: Quartz for measuring acceleration


JJ Harrison

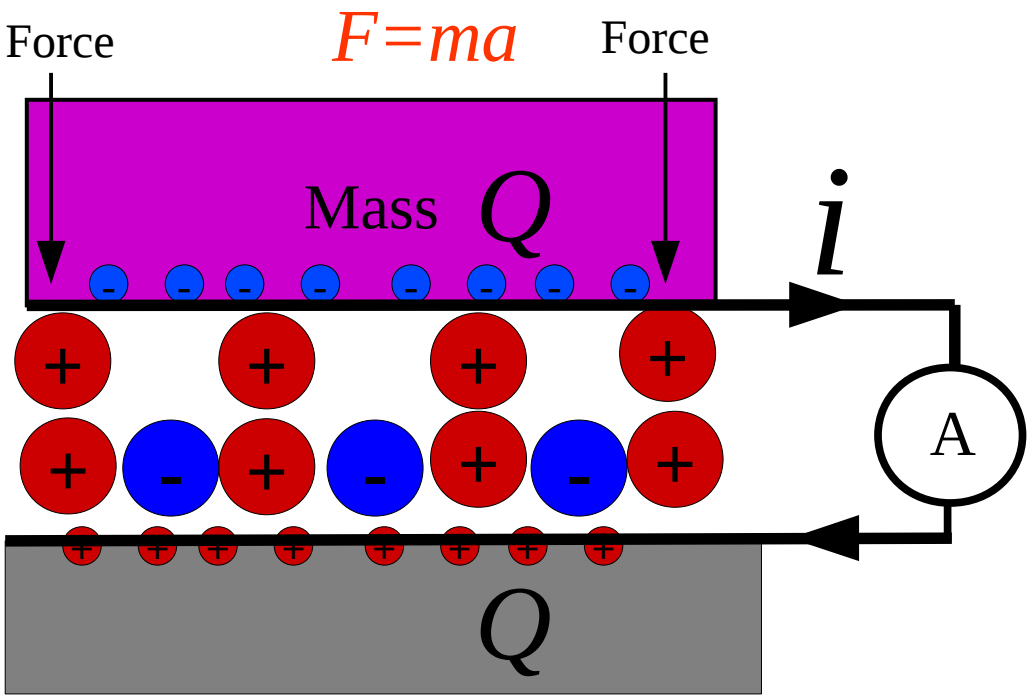
- Normally quartz has a regular arrangement of positive and negative ions

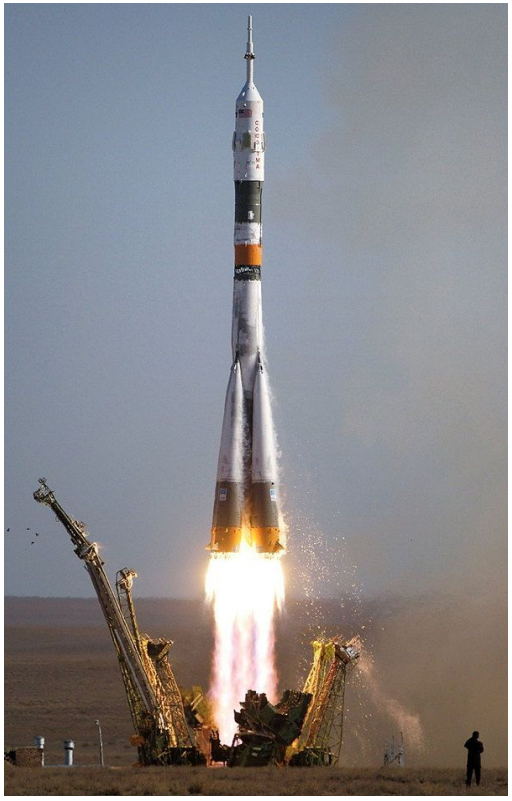
- However, when a force is applied, the lattice is distorted and charge forms on the surface of the crystal.





Recap: Accelerometers and piezoelectric crystals

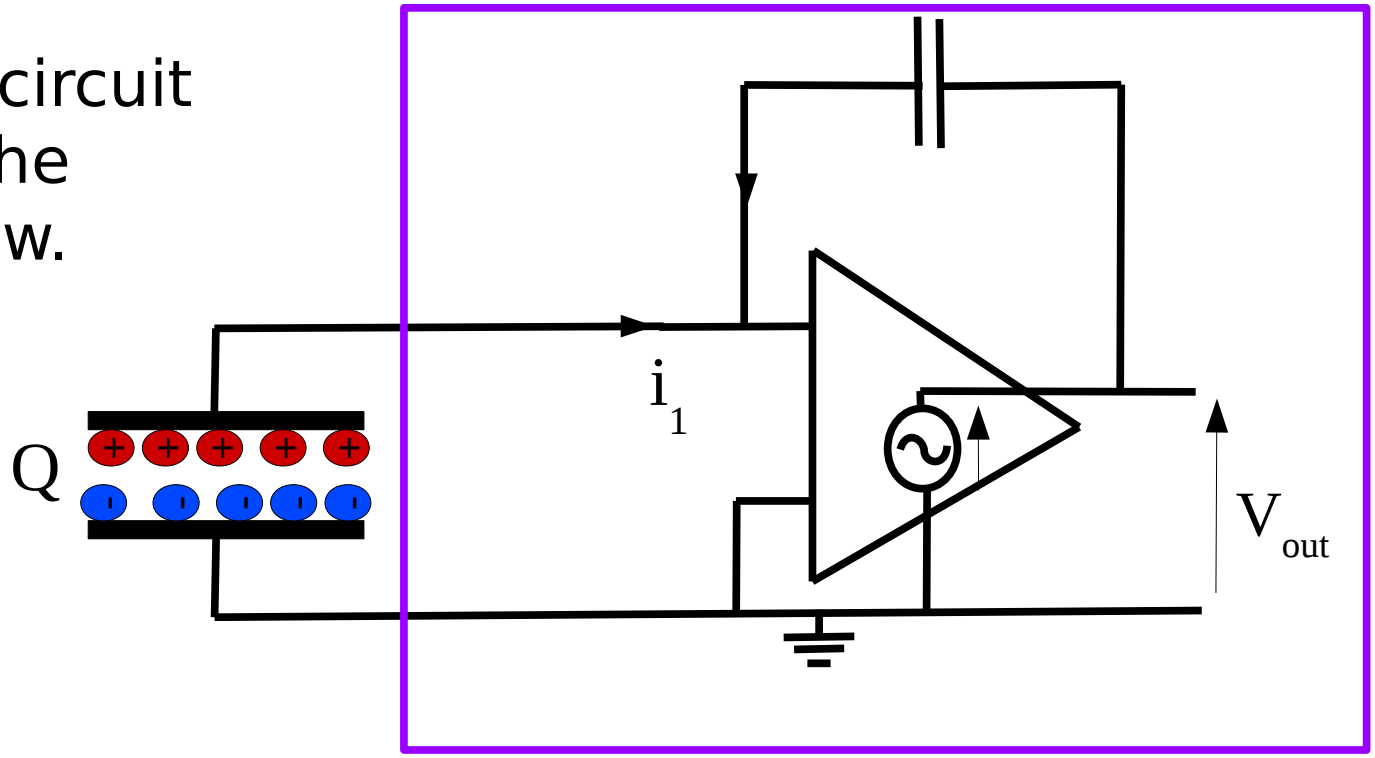




$$Q \sim F \sim a \longrightarrow i \sim \frac{da}{dt} m \longrightarrow \frac{1}{m} \int i\,dt \sim a$$

Recap: To do the integration we need an integrator circuit

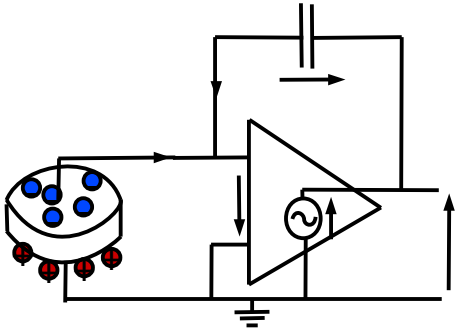
We drew this circuit and derived the equation below.



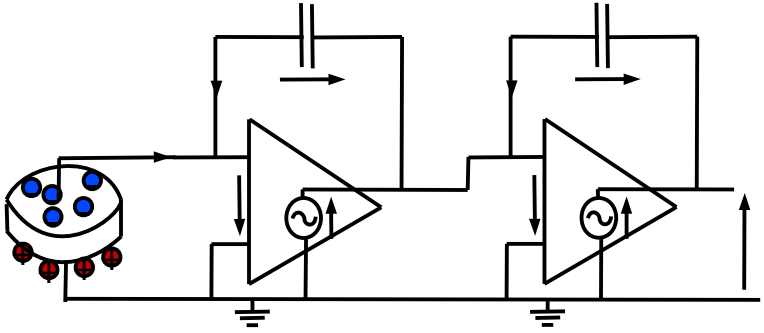
$$V_0 = -\frac{Q}{C} \sim \frac{F}{C} \sim \frac{a}{C}$$

Integrator circuit

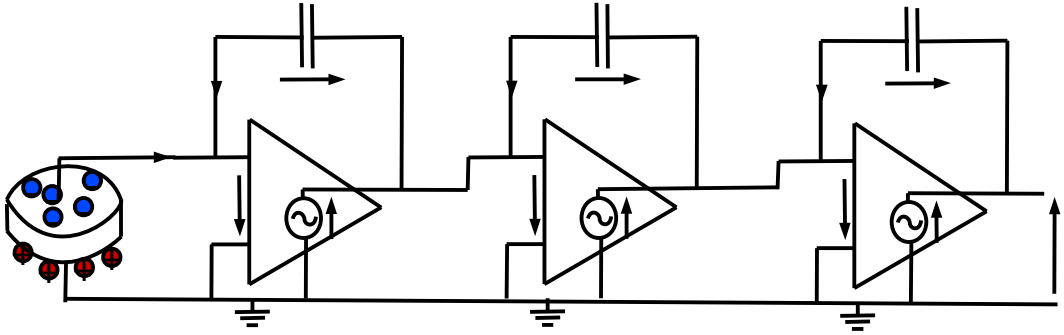
Recap: We can cascade these integrator elements to get



$$V_0 = -\frac{Q}{C} \sim \frac{F}{C} \sim \frac{a}{C}$$



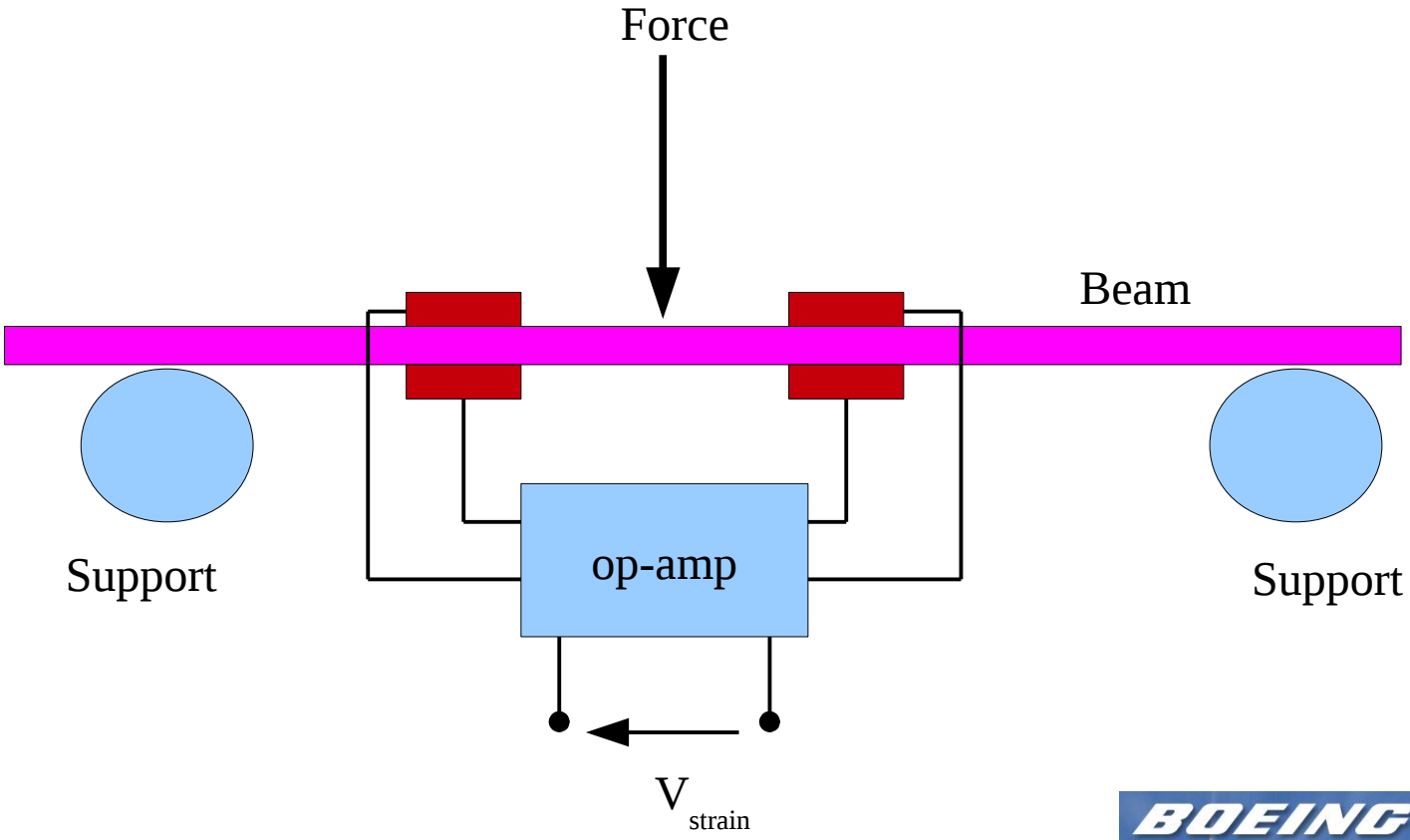
$$V_0 \sim velocity$$

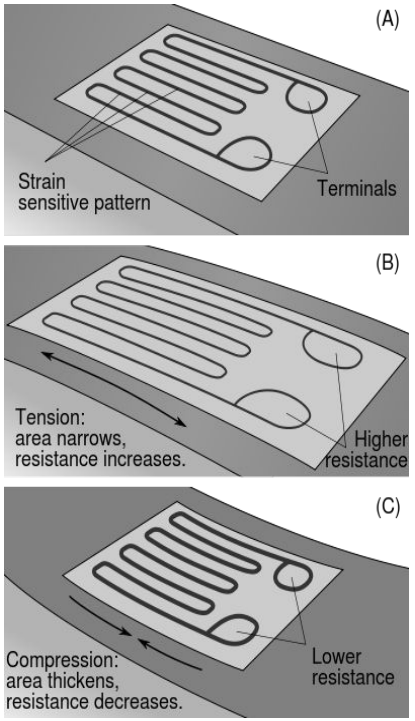


$$V_0 \sim distance$$

Recap: All engineers must know about op-amps and accelerometers :)

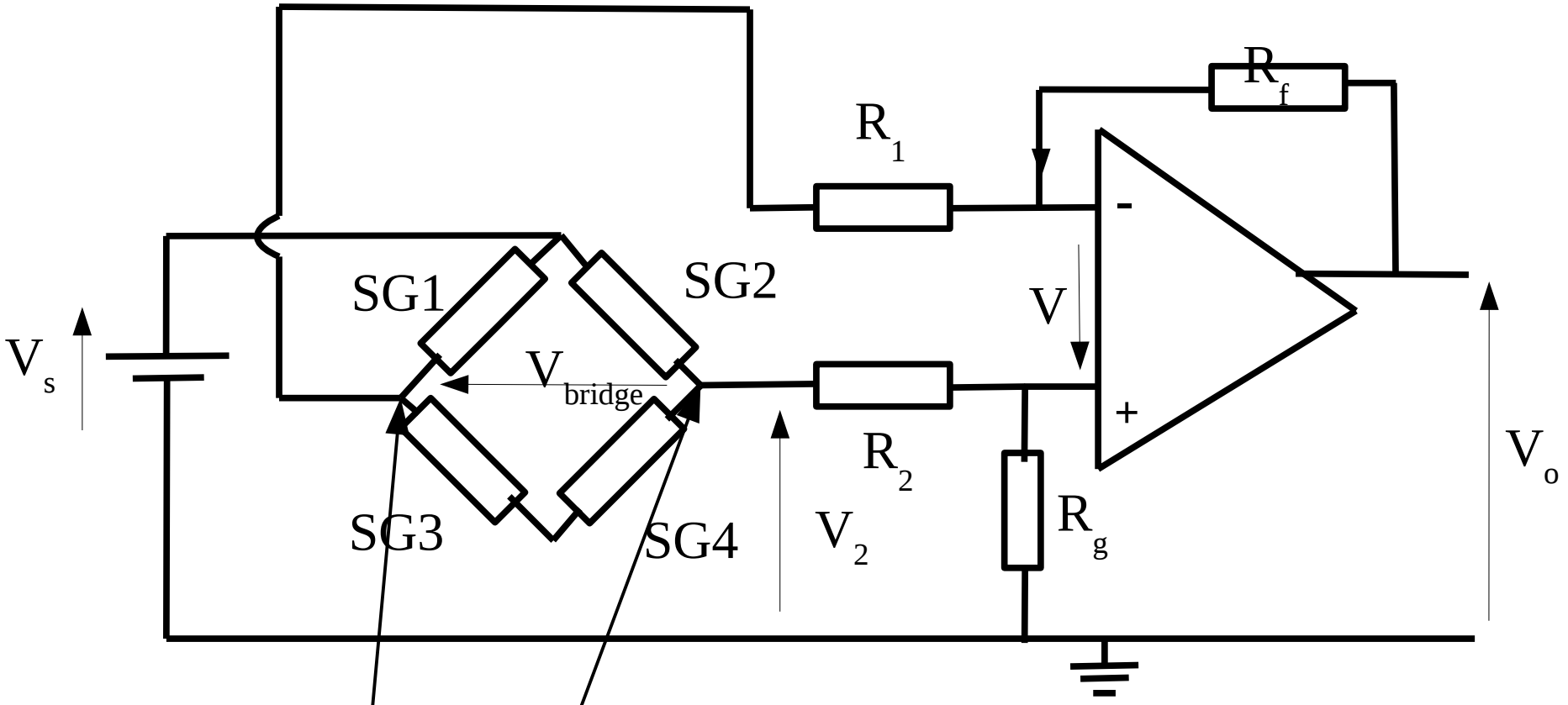
Recap: Application of op-amps to strain gauges..





The signal that comes out of a strain gauge is very small so it needs amplifying...

Recap: With this op-amp circuit



$$V_0 = [V_2 - V_1]\frac{R_f}{R_1}$$

And we derived this equation

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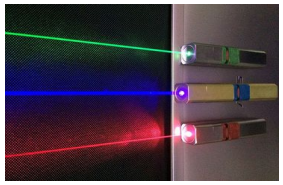
Book chapters

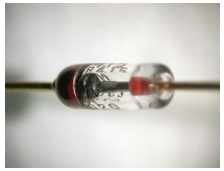
- All material you will need for the exam is in this lecture and the example sheets, but if you want to do more reading you can look in:

An Introduction to Mechanical Engineering: Part 1, pages 348-360

This lecture is about diodes!

- Diodes are a huge ***exciting*** topic which encompasses:
  - Laser diodes
  - Light emitting diodes
  - Power diodes
  - Solar cells


彭家杰


Morcheeba

- I've spent the last ten years of my life researching on light harvesting diodes (solar cells.)

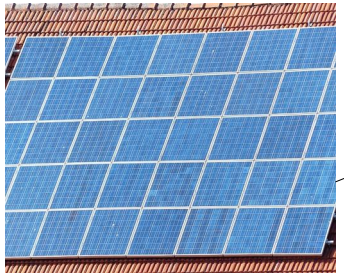
Diodes

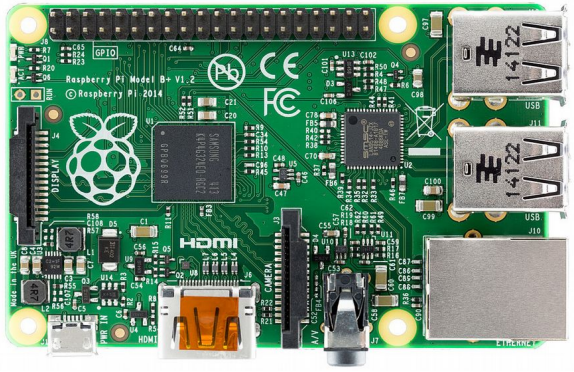
•The focus of this lecture will be on using diodes to power electronic devices.

•This is because whenever you make/design an electronic device you will need to power it.

Mains

Sun





Lucasbosch

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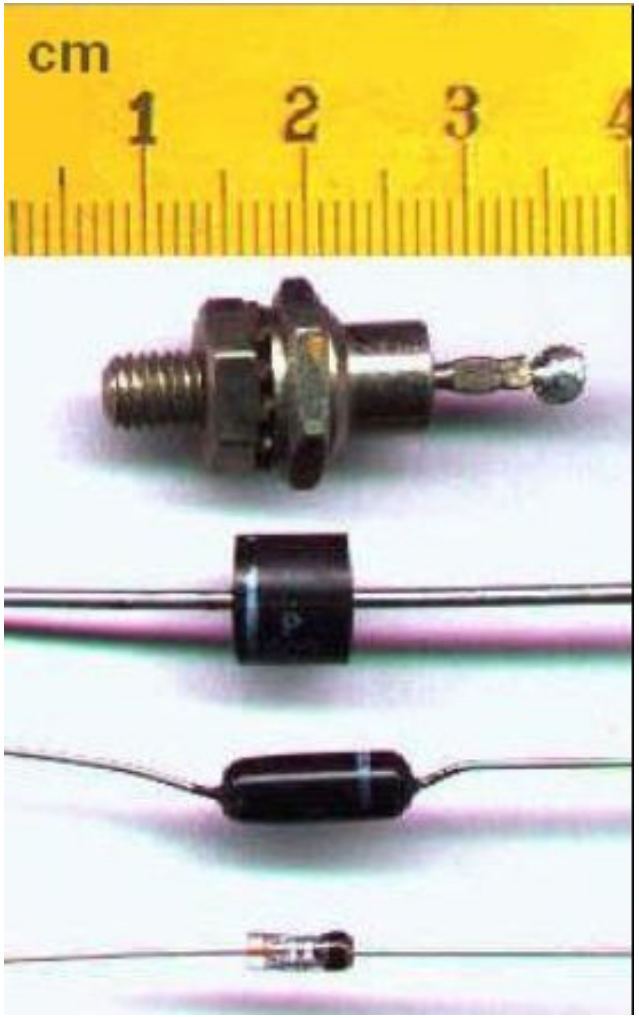
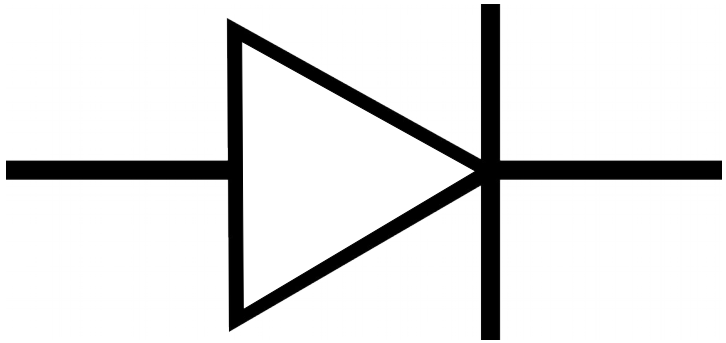
Diode basics: Diodes for power electronics – what do they look like?

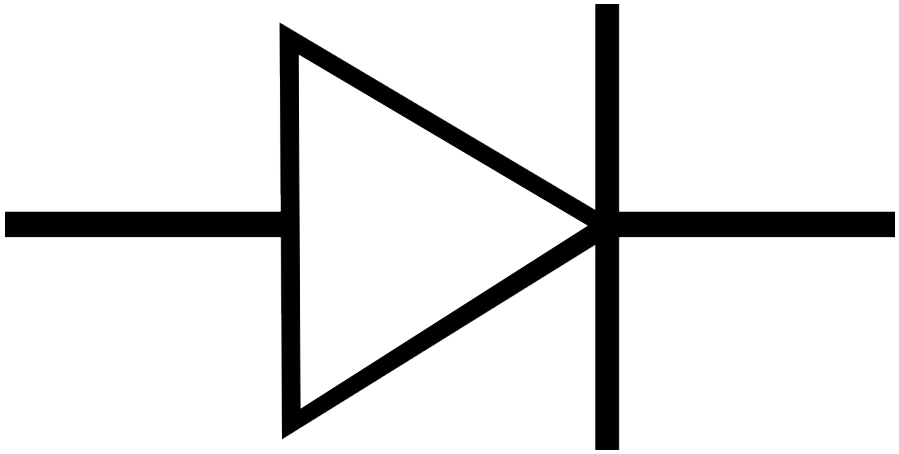
- Diodes you find in high power electronics look like this

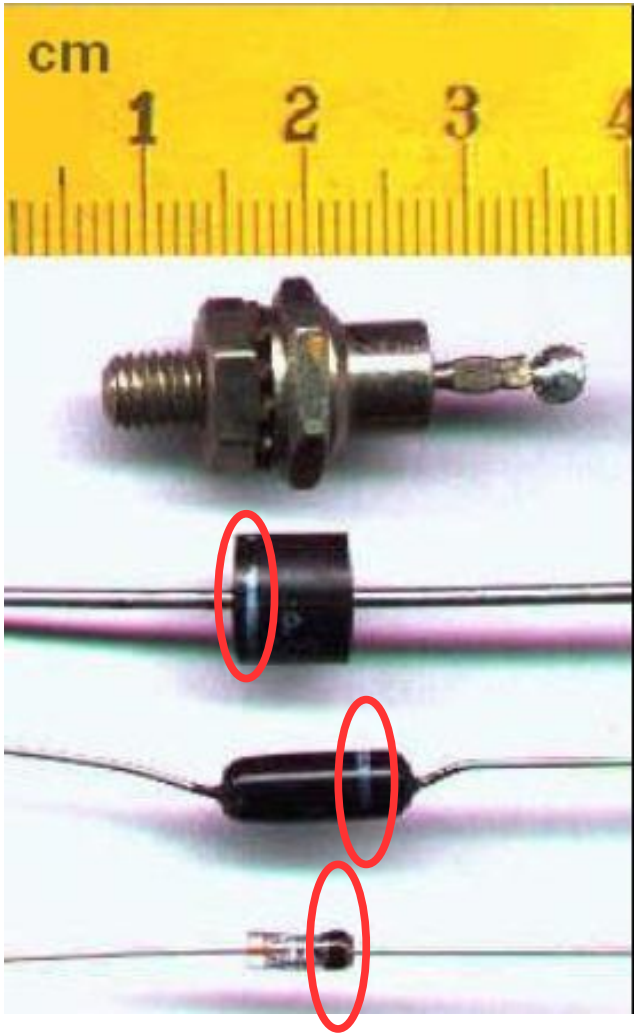


- Little black beads with two wires sticking out.



Diode basics: Notice...



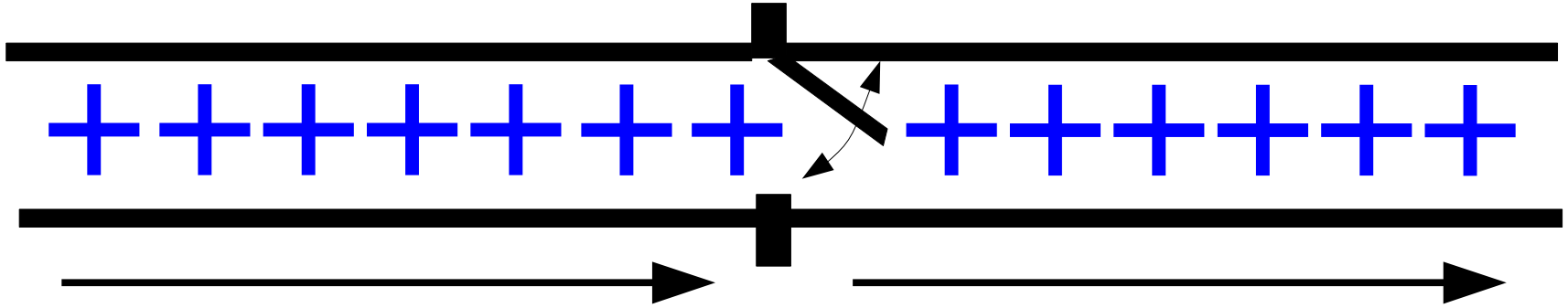


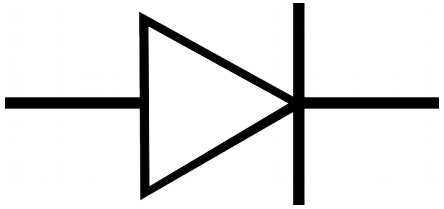
•Notice the silver bar on the end, this is the same as the bar in the diagram.

Diode basics: What do they do?

The University of Nottingham

You can think of a diode as a one way valve for electrons

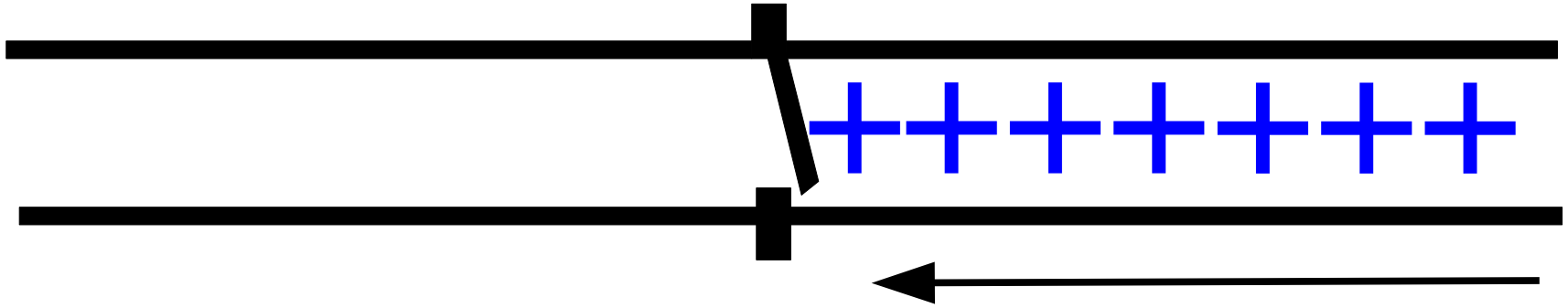


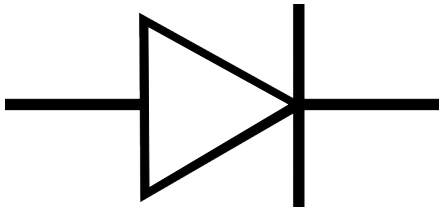


If current flows in one direction the diode will allow it to pass.

Diode basics: What do they do?

If current tries to flows in the **other direction** it will not be allowed to pass.





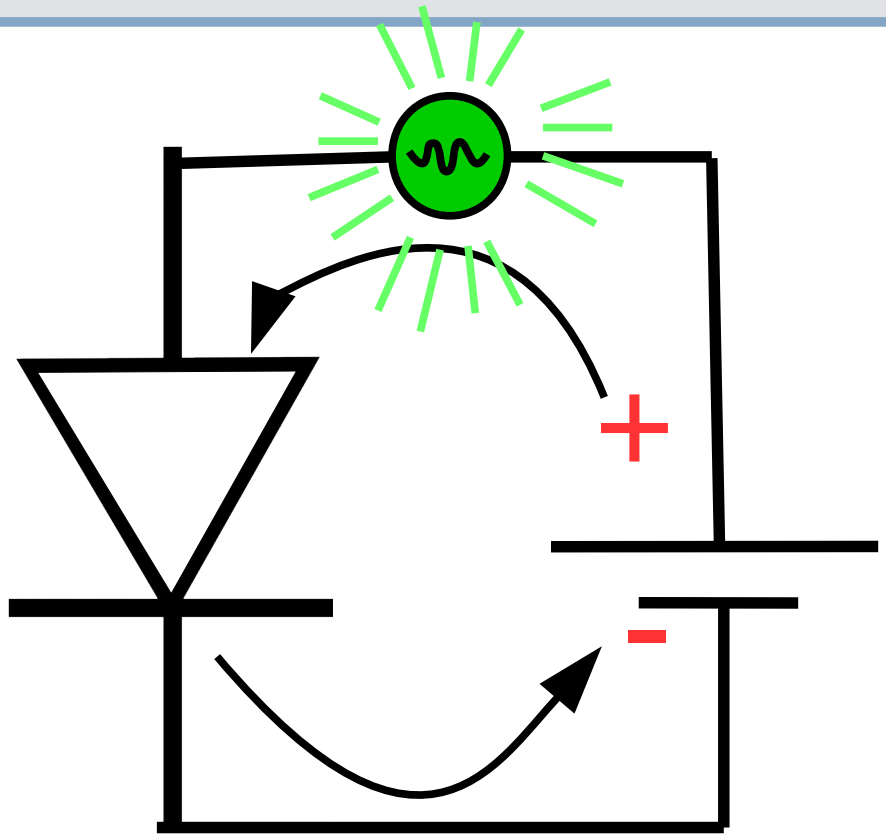
Diode basics: A one way cat flap....

You can also think of a diode as a one way cat flap for electrons.

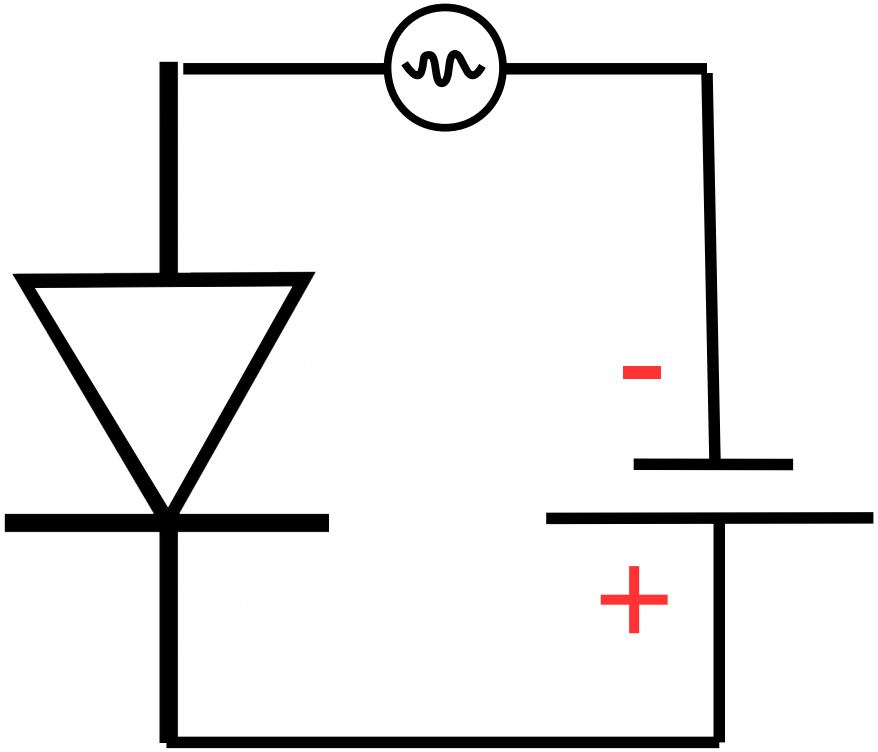
•Electrons (or the cat) are only allowed to go through one way but not the other.

Andrew Dunn

Diode basics: A diode as a one way trap door for current

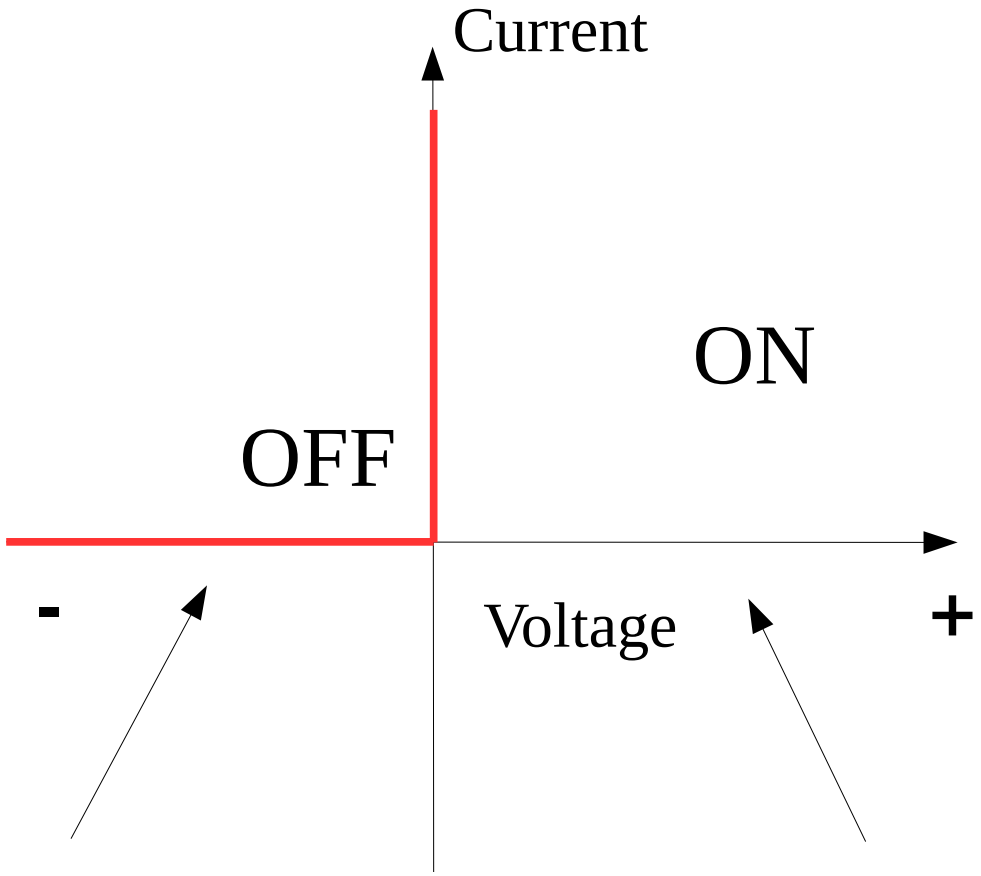


With positive applied voltage current flows



With negative applied voltage no current flows

Diode basics: What does the ideal current voltage curve look like?



At negative voltages it blocks current

At positive voltages any amount of current can flow

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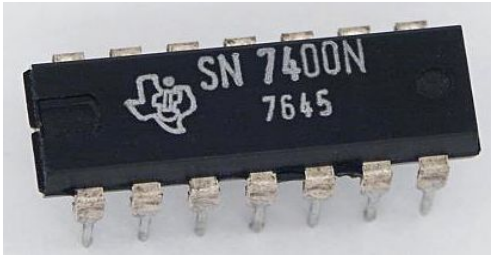
Power supplies, the interface between electrical and electronic engineering

- Think about **digital devices** like your **phone**, **mp3 player** or **tablet**, they run on no more than **5 volts.**

- However, mains gives us **230 V**.

- If we want to power digital electronic circuits off the mains we must convert **230 V to 5V**.

230 V

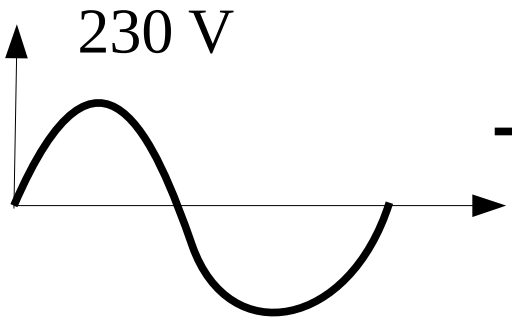


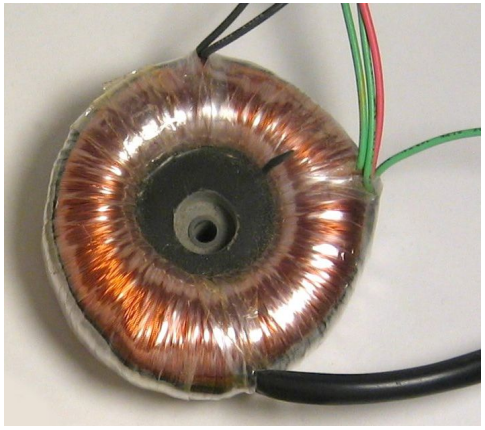
5 V

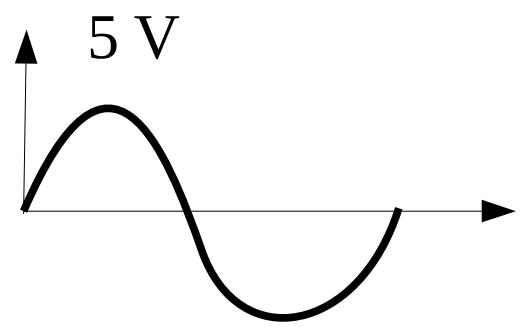
A transformer...

Last lecture Arthur taught you about transformers, which can convert **high voltages to low voltages**.

Transformer

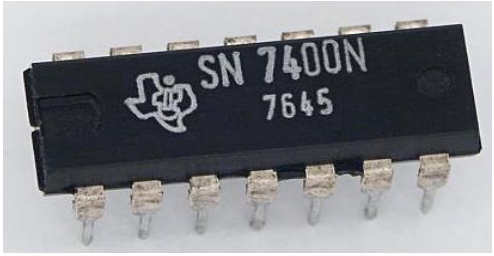






230 V

So we could use a transformer to get our **5 Volt** supply.....

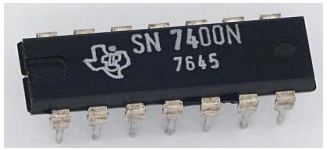


5 V

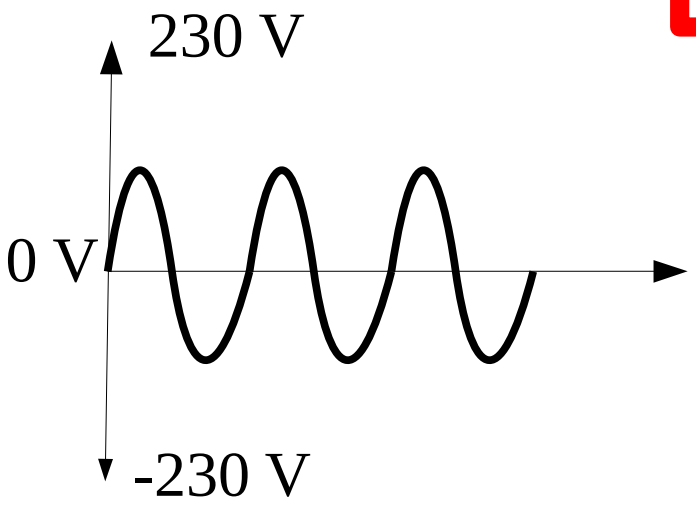
So to summarize we have this situation...

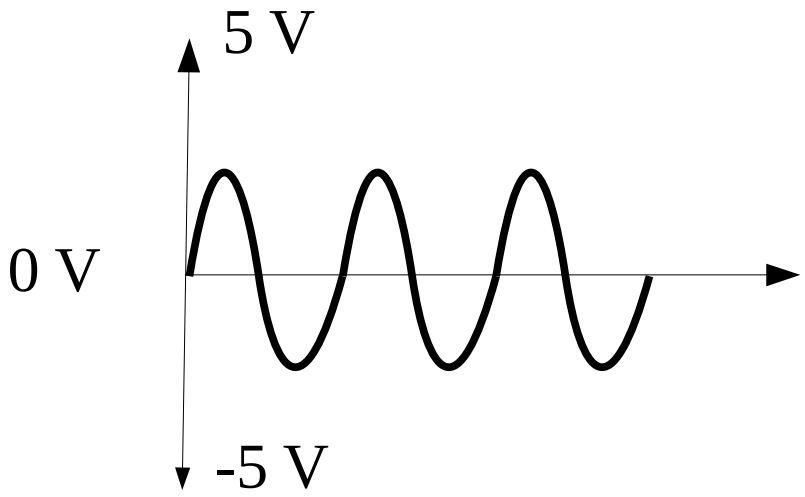
Input
230V

Transformer

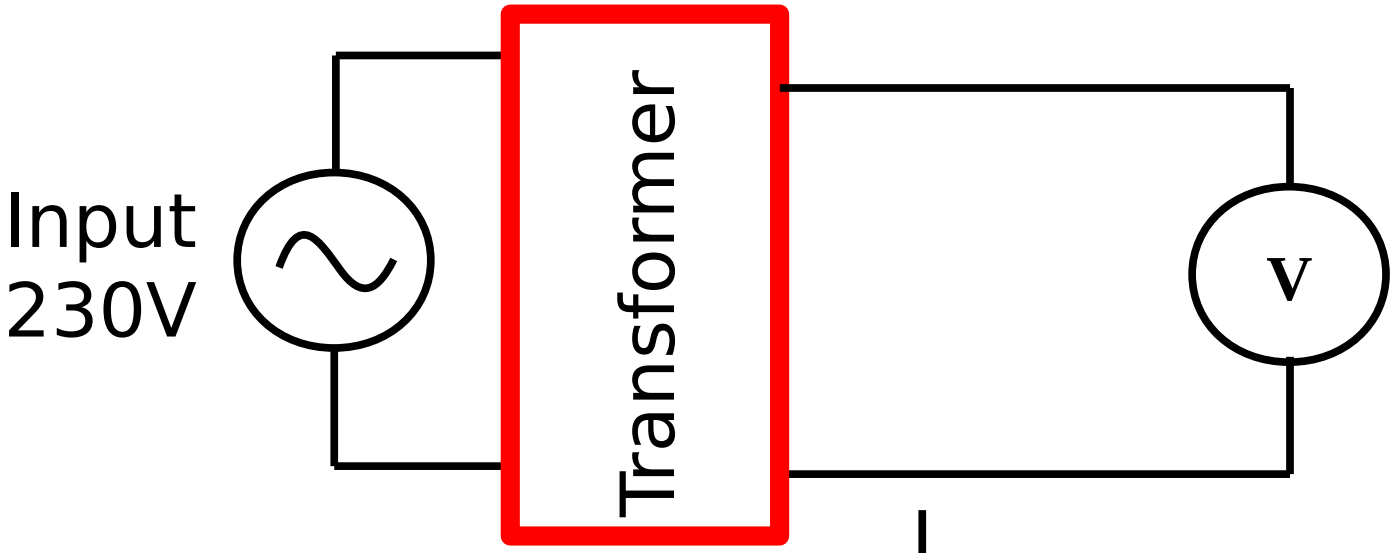


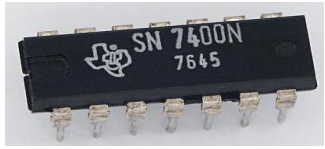
Output
5V

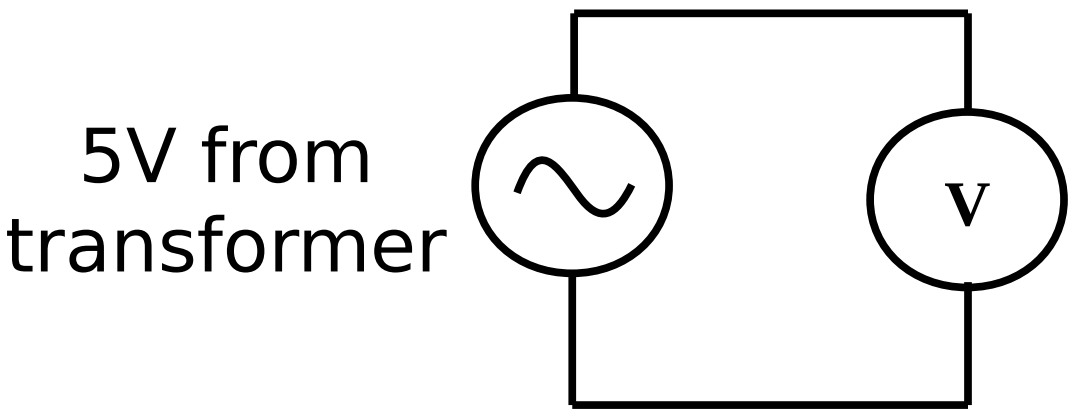




From now on I will not draw the transformer and we will only look at the low voltage side....

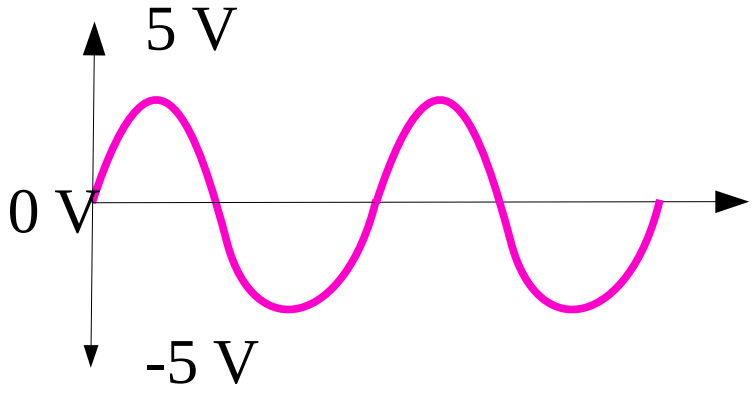


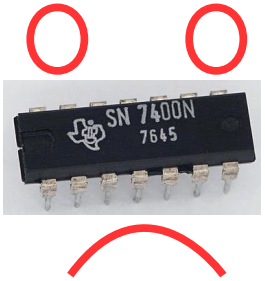




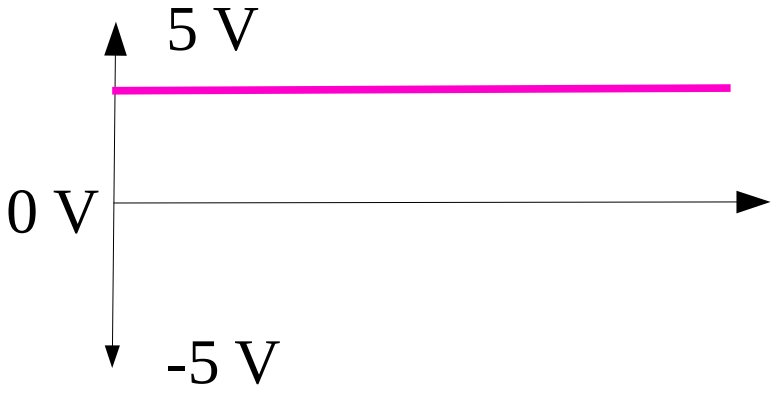
However.....

- AC switches **ON** and **OFF** again 100 times a second (50 Hz).



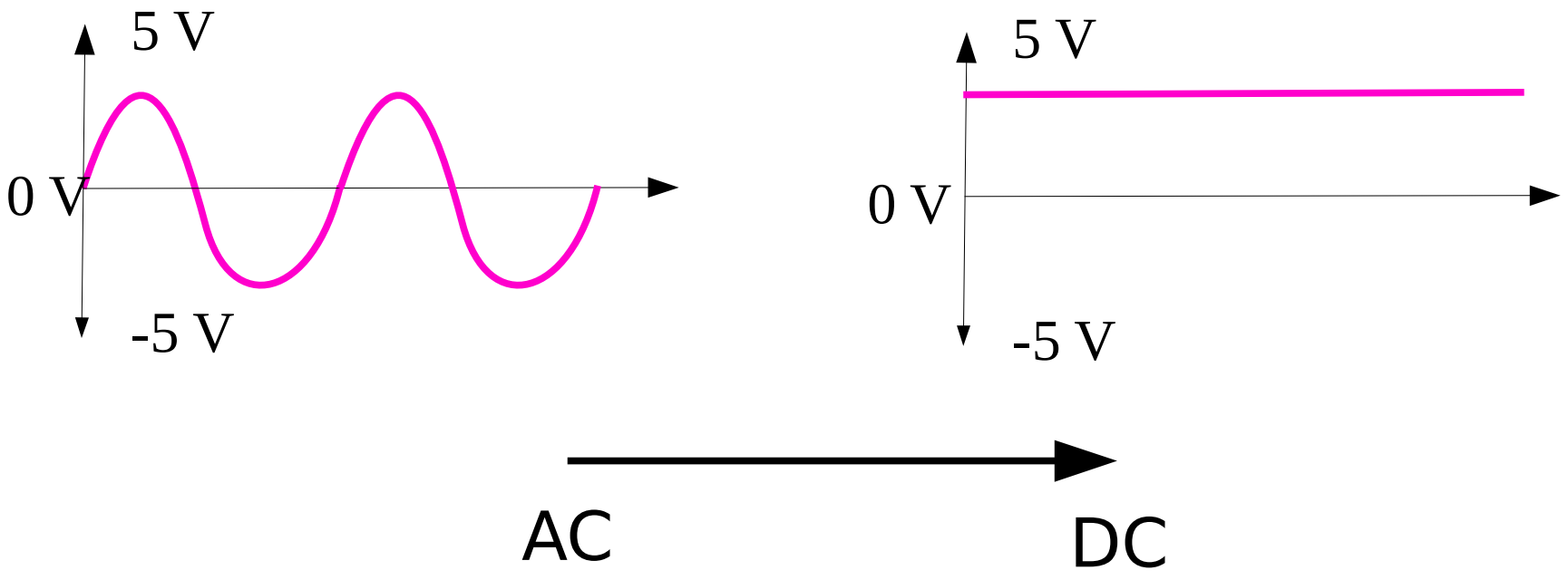


- But most chips need a steady **DC 5V** supply to run.

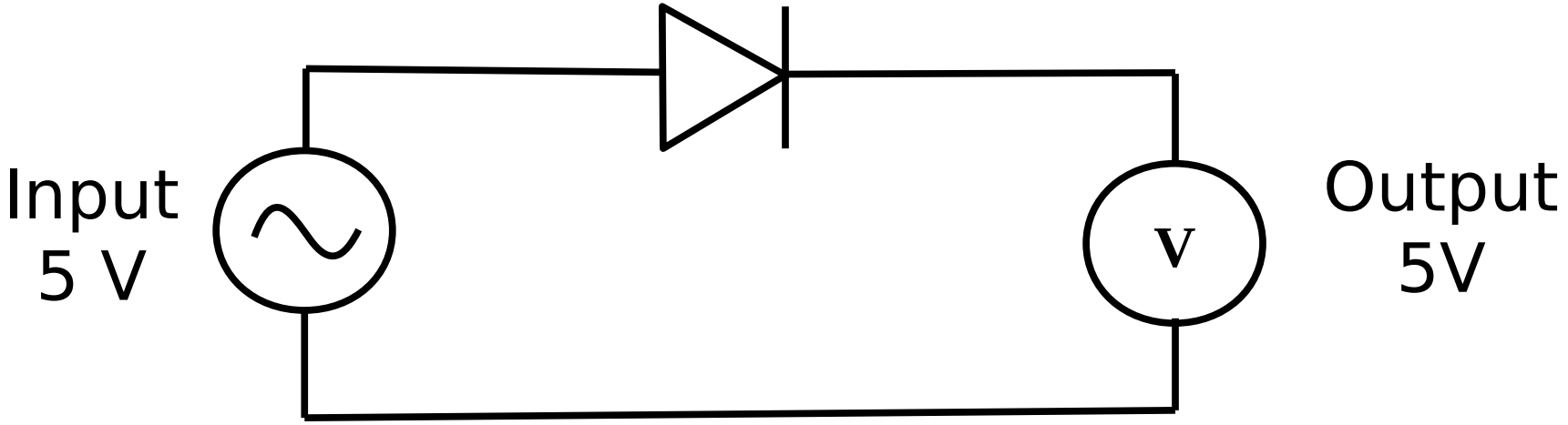


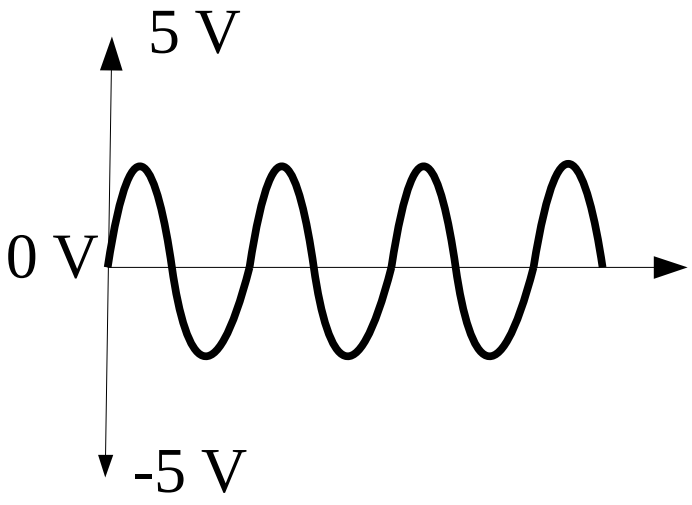
Question?

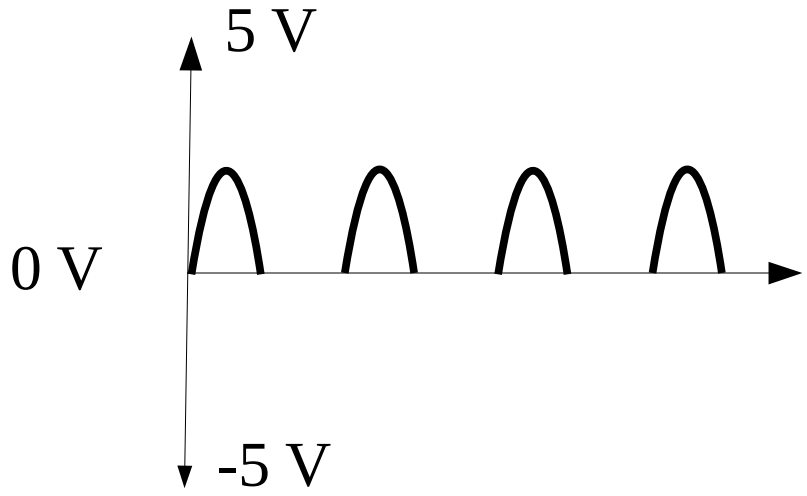
Can anybody guess what we might use to turn an AC voltage into a DC voltage?



A diode!! - the diode only lets through the positive voltage





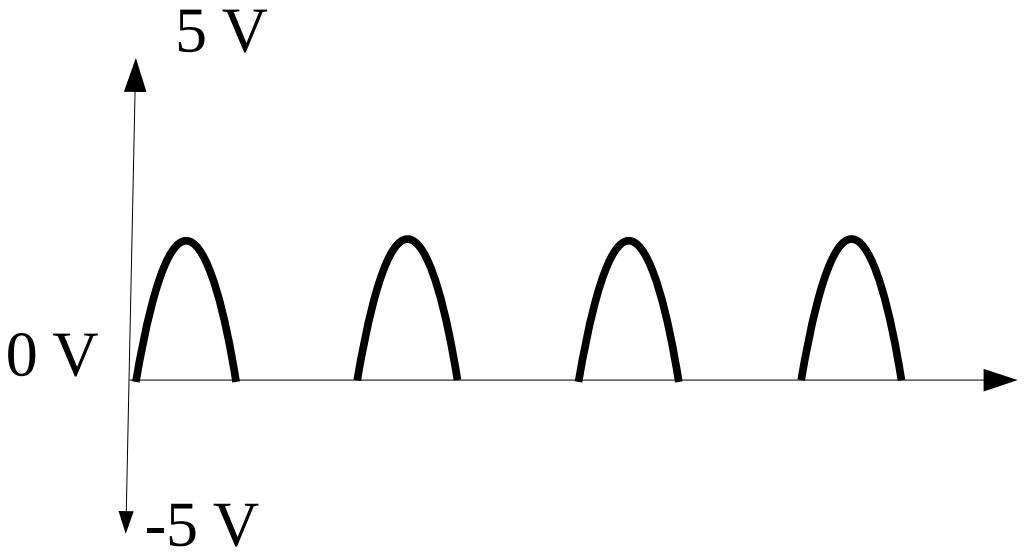


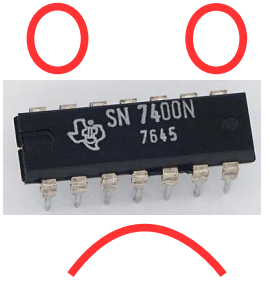
- That's not really DC is it....

This is better, because we no longer get negative voltages...

- But our circuit will still have it's power turned ***on*** and ***off*** 50 times a second.

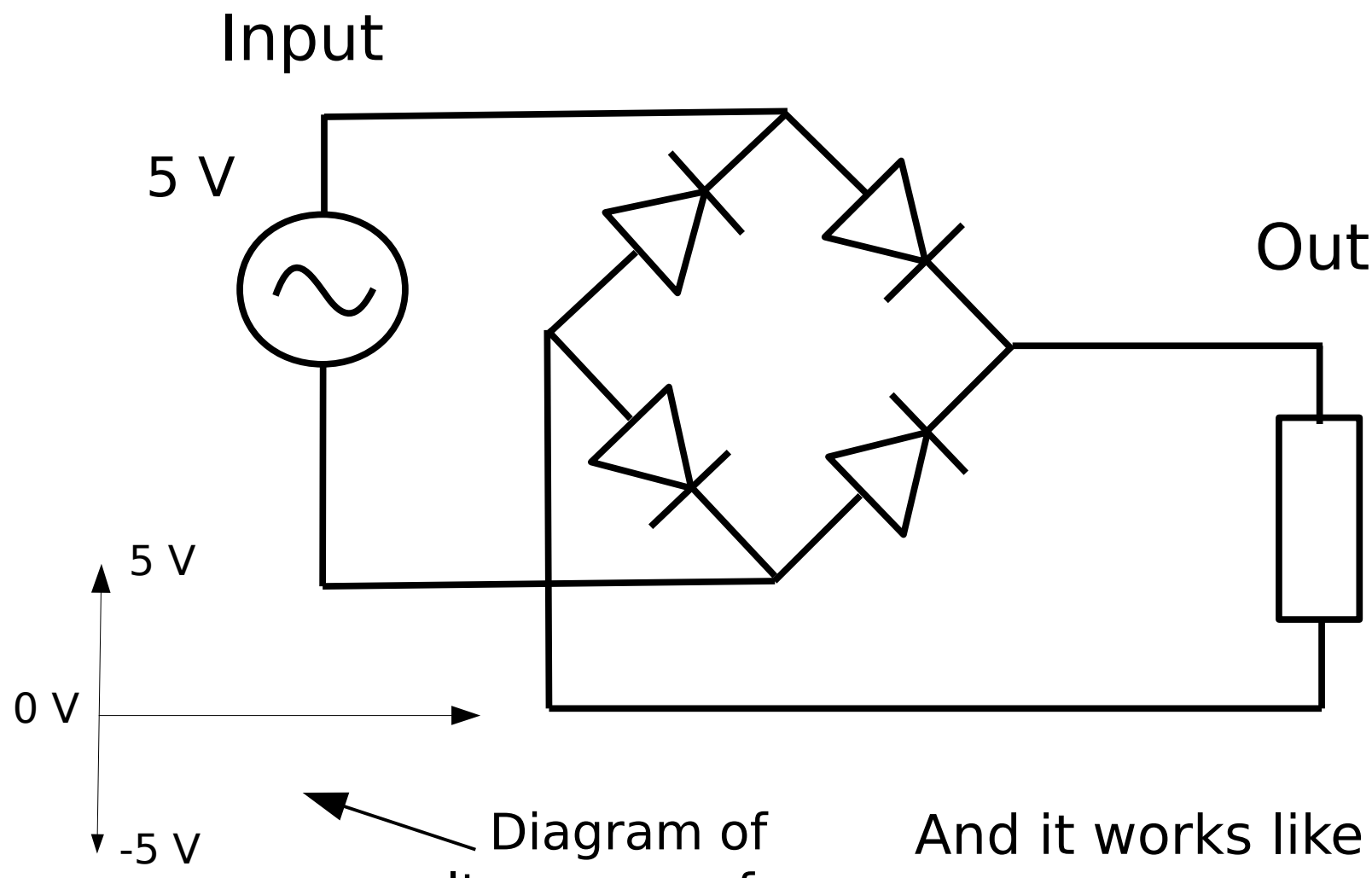
- Again imagine a computer being turned on and off 50 times a second – not good.





- So what we do is the following....

We use four diodes in a square, this is called a **bridge rectifier**.



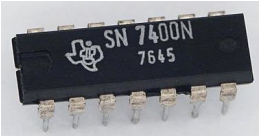
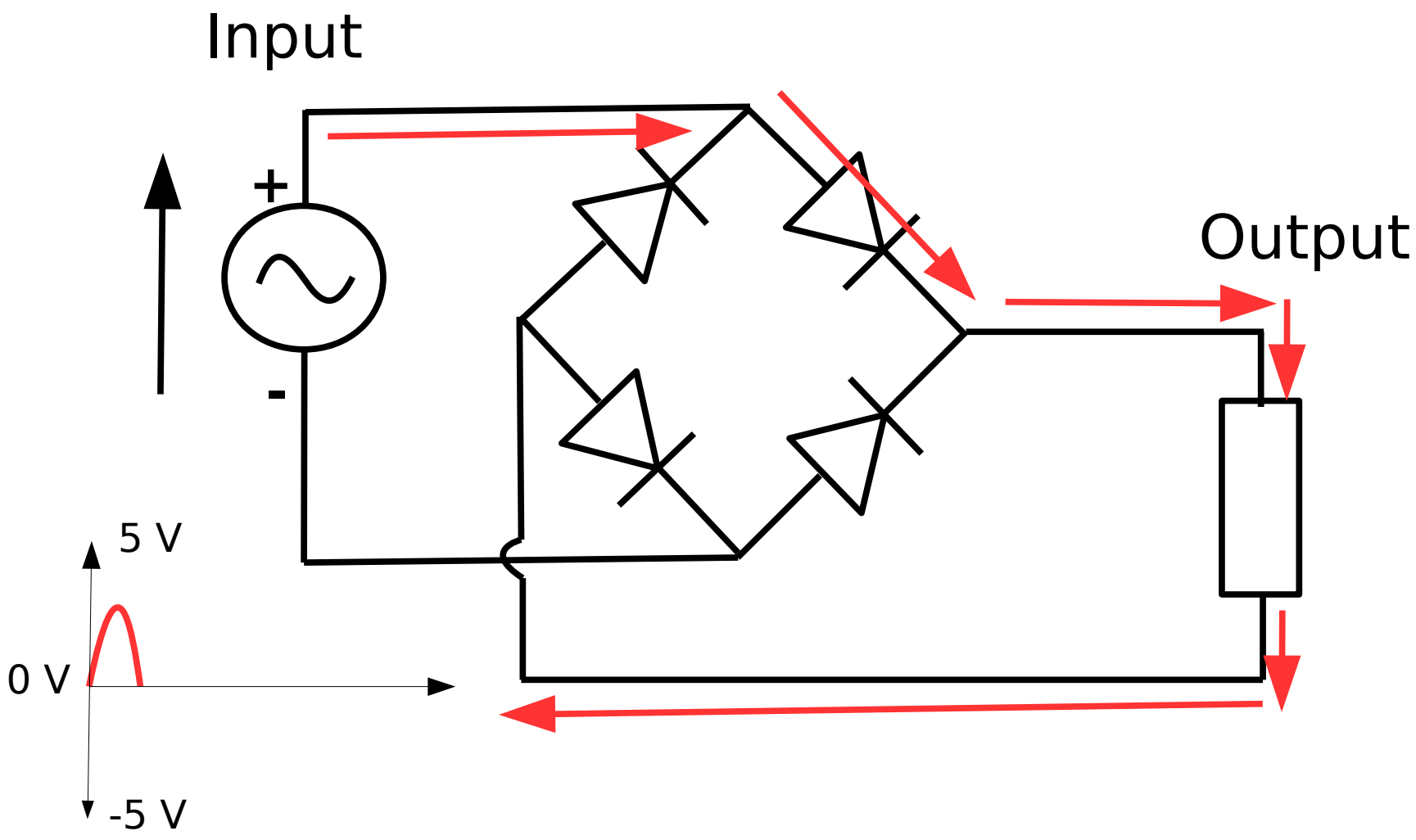


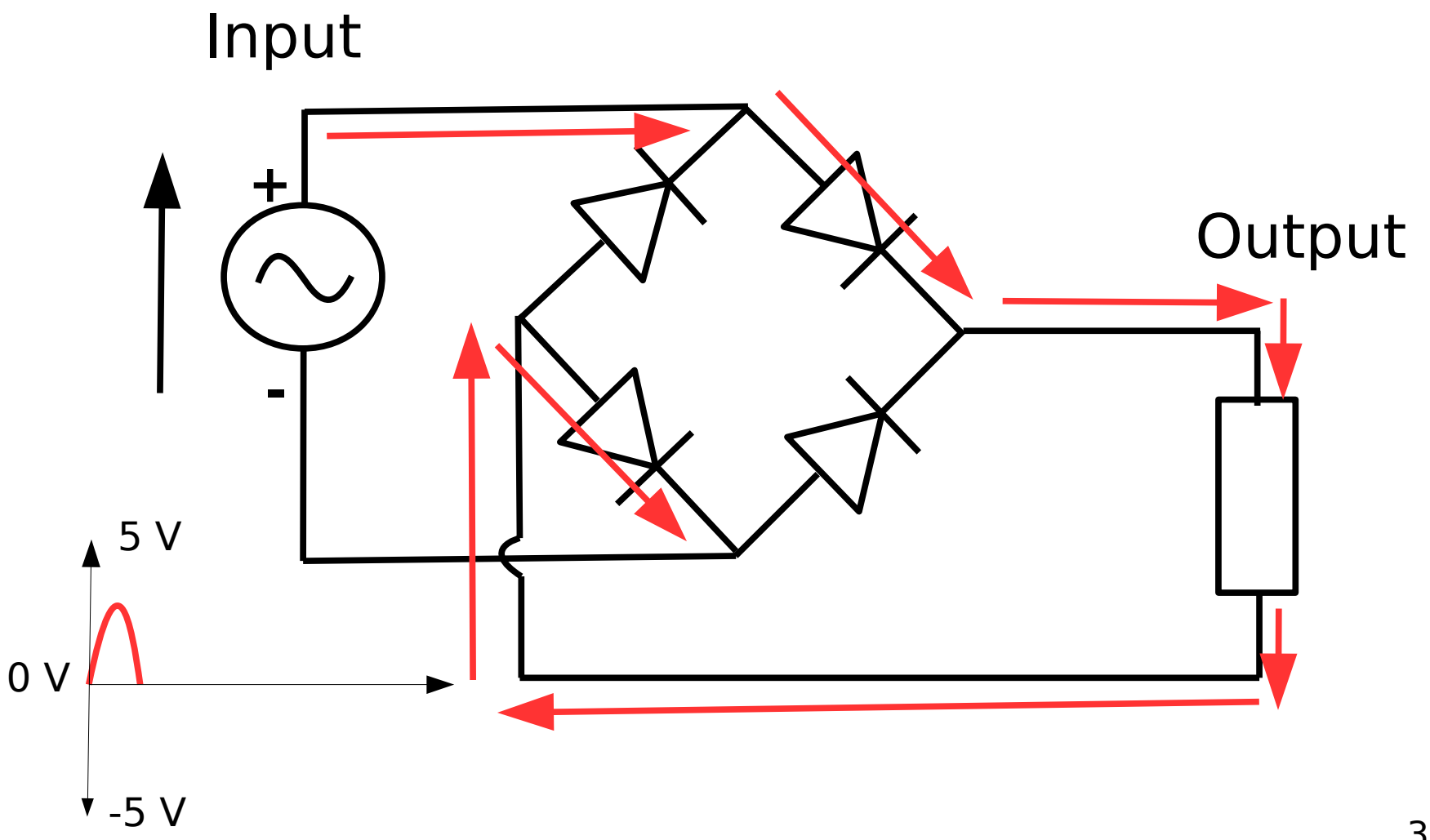
Diagram of voltage wave form

And it works like this.....

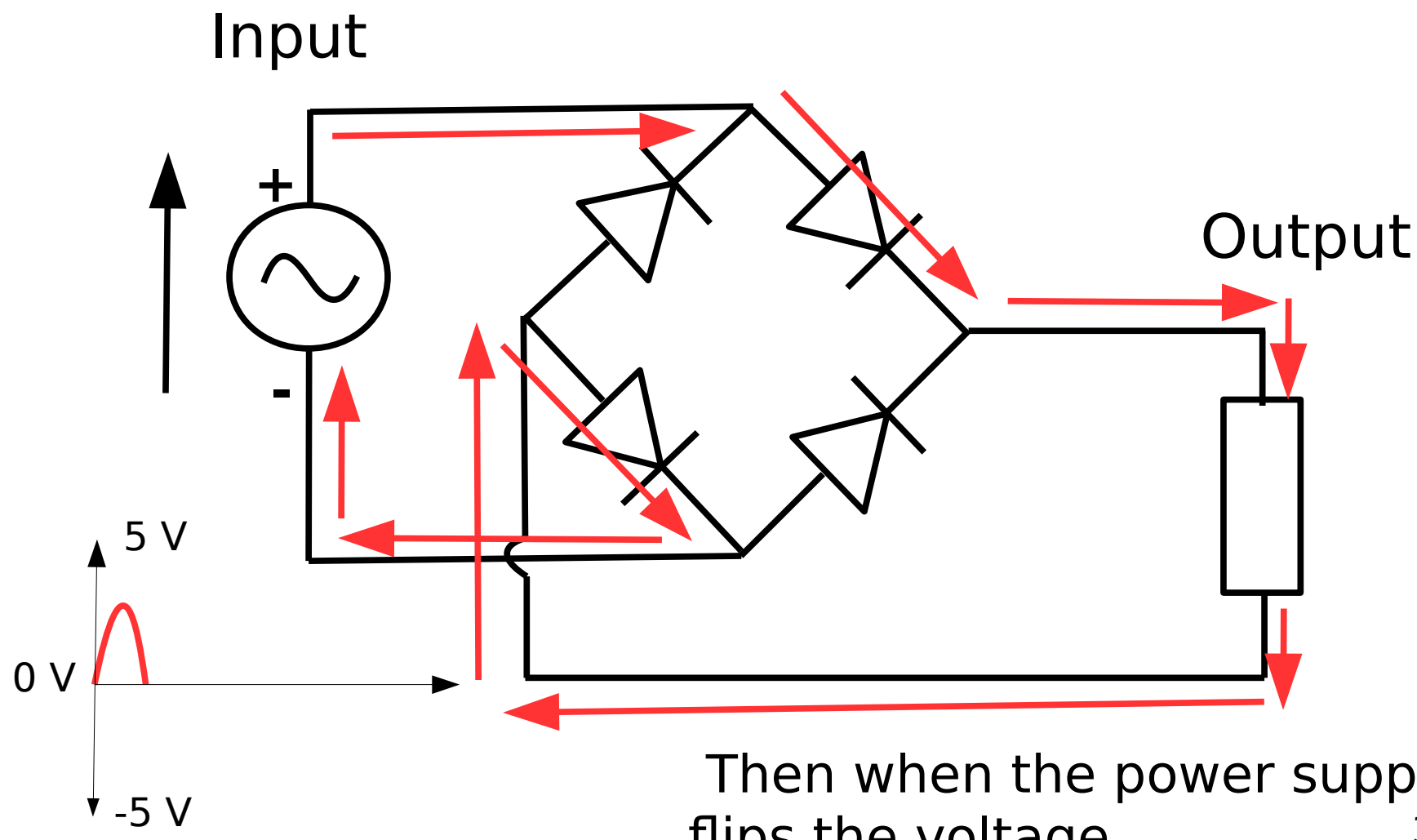
When the voltage is positive..



When the voltage is positive..

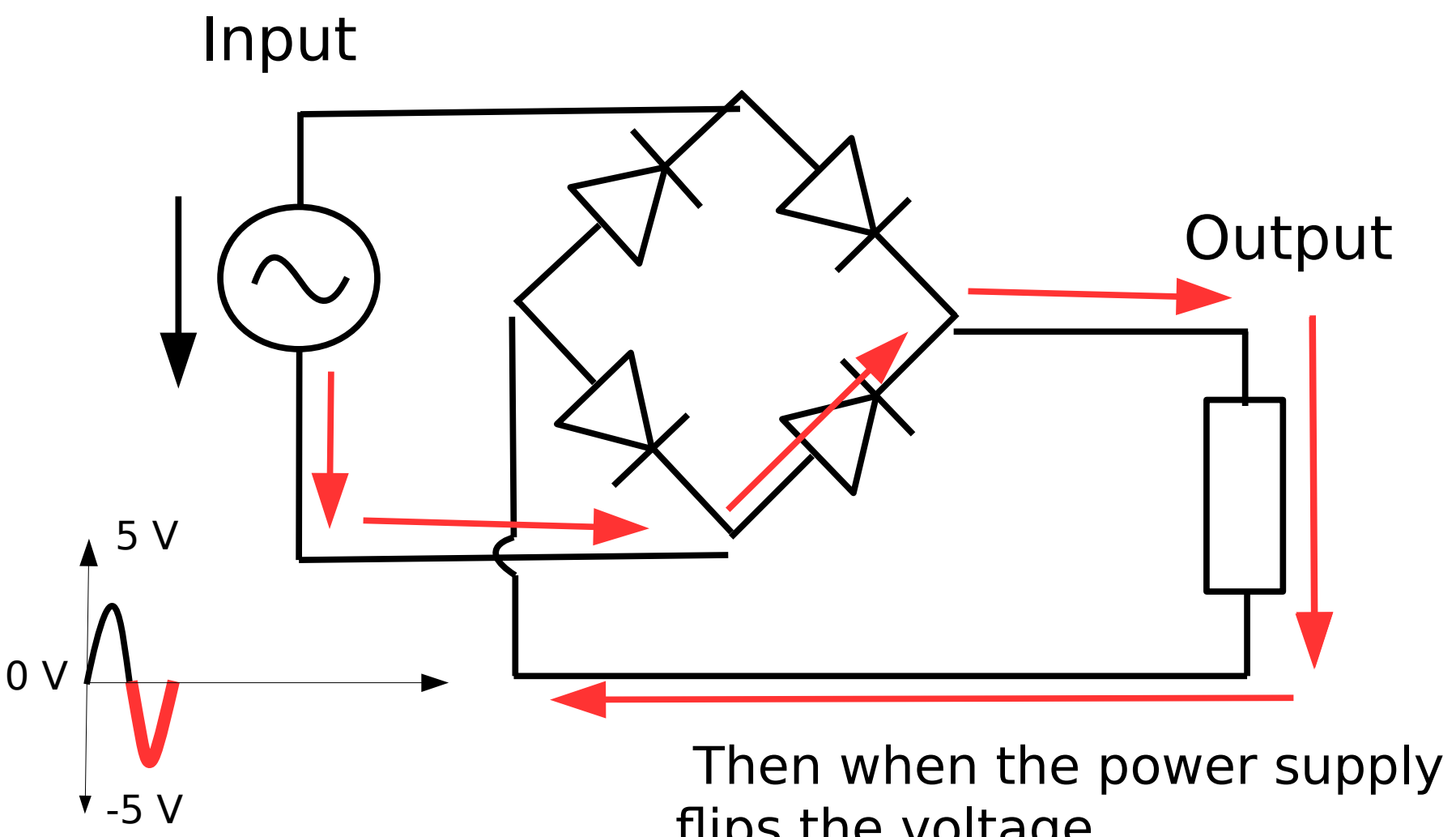


When the voltage is positive..



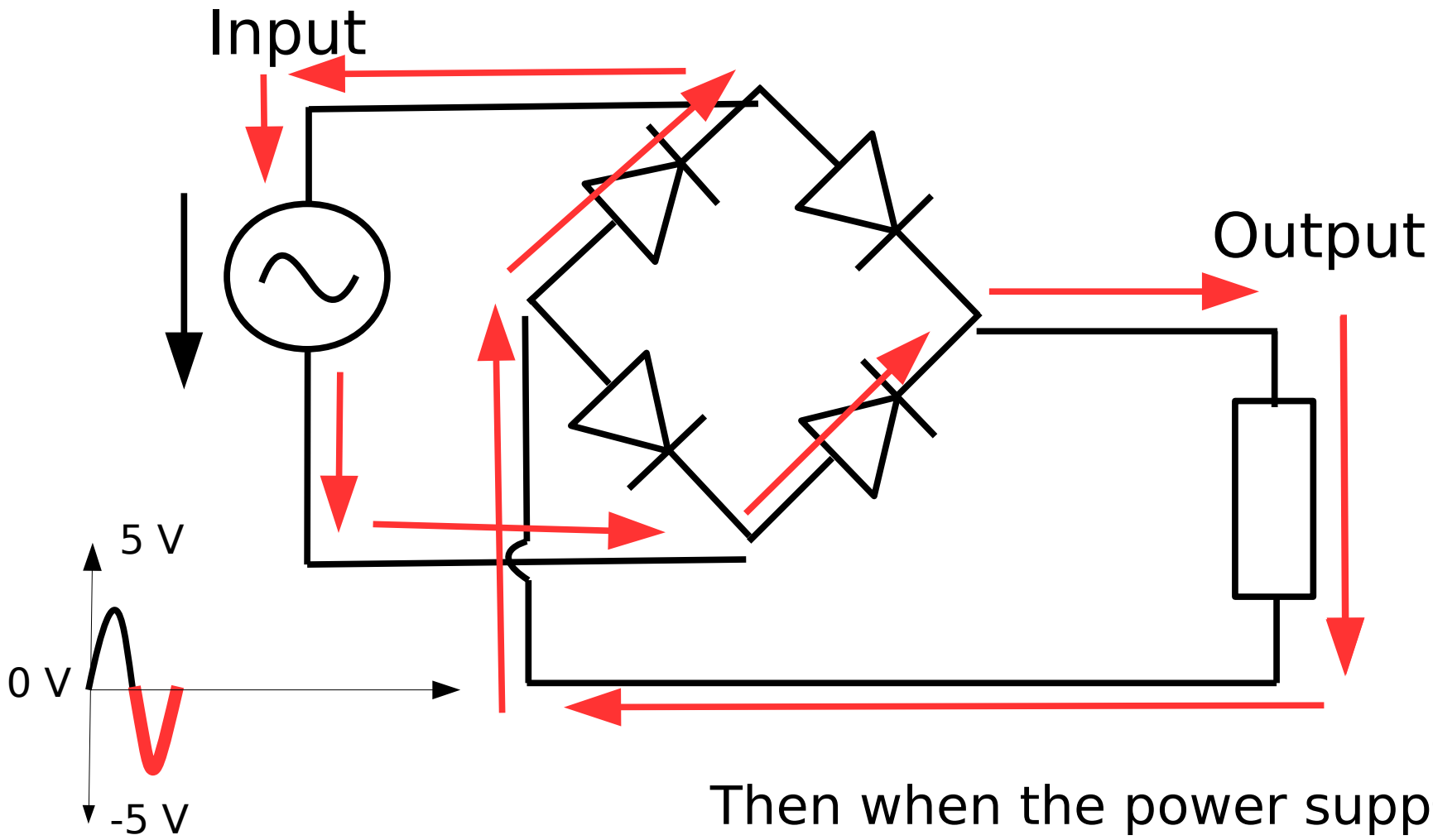
Then when the power supply flips the voltage.....

When the voltage is negative..



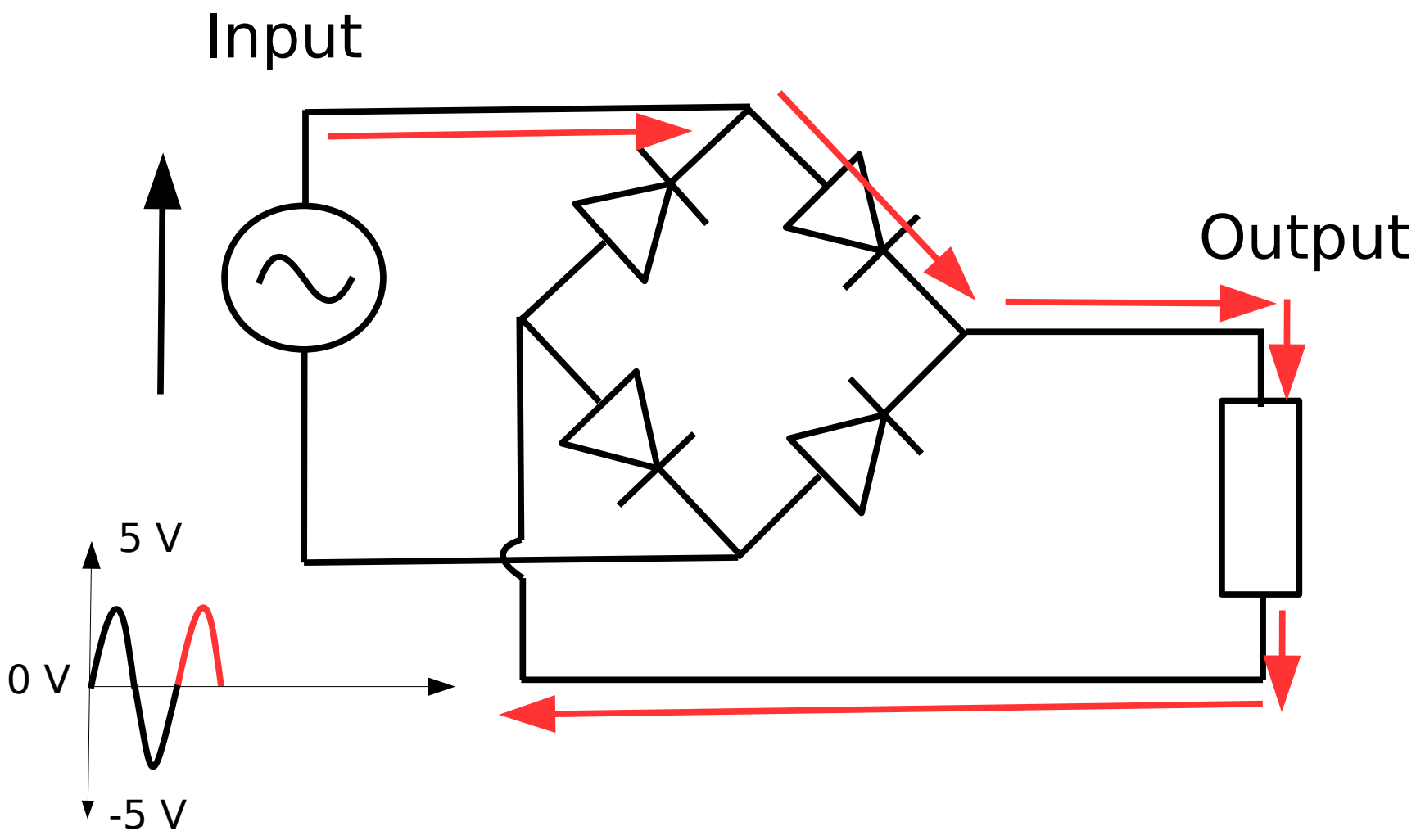
Then when the power supply flips the voltage

When the voltage is negative..

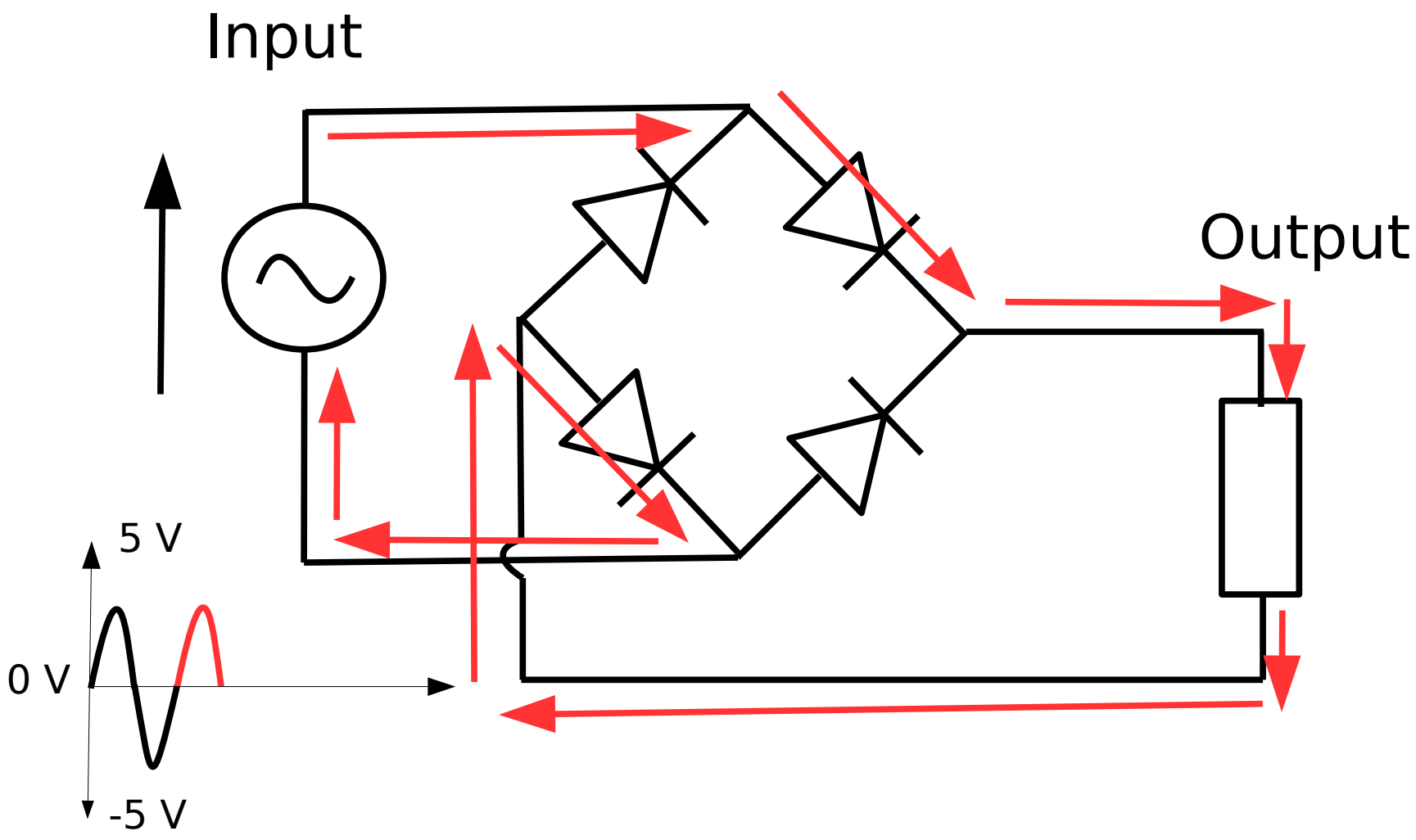


Then when the power supply flips the voltage

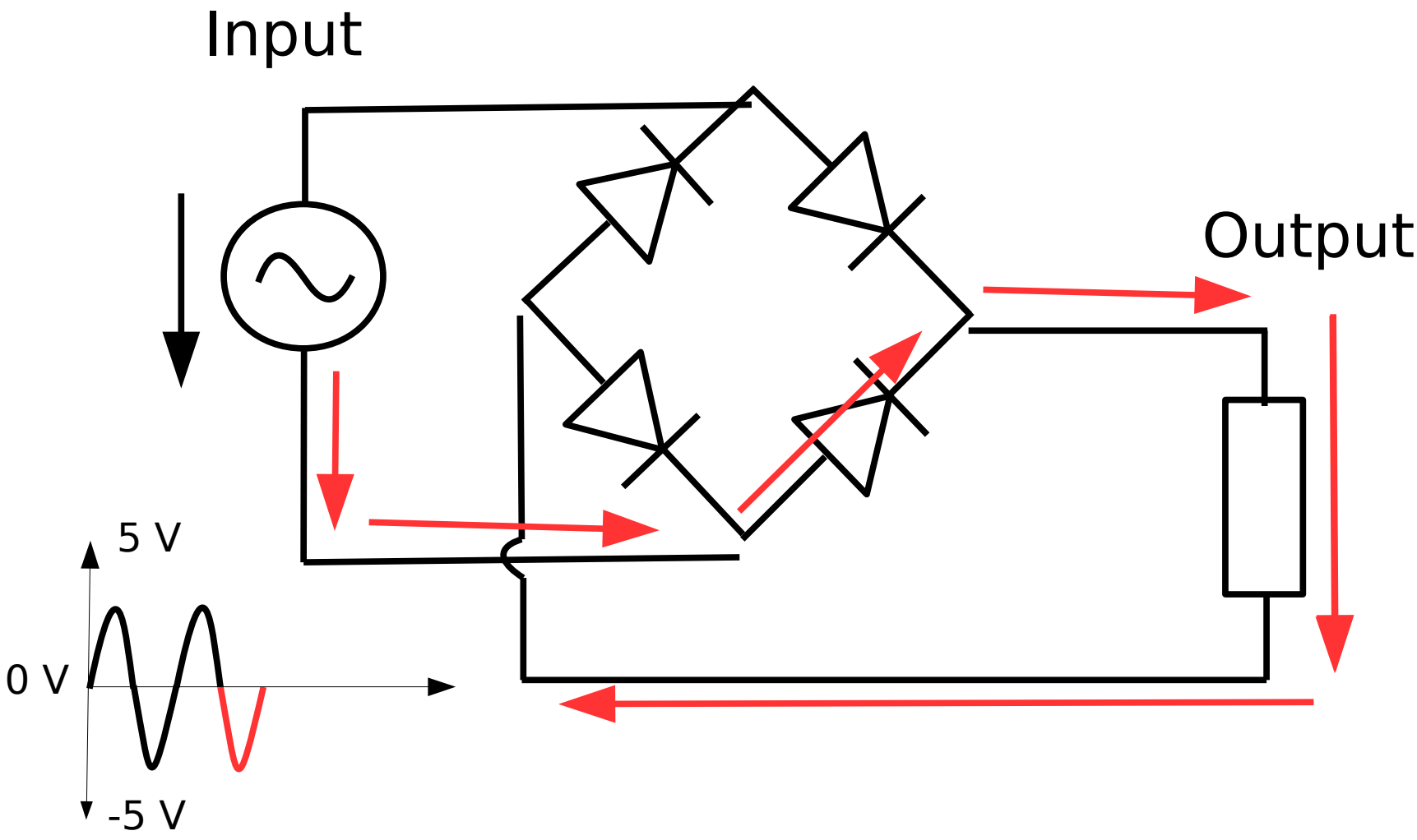
When the voltage is positive...



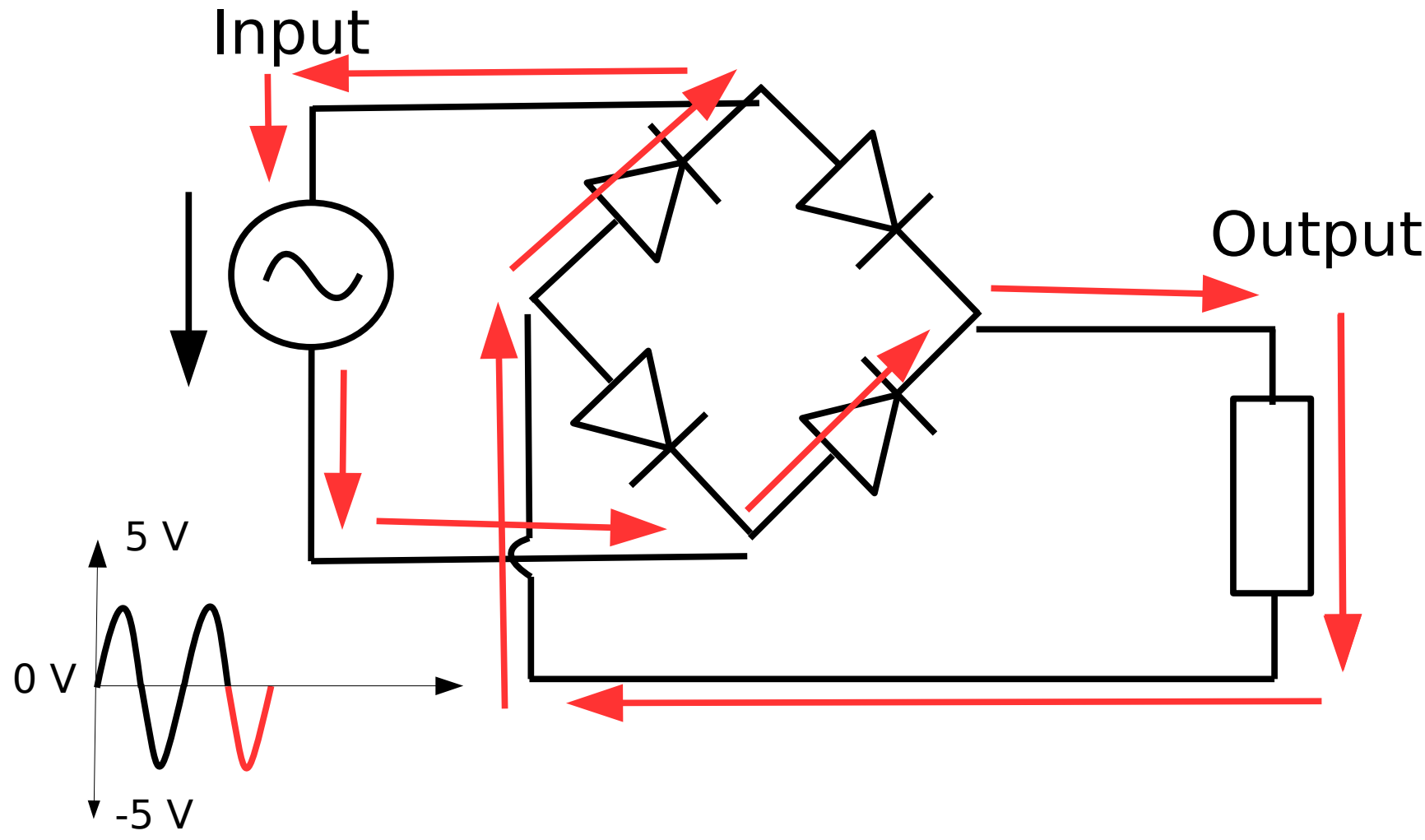
When the voltage is positive...



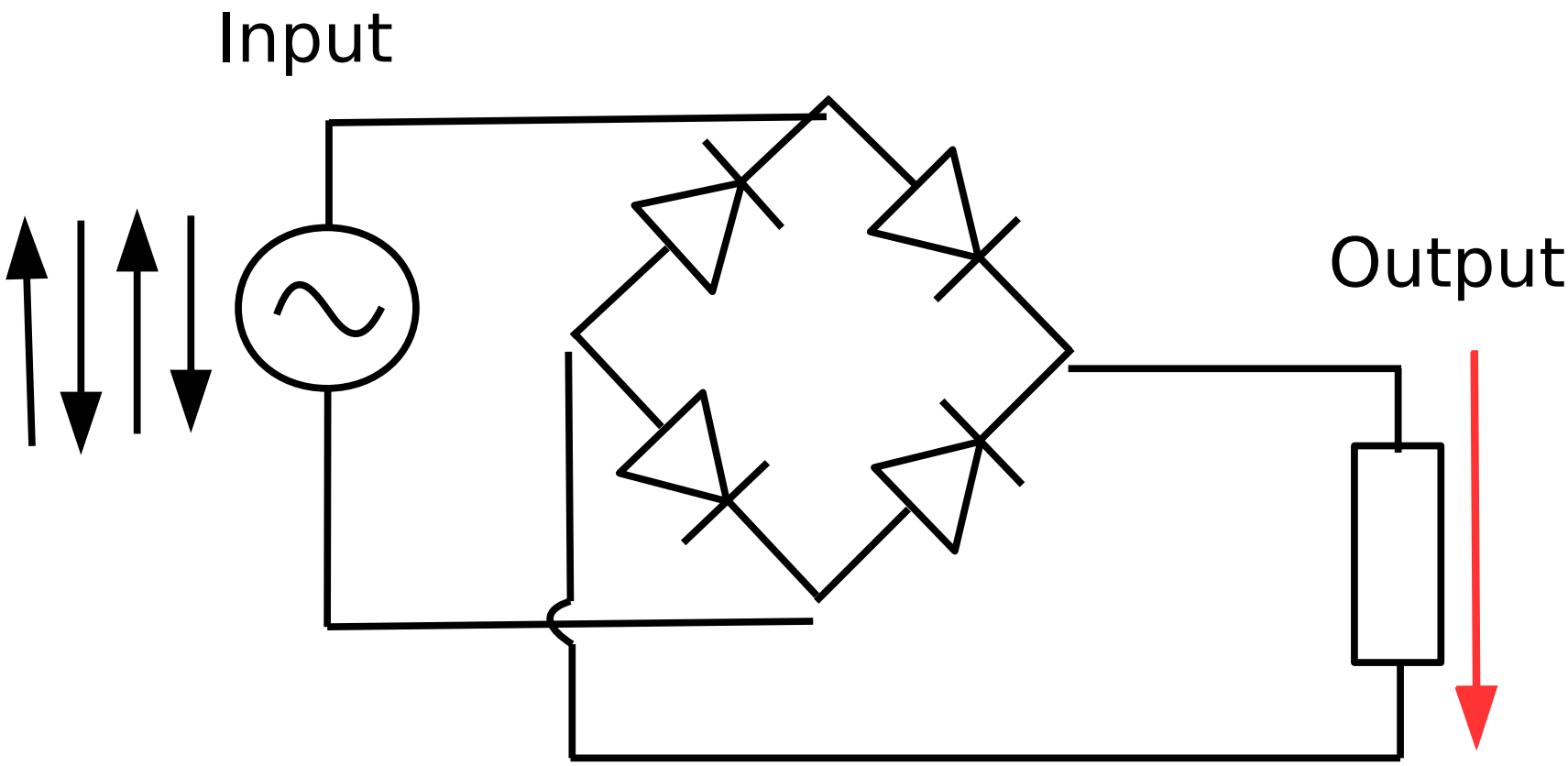
When the voltage is negative..



When the voltage is negative..

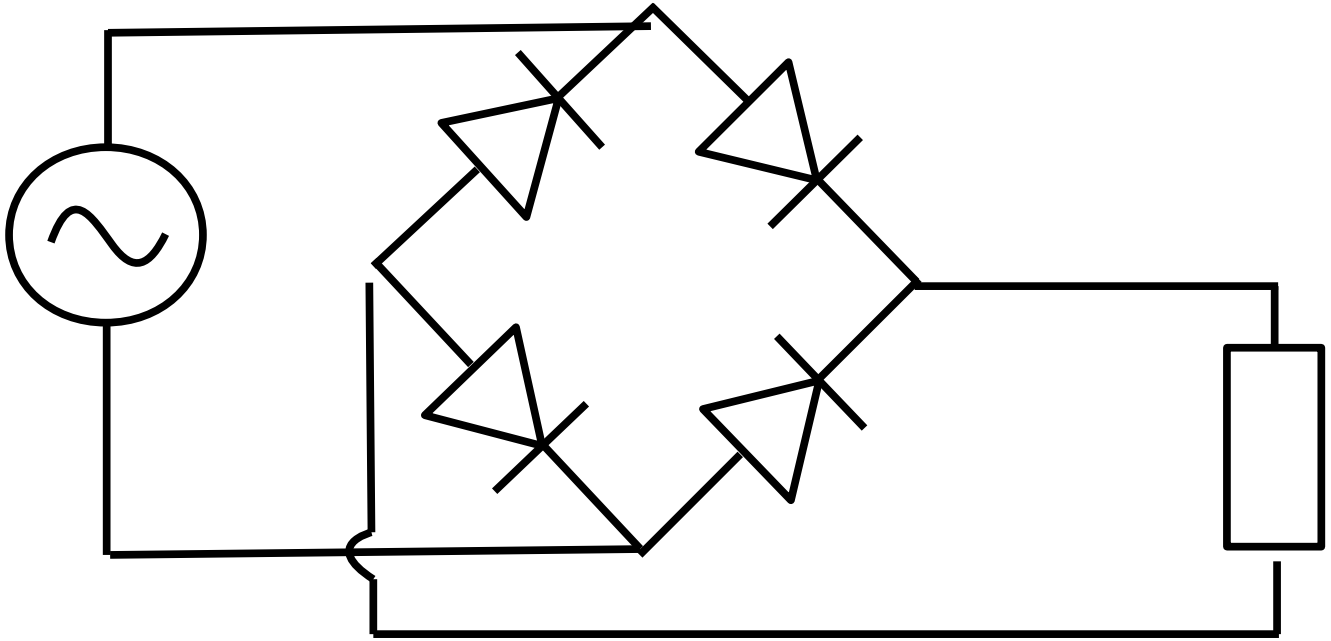


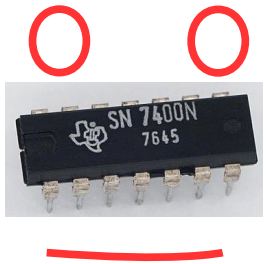
Notice, what ever happens to the input voltage the output voltage is always in the same direction

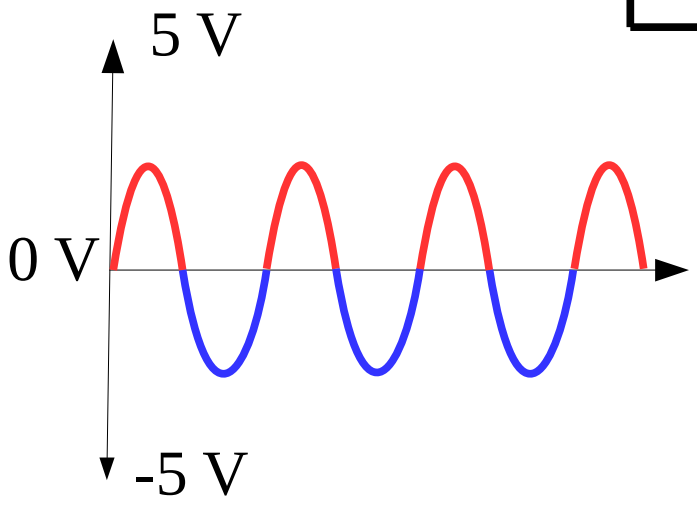


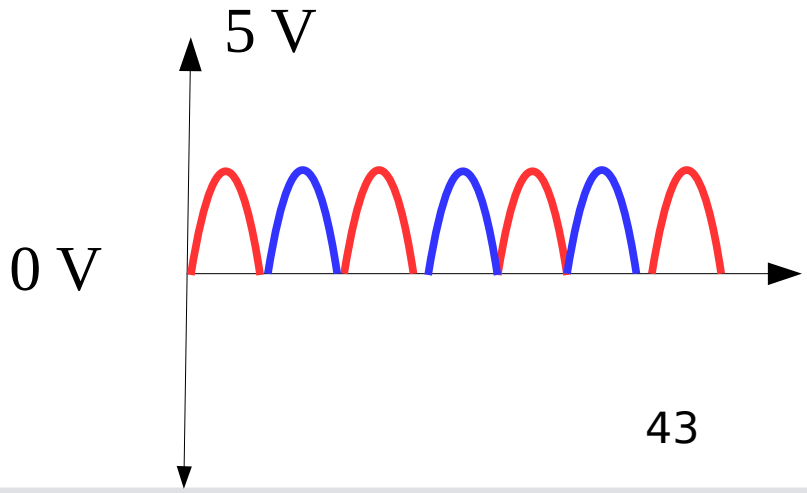
Let's look at the wave forms...

And the result....



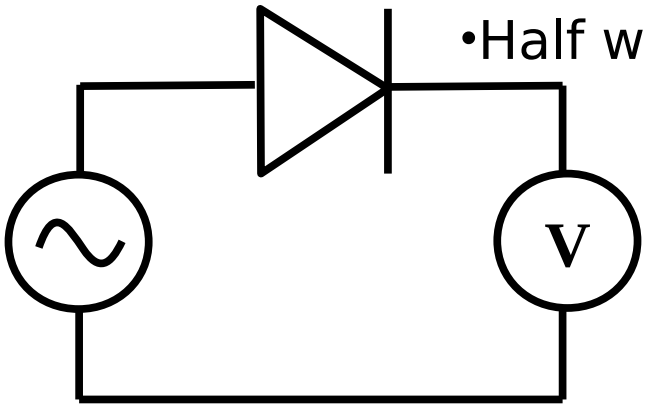


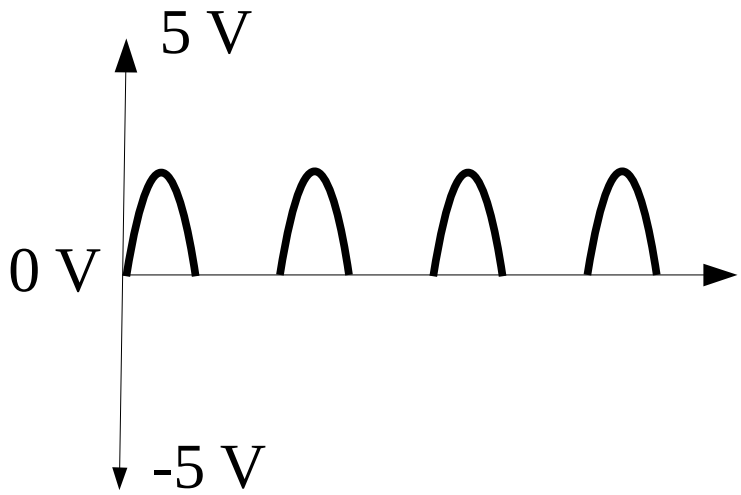




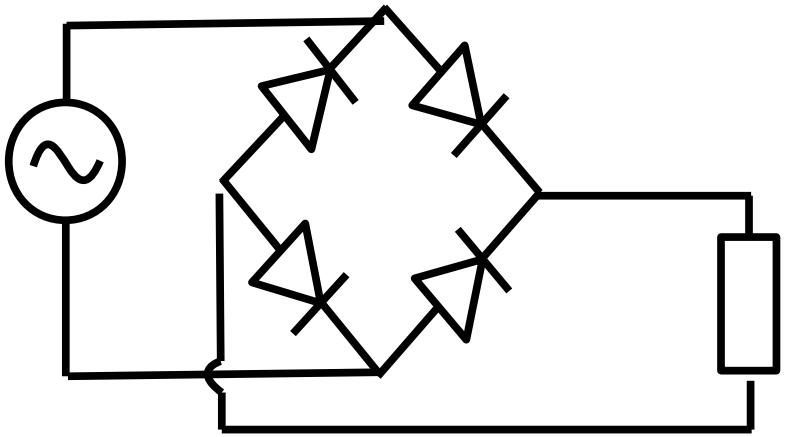
We now have positive voltage more of the time.

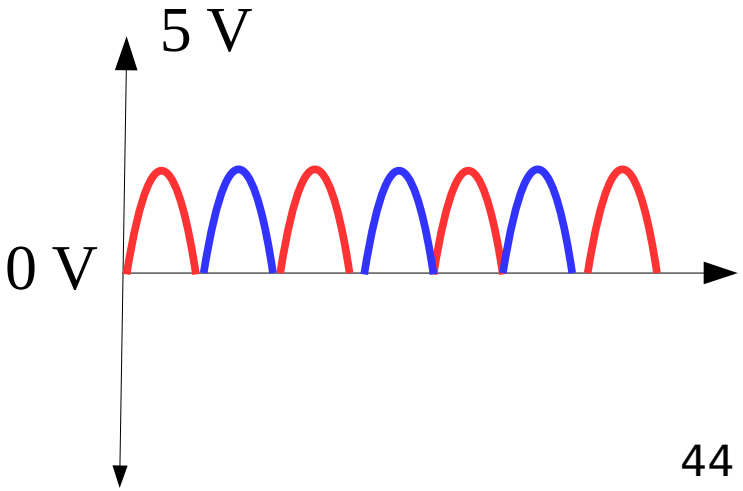
•Half wave rectifier





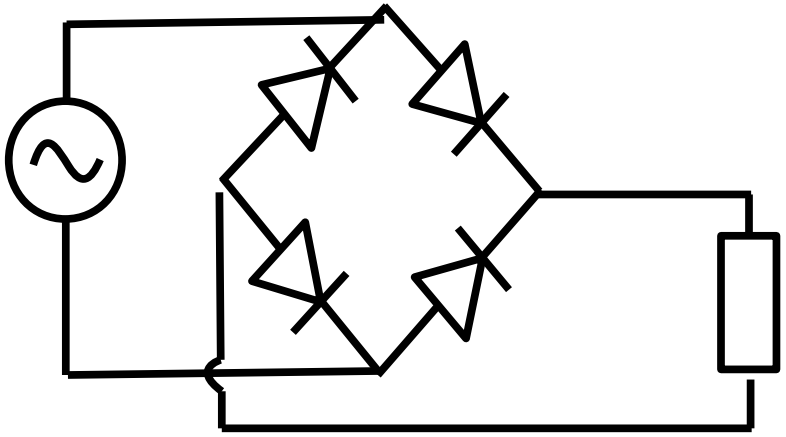
•Full wave rectifier

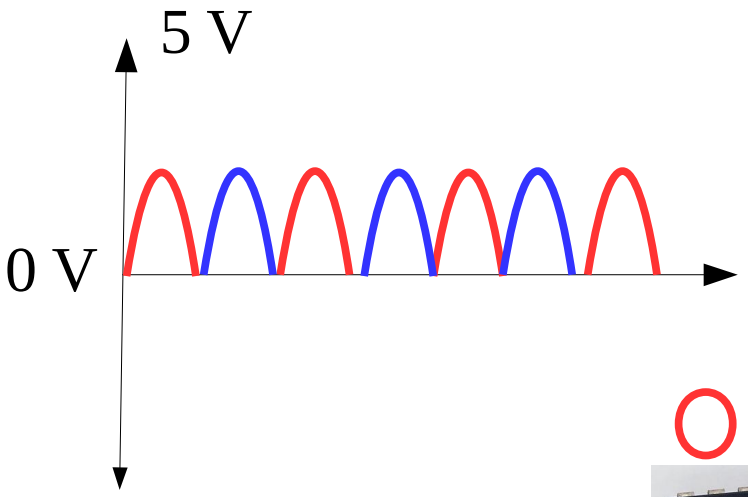


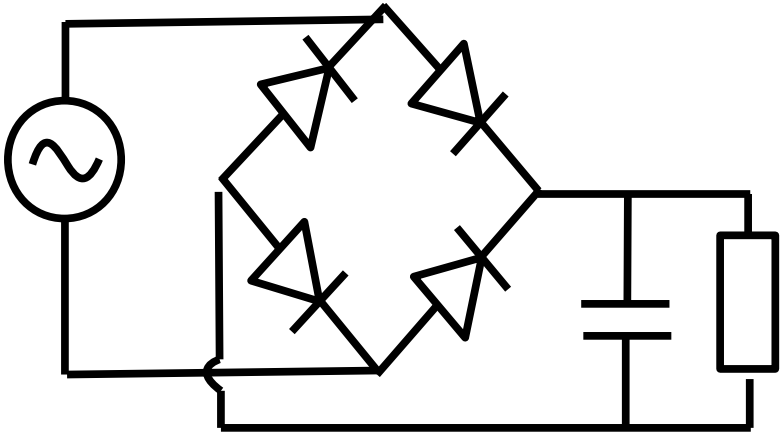


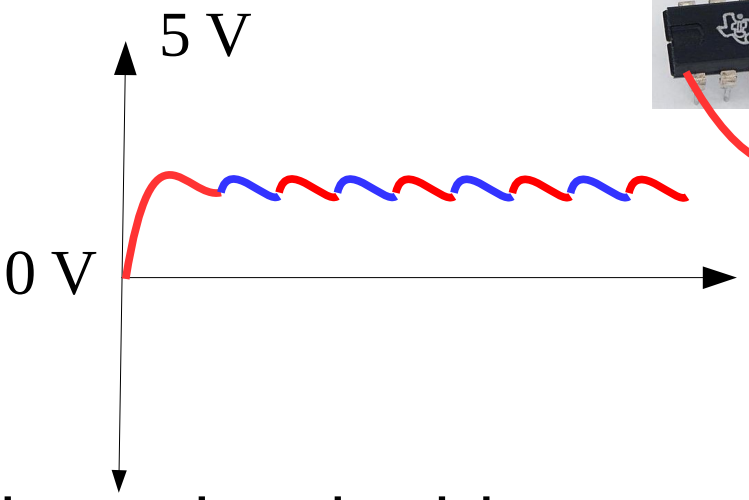
•Looks useful, but our circuit is still off 100 times a second.

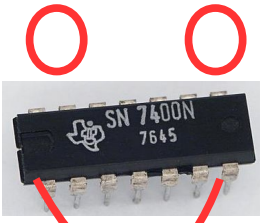
Add a smoothing capacitor....







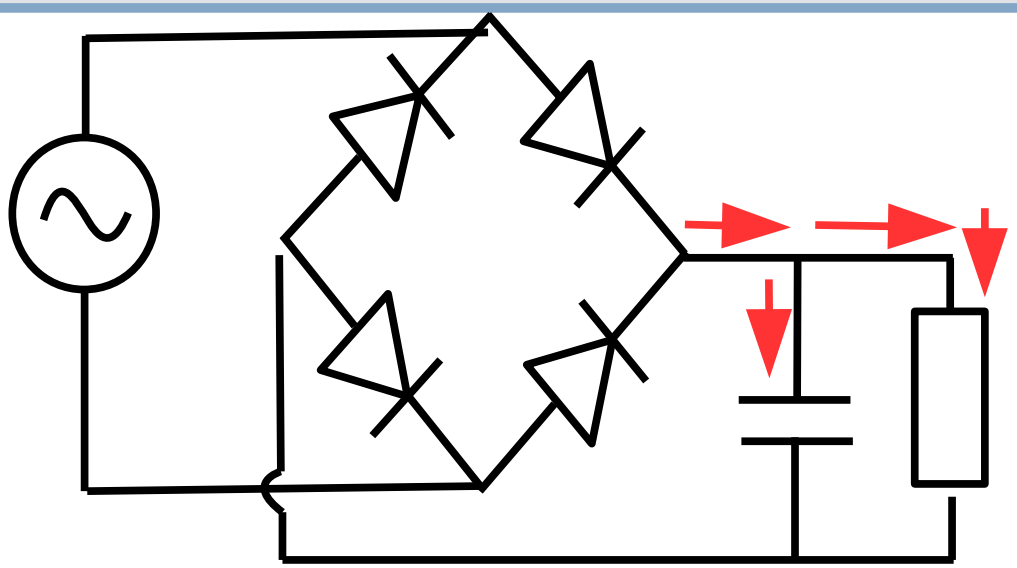


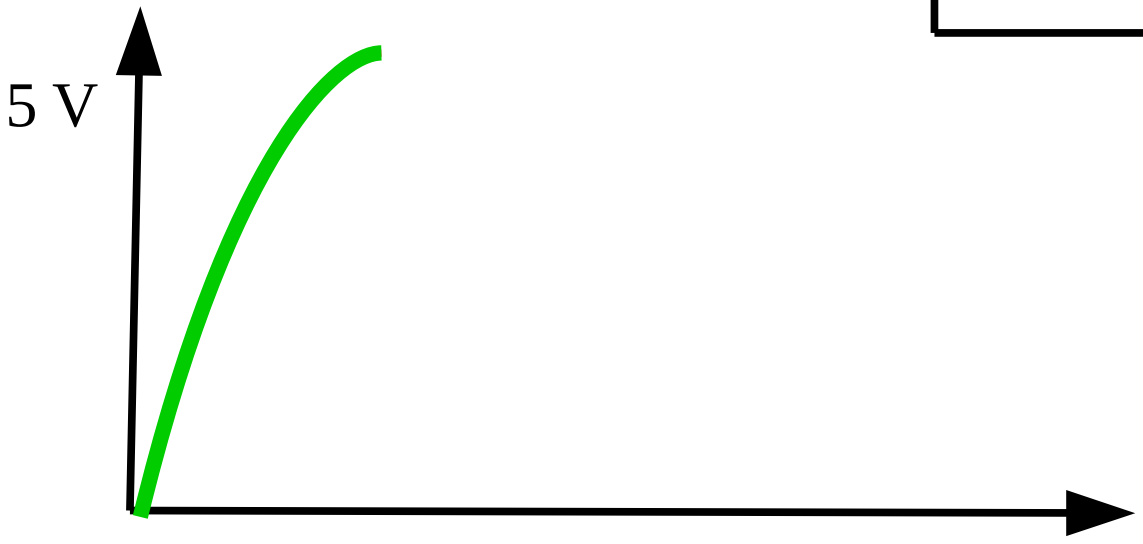


- And we sort of get nice DC, but what is this capacitor doing?

But why is this?

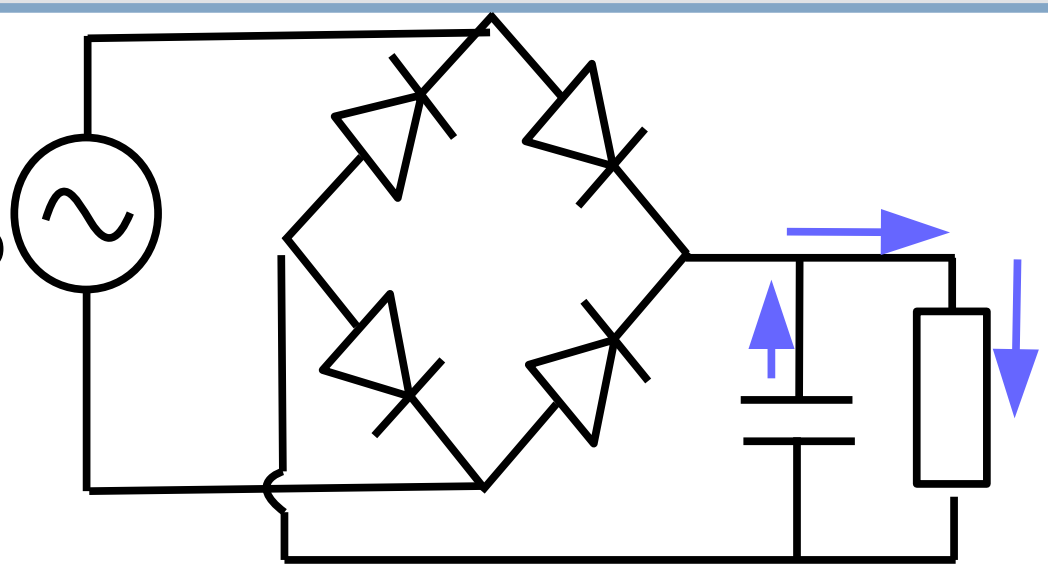
When the supply is first switched on the rising supply voltage will charge the capacitor.

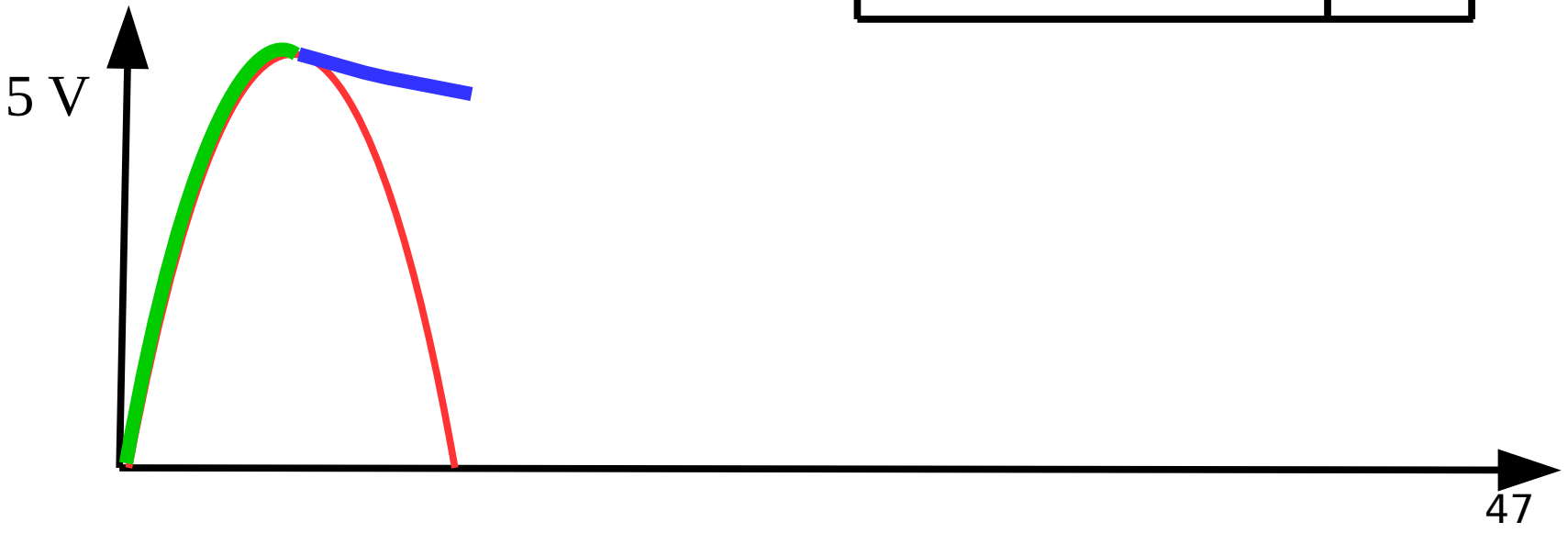




But why is this?

When the supply voltage starts to dip the capacitor will keep the voltage high and supply the circuit with voltage/charge.





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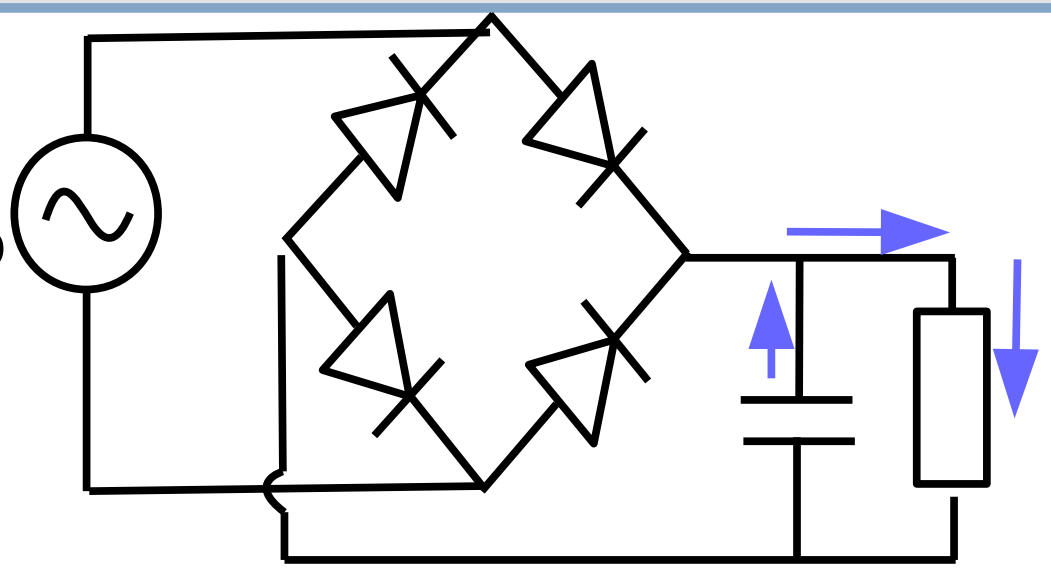
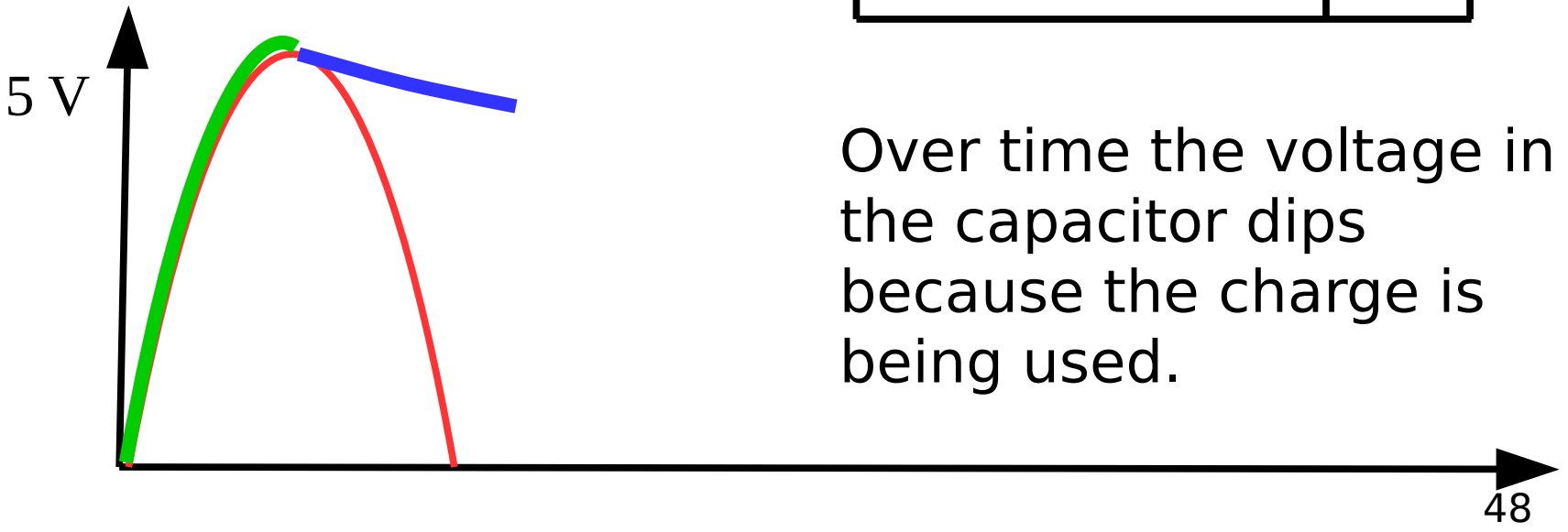
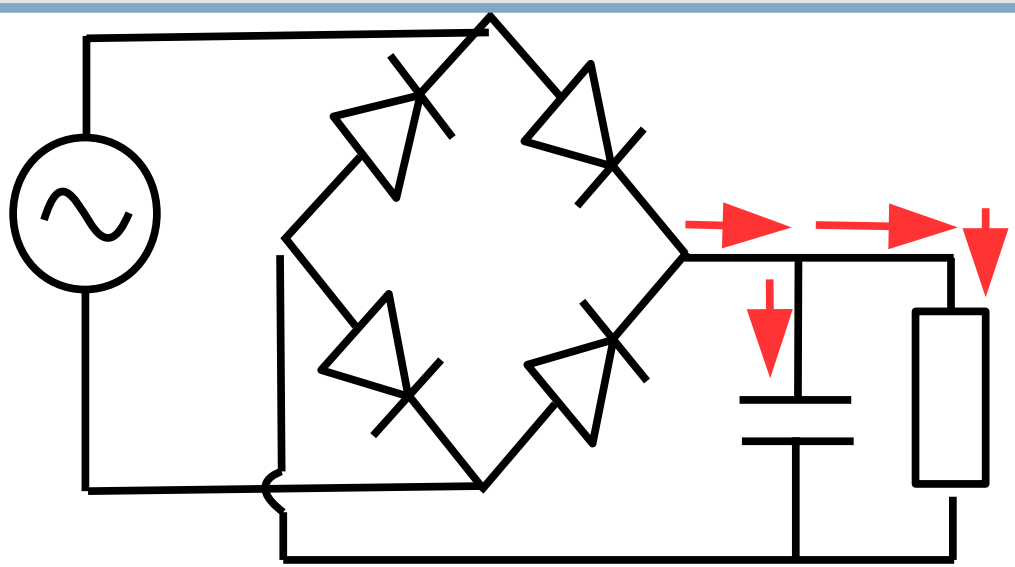


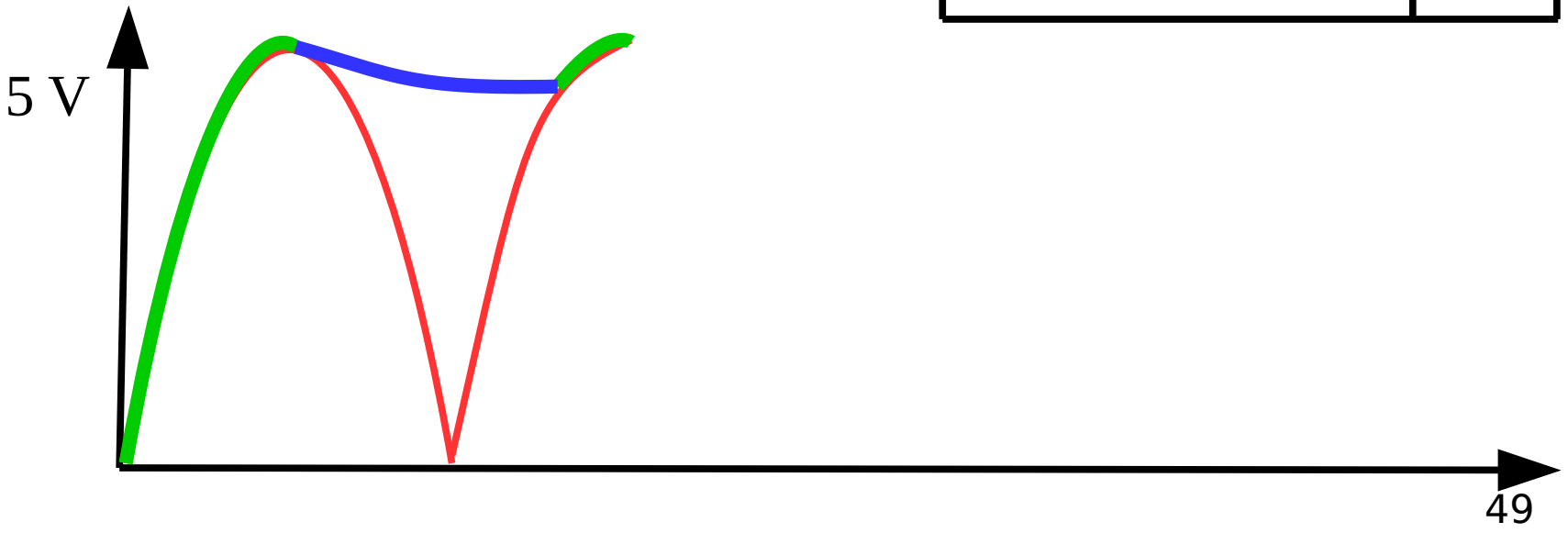


Over time the voltage in the capacitor dips because the charge is being used.

But why is this?

On the next cycle the capacitor will charge and power will be supplied to the circuit.





But why is this?

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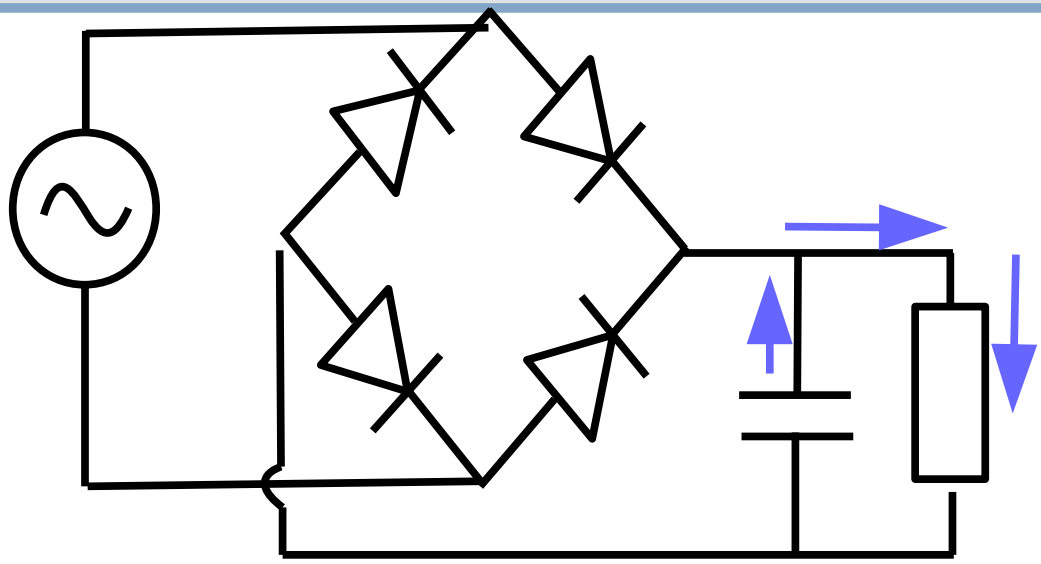
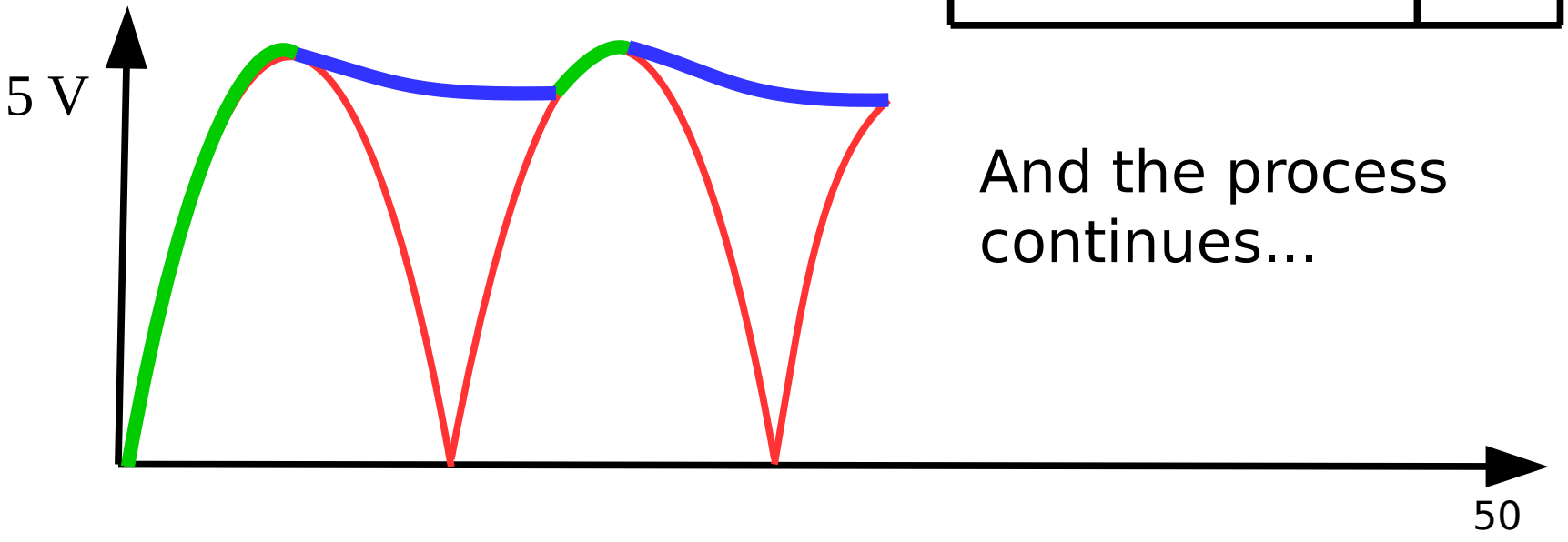
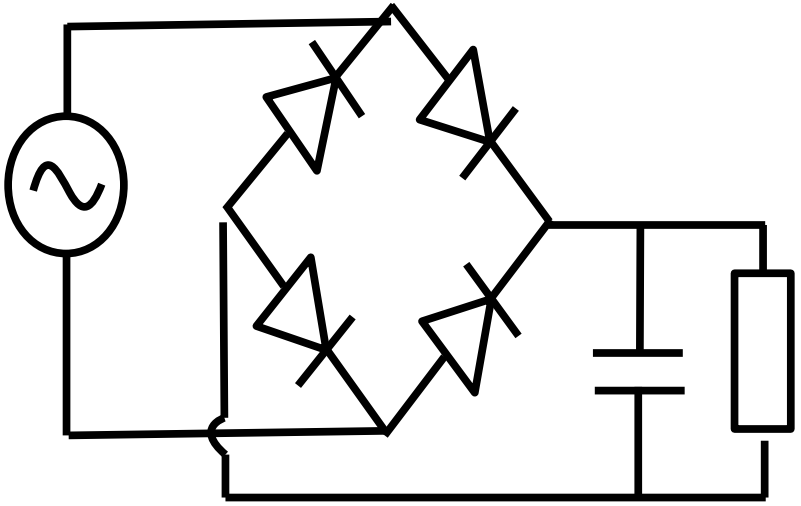


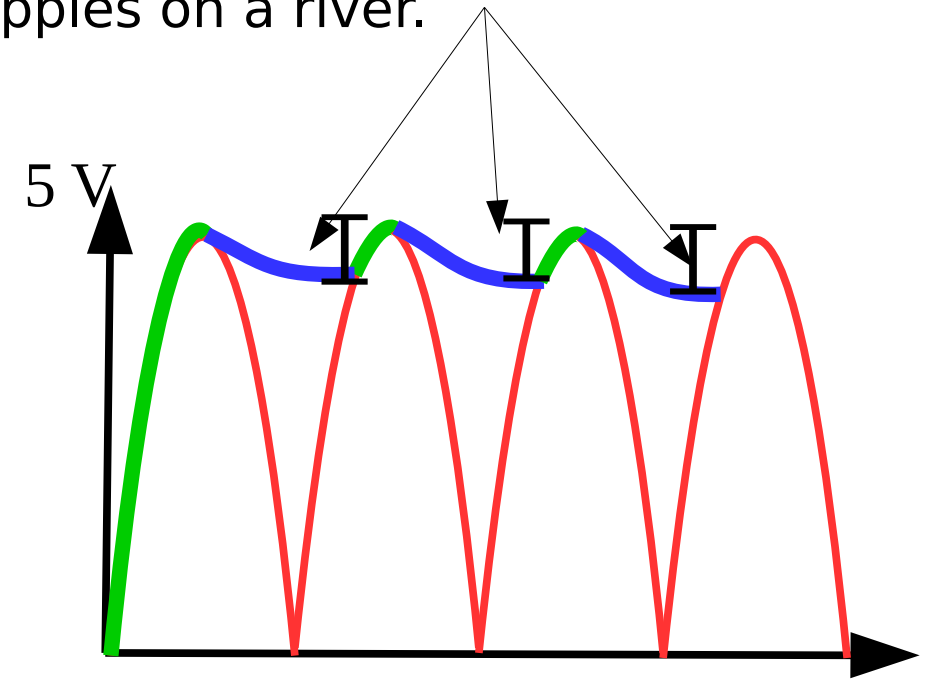


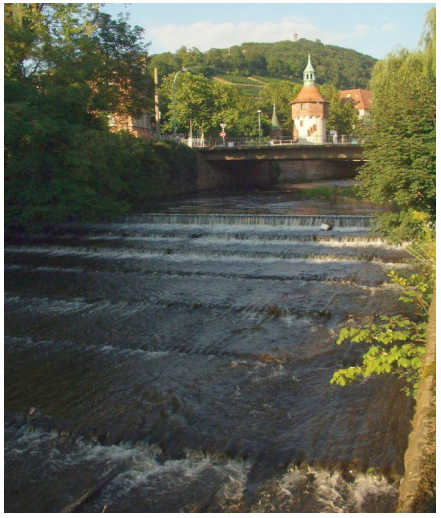
And the process continues...

A non perfect DC supply



This voltage here is called the ripple voltage – think of it as the ripples on a river.

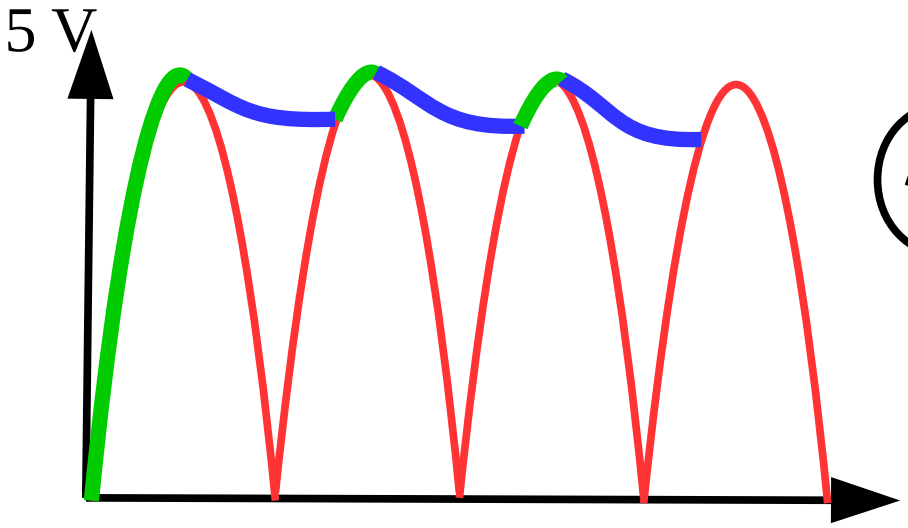


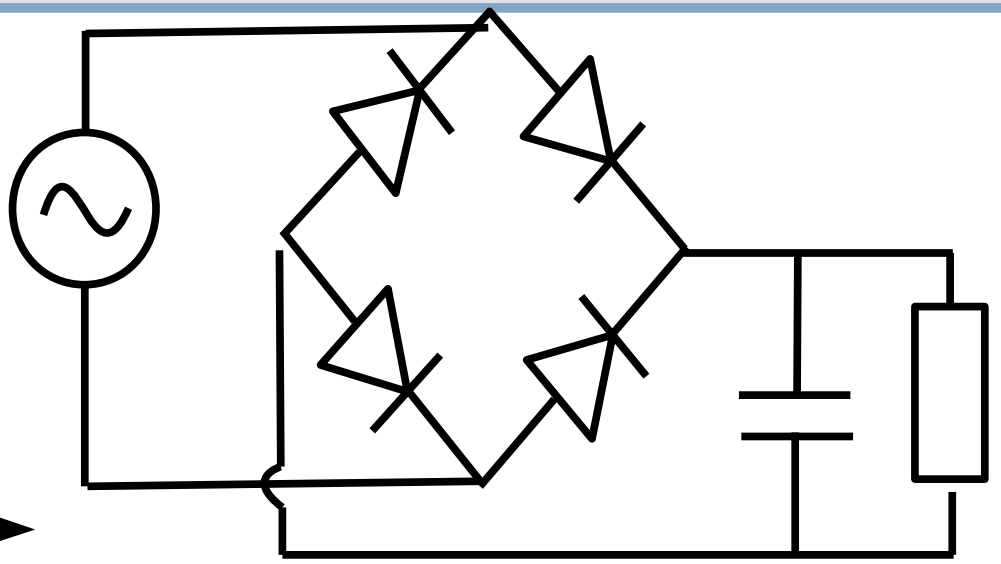


Philipp Hertzog

How might you make this ripple voltage smaller?

Ripple voltage

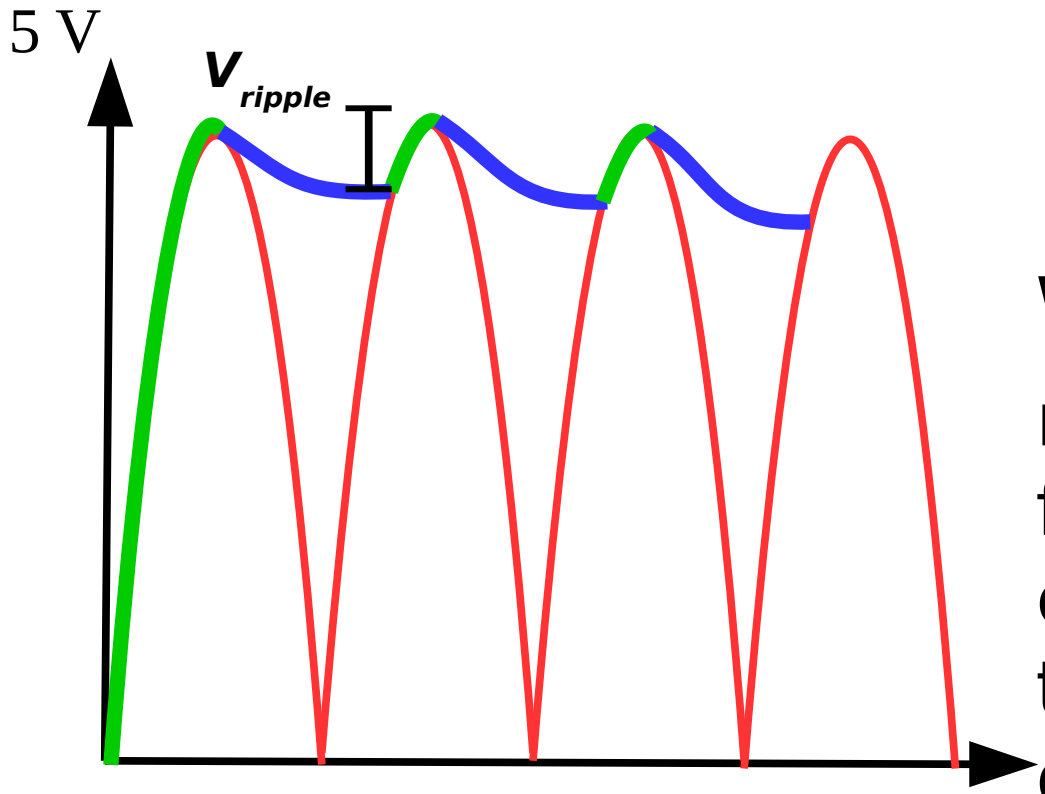




a) Increase the size of the capacitor so it can supply more charge for longer.

b) Make your device uses less charge.

Calculating the ripple voltage



$$V_{\text{ripple}} = \frac{I}{fC}$$

Where V_{ripple} is the ripple voltage, f is the frequency, C is the capacitance and I is the current being drawn.

Exam question

$$V_{\text{ripple}} = \frac{I}{fC}$$

You are designing a 5V DC power supply to deliver 10 mA, from a 50 Hz supply. You pick a 100×10^{-6} F capacitor.

What ripple voltage would the power supply have? Is this reasonable?

What value of capacitor would you need to have a ripple voltage of 0.2 V.

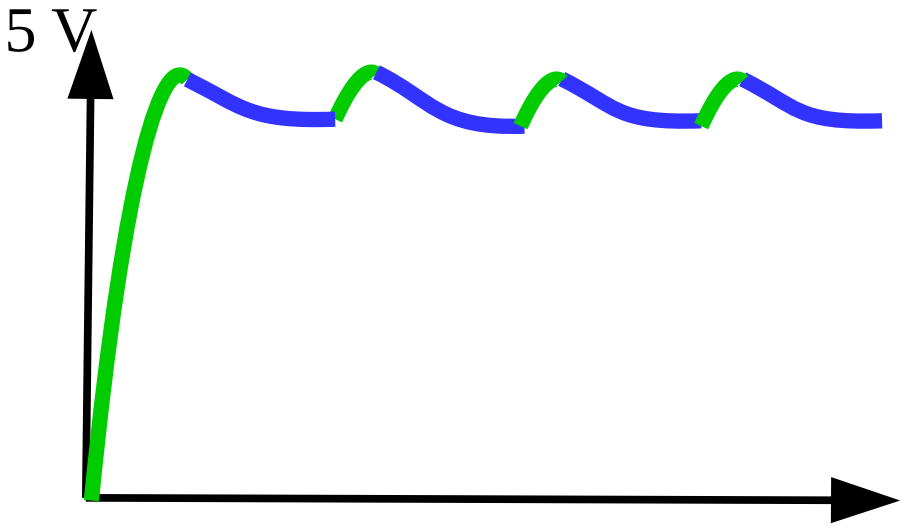
Exam question

A: 2V

A: No.

A: 1000×10^{-6} F

Getting rid of ripple

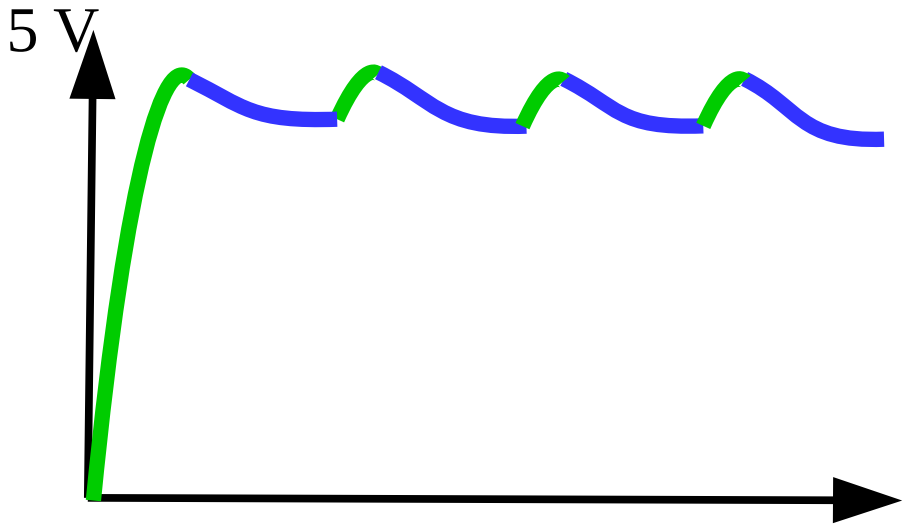


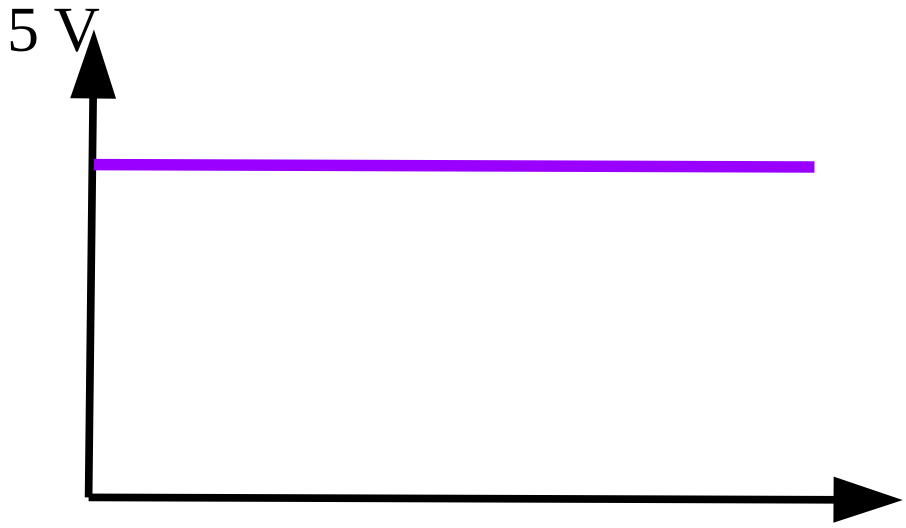
However, in reality no matter what you do to the size of the load or the capacitance of the supply **you will always get ripple**.

- Sometimes this does not matter – **driving a DC motor – simple digital circuits** (may be).

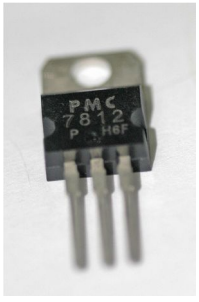
- Sometimes this matters a lot, ***powering complex digital circuits***, ***computers*** and ***audio amplifiers***.

Perfect DC – the voltage regulator





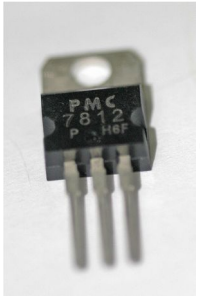
- If you want a perfect DC voltage source you have to use a voltage regulator which looks like this:



Matarasephotos

Voltage regulator

- You stick it on the output to your capacitor and you get nice DC out.



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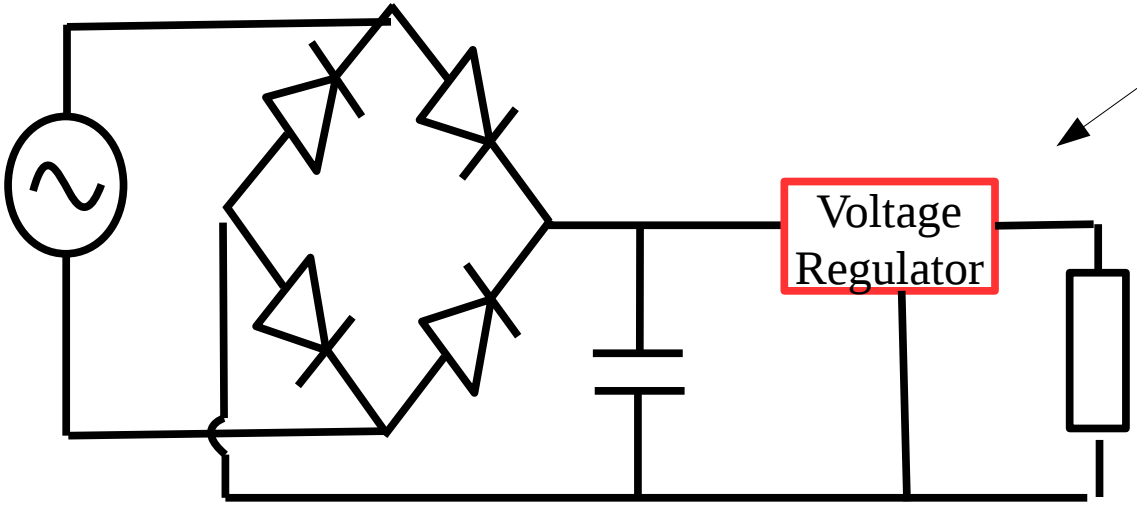
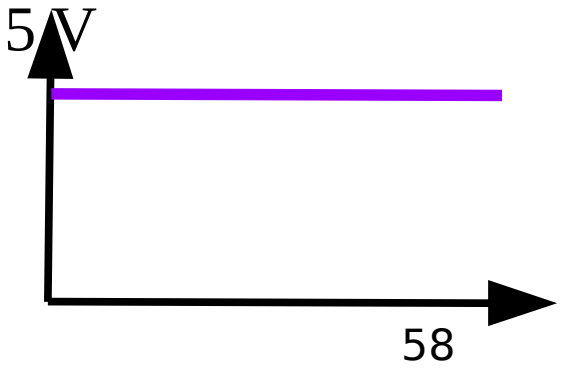
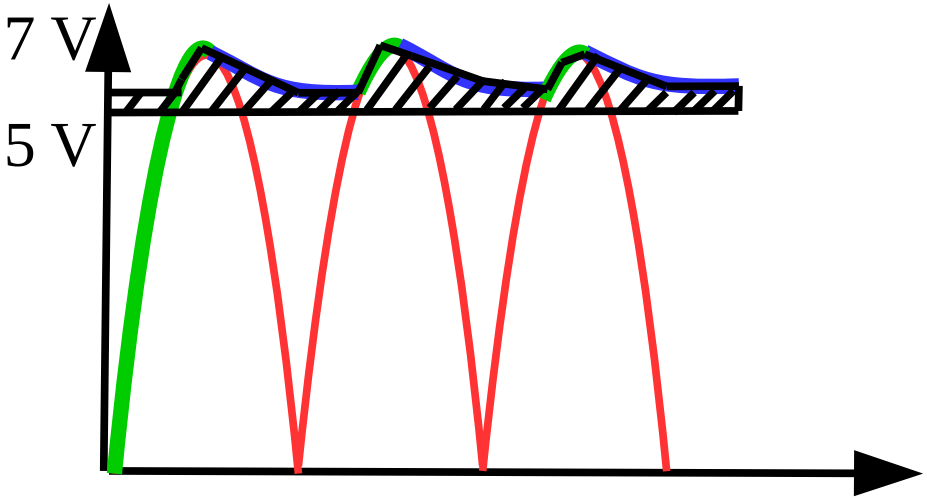
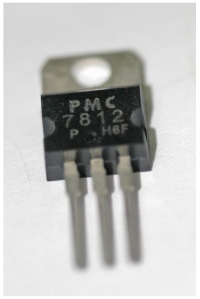




How does the voltage regulator work?

- In simple terms, it's got a smart resistor in it that absorbs any excess voltage.





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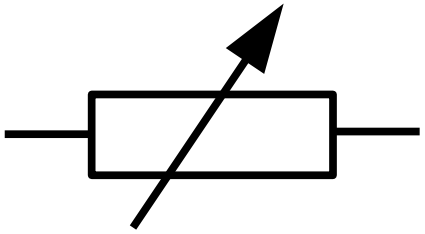
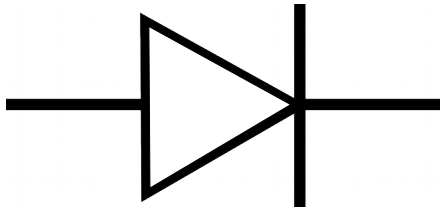


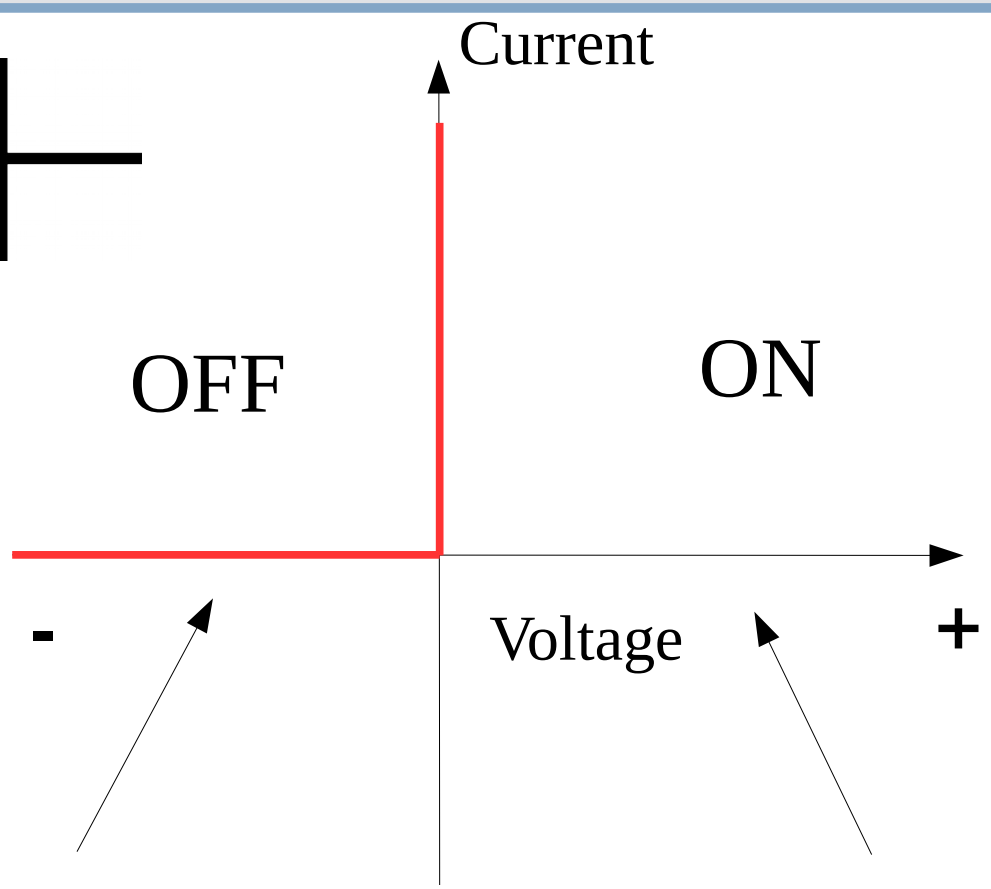
- This means it will waste quite a lot of power and get hot! So bolt it to a heat sink to it.

How does the voltage regulator work?

- Recap of last lecture
- Introduction to diodes.
- Power diodes – the basics.
- Designing a power supply
  - Diodes the bridge between AC and DC
- **The less ideal diode**
- Other kinds of diodes including Solar cells
- Summary

Recap: The ideal diode

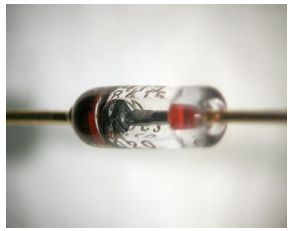




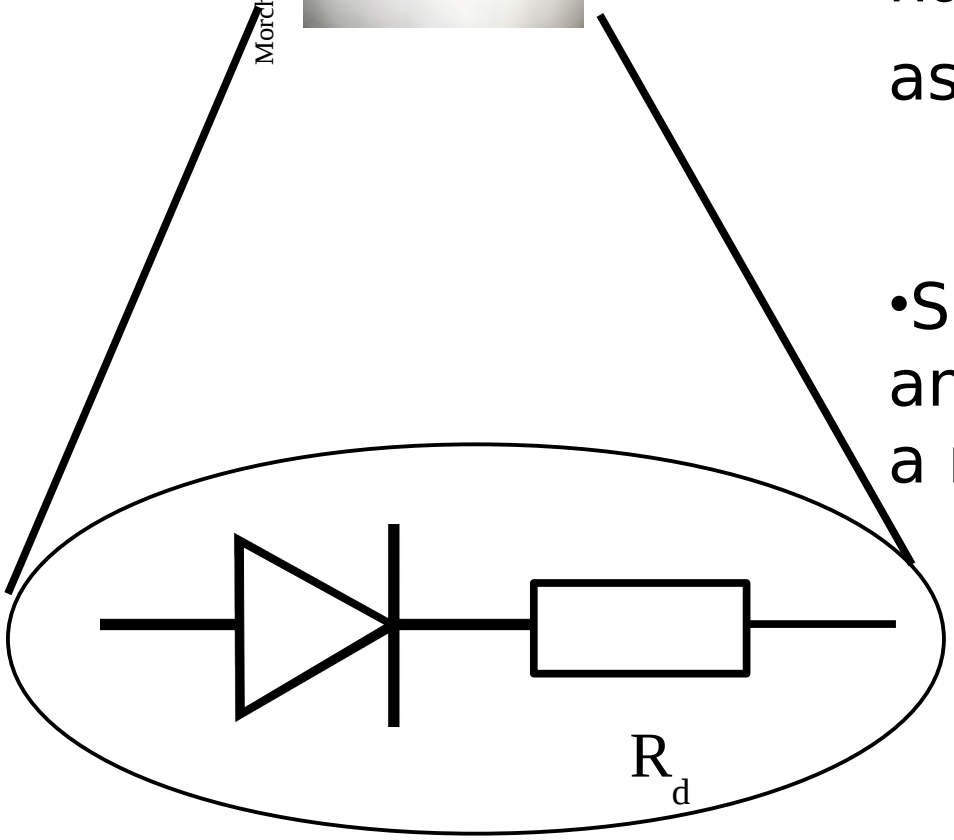
At negative voltages it blocks current

At positive voltages any amount of current can flow

A less ideal diode



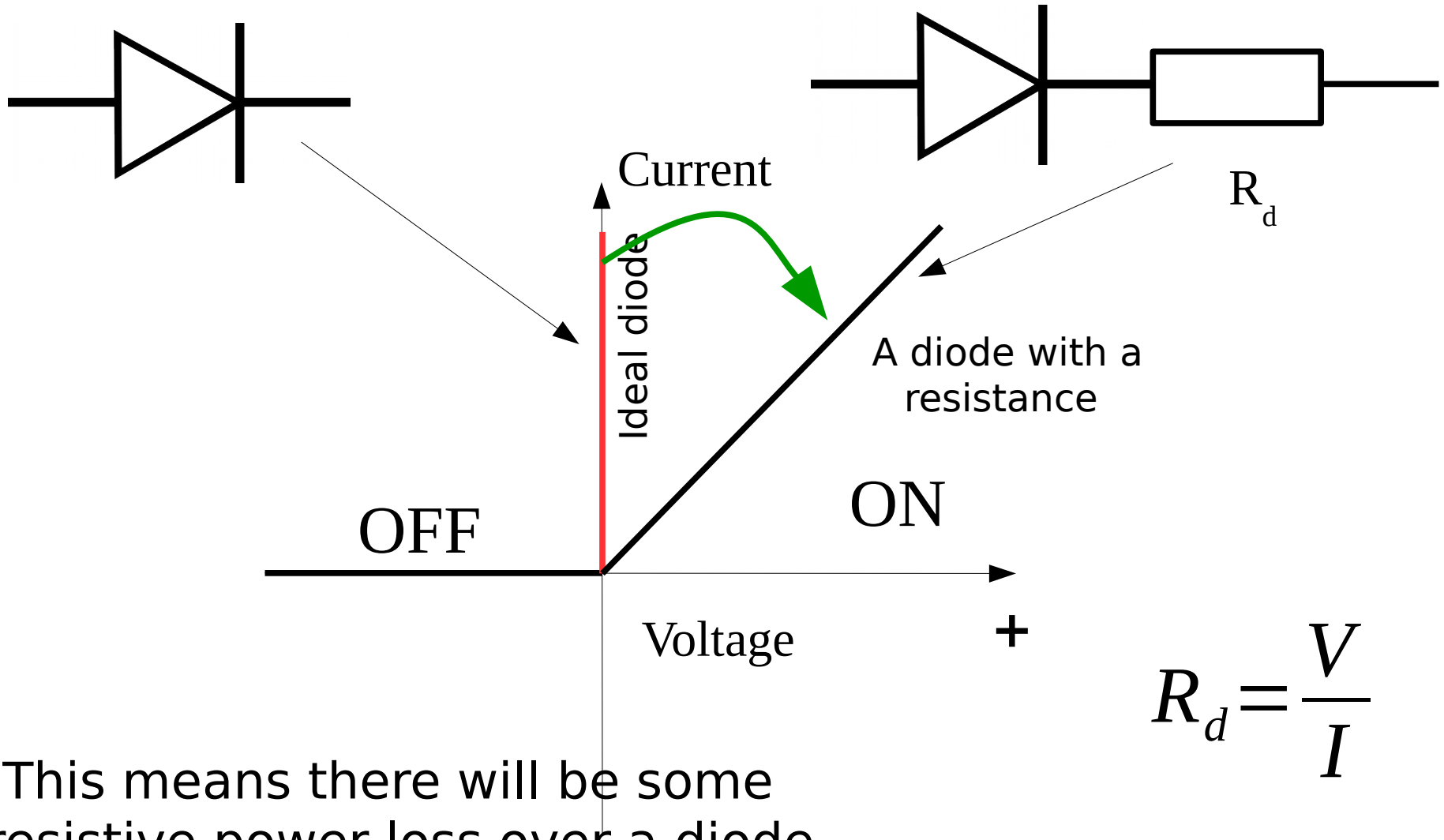
Morcheeba at en.wikipedia



- However real diodes are like any other device they have a resistance R_d associated with them.

- So you can think of them as an ideal diode in series with a resistor.

A less ideal diode

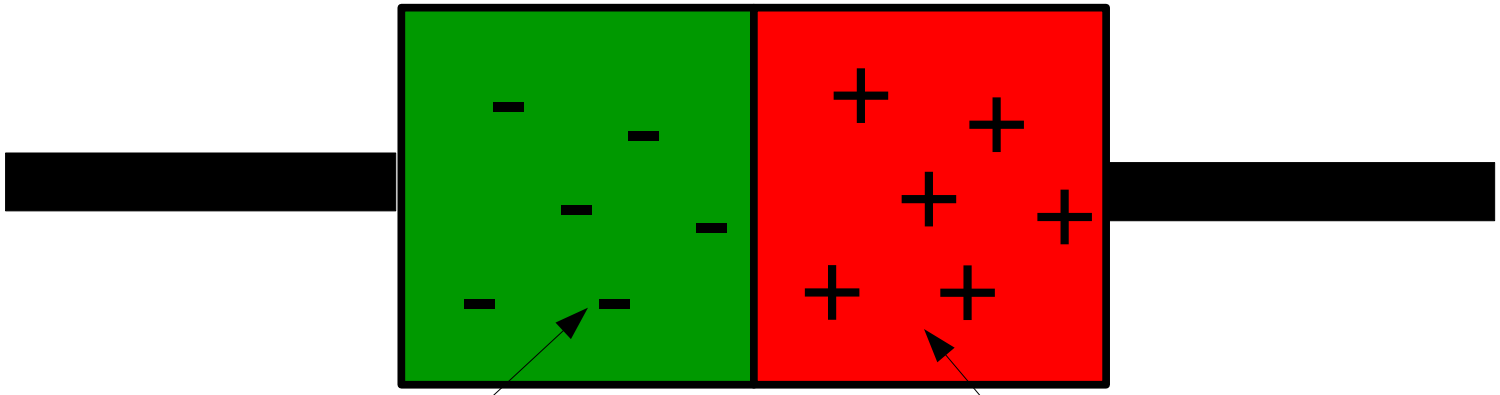


$$R_d = \frac{V}{I}$$

- This means there will be some resistive power loss over a diode.

Furthermore.....

- Diodes are made of two materials, one with lots of negative charges and one with lots of positive charges

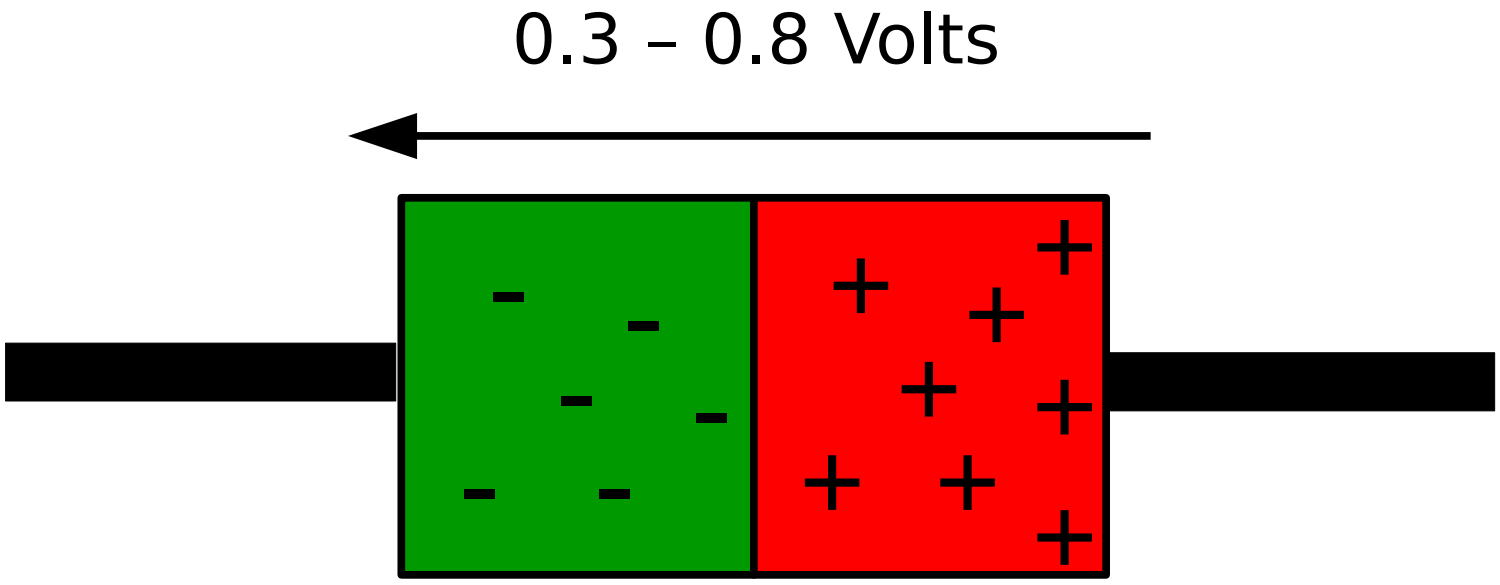


Negative charges called an **n-type** material

Positive charges called a **p-type** material

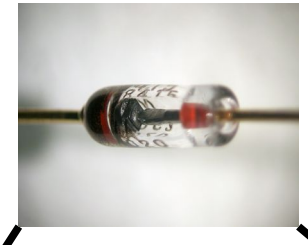
Positive and negative charges

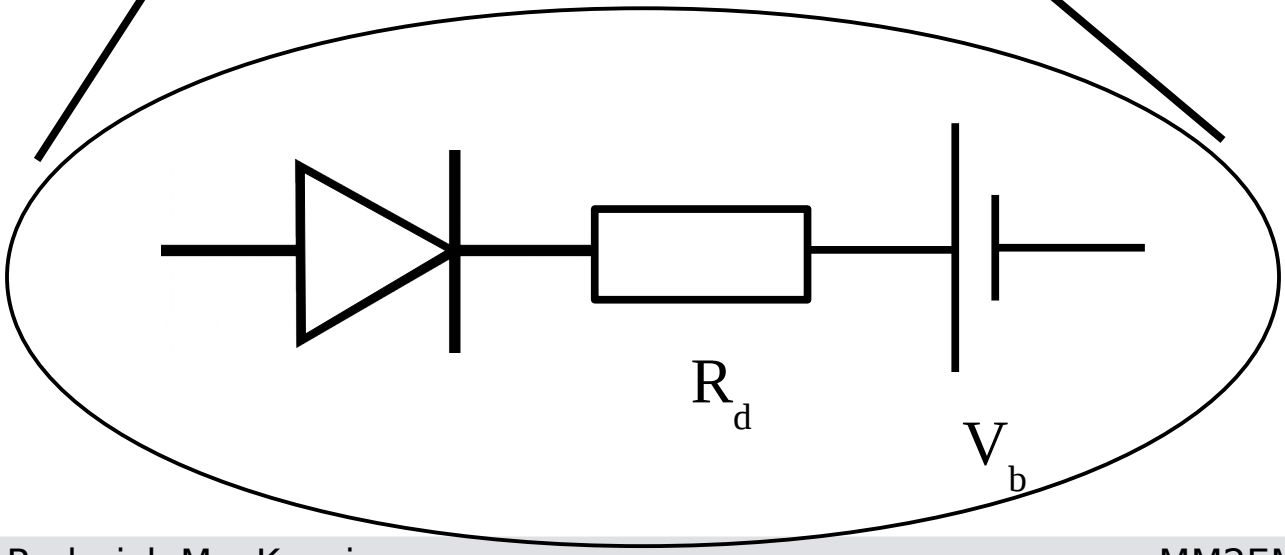
- This charge build in the device means that every diode produces a voltage of between 0.3 V to 0.8 V.
- This is called the built in potential.



- In some applications this built in potential is a pain, in others it is really useful

A diode with a built in potential

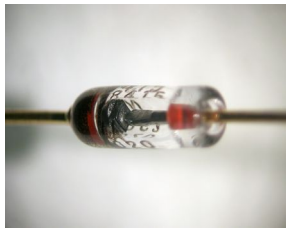




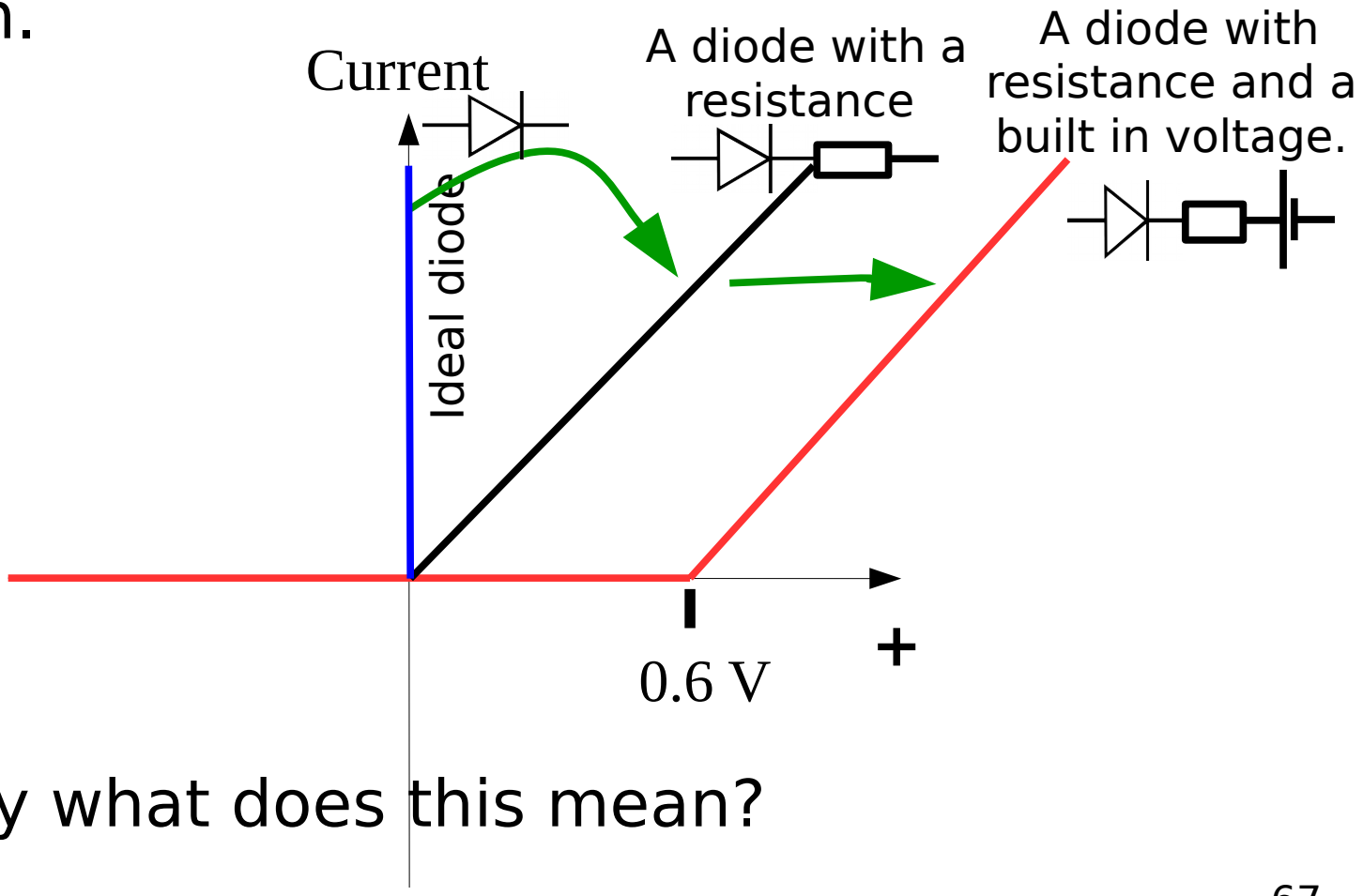
- Because of this built in charge you can actually think of a diode as having a small (0.3 V-0.8 V) battery in series with it.

The built in potential

- This means you need to apply 0.3-0.6 V to a diode to turn it on.



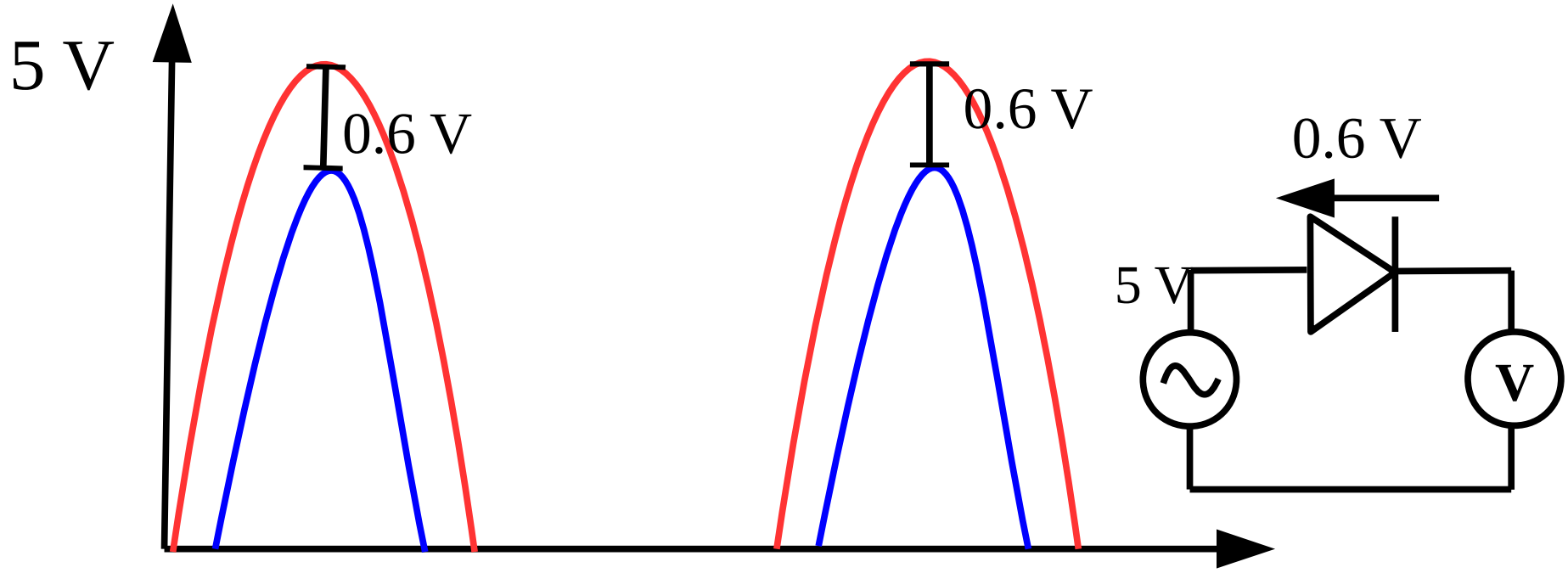
Morcheeba at en.wikipedia



- Practically what does this mean?

What does this built in voltage mean in practical terms.

- We will always get 0.3-0.8 V lost when we use a diode.

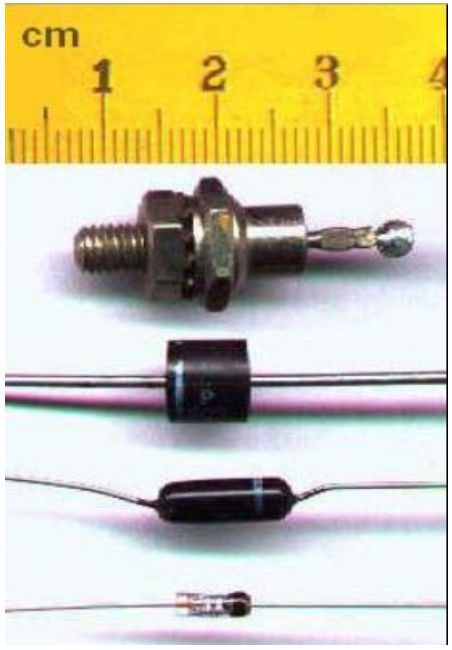


- So when ordering a transformer for a 5V chip – make sure it provides at least 6V.

How does the voltage regulator work?

- Recap of last lecture
- Introduction to diodes.
- Power diodes – the basics.
- Designing a power supply
  - Diodes the bridge between AC and DC
- The less ideal diode
- **Other kinds of diodes including Solar cells**
- Summary

Different types of diodes



The diodes we have talked about up to now look like this and are made of silicon.

Silicon (**Si**)

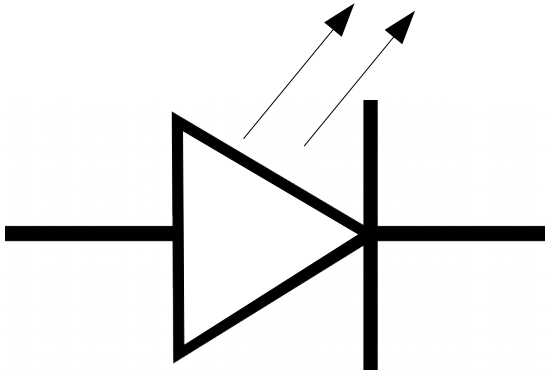
•However if you change the material from which a diode is made it can do far more than just block current.

Or Light Emitting Diodes

- If you make the diode of **gallium** (**Ga**) and **arsenic** (**As**) the diode will generate light.

- And you get an Light emitting diode (LED)

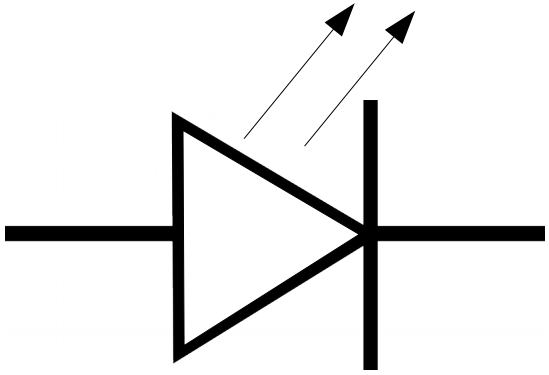
PiccoloNamek

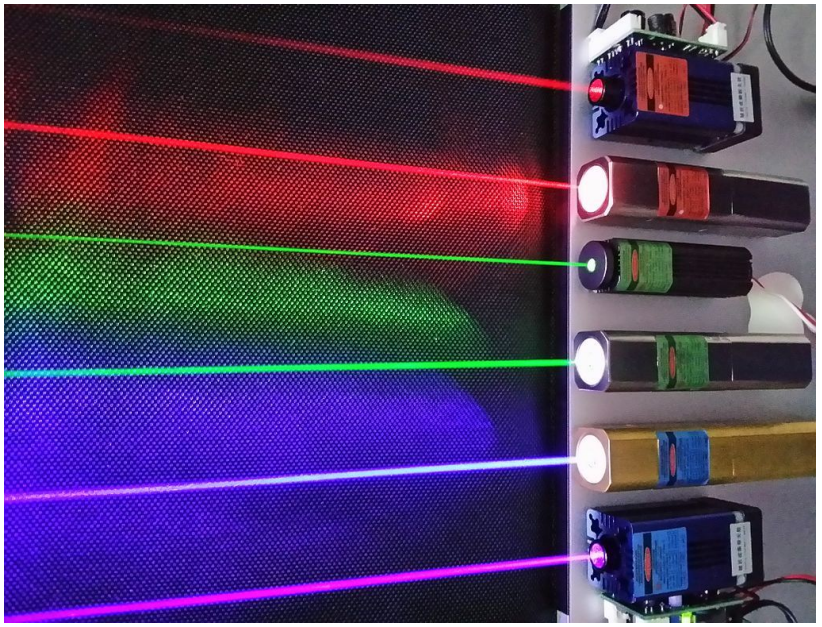


Gallium (**Ga**)

Lasers

- If you focus the light coming out of a LED structure you can get a laser.





Bành Gia Kiệt

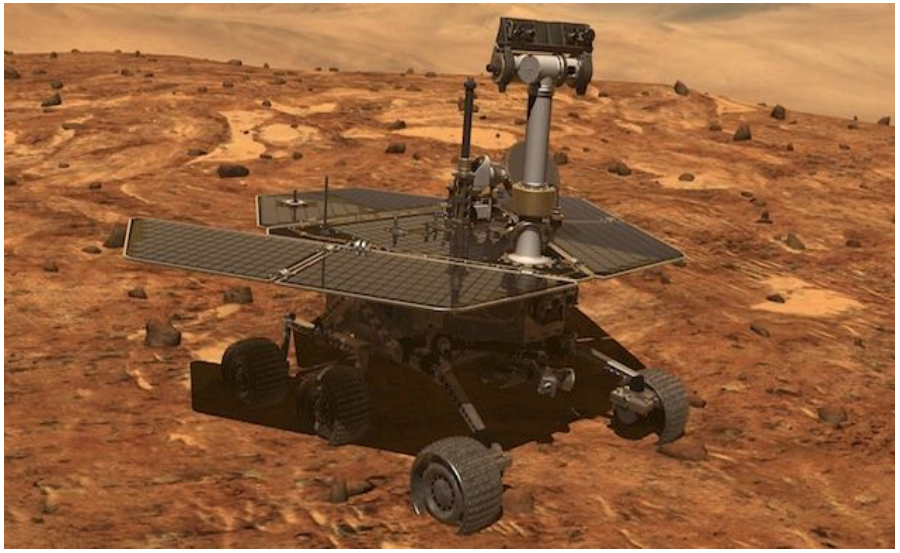
Gallium (Ga)

Outline of the lecture

- Recap of last lecture
- Introduction to diodes.
- Power diodes – the basics.
- Designing a power supply
  - Diodes the bridge between AC and DC
- The less ideal diode
- **From a diode to a solar cell**
- Summary

Why learn about solar cells?

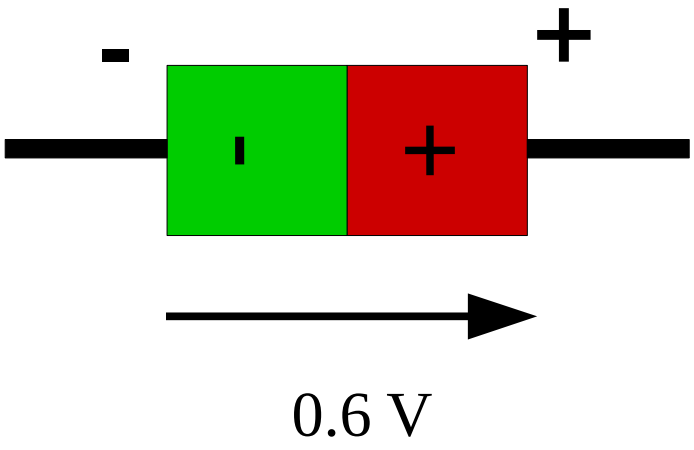
Dwernertl

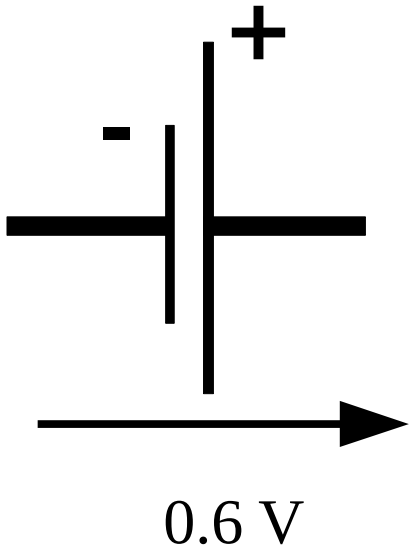


From a diode to a solar cell..

•I said previously that a diode is made of two types of material and **n-type** material and a **p-type** material.

•Because of this a diode always has a voltage across it a **bit like a battery**.

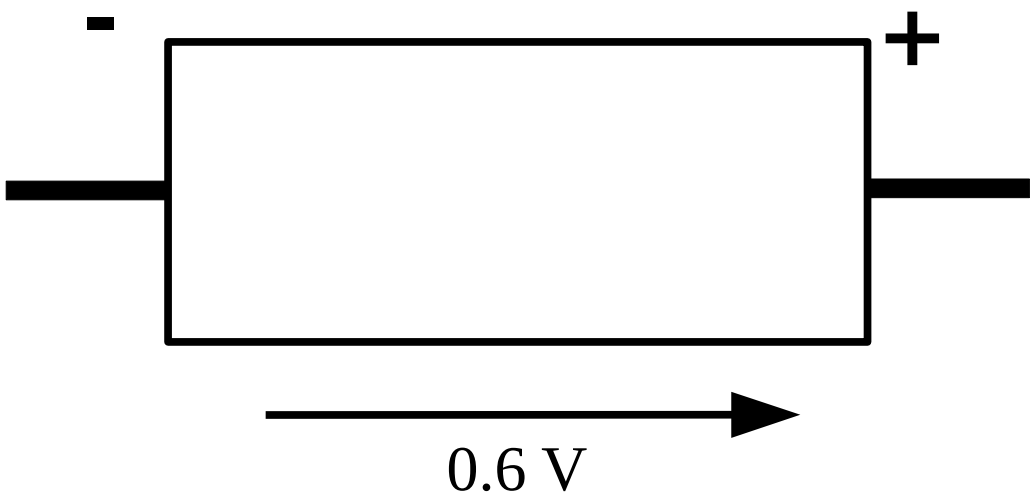




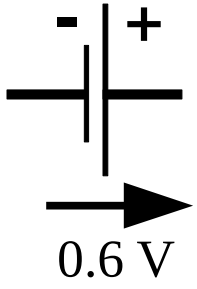
•Let's draw this a bit bigger....

From a diode to a solar cell..

- Here is our diode again.

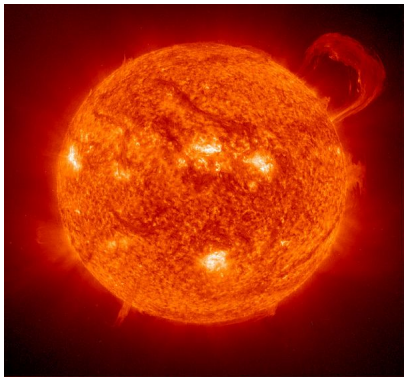


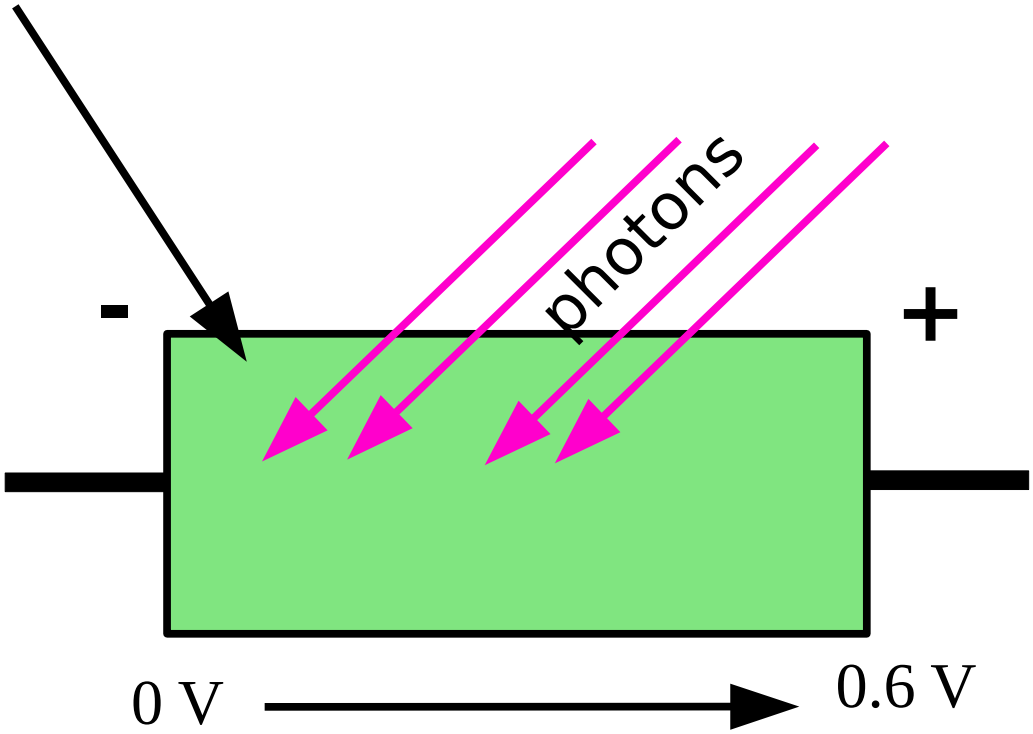
- Now let's change the material so it absorbs light.

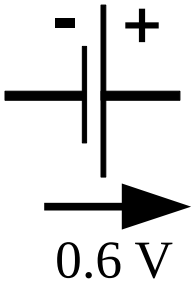


A light adsorbing diode...

- Light adsorbing material.

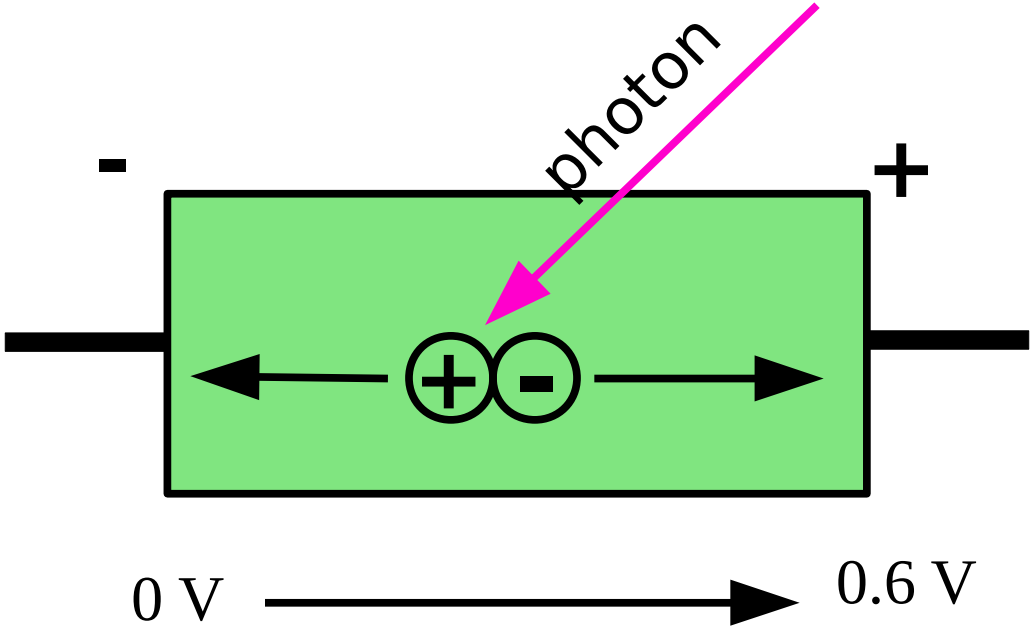






Generation of charge...

•When a **photon** is adsorbed, it generates an positive and a negative charge...

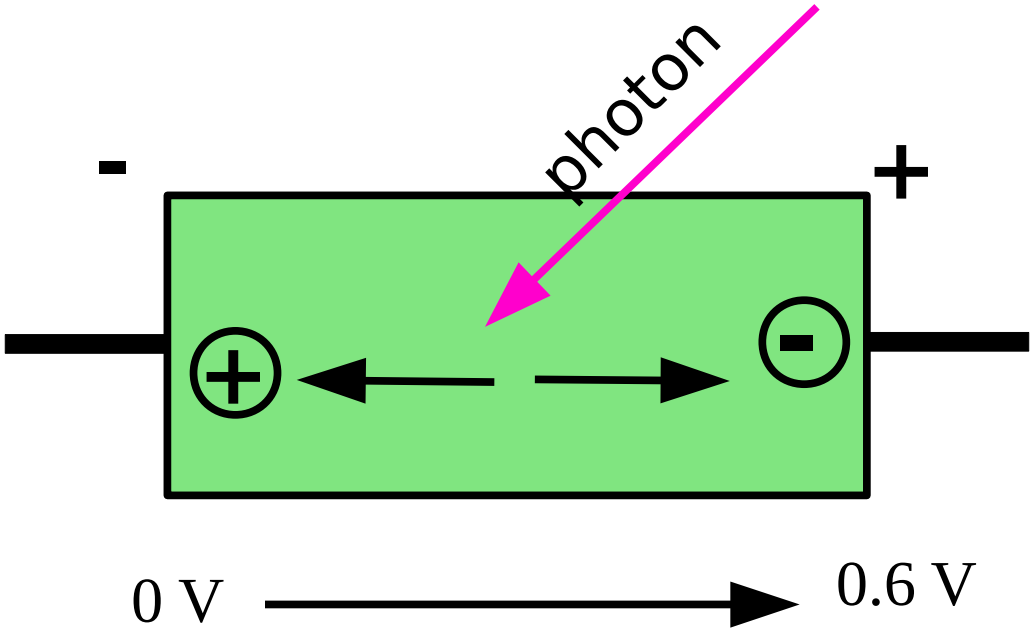


•The field forces these charges to move towards the contacts.

0.6 V

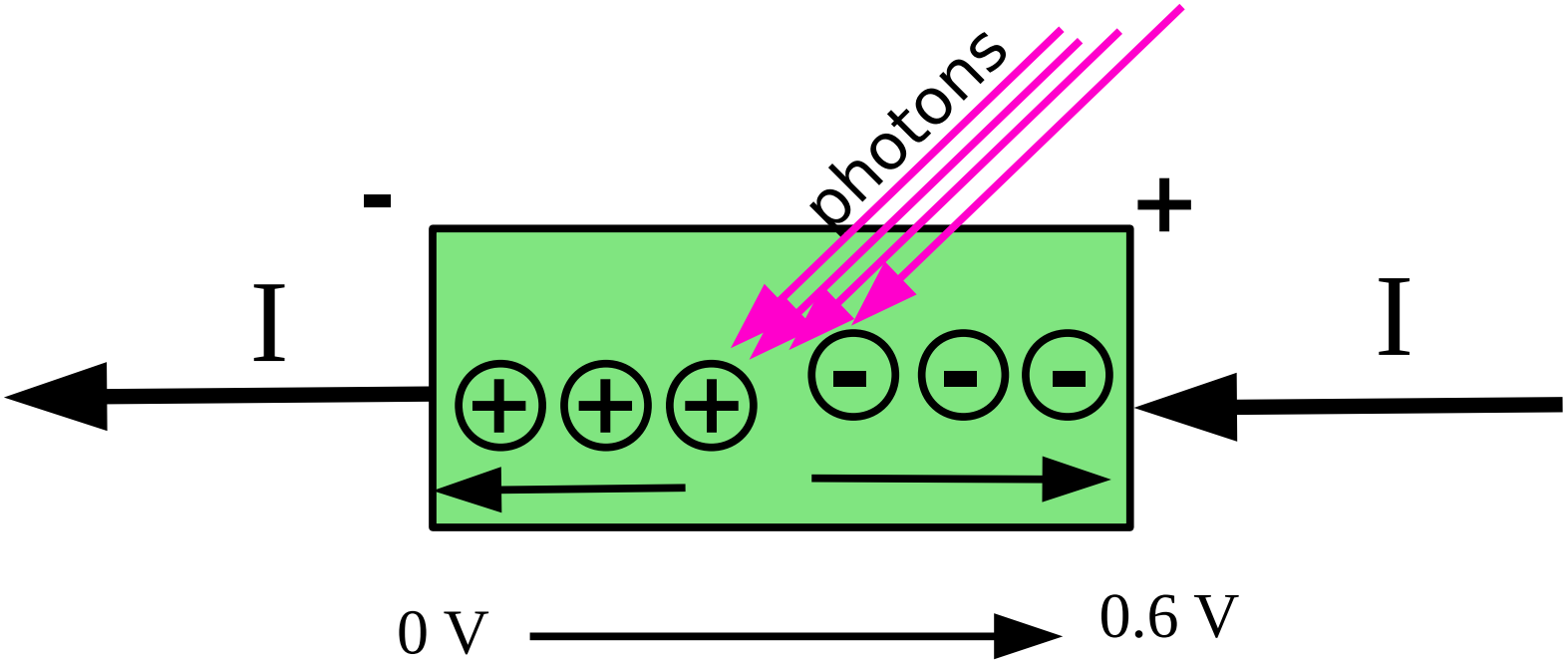
When a photon is adsorbed in a material.....

- The positive charge goes to the negative contact and the negative charge goes to the positive contact.

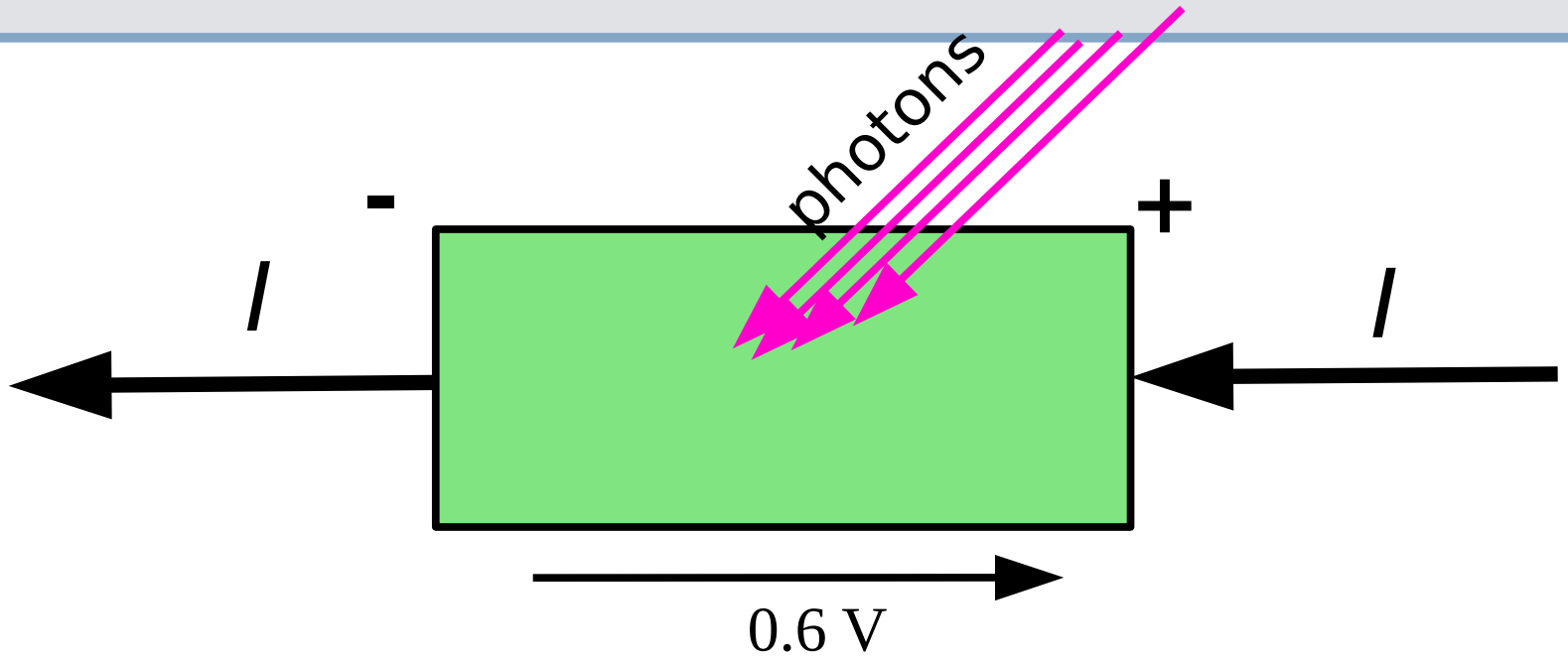


When a photon is adsorbed in a material.....

- If lots of photons hit the diode lots of positive and negative charges move to the contacts and we get current in the external circuit.



Power generation.....



Power=I*V

N=Number of photons adsorbed per second per unit area.

A=Area of solar cell.

Power=A*N*q*V

And we have a solar cell!!

Exam question

a) A ***0.01 m²*** solar cell produces a voltage of **0.6 V**, it adsorbs **1x10^{20} m^{-2} photons per second** if the charge on an electron is 1**.6x10^{-19} coulombs** how much power will it produce.

Power=A*N*q*V

Power produced by cell=???

b) How many pink ***500 Watt*** 'Hello Kitty' toasters would that run??

Janine from Mililani

Exam question

A 0.01 m^2 solar cell produces a voltage of 0.6 V, it adsorbs $1x10^{12}$ m^{-2} photons per second if the charge on an electron is $1.6x10^{-19}$ coulombs how much power will it produce.

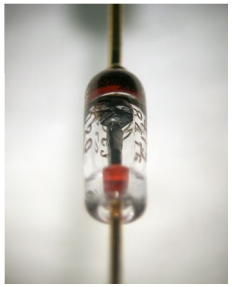
Power=A*N*q*V

Therefore Power=0.06 W

That's not enough to run anything – let along a toaster...

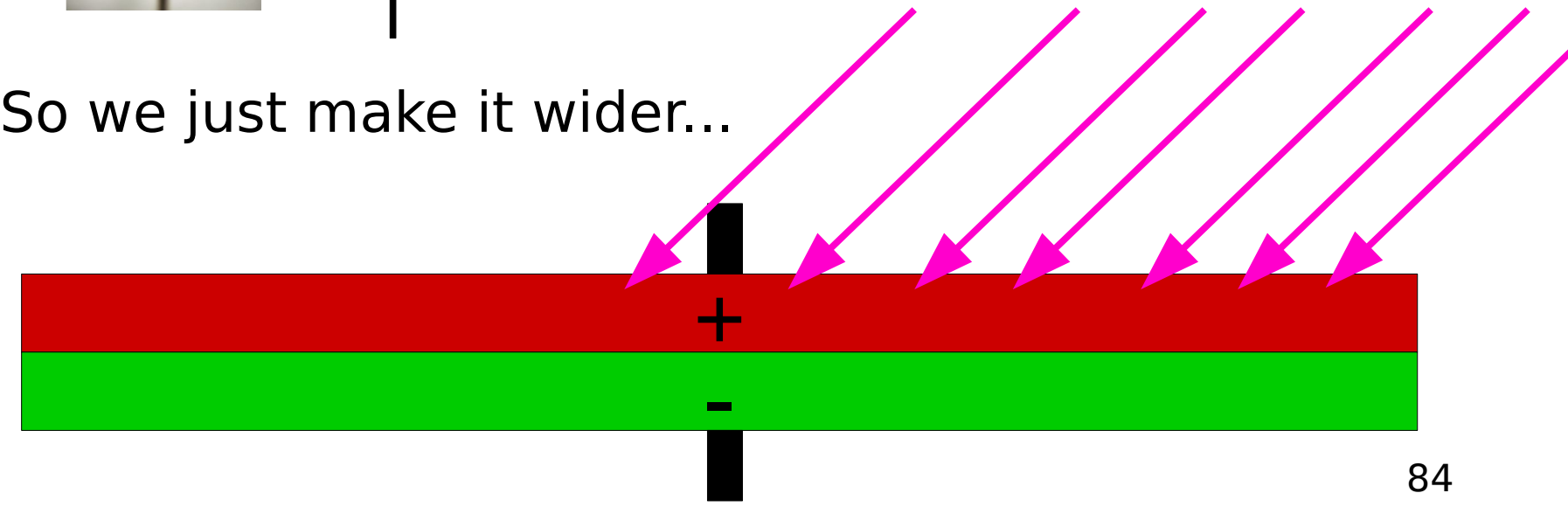
Power generation.....

- So what we do is firstly make the diode (solar cell) as big as possible

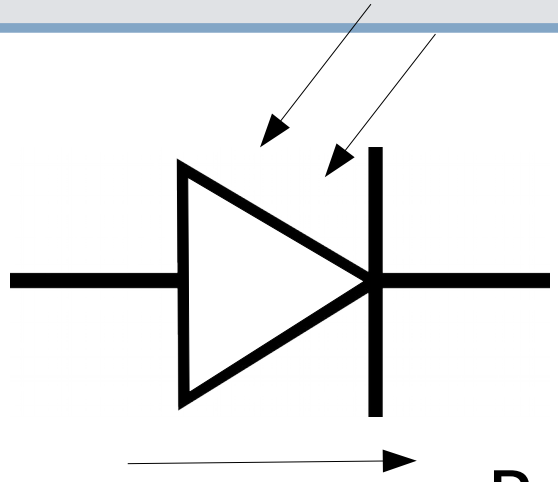


Power=A*N*q*V

- So we just make it wider...



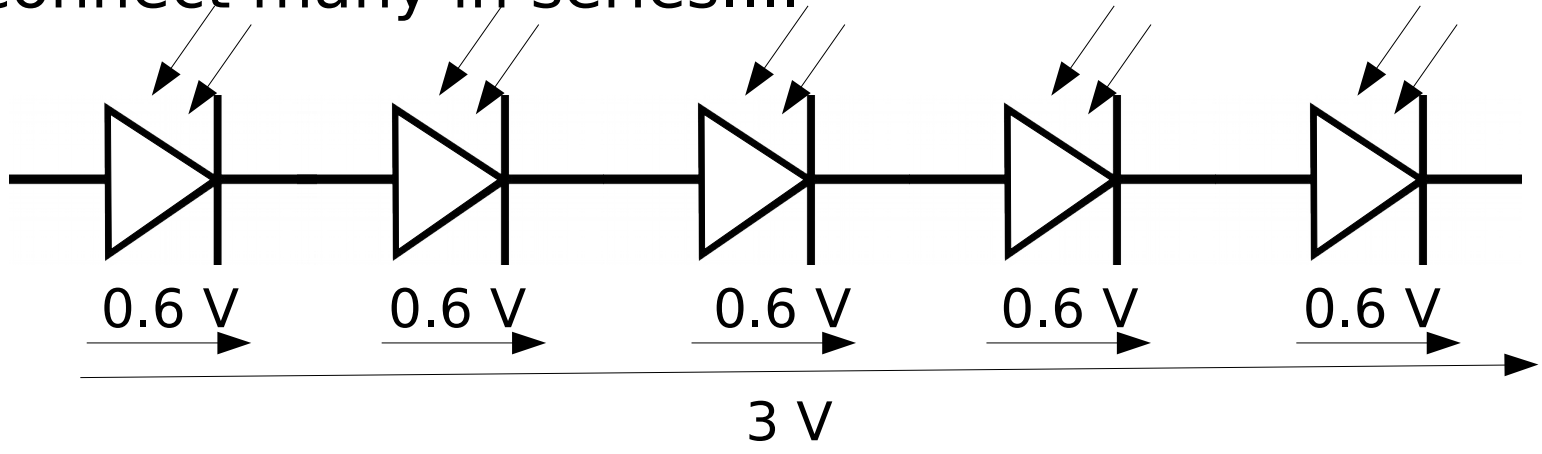
And then we stack lots together



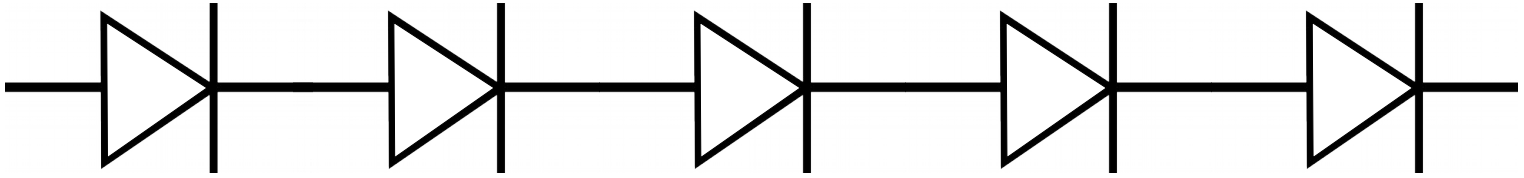
0.6 Volts

Power=A*N*q*V

•However 0.6 V is not very much voltage, so we connect many in series....

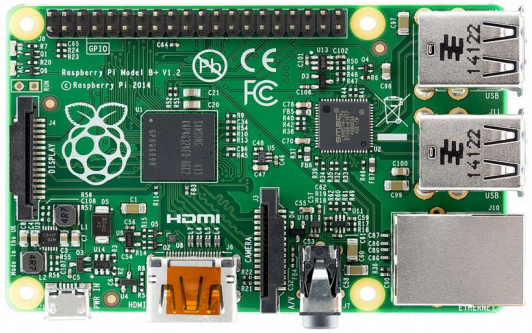


To make a solar module

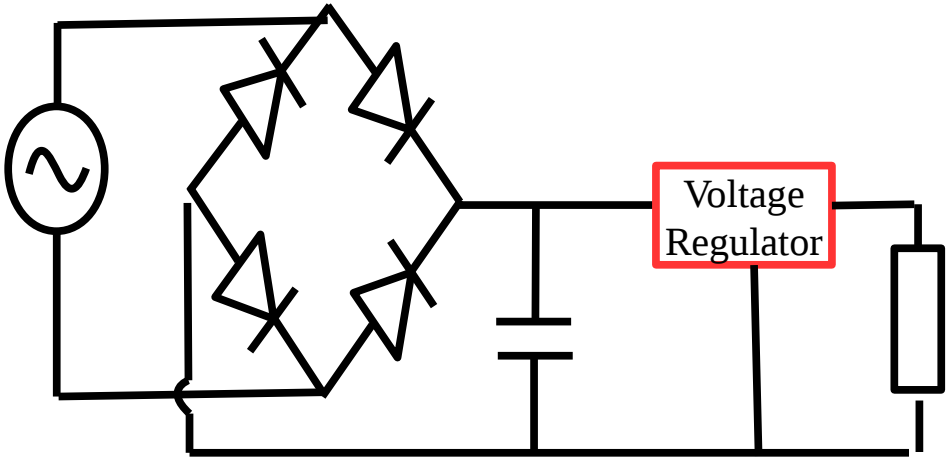


Powering your device

- Now you can power your device



Lucasbosch



- From the mains

- And from the sun

Outline of the lecture

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