Fireball Generation in a Water Discharge

Youichi SAKAWA, Kazuyoshi SUGIYAMA[1)], Tetsuo TANABE[1)] and Richard MORE[2)]

Institute of Laser Engineering, Osaka University, Suita 565-0871, Japan
[1)]*Interdisciplinary Graduate School of Engineering Science, Kyushu University, Fukuoka 812-8581, Japan*
[2)]*Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*

(Received 30 June 2006 / Accepted 12 July 2006)

Fireball generation in a water discharge has been investigated. Time evolution of visible spectra of the fireballs revealed that the emission of ionic lines of Ca and atomic lines of Na, K, Li, and Ca appeared early in time, followed by un-identified molecular-like spectra, and the emission of NaI resonance lines (588.9 and 589.5 nm), remained at the final stage of the fireball.

Keywords: fireball, ball lightning, water discharge, plasmoid, fast camera, plasma spectroscopy

DOI: 10.1585/pfr.1.039

Fireball or ball lightning has been studied for centuries (see detailed review in Ref. [1]). In laboratory experiments, the fireballs are generated in air either by electric breakdown or electromagnetic discharges [1]. Recently, Egorov *et al.* have conducted experimental investigation of long-lived plasmoid (fireball) generation in humid air by electric breakdown [2,3]. They have explained that the fireball contains stable clusters which consist of two hydrated ions of opposite sign, H_3O^+ and OH^-, and water molecules. Water molecules prevent the hydrate ions to recombine, and hence the life-time of ions is much longer than the usual electron-ion recombination time [4]. However, no detailed measurements were made except for photographic pictures of a fireball [3]. In this communication, we present time evolution of visible spectra of fireballs generated in a similar method as shown in Refs. [2, 3].

Two or three capacitors with a capacitance of 210 μF each are connected in parallel and charged up to ~4.5 kV. A polyethylene cup 18 cm in diameter and 20 cm in height is filled up to 10~15 cm with a water solution (pure water with for example 7~20 mM of $NaHCO_3$). A copper ring electrode is placed at the bottom of the cup and connected to the positive pole of the capacitors. The negative pole of the capacitors is connected to a carbon-rod electrode with 1 cm in diameter and 5 cm in height placed at the surface of the water at the center of the vessel. A quartz tube surrounds the carbon rod and rises above the end of the electrode by ~2 mm and above the water surface by ~3 mm. The carbon rod and connecting wire are electrically isolated from the water bath. An electrical switch is used to close the circuit and a discharge begins between the water and the end of the carbon rod. A plasma jet appears above the surface of the water and a luminous fireball or plasmoid rises into the air.

A fast CCD camera (Kodak Motion Corder Analyzer SR-1000) is used to record time evolution of the fireball with a frame rate of 125 frames/s (Δt = 8 ms). Time and specially resolved (time resolution of ~58 ms) visible-emission spectra are measured by focusing the emission to an optical fiber using a lens, which leads to a spectrometer (Hamamatsu C7473).

Figure 1 shows time evolution of a fireball. Time separation between each frame is 32 ms. First, the discharge occurs above the carbon rod (see #1). 8 ms later, the whole surface of the water emits light (not shown), and a fireball starts to grow (#2 - #5). Then the fireball detaches the carbon rod (16 ms after #6). We have tried Na_2CO_3, $NaNO_3$, Na_2SO_4, Li_2CO_3, and Li_2NO_3 in addition to $NaHCO_3$. Clear ball-shaped fireballs appeared only when $NaHCO_3$ was used and did not detach from the carbon rod when Na_2CO_3 or Na_2SO_4 was used.

Figure 2 shows a typical time evolution of visible spectra measured at 4.5 cm from the bottom of the vessel when $NaHCO_3$ are used. Early in the discharge, atomic lines of Na (NaI), K (KI), and both atomic (CaI) and ionic (CaII) lines of Ca [Fig. 2 (a)] are observed. The strongest emission is NaI resonance lines at 588.9 and 589.5 nm; both are the lines with excitation energy of 2.1 eV. 58 ms later, many atomic and ionic lines with larger excitation energy disappear, and new molecular-like peaks at 420 - 640 nm appear with a separation of 16 - 32 nm [Fig. 2 (b)]. These peaks do not fit to any known molecular lines such as N_2, N_2^+, O_2, O_2^+, C_2, CO, CO^+, CH, OH, OH^+, CN, NO, NO^+, and are not identified yet [5]. Emission at 623.54 nm is Meinel (vibration-rotation) band ($X^2\Pi$) of OH [5]. The molecular-like peaks appeared and NaI resonance lines were the strongest emission not only for Na_2CO_3, $NaNO_3$, or Na_2SO_4, but also Li_2CO_3 or Li_2NO_3 was used; Na, K, Li, and Ca atoms appeared probably from impurities in the pure water used or the surrounding.

In conclusion, we have investigated fireball generation

author's e-mail: sakawa-y@ile.osaka-u.ac.jp

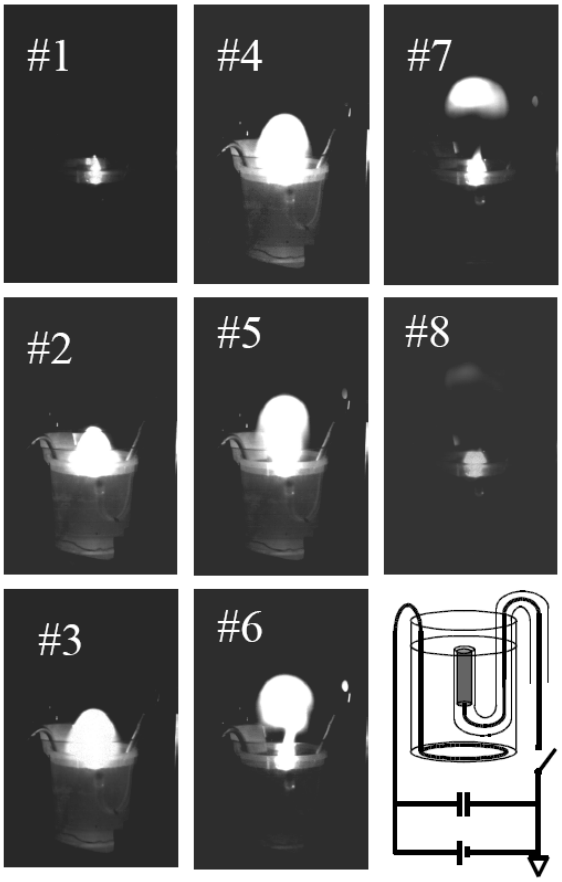

Fig. 1 Time evolution of a fireball when $NaHCO_3$ is used (#1~#8) and experimental setup. Time separation between each frame is 32 ms.

in a water discharge. Clear ball-shaped fireballs appeared when $NaHCO_3$was added to pure water. The emission of ionic lines of Ca and atomic lines of Na, K, Li, and Ca appeared early in time, followed by un-identified molecular-like spectra, and the emission of NaI resonance lines remained at the final stage of the fireball.

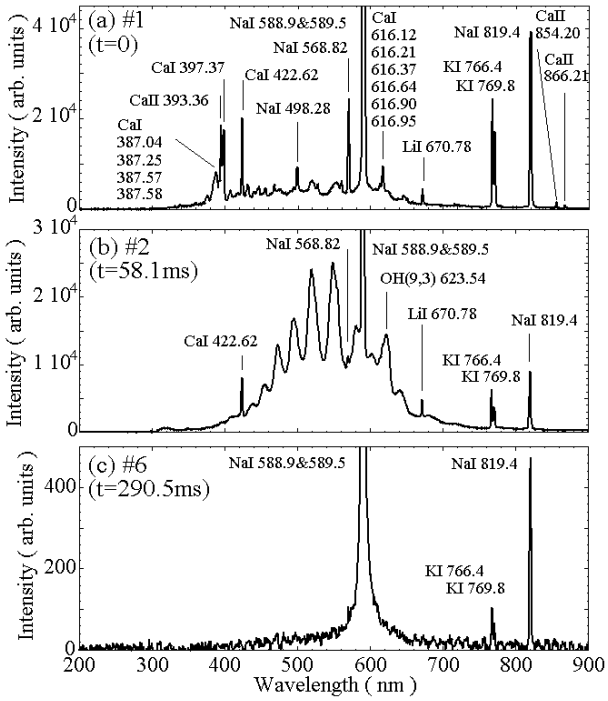

Fig. 2 Time evolution of visible spectra measured at 4.5 cm from the bottom of the vessel when $NaHCO_3$ is used.

[1] Special issue on *Ball Lightning* (compiled and edited by J. Abrahamson), Phil. Trans. R. Soc. London A **360**, 1 (2002).
[2] A.I. Egorov, S.I. Stepanov and G.D. Shabonov, Uspekhi Fizicheskikh Nauk **174**, 107 (2004) [Physics-Uspekhi **47**, 99 (2004)].
[3] A.I. Egorov and S.I. Stepanov, Zhurnal Teckhnicheskoi Fiziki **72**, 102 (2002) [Technical Physics **47**, 1584 (2002)].
[4] S.I. Stepanov, Dokl. Akad. Nauk **379**, 181 (2001) [Dokl. Phys. **46**, 467 (2001)].
[5] R.W.B. Pearse and A.G. Gaydon, *The identification of molecular spectra* (Wiley, New York, 1976).