“Plasma speaker – exploring unusual properties of plasma”

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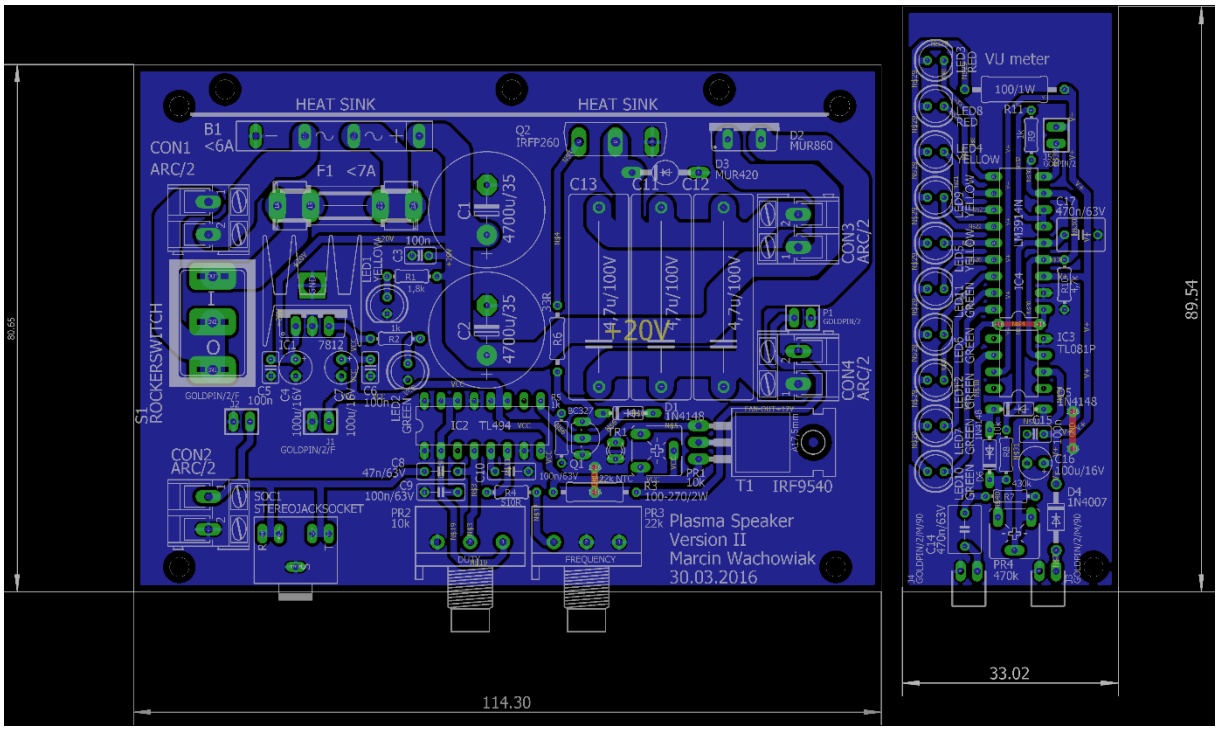
During the study of properties of ionized gas, a plasma speaker set is used, which had been built by the author. The original application of plasma recreating music reefers to the year 1946 and inventor Siegfried Klein, who patented it in 1946.

The electronic circuit has been accomplished basing on commonly uploaded projects of this type, without any precisely mentioned author. Before designing the scheme and the circuit board the constructor decided to support himself with the advices and experiences of other designers. This resulted in introducing new solutions improving the performance of the speaker. After the analysis, he designed a schematic and a circuit board in Eagle CadSoft. The last stage was to mount everything on an exposure board, to test it and carry out little repairs. Whole project has been carried out in the home workshop of the creator using collected materials and acquired experience in electronics.

The order of activities examining and describing the properties of plasma came up as a result of observation of different phenomena affecting plasma. In the experiment included were also interactions of everyday objects with plasma which came across as a result of search. Carried out to enrich the form of presentation to deliver as much information about plasma and its forms as possible.

WARNING! During the experiment a device generating high voltage and ozone is used. It may pose a threat to health or life of the users. It must be performed by an experienced or mature physician or student who will avoid any dangers. The user carrying out the experiment must be very cautious.



Printed circuit board design

Before attempting to perform the experiment, we must have the basic knowledge about plasma and physical phenomena concerning it. This will help us understand the processes and physical laws ruling it better.

During the experiment important will be the concepts of:

- Cold plasma - highly ionized gas (conducting current), due to its' specific properties is called the fourth state of matter. It is a cloud of gas electrically neutral, with a high concentration of electrons and ions. It is present in relative low temperatures and pressures.
- Electrical discharge – flow of current through an isolating environment due to very strong electromagnetic field (very high voltage)
- Electric arc – a continuous electrical discharge in normal conditions
- Fluorescence – a phenomena of emitting light by an excited (mostly by light) atom or particle

Necessary is also the acknowledgement of basic physical phenomena like:

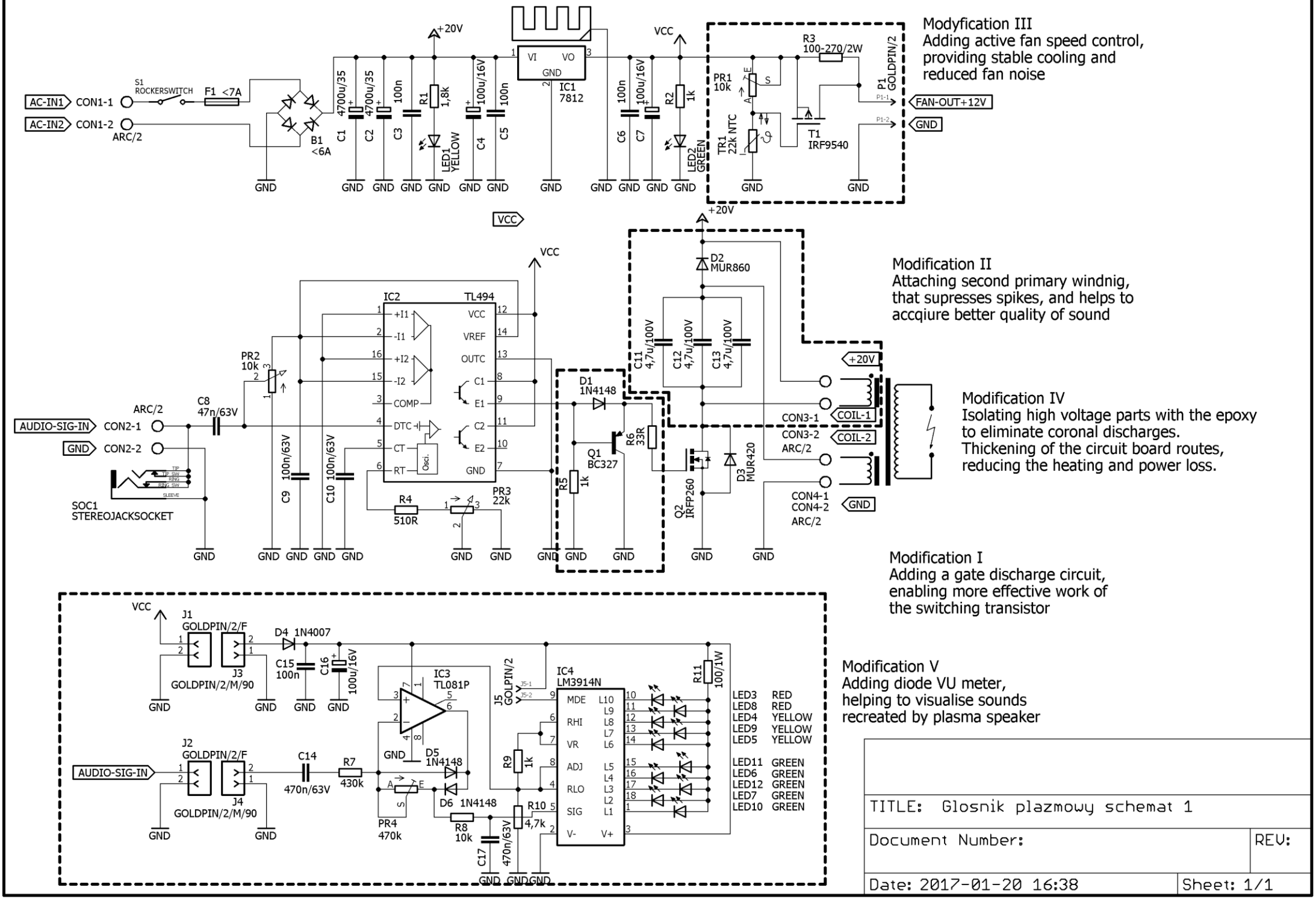
- Creation of an acoustic wave
- Definition of a flame
- Magnetic interactions and magnetic field properties
- Optical spectrum
- Ionization of gas in energy-saving light bulb
- Rule of transformer and it's ratio

To carry out the experiment is needed:

- Plasma speaker circuit with electrodes - used as plasma source
- Regulated laboratory voltage supply - providing the power needed for the set
- Source of sound signal ex. MP3 player
- A candle, ferrite magnet, probe of tonic containing quinine, whole piece of spiral energy-saving light bulb bubble, simple Jacob ladder made of wire

To understand in what way the high voltage appears at the electrodes and electric arc is produced, we need to analyze the circuit and determine the functions of each block. After simplifying, that means omitting the inessential minor circuits like filters or signalization devices the oncoming analysis is much easier.

The device works in a a folowing way: in the idle state the PWM generator produces a square wave signal with a defined length time and frequency, which are set by potentiometers. The signal generated by the integrated circuit is delivered to the gate of a switching power MOSFET transistor. At the transistor the small signal is processed into adequate in properties high current pulses, which are provided by the power supply to the primary winding of a modified flyback transformer. As a result at the secondary winding appears very high voltage, mutliplied many times because of the very high flyback transforming ratio. The transformer output is connected to the electrodes. Between them a very strong magnetic field is created. This causes the ionisation of the air between the outputs and allows the current to flow through it creating a stable electric arc – our source of plasma flame.


Modyfication III
Adding active fan speed control,
providing stable cooling and
reduced fan noise
Modification II
Attaching second primary windnig,
that supresses spikes, and helps to
accqiure better quality of sound
Modification IV
Isolating high voltage parts with the epoxy
to eliminate coronal discharges.
Thickening of the circuit board routes,
reducing the heating and power loss.
Modification I
Adding a gate discharge circuit,
enabling more effective work of
the switching transistor
Modification V
Adding diode VU meter,
helping to visualise sounds
recreated by plasma speaker
AC-IN1
AC-IN2
CON1-1
CON1-2
ARC/2
S1
ROCKERSWITCH
F1 <7A
B1
<6A
IC1
7812
+20V
VCC
GND
R1 1,8k
R2 1k
R3
100-270/2W
PR1
10k
TR1
22k NTC
T1
IRF9540
P1
GOLDPIN/2
FAN-OUT+12V
LED1
YELLOW
LED2
GREEN
IC2
TL494
PR2
10k
PR3
22k
R4
510R
R5
1k
R6
33R
C8
47n/63V
AUDIO-SIG-IN
CON2-1
CON2-2
SOC1
STEREOJACKSOCKET
D1
1N4148
Q1
BC327
D2
MUR860
D3
MUR420
Q2
IRFP260
CON3-1
CON3-2
CON4-1
CON4-2
COIL-1
COIL-2
IC3
TL081P
IC4
LM3914N
J1
J2
J3
J4
J5
GOLDPIN/2/F
GOLDPIN/2/M/90
D4 1N4007
D5
1N4148
D6 1N4148
R7
430k
R8
10k
R9
1k
R10
4,7k
R11
100/1W
PR4
470k
C14
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LED4 YELLOW
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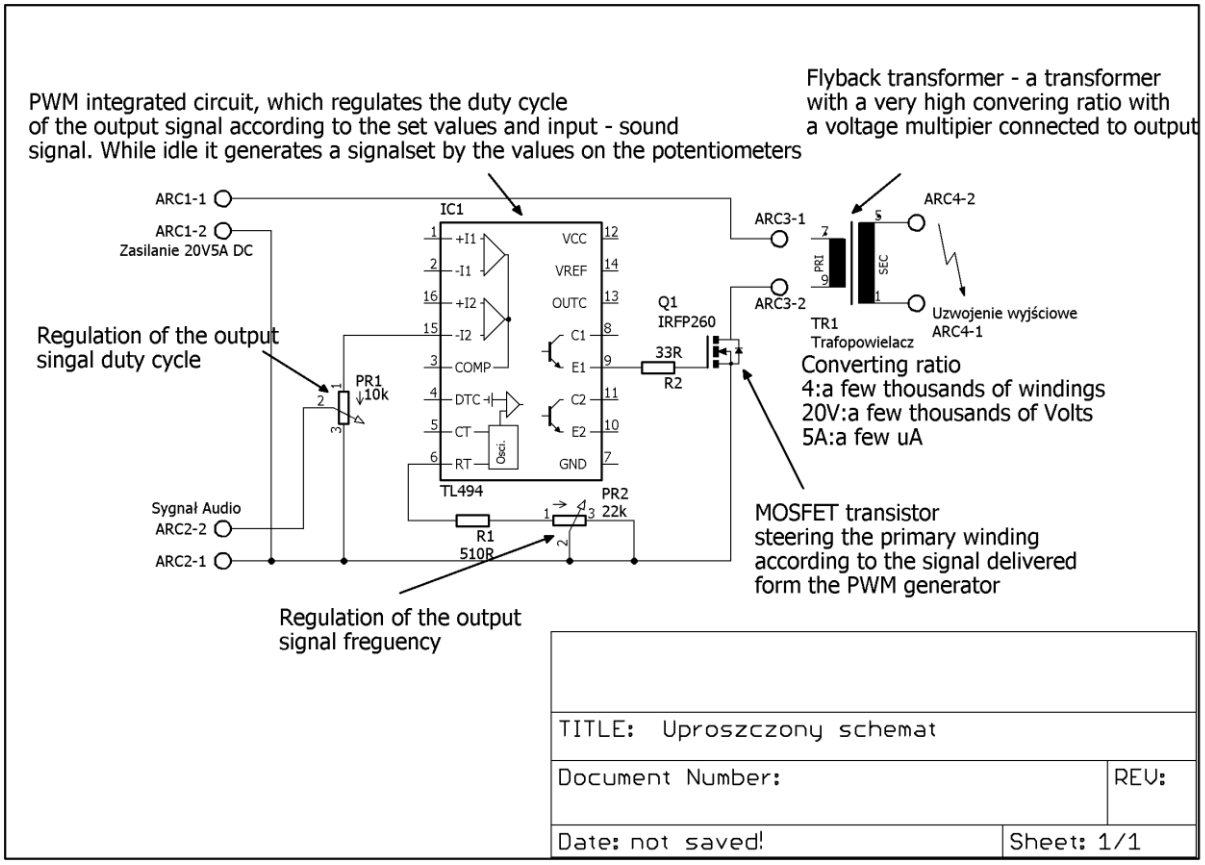

Functional diagram of the device

Exploring the properites of plasma

„Musical plasma" – recreating music by plasma

After connecting the experimental kit to the source of elecrical sound signal (in our case radio player) and setting the working parameters for the device to maintain stable arc we are able to replay the song. The chosen track is being heard by us straight from the electric arc. A variety of sound is being recreated and delivered to our ears just from the tiny plasma flame. We are able to notice that the speaker does not maintain great powers, although it consumes about 100W of power. The emitted sound is comparably as loud as if it was played from the mobile phone. What is more, we can hear that the music is not perfect as it lacks some lower frequencies. However the "colour" of the tone is a subjective feeling. It is clearly distinguishable that the speaker simply does not produce low frequecy – bass tones. When we try to play certaing kinds of music ex. dubstep ot techno, theyir sounds are completely unrecognizable. The reason why the speaker has such characteristic of produced tones is that the membrane layer role is played by the small plasma flame, which is inable to vibrate in greater amplitude to move greater amounts of air to properly recreate basses. On the other hand the plasma speaker perfectly recreates the high pitched sounds as the plasma arc has a small inertia, which enalbes it to quiver without significant limits. In this way they may be heard as piercing and sharp.

Plasma recreates sound due to it's proper modulation . Depending on the input wave the PWM generator stretches or reduces the time of the output driving signal with a constant frequency and by this process it creates condensation and rarefactions of plasma, which transforms it into condensations and decondensations of air. Those changes of air density, which are defined as sound waves, come to our ears as the sensation of music.

„Plasma compared to ordinary flame and their interaction"

Continuing our experiment, without changing anything we place a candle end into the arc. We can observe the quick enlightning of the candle and permeate of elecrical arc and candle flame. The plasma arc is barely seen as it almost disappears in the flame. The light emmited by the flame seems multiplied and the music is played on mostly by the flame.

The quick ignition suggests that the plasma tunel has a very high temeperature. From literature we are able to tell that in our case the plasma has about 6000K degrees. The addiditonal brightness of light is emmited by the carbon atoms, which set in the plasma area are addiditonally heated so that they emit more light than an ordinary burning candle. We can also suppose that flame is quite similar to plasma: it conducts electricity and has a high temperature. Plasma and flame are quite similar phenomena and are affected by the same physical laws, but we are not able to assert that those two objects are the same. This is because flame has much lower temperature than plasma, although it may not be seen at a first sight. (it is an argumentative case between physicians, in various articles and videos we may come across opposing statements). Huge amount of heat and various was of emitting the energy to environment turn our minds to the great amounts energy stored in plasma. Following the idea we see that after delivering the energy to states of matter they change. Firstly form solid state to fluid, then the to gass which in the end transfroms into plasma. This is why plasma is often called the fourth state of matter and where the great internal energy comes from.

"Plasma - magnet interaction"

To examine another property of plasma we need a stable electric arc. In this case we turn off the music signal and perform the experiment. To investigate plasma and magnetic field interaction we slowly move a ferrite magnet toward the plasma flame and observe the effects. While we slowly set position of the magnet in space, we are able to see that each time the arc shapens itself towards the magnet and the strong magnetic field around it. It even dispatches the electrodes to try to follow the lines of the magnietic field, where they are the strongest – at the surface of the magnet.

By this interation we might draw a conclusion, that plasma consists of magnetically affective particles. Looking into the plasma we would see that it is a cloud of elecrons and ions, Those elements create their own magnetic field while they flow and are also affected by the exterior magnetic field causing the flame to shape itself on the magnet.

„Light emmited by plasma and ionisation of gas in the energy-saving lightbulb"

After observing the plasma arc for a while we can clearly see what colour of light it generates. It has a birght white-violet colour .To check whether it is ultraviolet light we approach a probe with UV-sense substance. In this case it is a quinine coming from Shweppes tonic. In absolute darkness we can see a faint blue light coming from the fluid in the probe. It means that plasma arc emits UV light wich causes the quinine to fosforize.

Again, the variety of ways of emmiting energy by plasma confirms our previous theory that it is the most energetic state of matter. The fluid fluorizes because particles of quinine are excited by the highly energetic UV light. Coming back to their previous orbits they emit quants of light, which we are able to see as a faint blue light. By this action we might associate plasma with the emission of ultraviolet light. The examples of everyday life containg plasma like: lightning, stars, the Sun, seem to confirm our thesis.

Continiuing the part about ionised gases and light emission to experience other forms of plasma we attach a disassembled bulb of an energy-saving ligh bulb. When the connection appears we are able to see a bright light coming from ionised gas inside the spirale. The exact kind of light depends on the gas and phosphor we are using. We may change the bulbs to experience warm white or cold white xenon light.

Ionisation of the gas in the light bulb convinces us about various properties of plasma depending on the environment it has been created in. The properties may differ for example: the colour, temperature, radiation emission. Seeking for more infrormation we find that there are several types of plasma. The cold one and the hot one. The first one is produced in the plasma speaker while the latter builds the stars. We can also notice that simple energy-saving light bulb has some kind of plasma inside it's coil. This makes us see that plasma is not so rare state of matter.

„Plasma as a ionised gas – Jacob's ladder"

While the plasma speker generates the arc we notice that the plasma is shapen as a arch heading upwards. To examine this phenomenon the electrodes of the device are changed to a couple of straight wires formed in a V letter separated in the bottom. Then we turn on the speaker once more and set the proper values to maintain the arc. After the switching on at the bottom of the new electrodes appears a small electric arc which moves up in the air following the electrodes and rapidly stretching itself. The situation repeats after the arc finishes in the top and then another one small starts is journey up.

This observation proves that plasma still preserved a few properties of a normal gas and is affected by the phenomena of convection. It travels up due to the diffrence in densities of a cold and heated gas. It is confirmed now that plasma is a strongly ionised gas and has maintained a few properties of it. The most significant things to remember are also that it is able to conduct electricity and has a very high internal energy, which emits into the environment.

All the previously conducted experiments have shown us some of the most amazing properties of plasma and convinced us that it is not such a rare state of matter and has various useful applications.

After some time with the device working we are able to smell the odour of air as if a storm has just passed by. It is a characteristic feature of ozone, which is produced by the electric arc and the presence of high voltage in our conditions. Plasma, depending on the environment which it is present in, can cause a variety of chemical reactions. In our "oxygen" environment it produces ozone as following $3O_2 \rightarrow 2O_3$. Ozone is a toxic gas with antiseptic properties. Therefore, we must pay attention not to get any contamination in the places, where we are presenting the experiment. It can be easily avoided, by doing it in spacious rooms or any others with air circulation or open window.

All the previously conducted actions have shown us some of the most amazing properties of plasma and convinced us that it is not such a rare state of matter and can have some useful applications.