JACOB'S LADDER FOR THE PHYSICS CLASSROOM

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Abstract. Jacob's ladder is a relatively simple experiment simultaneously demonstrating the physical effects of gas discharge and buoyancy (Archimedes force) acting on an arch. The goal of the present work is to describe an experimental set-up for the Jacob's ladder built by high school student and their teacher and meant for the physics classroom in any high school around the world.

Keywords: demonstration experiment; high-school; Jocob's ladder; gas discharge; Archimedes force.

One of the purposes of the competition "Devices for Physics laboratory" is to promote motivated student to develop himself new experimental set-ups which is related with deep understanding of the science. As a rule, this work is supervised by teachers but very often this is a common work by father and son. With the global degradation of the physics education, such experimental set-ups will become more and more valuable. Moreover, the participation of the students in the design and building is much more educatory than any boring physics textbook and last but not least, it was fun.

Introduction

Metal processing is a technological process of work with metals to create everything, from little parts to big structures. The term covers a wide range of work, from big parts for boats and bridges, all the way to the smallest details for jewelry and engines. Because of that, in metal processing, people use a big set of skills, processes and tools. One of those tools is the plasma cutter. It is a tool used for accurate cutting metals using plasma.

The "Jacob's Ladder" is an experiment, which has a similar way of working like the plasma cutter. It is mainly used to explain the state of plasma, but still there are differences. The plasma from the plasma cutter is static, i.e. it does not move, while in the described experiment it moves vertically upward due to the higher buoyancy (Archimedes force) of the heated ionized gas in the arc (Orr et al., 2008).

Principle of operation

To create an arc, you need to connect both the conductors (electrodes) with a third conductor.

For this experiment, the necessary ingredients are a transformer, two electrodes, an additional insulated conductor and two connecting cables between the transformer and the electrodes. The experimental set-up in operation is depicted in Fig. 1. In the most left picture the arc is generated, then it begins rising in both middle pictures until it reaches the top of the electrodes in the most right picture. At the top part, the distance between the electrodes becomes visibly larger, making the electric field between them smaller (the electric voltage is unchanged, while the distance has become larger). When this electric field becomes less than the minimal electric field needed for the arc creation, the arc is disconnected. In other words, the electrons from both electrodes are not supplied enough energy by the electric field to cross the gap in between. The very same mechanism works in the giant arc discharges in our atmosphere we call lightings (Feynman et al., 1965).

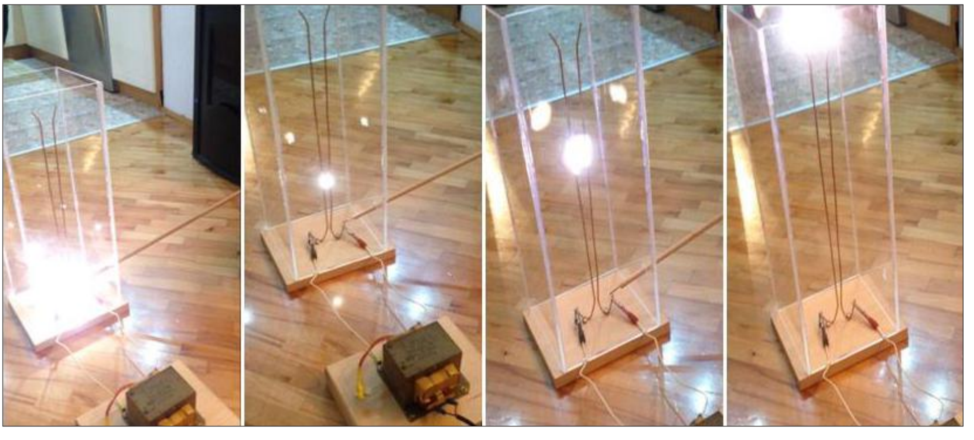

Figure 1. Operation of the Jacob's ladder experimental set-up. Most left picture shows the generation of the arc, which starts rising in the next picture to the right. It continues to rise in the next picture (third from left to right) until it reaches the top of the electrodes in the most right picture. The electrodes are enclosed in transparent Plexiglas boxes for protection easily seen in all pictures

Some useful technical details

A transformer is an electrical device, which converts the electrical energy to an electromagnetic field, from one circuit to another, with no moving parts. Transformers are used to increase or decrease voltage, change the resistance, or to ensure electrical insulation between the circuits. The simplest transformers are made of two coils – primary and secondary, Fig. 2.

The AC running in the primary creates a magnetic flux which, through the iron core, causes an electromagnetic induction in the secondary. In the described experiment here, a transformer with 100 windings on the primary and 1136 on the secondary is used.

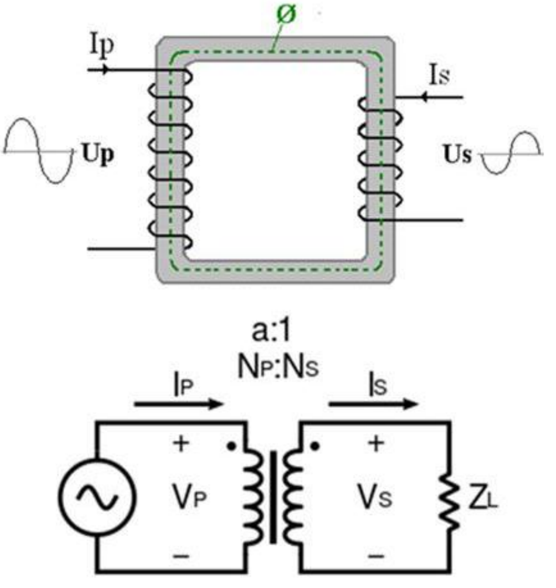

Figure 2. Schematic representations of a transformer.[1)] The voltage and current of the primary coils are correspondingly denoted U_p and I_p, while the voltage and current of the secondary coil are denoted with U_s and I_s. The number of coils presented here is just for illustration purposes

The used conductors in the experiment are copper wires since copper is the most commonly used metal for conductors. The best conducting metal is silver (with resistance of ≈ 1.6×10^{-8} Ω-m (Mitchell, 2004), but it is also very expensive and therefore not suitable for our purposes.

The used insulators in the described experiment are two wooden bases, two Plexiglas boxes and a wooden stick for the third inductor. Since the air discharge electric field to maintain the arc is in the range of kV/cm, good insulation is a must. The wooden bases provide insulation of the electrodes and transformer from the bottom, while the transparent Plexiglas boxes provide protection from all sides and top and in the same time allow observation of the experiment. Of course, they are over 10 000 different materials used for insulations (plastic, paper, rubber, glass, wood, oils, etc.) widely used today depending on the requirements for insulation.

NOTES

1. https://en.wikipedia.org/wiki/File:Ideal_transformer.svg

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