COLUMBUS - A SMALL CYCLOTRON FOR SCHOOL AND TEACHING PURPOSES

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Abstract

In the early 2012 the project "COLUMBUS - a Small Cyclotron for School- and Teaching Purposes" started. Supported by the FZ Jülich and some German companies a small cyclotron was built at the University of Applied Sciences of Coburg, Germany. After the first beam was detected in 2014, the cyclotron was continuously improved and expanded. At the same time, an educational concept based on the studies and curricula in Germany was developed. Since then, workshops and internships, which are the two columns of the concept, have enjoyed increasing popularity among students and, fortunately, among female students as well. Furthermore, future improvements of the accelerator and the educational concept are presented.

INTRODUCTION

A cyclotron is, in theory at least, an easy-to-understand accelerator. It is therefore part of the standard repertoire in all physics books in secondary schools. In practice, however, it looks very different. This shows that a cyclotron is a complex structure made up of a wide variety of systems that must be precisely coordinated with one another. For this reason, hardly any student has had any practical experience with this accelerator. This is where the COLUMBUS project comes in, providing students with a functioning small cyclotron with which they can learn accelerator physics and carry out their own experiments.

TECHNICAL DEVELOPMENT

After the FZ Jülich provided a magnet, VACOM, a company for vacuum components, sponsored a suitable vacuum chamber and a pumping station was bought by the University of Applied Sciences of Coburg, the assembly of the cyclotron COLUMBUS began in 2012. The first results were presented at Cyclotrons'13 in Vancouver [1]. Figure 1 shows the setup of the cyclotron COLUMBUS at the end of 2013.

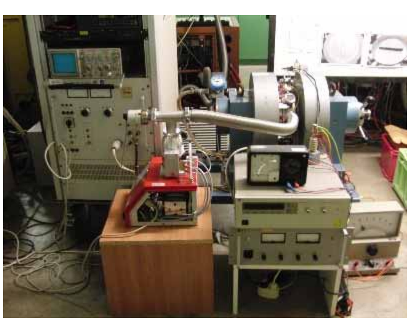

Figure 1: Cyclotron COLUMBUS 2013.

The first beam was registered in April 2014 (see Fig. 2), which was followed by the first workshop with students in autumn of the same year.

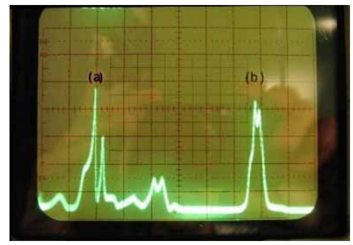

Figure 2: First Beam (a) H^+ (b) H_2^+.

The cyclotron was continuously improved and expanded with the involvement of pupils and students. A cooling system for the magnet, a linear translator for the detector and many other improvements complemented the accelerator.

A mechanical cyclotron, as shown in Fig. 3, and a simulation of the ion paths which was presented at Cyclotrons'16 in Zurich [2], improved the educational concept.

Figure 3: Mechanical Cyclotron.

Pupils and students are currently dealing with topics related to the accelerator in workshops and internships. For example, the first 3D-printed vacuum chamber was shown at Cyclotrons'19 in Cape Town [3].

The cyclotron available today (see Fig. 4) has a vacuum chamber with a diameter of 200 mm and a height of 75 mm. With an improved matchbox, two cyclotron frequencies of 2.82 MHz and 5.64 MHz are available. The technical data of the cyclotron are shown in Table 1.

Figure 4: Cyclotron COLUMBUS 2022.

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Table 1: Technical Data of the Cyclotron

Description	Value
Diameter of the Dees	140 mm (5.5 in)
Flux density	185 mT (H^+) | 370 mT (H_2^+)
Vaccum in the chamber	10^{-6} mbar
dto with H_2	10^{-5} mbar
Cyclotron frequency	2.85 MHz | 5.64 MHz
Dee Voltage	0.5 – 3.0 kV
Final Energy	~ 4,1 keV (H^+) | 7,5 keV (H_2^+)

EDUCATIONAL CONCEPT

Parallel to the construction of the cyclotron, an educational concept was developed to bring the theory closer to the pupils and students. This concept rests on two pillars:

- Workshops.
- Internships.

While the workshops are aimed at pupils, the internships are primarily intended for students.

Workshops

The workshops are available in several formats:

- Two-day in-depth workshop.
- One-day workshop.
- Online workshop with three sessions and one face-to-face session in the lab.

A workshop takes place in groups with up to 6 participants. If more people register, up to 12 persons can be accepted, who will then be divided into two groups. Online workshops were added due to the pandemic situation, but were also used in a cross-border workshop.

The program of all workshops is primarily based on the valid curricula for physics in Germany, so that the participants can use the knowledge they have acquired directly at school.

All workshops have similar programs. In the first part, the participants receive an interactive presentation in which the development of the accelerators is shown. In particular, the difference between DC- and AC-accelerators is explained. A special focus lies on the discussion of the acceleration principle as the resonance of an alternating electric field with the circulation of the ions. A mechanical cyclotron is used to illustrate this. Finally, the formulas for the cyclotron frequency and the energy of the ions are derived.

The second part introduces the accelerator itself. The subsystems as shown in Fig. 5 (magnetic-, vacuum-, ion-, acceleration- and detector-system) are explained. The students are involved so that they can operate the accelerator themselves under supervision.

In the third part, an experiment is carried out in which the students analyse the ions occurring in the beam. To do this, the detector is set to a specific position and the magnetic field is continuously increased. With very specific magnetic fields, there are peaks in the beam current as evident in Fig 6. Using a computer interface, the beam current and magnetic field are caught, saved, and plotted. As

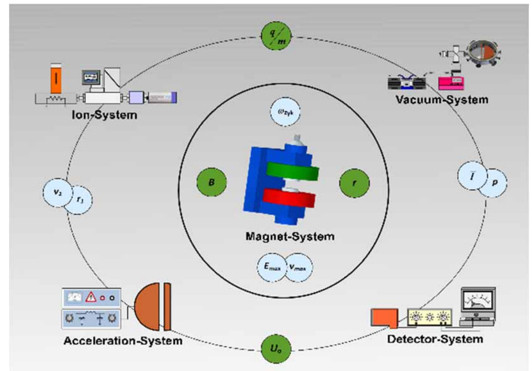

Figure 5: The Cyclotron and its Subsystems.

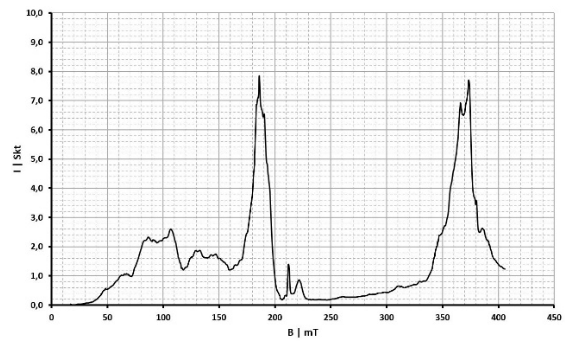

Figure 6: Beam Spectrum.

a result, the experiment is largely automated, so that several beam spectra can be recorded. The students change various parameters, such as acceleration voltage, gas flow or the heating current of the filament and observe the effects on the beam spectrum.

One of these spectra is evaluated as an example by assigning the corresponding ions to the individual peaks by calculating the specific charge. This is done dividing the known cyclotron frequency by the measured flux density.

Since the participants receive the measurement data of all experiments carried out, they can be used for further evaluations at home, at school or for seminar papers.

The one-day workshops focus on the two main peaks for H^+ and H_2^+ ions, while the two-day workshop can also analyse other peaks e.g., the peaks that correspond with the third or fifth of the nominal velocity.

During the two-day workshop, this program will be supplemented by additional elements such as simulations and specialist lectures, for example on the vacuum system or the RF system.

In recent years, these workshops have also been increasingly popular with girls. There have even been a few workshops where the number of girls exceeded that of the boys.

Internship

In addition to the workshops, internships are offered, especially for students. Here the participants carry out in-depth experiments such as spatially resolved measurement of the flux density of the magnet, develop parts that supplement the cyclotron, e.g., a linear translator with which the Faraday cup can be positioned, or investigate a Penning ion source with the aim of using it for the installation in the accelerator.

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Reports, papers, bachelor, or master theses then emerge from these activities. Publications in specialist journals were also the result of internships.

Pupils who take part in such internships mainly work on competition topics, e.g., for “Jugend forscht” or the “Innovation Award” by the Schaeffler company.

FUTURE PROJECTS

Finally, an outlook on future projects should be given.

In August last year, with the support of the IBA, Belgium, the constructing of an extraction system for the ions was started. The aim of this project is to deflect the ion beam and guide it through a Wien Filter to measure the speed and energy of the ions. These values can be compared with the calculated ones. A further advantage arises from the use of a Wien Filter. Like the cyclotron, this also belongs to the classic applications of electromagnetic fields and is - unfortunately only theoretically - known to the students from school. Thus, a Wien Filter represents a valuable practical addition to the school material.

But not only the accelerator itself should be improved and supplemented, an addition to the educational concept is also planned. This is a questionnaire about the material of the workshop. This should be filled in by the participants before and after the workshop. From the difference in the respective answers, you can see which parts of the workshop have been understood and how much the students have caught. In this way, targeted improvements can be made in the educational concept.

CONCLUSION

The COLUMBUS project, started in 2012, has developed very positively in the last 10 years. In addition to the technical development of the actual accelerator, an educational concept was created that has become increasingly popular with both male and female students. The additional online format of the workshop was not only able to adequately replace the face-to-face events during the pandemic, but also seems to prove itself in cross-border workshops.

In addition, the internships offered by this project give the students the opportunity to enlarge meaningfully their theoretical knowledge.

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