Place a flame (e.g. from a Bunsen burner) between two charged parallel metal plates. Investigate the motion of the flame.
Presentation Plan

1. The structure of Bunsen burner and candle flames
   - Temperatures in flames
   - Ion structure of flames
   - Dynamics of combustion process

2. The influence of electric and magnetic fields on the flame
   - Ionic wind
   - Transformation of electric energy into thermal energy
   - Direct influence of electric field on combustion process

3. Experiments and measurements
   - Temperature and Ion distribution measurements in flames
   - Influence of different electric fields on flames
   - Influence of magnetic fields on flames
   - Current fluctuations in flame

4. Conclusion
Zone 1 (Unburned gas Preheat zone)
- unburned gas is being heated up to burning temperature.

Zone 2 (Luminous inner cone) flame front
- reaction zone, where chemical reactions are held on.

Zone 3 (Outer cone of flame) Product zone
- Where final burning proceeds.
DYNAMICS OF COMBUSTION

- Reaction speed (i.e. how fast is burning reaction process);
- Flame front normal velocity
- incoming gas flow velocity;
- gas consumption;
- Flame front (internal cone) surface area;
- height of internal cone;
- half-angle of top of internal cone;
- thermal conductivity.

Flame front normal velocity describes the combustion (burning) process

\[ u_n \sim \sqrt{\alpha \omega} \]  

(1)

“Dynamical equilibrium” principle must be satisfied:

\[ u_n = u_{flow} \cdot \sin \varphi \]  

(2)

For the given gas mixture

\[ \bar{\omega} \uparrow \Rightarrow u_n \uparrow \Rightarrow \sin \varphi \uparrow \Rightarrow \varphi \uparrow \Rightarrow h_c \downarrow \Rightarrow S_c \downarrow \]
Ions in Flame

• In flames there are charged particles – ions.
• Ions in flames are created mainly by chemical ionization

\[
CH + O \rightarrow CHO^+ + e^-
\]

\[
CH + C_2H_2 \rightarrow C_3H_3^+ + e^-
\]

(3)

• Maximal concentrations of ions must be in the “reaction zone” of flame.
• Charge separation in laminar flames
  – Reaction zone and outer cone are positive (+)
  – Inner cone is negative (-)
• This is caused by different mobility of electrons (-) and positive ions (+).

Existence of ions in flames causes possibility of influence of electric and magnetic fields on flames.
Influence of Electric Field on Flame

1. **Ionic Wind**
   - Ions flow along the field lines entraining the neutral particles with themselves.

2. **Transformation of electric field energy into thermal energy within flame.**
   
   Current flow through the flame increases the flame temperature. According to Arrhenius equation
   
   \[
   \bar{\omega} = A e^{E_A / kT}
   \]
   
   This increases chemical reaction speed. Here
   
   - \( A \) - pre-exponent factor
   - \( E_A \) – “Activation Energy” – minimal energy necessary to reaction to proceed
   - \( k \) - Boltzmann constant
   - \( T \) - Temperature

3. **Direct influence of electric field on combustion.**
   - Additional polarization of interacting particles
   - Electrons and ions existing in flame acquire additional energy

- Flame Temperature
- Flame Ionization level
- Chemical reaction speed
- Combustion speed
- Flame height and surface area
- Flame Shape
EXPERIMENTS

Our Installation
Measurement of Temperature

K-type Chrome-Alumel Thermocouple
Measurement of Conductivity

A view from above

Nickel Plates

Insulator

A view from side

Nickel Plates

Insulator

Voltmeter

990
Temperature and Conductivity

• The highest conductivity is in the reaction zone and a little above it.

• Thus the highest concentration of ions is in reaction zone and a little above it.

• This can be caused by the ions entrained by gas flow from the reaction zone.

• Ion concentration has a sharp peak, while temperature distribution is not so steep. This points towards chemical ionization nature in flames rather than thermal ionization.
Application of Electric Field to Flame

1. Longitudinal application. Positive pole at burner.

a. **Ionic wind** is in flame direction
   – Flame "blow off" possibility increases
   – Flame height must increase

b. **Temperature growth**
   – Due to flow of electric current through flame temperature increases
   – Combustion speed does increase
   – Flame front surface area and height must decrease

c. **Direct influence of field on combustion process**
   – Electrons are accelerated towards positive burner against gas flow
   – Their collisions with particles creates more active centers and ions
   – Electric field polarizes gas molecules
   – Reaction and Combustion speed does increase
   – Flame front surface area and height must decrease

In this case processes (b) and (c) together act more effectively than (a).

Videos on the next page
In our case processes (b) and (c) together acted more effectively than (a).
— **Temperature** increases approximately by 20%.
— **Conductivity** increases 100 times.
— So do increase the concentrations of ions.
— This causes high increase of combustion speed.

**Temperature increase Video**

**Resistance decrease i.e. conductivity increase Video**

For very strong upward field or high gas flow speed flame still can be blown off.

**Blow Off**
Application of Electric Field to Flame

2. Longitudinal application. Positive pole above burner.

a. Ionic wind is towards burner.
   – Flame tries to rush into burner
   – Due to flow of heavy positive ions towards the burner, the high temperature and reaction zone also moves down towards the burner.
   – Flame front and height decrease
   – Flame "blow off" possibility decreases

b. Temperature growth
   – Due to flow of electric current through flame temperature increases
   – Combustion speed does increase
   – Flame front surface area and height must decrease
   
field downward video

As we can see, in this case process (a) changes the flame shape effectively and “presses” it to the burner.
3. Normal application.

- Positive electrode is to the left side and negative to the right side.
- Most significant effect of electric field is in the vicinity of the reaction zone level.
- Upper part of flame bends to the right and lower – to the left. This shows that there does exist the charge separation in the flame.
- Two jets of smoke flowing towards electrodes.
- Ion absorption by smoke particles.

Video_candle normal

Video_charge separation normal

Video_smoke flow
Magnetic field influence on flame

Quartz tube

Magnetic field is created by varying electric field (during the time till the voltage on the positive pole reaches 27KV).

After that electric field is constant and there is no magnetic field.

Electric field refracts on the walls of quartz tube and is much weaker inside this tube.

Strong field video
Voltage Oscillations in Flame

- One electrode above reaction zone; Other - on burner;
- Voltage oscillations appear;
- Different mobility of positive and negative ions.

Video. Oscillations

Positive ions are entrained by gas flow to layer above reaction zone. Electrons can diffuse to layer below reaction zone. This causes potential difference. Potential difference creates electric field which forces these positive and negative ions to move towards each-other. This decreases potential difference. Process starts again.
Basing on our investigation we can make the following conclusions:

1. Ions in flame are concentrated mainly in reaction zone

2. Positive and negative ion concentrations are shifted relatively to each other.

3. There is large influence of electric field on flames. 
   The main factors are:
   a) Ionic Wind;
   b) Increasing of reaction and combustion speed.

4. There is large influence of magnetic field on flames.

5. We observed two interesting phenomena (description of which we did not find in literature):
   - Ion absorption by smoke particles
   - Voltage fluctuations in flames
Thank you for attention!