Topic: C10

Relaunch of the water plasmoid experiment for investigations of ball lightning phenomena

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The experiments on the long-living plasmoids from an atmospheric water discharge which revealed some reported ball lightning phenomena [1] have been continued after the transfer of the components from the Berlin group to the Max-Planck-Institut fuer Plasmaphysik in Garching. The revised setup allows for systematic investigations of the energy supplied to the water discharge by variations of the number of the capacitors, the voltage-on time, the gap between the electrodes, the size of the water container and the electrical conductivity of the water. A clear dependence of the duration of the autonomous phase and the ascent velocity of the plasmoid on the energy is observed. The autonomous phase saturates in the present setup at about 450 ms whereas the ascent velocity increases to values up to 2 m/s. Electrical measurements of voltage and current are coupled with video recording and optical emission spectroscopy of the plasmoid.

1. Introduction

The generation of luminous plasmoids with a diameter of about 20 cm from a water discharge at atmospheric pressure has been reported first by Shabanov et al. [2, 3]. The existence of an autonomous phase of some 100 ms, the size, the brightness and the colour of the plasmoid associates the plasmoid with the ball lightning phenomenon. Thus, the experiment received remarkable attention, not only in the press but also from the point of view to answer the question on the energy source for the autonomously radiating behaviour. Furthermore, the water plasmoid is also an interesting object for plasma physics investigations.

A few years ago, the plasma physics group at the Humboldt-Universitaet, Berlin decided to rebuild the experiment and to apply several diagnostics with the aim to get a better insight into the processes and parameters of the plasmoid. The results of their systematic investigations with high-speed cameras, electric probes, calorimetric measurements and emission spectroscopy are reported in [1,4,5] and can be briefly summarized as follows.

The plasmoids arise from a hot expanding water-plasma with relatively high electron density decreasing from 10^{22} m^{-3} to 10^{20} m^{-3} (from t = 0 ms to 75 ms), in the initial (formation) phase. The electron temperature is estimated to be 2000–5000 K during most of the lifetime of the plasmoid. The temperature of the neutral particles is 600–1300 K. The plasmoids are surrounded by a cold envelope. An autonomous phase of up to 300 ms has been achieved after the voltage-on time of 100–150 ms with an ascent velocity of the plasmoid of 0.8 m/s.

The spectra show a temporal behaviour. Weak hydrogen (Balmer) lines are measured at the beginning, changing to spectra in which OH band emission dominates followed by strong emission of CaOH molecules. Calcium lines (atoms and singly ionized) appear as well as sodium lines, both detectable until the plasmoid vanishes. Due to the usage of copper electrodes, Cu lines appear in the spectra as well. Besides Cu all other radiators are attributed to the tap water. Since the strong temporal changes of the emission indicate chemiluminescence reactions between dissociation products of water and dissolved calcium are proposed as a source for the strong emission.

In 2010, the experiment has been transferred to the Max-Planck-Institut fuer Plasmaphysik in Garching with the purpose to continue the investigations on the long-living plasmoids. The results of the first experimental campaign with the revised setup are described in this paper.

2. Experiment

2.1. Setup

The experimental setup is shown in figure 1 and in principle the same as described in [1] and in the original work [2,3]. Changes made concern basically the water container, the electrodes including feed-throughs and connectors, and the fast switch for the rapid opening of the switcher determining the voltage-on time. Emphasis has been laid on the reduction of power losses in the connecting lines, and on the controlled triggering of the system.

The container is made of acryl glass which allows for a feedthrough in the bottom plate of the water filled container. No cables except the electrodes are inside the water. Details of the central electrode are illustrated also in figure 1, using tungsten instead of copper to eliminate copper

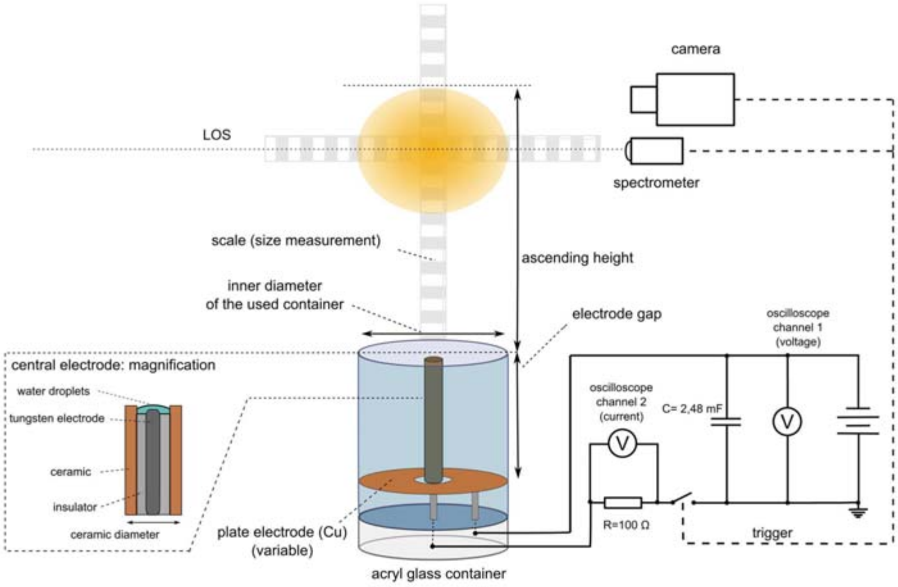

Figure 1: Schematic drawing of the experimental setup.

evaporation and thus the Cu emission lines. The central electrode is aligned to the water level and is electrically on ground. The ceramic cylinder separates the central electrode from the main water content protruding the water level such that a few water droplets are stored inside the ceramic cylinder surrounding the central electrode. The plate electrode (Cu) is powered and the position is made variable by placing insulated distance holders.

A capacitor bank with a maximum of 18 capacitors of 137.5 µF each, in total 2.475 mF, is charged to 4.8 kV. Closing the switch for a certain time interval generates a discharge with currents up to 115 A, decreasing to typically 10 A in the typical voltage-on time of 150 ms. When the switch is opened the autonomous phase of the plasmoid starts. In comparison to the Berlin setup which operated with 8 capacitors, a flexible and higher number of capacitors is now available. Due to the fast electrical switch, the voltage-on time can be regulated as well. Capacitance and voltage-on time determine the supplied energy to generate the plasmoid. Figure 2 shows a picture taken during the voltage-on time, i.e. in the start-up phase of the plasmoid and a picture during the autonomous phase. The diameter of the container filled with tap water is 22 cm with a height of 16.5 cm, corresponding to the electrode gap.

2.2. Diagnostics

The electrical parameters, such as voltage, current and voltage-on time are recorded by a fast storage oscilloscope as indicated in figure 1.

A fast camera with 600 frames per second (fps) in standard resolution and 1200 fps in the reduced mode is used to detect the temporal behaviour of the plasmoid. Together with the cross lines at the back board (indicated in figs. 1 and 2) several parameters are deduced: the size and rising height of the plasmoid, the duration of the autonomous phase, and the ascent velocity.

Spectra of the plasmoid are recorded by a low resolution survey spectrometer (spectral resolution of about 1.5 nm, wavelength range 200–850 nm) at a fixed position above the water surface (22 cm). An exposure time of 3 ms is used, spectra are obtained roughly every 70 ms. Although the spectrometer is triggered as well, a precise temporal correlation is missing due to an unknown delay after triggering.

The temperature and the electrical conductivity of the water are measured by a standard temperature

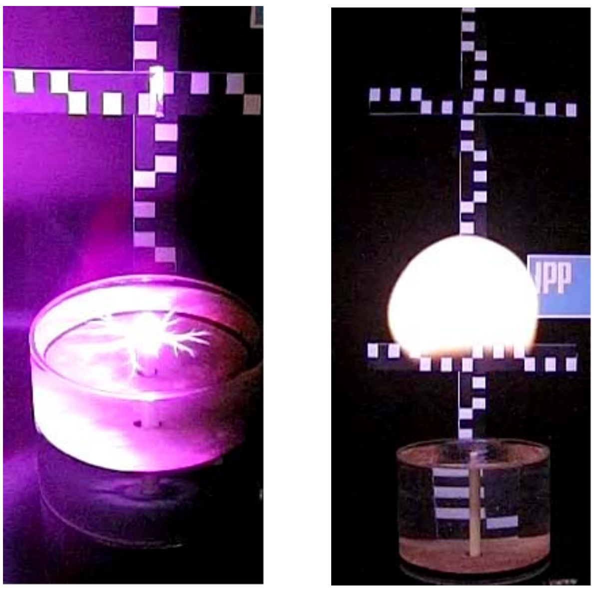

Figure 2: Inclined top-view during the start-up phase of the plasmoid (< 150 ms) (left) and side-view of the plasmoid in the autonomous phase (right).

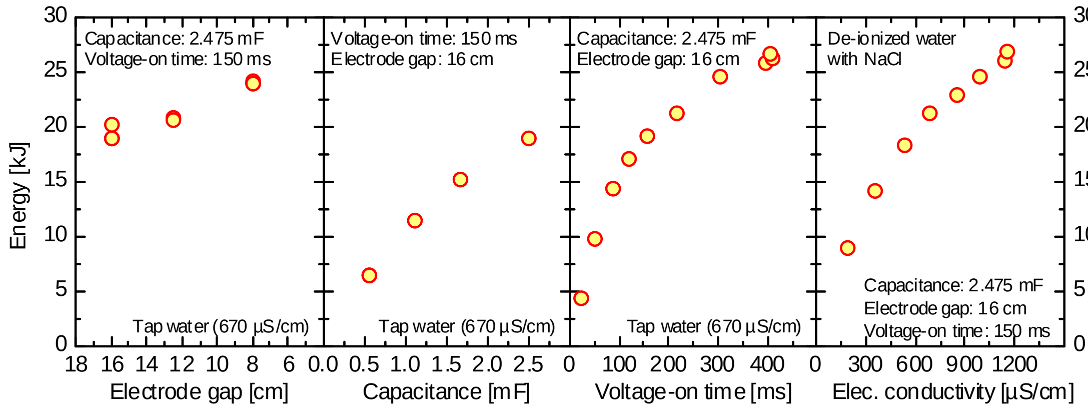

Figure 3: Energy supplied to the plasmoid as a function of several parameters.

and conductivity meter.

2.3. Parameter studies

Two cylindrical containers (22 cm in diameter, 16.5 cm height) have been used for the present investigations being different in the size of the ceramic tube surrounding the inner electrode: container 1 (= standard container) with 8 mm and container 2 with 38.5 mm inner diameter of the tube. The flexible setup allows for variations of the electrode gap, the number of the capacitors and the voltage-on time. As standard, tap water at room temperature is used slightly rising by a few degrees after several discharges.

The electrical conductivity of the water is changed by additives supplied to de-ionized water. One parameter scan was performed with adding successively NaCl another with $CaCl_2$, both salts having a good solubility in water. For pure de-ionized water no discharge could be generated.

3. Results

Figure 3 shows the electrical energy supplied to the electrodes and thus available for the generation of the plasmoid from the water container. In the various parameter scans the last data point is limited to peak currents close to 120 A to avoid uncontrolled high voltage events.

As expected the energy depends on the electrode gap, the capacitance, the voltage-on time and the electrical conductivity of the water. No difference is observed between NaCl and $CaCl_2$. Except for the variation in the electrode gap, the energy seems to saturate. It is observed that this behaviour correlates with the size of the plasmoid reaching the diameter of the water container. More energy results in some kind of overflow of the plasmoid over the container's edge before it starts to rise. For long voltage–on times the plasmoid detaches before the switch opens, such that sometimes a secondary discharge starts.

Figure 4 and figure 5 show the duration of the autonomous phase and the ascent velocity of the plasmoid after being detached as a function of the energy. Except for the filled squares, all data points are taken at full capacitance with a voltage-on time of 150 ms. A typical data point from the Berlin experiment is plotted for comparison.

At low energies an increase of the energy extends the autonomous phase and increases the ascent

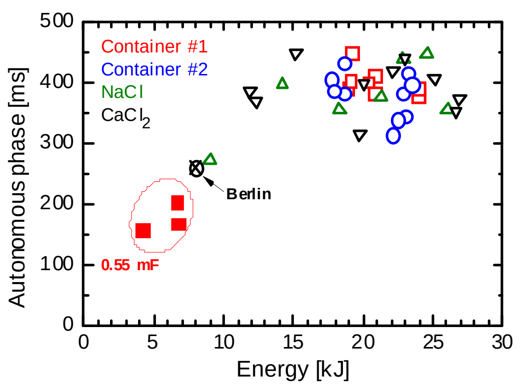

Figure 4: Duration of the autonomous phase as a function of energy for different experimental parameters.

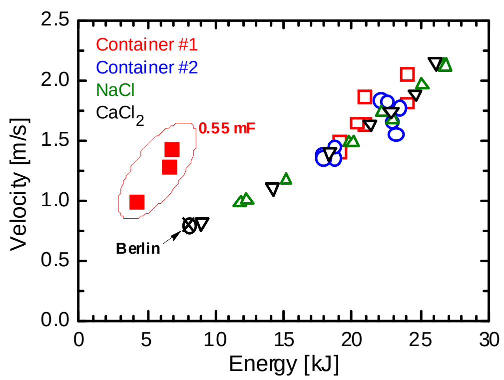

Figure 5: Ascent velocity of the plasmoid (taken after voltage-on time) as a function of energy for different experimental parameters.

velocity simultaneously. At some point the duration of the autonomous phase cannot be extended anymore and the increased energy causes a further increase of the ascent velocity. The rising height is about 50–90 cm depending also on the energy.

The shape of the plasmoid changes also with energy, having a ball-like shape with 15 cm in diameter up to roughly 30 cm, expanding and changing to a mushroom-like structure with increasing energy.

In comparison to the Berlin experiments the duration of the autonomous phase is extended by roughly a factor of 1.5 to 450 ms. The ascent velocity is increased by a factor of 3.

The figures suggest that there is almost no influence of the diameter of the ceramic tube surrounding the central electrode on the plasmoid. Looking at the results in more detail reveals that the shape of the plasmoid tends to be more mushroom-like at the larger tube diameter.

Almost all plasmoids have in common that in the temporal emission first the Balmer line emission appears, followed by the OH band emission. OH bands and CaOH bands dominate the duration of the autonomous phase followed by a time interval in which the Na lines are prominent. This explains the weak and yellow light towards the end of the plasmoid. The bright and luminous phase is dominated by OH, neutral and singly ionized Ca lines, and CaOH molecules. Due to the usage of tungsten electrodes and of tap water from Munich, neither Cu lines nor Mg lines appear in the spectra as have been seen in the Berlin experiment.

Spectra from plasmoids with NaCl additives are dominated by the strong Na line giving the plasmoid the yellow colour. OH can still be observed clearly whereas the Ca neutral line and CaOH bands are very weak but still detectable. With $CaCl_2$ lines from neutral Ca, singly ionized Ca, and emission from the CaOH molecules dominate the temporal evolution of the spectra. Obviously more plasma chemistry is taking place in the $CaCl_2$ case. The duration of the autonomous phase and the ascent velocity however seem to be unaffected as NaCl and $CaCl_2$ additives have almost identical influence on the energy.

4. Conclusion and outlook

The Berlin experiment on long-living plasmoids from a water discharge has been rebuild and improved with respect to the opportunity for more parameter variations. In particular the supplied energy has been made variable and extended by more than a factor of two. This resulted in an increase of the duration of the autonomous phase. Values very close to 0.5 seconds have been achieved. The ascent velocity of the ball-like plasmoid which changes to a mushroom-like shape for high energies has been almost tripled. A rising height of almost one meter is obtained. Additives like NaCl and $CaCl_2$ increase the electrical conductivity of the water and thus the energy. The duration of the autonomous phase and the ascent velocity are almost the same although the spectra show radiation from different compounds.

Since the observed saturation of the absorbed energy as a function of the supplied energy indicates that the diameter of the container is the limiting parameter, a larger container will be built next. Additionally, investigations will be carried out with smaller containers combined with reduced energy for studying size scaling effects. In order to get a better insight into the plasma chemistry the temporal correlation of the recorded spectra with the position and shape of the plasmoid will be improved. In addition a multi-channel system will be used together with a high spectral resolution spectrometer. Fast thermocouple measurements will be performed also. Langmuir probes are envisaged.

Similarities with the controversially discussed phenomenon of ball-lightning are obvious. Systematic investigations of this plasmoid experiment might help to explain correlations and differences. Of particular interest is the explanation for the energy source to sustain the autonomous phase and how this phase can be extended to several seconds as reported by persons claimed to have seen ball lightning phenomena.

5. Acknowledgement

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6. References

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