Effective voltage

Experiment number	136220	Topic	Electricity, alternating voltage and rectification			
Version	2018-08-20 / HS	Type	Student exercise	Suggested for grade 9-11	p.	1/4

Objective

Measuring the effective value (RMS value) of different voltages: AC voltage, half-wave rectified voltage as well as rectified and smoothed voltage.

Principle

The effective value of the different voltages are found by comparing the light yield from two bulbs, of which one is connected to a known DC voltage and the other is connected to the voltage to be investigated.
When the bulbs are equally bright, the effective value of the unknown voltage is just the same as the DC voltage.

Equipment

(See detailed equipment list on p. 4)

Power supply AC/DC
(The DC voltage must be continuously adjustable, and the DC voltage should be read out on a meter - our **361700** is a good choice.)

Incandescent bulbs 6 V 0.05 A (two ***identical***)
Lamp holders (two pcs. – possibly on a common base)

Rectifier diode

Large electrolytic capacitor (15000 µF)

Cables

Power supply without voltmeter

Our 361700 has a built-in voltmeter for the DC voltage. A power supply without a voltmeter can also be used if you connect an external voltmeter in parallel with the DC output.

It is an important point in this lab exercise that *only* this voltage is measured.
(Most multimeters would not be able to measure a pulsating direct voltage correctly anyway.)

Procedure

The room can preferably have dimmed light, but should not be dark.

In all of the four steps of this lab, the light emissions from two bulbs are compared – it is vital for a good result that you are careful and take your time.

Don't turn on the power supply until the setup is complete. Select 6 V AC voltage. (Keep this value from now on.)
Turn the DC knob completely down.

1 – Alternating voltage

Connect the DC output to one of the lamp sockets with a red and a black lead (See fig. 1.)

Connect the AC output to the other lamp socket with the two blue leads.

Initially, we don't use the rectifier, the capacitor or the three short leads.

Turn on the power supply.

Adjust the DC voltage slowly, until the two bulbs are equally bright. Notice both the amount and the colour of the light. Take your time.

Read the DC voltmeter (write down)

Turn down the DC voltage and shut off.

2 – Voltage drop in a diode

Before using the diode for rectification, we will have a look at what it does to a DC voltage.

Insert the diode between the red DC socket on the power supply and the lamp socket. (See fig. 2.)

Turn on again and adjust carefully the DC voltage until the bulbs are equally bright. Now, the *DC bulb* must get the same voltage as before.

Does this happen at the same voltage *at the power supply* as before? Write the new voltage down.

Turn down, turn off. Take the diode out of the DC circuit, and connect the bulb directly to the power supply again.

3 – Half-wave rectification

Now we remove the negative half of the voltage waveform by inserting the rectifier diode in one of the connections from the AC output of the power supply and the lamp holder. (See fig. 3.)

Turn on and adjust again carefully the DC voltage until the bulbs are equally bright. As we are preventing the negative half of the AC voltage from reaching the bulb, it is hardly surprising that it is less bright than before.

Read and write down the new DC voltage.
Turn down and turn off the power supply.

4 – Rectified and smoothed voltage

Now, connect the capacitor in parallel with the bulb. (See fig. 4.) The capacitor polarity is important!

Check once more that the way the diode and the capacitor is turned are as shown!

Fig. 1

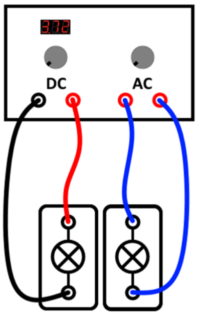


Fig. 2

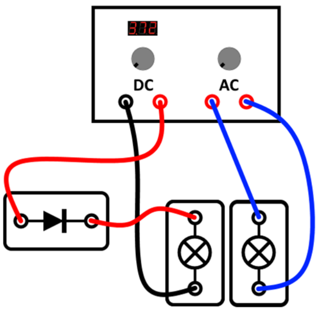


Fig. 3

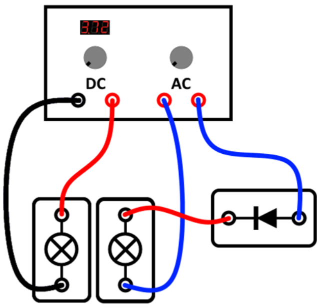
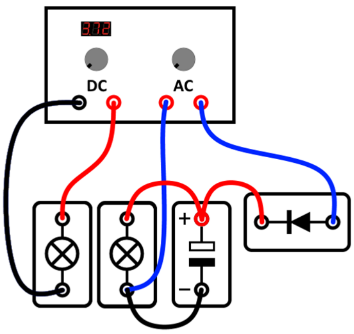


Fig. 4



Turn on the power supply and adjust one last time the DC voltage until the bulbs are equally bright.
As before: Work carefully.

Read and write down the DC voltage.
Turn down and turn off the power supply.

Theory

Fig. 5 shows how the AC voltage varies with time.

The AC voltage that is selected on the power supply is specified as an *effective voltage*. This means that a DC voltage of this size will heat up a metal wire precisely as much as the AC voltage – leading to equal brightness in the bulbs.

Part 1 of this experiment is therefore a measurement of the effective voltage of the AC – and the result should of course be close to the 6V you selected.

As the AC voltage is low for part of the time (going through zero 100 times[1] per second) – its maximum value – also called the *peak value* – must be correspondingly higher than the effective voltage.

Using a bit of heavy mathematics, you reach the result that the peak value is precisely $\sqrt{2}$ times larger than the effective voltage for a sinusoidal AC voltage. That is around 1.41 times larger.

When the diode removes the negative half of the AC voltage, the brightness goes down – and by definition, the effective value of this *pulsating* or *half-wave rectified DC voltage* goes down as well.

Imagining an "ideal" diode, this will result in a waveform as shown on fig. 6. Using some more mathematics, it can be shown that the effective value of the pulsating DC voltage is a factor of $\frac{1}{\sqrt{2}}$ times the original AC voltage. As a decimal number, this is around 0.71 times.
In Part 3, it was precisely this effective value that you measured.

Part 4 adds a capacitor. It gets charged every time the voltage is close to the peak voltage.

Thinking again of an "ideal" diode combined with a very large capacitor, the voltage across the capacitor will be the same as the peak voltage. In practice, the current consumption of the bulb will make the voltage drop a bit between the charging periods (fig. 7).

[1] Or 120 times if you have 60 Hz mains frequency

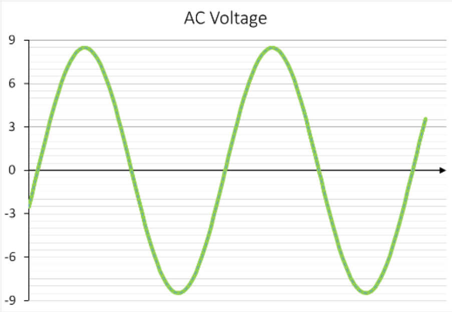


Fig. 5

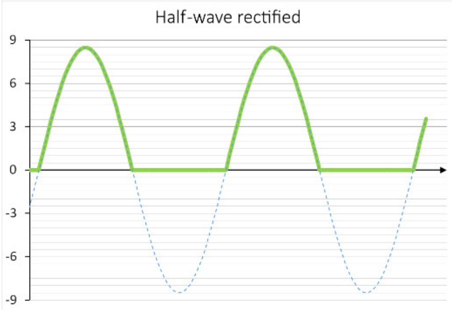


Fig. 6

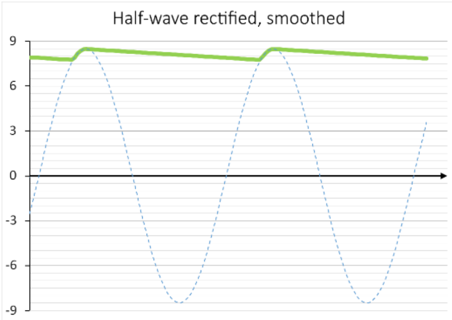


Fig. 7

Discussion and evaluation

1 – Alternating voltage

How much does the result deviate from the expected (as percentage)?
(This gives a hint of the measurement uncertainties.)

2 2 – Voltage drop in a diode

How large is the voltage drop through the diode when it is connected like here in the forward direction?

3 – Half-wave rectification

How large is the theoretical value for the effective voltage after half wave rectification?

Which effective voltage did you measure?

Explain a possible difference.

4 – Rectified and smoothed voltage

How large is the theoretical value for the effective voltage after rectification and smoothing?

Which effective voltage did you measure?

Explain a possible difference.

Teacher's notes

Concepts used

DC voltage
AC voltage
Effective value
Rectifying
Smoothing

Mathematical skills

Percentage
(Square roots)

About the equipment

Incandescent lamps are industrial products with some parameter spread from bulb to bulb. The students' learning will benefit from not being exposed to this variation when comparing the light of the bulbs.

As a teacher, you can sort the bulbs before the lesson starts. Apply a fixed voltage and measure the current consumption with an external ammeter. Give each student team two bulbs matched as well as possible.

About theoretical values

It is well known that the peak value of an AC voltage is a factor $\sqrt{2}$ larger than the effective voltage. (If you want to prove this, you will need integral calculus)

The effective value is less well known for a half-wave rectified, pulsating DC voltage (assuming an ideal diode.) But it follows fairly easy, when you think of the effective value as an RMS value (Root Mean Square), i.e. the square root of the mean of the squared voltage: The mean value of the square of the voltage must drop by a factor of $\frac{1}{2}$ when one half of the waveform is zeroed. When you then apply the square root, you end up with the factor $\frac{1}{\sqrt{2}}$.

Detailed equipment list

Specifically for the experiment

361700	Power supply
412000	Lamp holder (2 pcs.)
434000	Rectifier diode
430070	Capacitor 15000 uF

Standard lab equipment

105720	Safety cable, 50 cm, black
105721	Safety cable, 50 cm, red
105723	Safety cable, 50 cm, blue (2 pcs.)
105710	Safety cable, 25 cm, black
105711	Safety cable, 25 cm, red (2 stk.)

Diverse consumables

425025	Pygmy bulbs 6 V 0,05 A

You will need 2 bulbs per student team – each package contains 10 pcs. The bulbs should be reasonably identical – see *Teacher's notes*.

(This experiment is optimized for and tested with this type of light bulbs – other types will not necessarily lead to results as good as you will get from these.)