Rubens' tube

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In this text you'll find a guide to construct a device which can showcase gas depression using acoustic waves, standing waves, sound transmission in gas and more. This device was developed on the basis of Jakub Dvořák's work on his practical physics homework.

Introduction

In our lessons we try not only to share our knowledge and skills with the students, but also to nurture respect and love for physics, one of the more unpopular subjects in school. Therefore, we add lots of experiments, problem-based exercises, motivational tasks and physics problems based in our everyday life to our lessons. We do this so that students can realize that physics is present in every aspect of their lives and this helps them to understand and explain various physics phenomena.

Besides activities I prepare for the students, I also incorporate activities which the students themselves prepare. One of these activities is practical physics homework.

Practical physics homework

Practical physics homework is assigned to second-year students of the technical lyceum. Assigning these tasks has two main goals. First one is for them to brush up on and deepen their understanding of the knowledge they've gained last year of the theoretical side of physics and the experimental side by working on experiments and by measuring various physical quantities. At the same time some students can try to construct simple experimental devices, find parts for them and so on and hone new skills by doing that. That is why I choose to assign these tasks, so that students must think hard about certain physics phenomena and approach a problem differently than they're used to with definitions and equations. By that time the students know me well enough to know that for me memorizing a simple equation or a definition is no way to present physics.

The second goal, because of which I assign the homework, is an opportunity for the students to share their ideas, their tools and their own interpretations of an experiment with the class and the teacher. And even though it may seem that their classmates might not ask a lot of questions about it and not look for mistakes you'd be surprised, very often the students come up with questions which make their presenting classmate think deep and search for all the relevant connections. And this skill – to orient oneself in the topic of the question and think about a coherent and if possible, a proper answer, to swiftly react to supposed irregularities and mistakes in the experiment – is crucial in searching for a new job, in asking for a financial contribution for your research, in presentation of accomplished work and so on.

Some students then come back to their seats saying: "You don't have it easy, sir." This effect can also be desirable since students may realize that by asking certain difficult questions, they can also tip (at least for a moment) their teacher "of balance" during a prepared lesson.

This practical homework is assigned at the start of the school year, and they usually present it to others at the beginning of November. Every practice lesson there's one presentation.

In the list of assignments there are standard experiments the students had a chance to see in the first year of their study, there are also construction tasks of simple devices, a series of experiments using a chosen tool (a plastic bottle, a compact disc, a syringe…) or the students can come up with their own idea. These need to be consulted with me for their relevance.

I always stress to students that an assignment can be completed by simply presenting an experiment I showed them last year in the physics class. I also encourage them not to spend large amounts of money on their projects but to use tools and materials which they already have at home and they would otherwise throw out.

Despite that, sometimes there are students who don't listen.

Rubens' tube

Draft

"What would you think if I made a Rubens' tube?" I was asked by Jakub Dvořák, a student of the 15M class, one day. I had nothing against it, but I warned him it might be costly, that some technical problems with the construction might come up and also told him about the dangers of working with flammable gas. None of this discouraged Jakub. And I knew him well enough to not expect him to take my objections seriously. I know him not only as a student in my class but also as an experienced technician who is careful when working with high voltage or other dangerous tools.

On the day of his presentation he arrived to class with his "grill" as his classmates aptly called his device.

Device principle

The tube, which can be used to visualize standing sound waves, was first constructed by the German physicist Heinrich Rubens (1865 - 1922) as an aid for his lectures at the University of Berlin. His device was probably inspired by the Kundt tube created by his teacher. The Rubens' tube is a tube with a circular, rectangular, or square cross section with small holes drilled on one side. The tube, which is closed tightly on one side and closed with a flexible membrane on the other side, is filled with gas and a sound source is attached to the end with the flexible membrane (a speaker, a screaming person, ...).

Because of the sound propagating in the tube, the gas gradually dilutes and thickens - the sound propagates in the form of longitudinal waves. If the tube is firmly closed on the opposite side to the sound source, the ripples will bounce off this fixed end creating standing waves inside the tube. These standing waves will create periodic regions of low and high pressure correlating to nodes and antinodes of the standing waves.

If we ignite the gas that escapes from the holes drilled in the upper part of the tube, the height of the flame will correspond to the gas pressure below the corresponding hole. This way the height of the flame will determine the distribution of nodes and antinodes (and other types of points at which the waves generally have different amplitudes). By changing the frequency of the sound in the tube, the distribution of nodes and antinodes and thus the height of the flames above the individual holes in the tube will change.

Construction of a specific type of tube

It took Jakub about a week to build the Rubens' tube. He did not encounter any major problems during the construction. This was mainly because Jakub created a schematic diagram of the entire assembly before the production itself (see Fig. 1), which he followed exactly throughout the production. Based on the diagram, it was therefore relatively easy to select and purchase suitable materials for the construction of the entire tube.

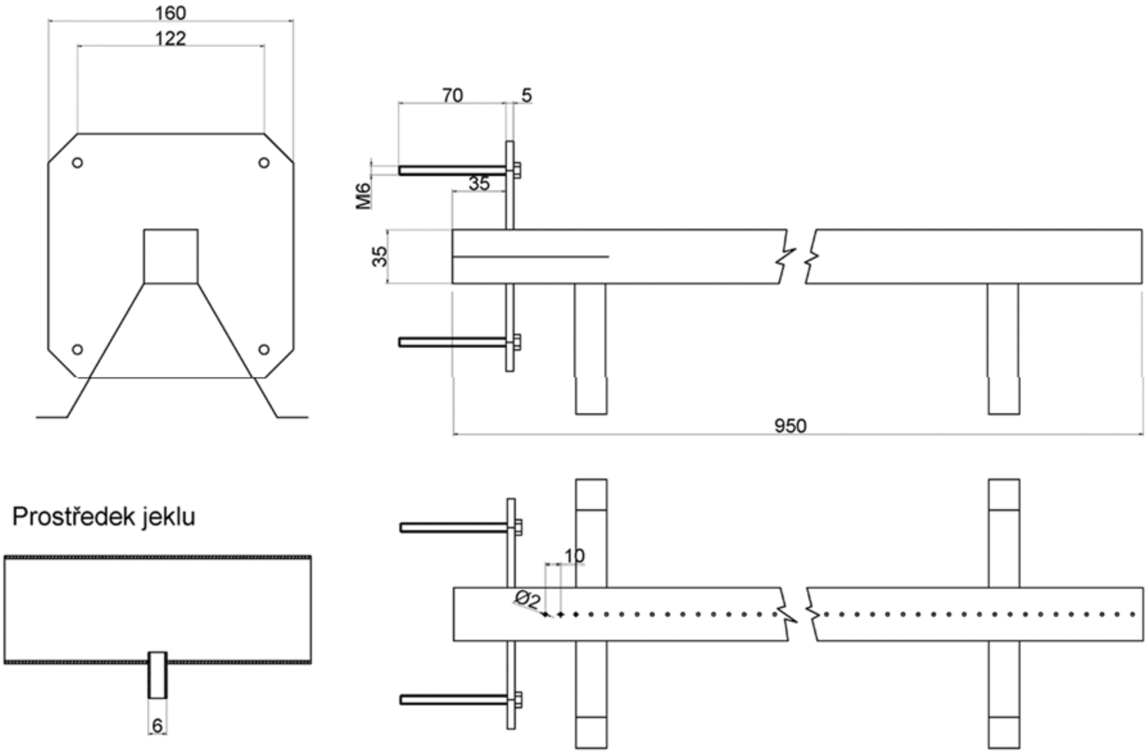

Fig. 1: Schematic diagram of the device

A 95 cm square aluminum pipe was used as the main part. Although Jakub used the internet as an inspiration for the construction of the Rubens' tube (e.g. [1]), there was not a complete manual with all the necessary data and dimensions of the individual parts. Therefore, he had to estimate several of the parameters (e.g., the diameters of the holes through which gas escapes from the tube and then burns). Fortunately, all the necessary parameters were chosen so well that the device was made functional on the first try without the need for additional changes. The only problem which occurred was the pedestal drill head breaking when drilling very small holes with a diameter of 1 mm. Nevertheless, in the end 59 holes were made.

Another problem that needed to be specifically solved was the membrane problem. For the Rubens' tube to be working properly, it was very important that the membrane at the end was very flexible (easy transfer of sound to the inner space of the tube), but at the same time very strong (prevents leakage of gas and larger changes in the volume of gas in the tube). In the end, a normal balloon proved to be the best candidate. To increase the safety of the entire apparatus, Jakub used two of these balloons; this prevented the undesirable gas leakage and the hypothetical undesirable explosion of the propane-butane and air mixture. Since the leaking gas burns along the entire length of the tube, the tube heats up which is not desirable. With prolonged experimentation with the tube the membrane can heat up so much that it melts. In order to prevent the membrane from melting, but also to stop the heat from damaging the speaker located inside the tube, Jakub used an aluminum plate attached perpendicularly to the pipe which formed the main part of the apparatus. This additional aluminum plate worked very well as a passive cooling component. At the same time, a temperature sensor was placed on the tube with which the operator can check the current temperature of the aluminum tube and, in the event of a significant increase, stop experimenting.

As the source of the gas for the tube a commonly available propane-butane tank with 190 g of gas was used. Its outlet valve is connected to a hose that is connected to the pipe of the apparatus, and this pipe is filled with gas. Before the actual experiment, it is necessary to wait a few minutes so that the gas is distributed evenly over the entire volume of the pipe. To ensure sufficient gas pressure in the purchased gas tank, Jakub devised a simple procedure: to immerses the gas tank in a bucket of warm water. The gas heats up in the tank and increases its pressure in an almost constant volume of the tank. The gas is then transported to the pipe more smoothly.

Experiments

On the set date, Jakub demonstrated his Rubens' tube at school. His classmates were fascinated by what he managed to create even though he didn't have to! He explained the basic principles of working with the device (see Fig. 2), described the construction and began the experiments.

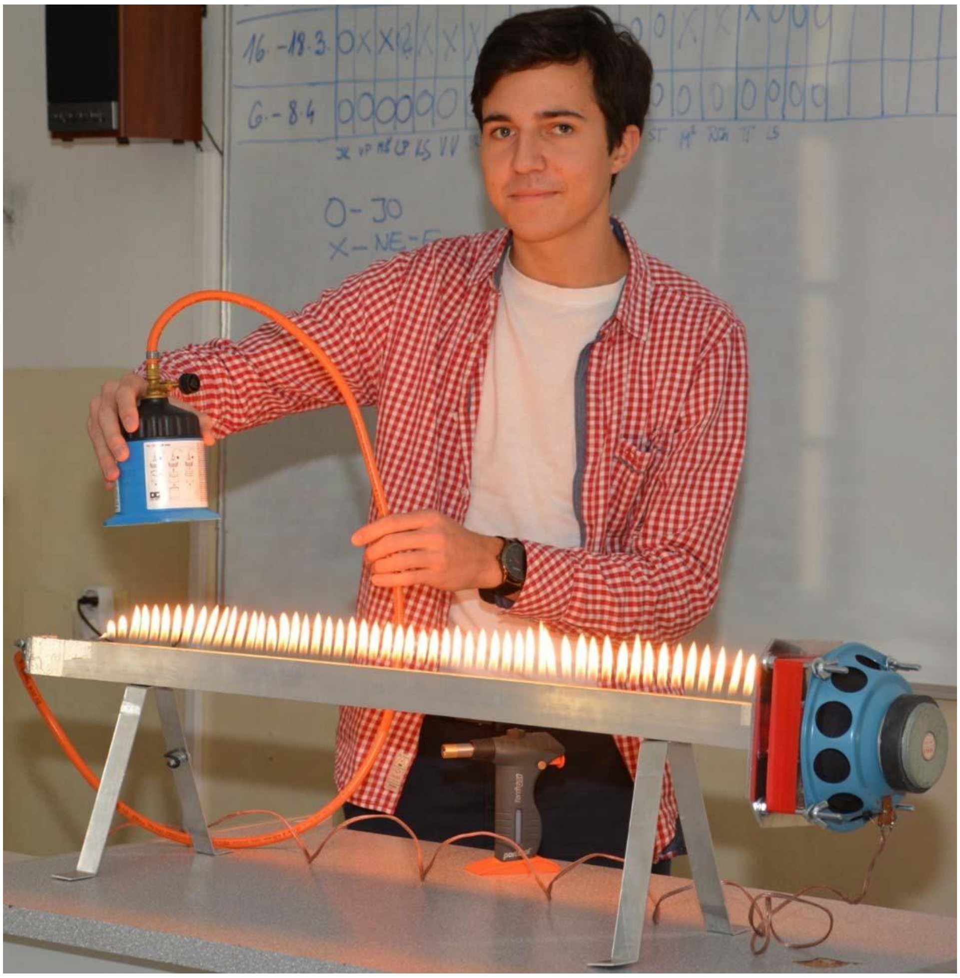

Fig. 2: Jakub Dvořák with his Rubens' tube

Firstly (after igniting the gas escaping the tube) he demonstrated the changing shape of the flames above the tube depending on the frequency of sound entering the tube. For this purpose, he used his cellphone with prepared suitable music tracks.

In the second part of the experiment he used sounds of defined frequencies in the tube and showed how the distribution of flames would change when using a sound with double, half,... the frequency of sound than the he had used originally. Some configurations of flames are shown in Fig. 3 to Fig. 5.

Fig. 3: Example of the shape of the flames

Fig. 4: Example of the shape of the flames

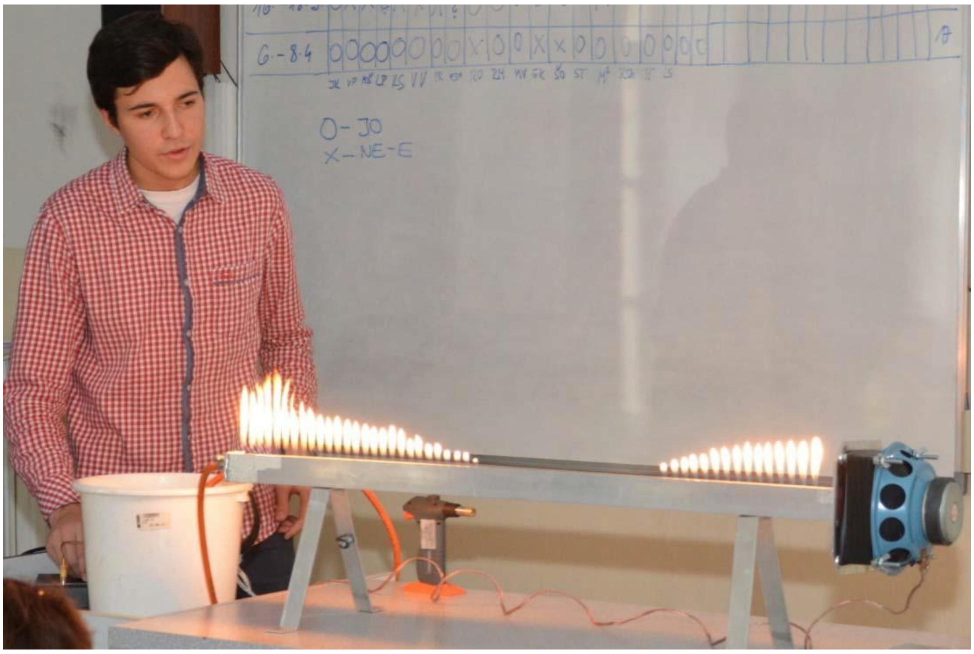

Fig. 3: Example of the shape of the flames

Based on the measurement of the mutual distance between two adjacent nodes (this distance is equal to half the wavelength of a given sound wave), it is also possible to determine the value of the speed of sound propagation in used gas. To compare these measurements with tabular values it would be necessary to add a suitable gas pressure sensor to the tube since the speed of sound propagation is dependent on the pressure of the gas.

Lastly, Jakub made use of my sonorous voice and asked me to try shouting at the membrane. After a few failed attempts during which I searched for the optimal distance from the membrane and pitch and intensity of the tone I did it: the flames above the tube created a similar pattern as before (see Fig. 6)

Fig. 6: Jaroslav Reichl as a source of sound

Other uses of the device

This successful presentation wasn't the last. Jakub presented his creation during other occasions.

Eureka seminar for high schools

The 8th *Eureka for high schools* seminar for interested teachers, which I lead, was devoted to mechanical oscillations and waves. I asked Jakub if he would show the device to the present physics teachers. Jakub agreed and not only showed the device to the teachers but was able to respond very well to their questions regarding both the presented physical phenomena and the design of the device.

MatFyz FEAT

At the start of 2017 Jakub entered the Matfyz FEAT competition (see [3]) organized by MFF UK in Prague for gifted and skillful high school students. For this competition Jakub decided to build a longer tube, for which he received a financial contribution directly from MFF UK.

The new tube measures 220 cm in length and is structurally very similar to the first model. When Jakub presented this tube at the competition, he found out that for such a long tube not even a hot water filled bucket is enough to provide sufficient gas pressure in the gas tank so that the gas evenly fills this tube. Even though the experiments weren't so successful as with the shorter tube, the judges of the competition awarded Jakub with an award for his achievement in innovative technical solutions in a problem.

A video for the "I Know How" website

Without any further help Jakub filmed a video about standing waves using the Rubens' tube (see [4]), which he presented at the regular school academy seminar and then sent it to the "I Know How" website [2] at the beginning of 2018. The experiments which he filmed were carried out using the original (shorter) tube.

Jakub's video uploaded on the website [2] was one of the most appraised by the visitors of the site and professional judges rated it as the best in the category. Jakub won a prize for himself and a financial contribution for the school for the purchase of physics tools. The prize was presented to Jakub by representatives of the ČEZ Foundation which sponsors the competition in June 2018.

The financial contributions to the school will be granted after the approval of the application, which the school had to write, by the representatives of the ČEZ Foundation. I, the class teacher and the members of the school management congratulated Jakub for the win and all of us were glad that we had such a gifted student at the school. However, this achievement had a bit of a bitter aftertaste because the school management now had an obligation to apply for the prize the school had won [2]. The application contained a number of questions, some of which could only be answered by an economist or the school headmaster.

References

[1] https://www.instructables.com/id/The-Rubens--Tube%253a-Soundwaves-in-Fire%21/, [cited on 20. 8. 2018]
[2] https://www.vimproc.cz/, [cited on 20. 8. 2018]
[3] http://matfyzfeat.mff.cuni.cz/, [cited on 20. 8. 2018]
[4] https://www.youtube.com/watch?v=TmbLOZCb60U&feature=youtu.be, [cited on 29. 8. 2018]