

Development of leaf electroscope to understand ionization for novice practical training

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Learning objectives

A textbook about radiation physics may begin with an explanation of "ionization", and the understanding of ionization is important for freshmen entered in a training radiology course (**Fig. 1**). Commonly known, the phenomena of ionization occurs due to interactions between X-rays and atoms, and in higher learning students obtain the knowledge that photoelectric and Compton scattering effects, play an important role in understanding ionization [**1-3**]. But actually, there are no proper educational experimental apparatuses to demonstrate ionization. The aim of our study is to fabricate a new experimental apparatus.

Our experimental apparatus is based on a leaf electroscope, which can detect the existence of charges. In the early stages of developmental radiation physics, the leaf electroscope was used to derive the phenomena of ionization. In recent years, the leaf electroscope is used as a basic experimental educational tool in the high school. The feature of this apparatus is, it is easy to understand, because it clearly demonstrates the existence of charges through visualized information (conditions of leaves). If the apparatus can explain ionization, we think that the leaf electroscope is still a valuable experimental tool for the education of radiation physics.

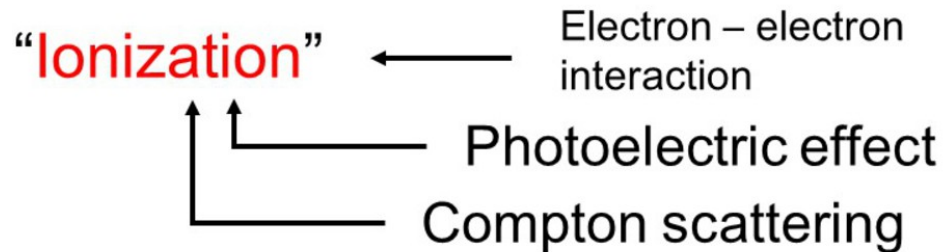
The main idea of our experimental apparatus was proposed by Matsuura *et al* [**4**]. They fabricated the original leaf electroscope which consisted of two spaces; the lower space was used to irradiate X-rays, and the upper space, where charged leaves were placed. First of all, positive charges are induced to the leaves and the two leaves are opened by repulsion force. When X-rays were introduced to the lower space, ions were produced through the phenomena of ionization. Then, produced electrons are transported to the leaves and recombined with positive charges on the leaves. Because no charges appear on the leaves, they are finally closed. The students can understand that the difference of "Open" and "Close" leaves is due to the irradiation caused by X-rays. This is basic concept of the educational experiment.

In this study, we improved the apparatus for a more convenient use. Moreover, we attempted to create a vacuum in the X-ray irradiation space. In an ideal condition, one can understand that the ionization is caused by air through a comparison between the two experimental conditions of normal (standard temperature and pressure, dry) and under a vacuum.

Images for this section:

Importance of education about basic physics

Physics textbooks may be start with an explanation about...



This knowledge is also useful for clinical diagnosis.

- Evaluation of **exposure doses**
- Reduction of **scattered X-rays**

We considered that **the education of beginners** is important.

Fig. 1: Importance of education concerning basic physics. In physics textbooks, one should understand the phenomena of the ionization.

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Background

Figure 2 shows photographs of a newly developed leaf electroscope. The left photograph shows a side view of the apparatus. The outer size is 130 mm width, 130 mm length and 170 mm height. The main body of the apparatus is made of 10 mm thick polycarbonate. X-rays are introduced from the left side. The entrance window has a 100 mm width and 90 mm height, and the thickness is 5 mm. To shield scattered X-rays from the movable diaphragm [5-7], the left side of the upper detection space is covered with 2 mm of lead. In the front, we can see a pressure sensor and a socket which is used to connect a vacuum pump. The top left photograph demonstrates an upper plate having leaves. To establish a vacuum, an O-ring was set in the upper plate. From the top, two types of separators can be inserted; one is a solid plate (polycarbonate), and the other is metal-mesh. The top right photograph demonstrates how to insert the separator. The right bottom photograph shows all materials used in our experiment.

The experiments were performed with the following four settings; a) normal (at 1 atm), b) with solid separator, c) with metal-mesh separator, and d) under vacuum (0.2 atm).

Figure 3 shows the experimental setup. Diagnostic X-ray equipment (Toshiba medical systems, Japan) was used. Tube voltage was set at 40 kV. Source to apparatus distance was set at 47 cm. The irradiation field was 10 cm width and 9 cm height on the surface of the apparatus. Tube-current-time products were 10 mAs and 20 mAs.

Images for this section:

Leaf electroscope: newly developed apparatus

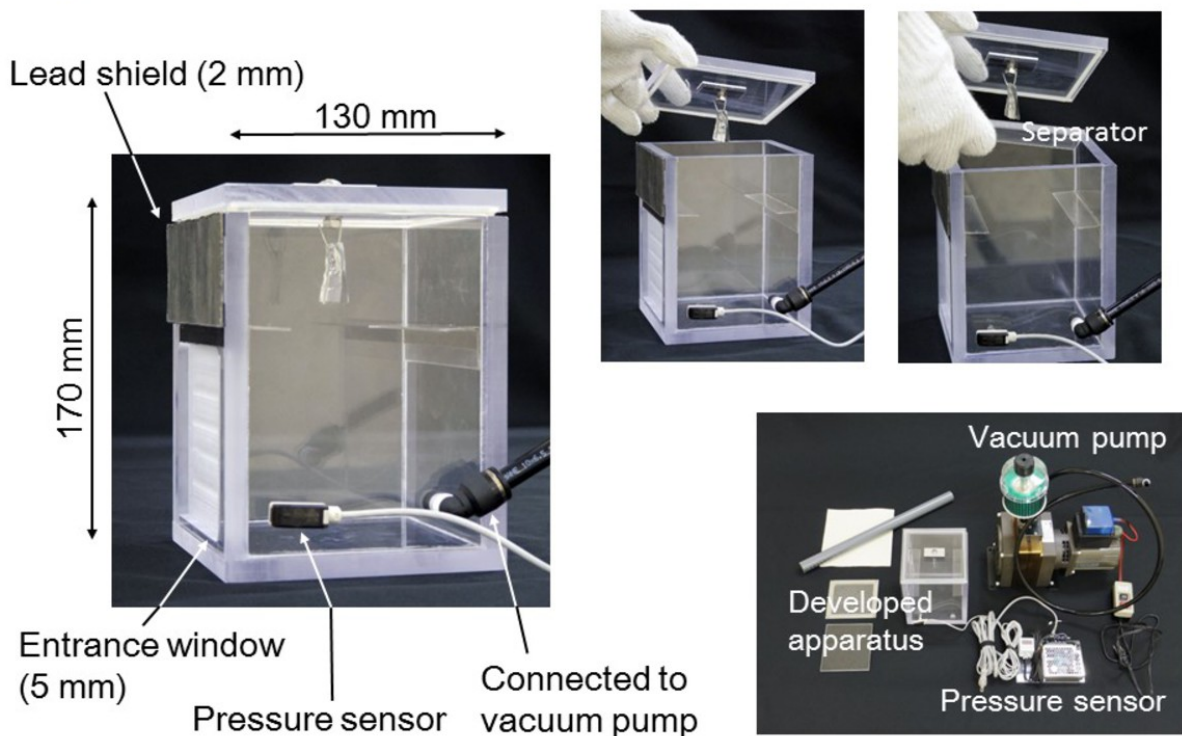
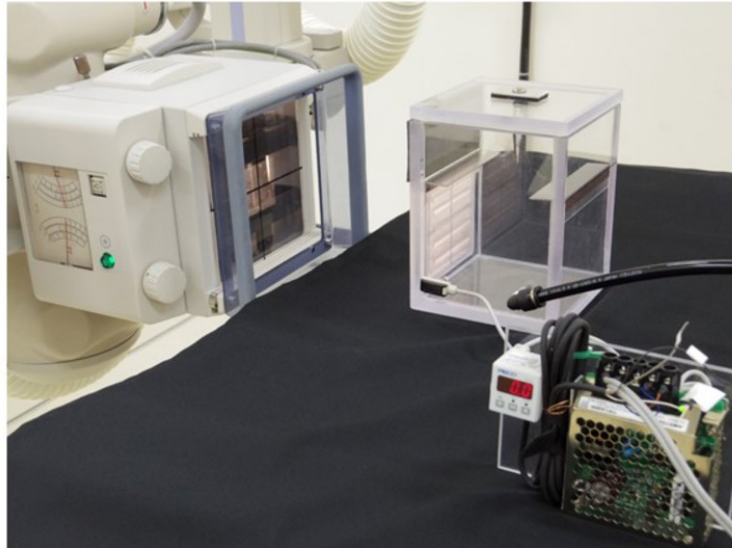


Fig. 2: Photograph of a developed leaf electroscope. X-rays are introduced to the inner space, in which the ionization process occurs. In addition to the normal condition, we can insert two types of separators. Moreover, the air inside the electroscope can be vacuumized.

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Experiment

Diagnostic X-ray
equipment



Tube voltage: 40 kV

Source to apparatus distance: 47 cm

Irradiation field: 10 cm × 9 cm

Fig. 3: Photograph of experimental setup. Diagnostic X-ray equipment was used.

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Findings and procedure details

Figure 4 summarizes the results of experiments. For four different settings, the experimental results concerning X-ray exposures of 10 mAs and 20 mAs are presented. The notation of "Open" and "Close" shows conditions of leaves after irradiation from X-rays; namely, in the settings with "Close" results, sufficient ions can be produced by irradiation from X-rays, and the "Open" indicates that sufficient ions to close the leaves are not produced. For results at 10 mAs, all of experiments show the same results, "Open", therefore the X-ray exposures of 10 mAs are improper for the current experiments. On the other hand, results of 20 mAs show differences between the four settings, therefore the exposure of 20 mAs is considered to be proper for these experiments. In **Figs.5-8**, we will describe more detailed results and explanations of the physical phenomena.

Figure 5 shows experimental results at the normal setting. The left photographs show a comparison between the two conditions of leaves before and after X-ray irradiations. We can clearly see that the "Open" leaves change to "Close" due to the X-ray irradiations. A schematic drawing of this experiment is represented on the right. As shown in the right upper figure, the charged leaves produce electric fields as shown by dashed arrows; at this time, the leaves are positively charged. Owing to the X-ray irradiations, many ions are produced in the lower irradiation space filled with the air. Then, the electrons are transported by an electric field, and finally electrons are combined with positive charges on the leaves. The phenomenon described above makes the leaves "Close", because there is not a sufficient repulsion force between the leaves. When observing this experiment, one can understand that the sufficient charges produced are caused by X-ray irradiation, and they neutralize the positive charges on the leaves.

Figure 6 shows experimental results for the setting in which a solid separator is inserted in the apparatus. From the left photograph, it is clearly seen that the result shows an "Open" condition. A schematic drawing of this phenomenon is presented in the right. X-ray irradiation causes ions to be produced. This situation is the same as **Fig.5**, but in the present case electric fields from the leaves do not exist in the lower space because of the solid separator. Therefore, the produced electrons may be recombined with the positive ions in the irradiated area. This is the reason why the leaves stay "Open". This result is important for the present study from the consideration of justification; namely, when scattered X-rays are produced and not shielded in the experimental system, the leaves will become "Close" even if a solid separator is inserted as shown in figure.

Figure 7 shows experimental results for the setting in which a metal-mesh separator is inserted in the apparatus. As clearly seen in the left photograph, the leaves stay "Open" when X-rays are irradiated. The schematic drawing in the right shows the phenomenon of this experiment. When X-rays are irradiated, ions are produced in the lower space.

Because electric fields caused by charges on the leaves can exist between the leaves and the metal-mesh separator, the electrons generated in the lower space are not transported to the upper space. From this fact, one can consider as the following description. In principle, even if there is no electric fields, charged particles (ions and electrons) can penetrate the metal-mesh separator through a diffusion process [1]. But in this case, the process of recombination occurs at a much higher rate than the process of diffusion. Therefore most of the electrons recombine with positive ions before they diffuse through the metal-mesh separator.

Upper photographs in **Figure 8** shows the comparison of experimental results between 1 atm (left) and 0.2 atm (right). They show the same results, "Close". In the condition of 0.2 atm, the amount of produced ions seems to be one fifth of 1 atm. As represented in **Fig. 4**, a normal setting of the condition of 10 mAs (half exposure dose of 20 mAs) shows "Open". Therefore, it should be "Open" for the experiment with 0.2 atm (20 mAs).

In order to verify the results represented in **Fig. 8**, the Monte-Carlo simulation was also carried out. We used EGS5 code [8-9], and as with similar experiments, photons with 40 kV X-ray spectrum [10] were introduced to the irradiation area. Computer graphics [8] of the simulation are presented in the lower figures of **Fig. 8**. From these figures, it was found that incident X-rays also interact with the entrance window which is made of 5 mm thick polycarbonate. Moreover, we calculated absorbed doses in the inner space using EGS5 code. The differences of the doses for 1 atm and 0.2 atm is only 20%. The above results indicate the necessity of improvement of the entrance window using thin material so as to reduce interactions with the window. Further research is now in progress.

Images for this section:

Summary of results

Settings	Results	
	10 mAs	20 mAs
Normal (without separator)	Open	<u>Close</u> Fig.5
Solid separator	Open	Open Fig.6
Metal-mesh separator	Open	Open Fig.7
Vacuumed (-0.8 atm)	Open	<u>Close</u> Fig.8

A condition of “Open” means that sufficient ions were **not** produced by irradiation of X-rays.

A condition of “Close” means that sufficient ions were produced by irradiation of X-rays.

Fig. 4: Summary of results. The detailed descriptions of each condition are presented in Figs. 5-8.

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Results and discussion: 1. normal

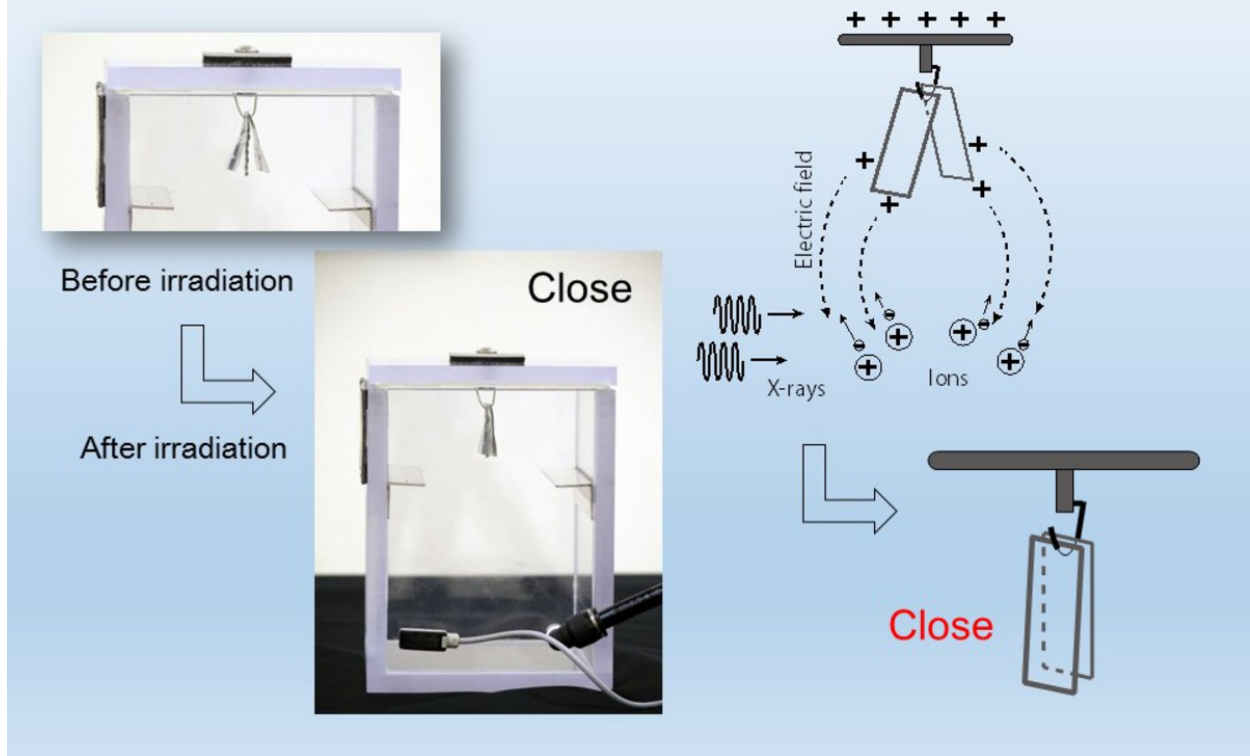


Fig. 5: Results and discussion of the experiment under the normal condition.

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Results and discussion: 2. solid separator

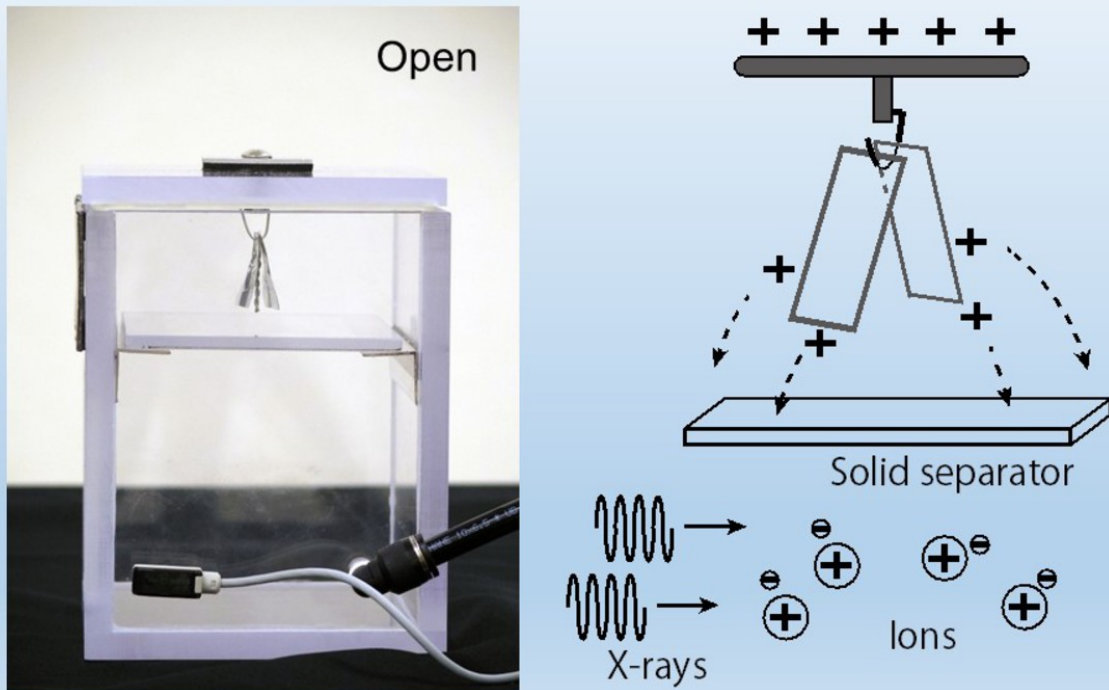


Fig. 6: Results and discussion of the experiment in which a solid separator was inserted.

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Results and discussion:

3. metal-mesh separator

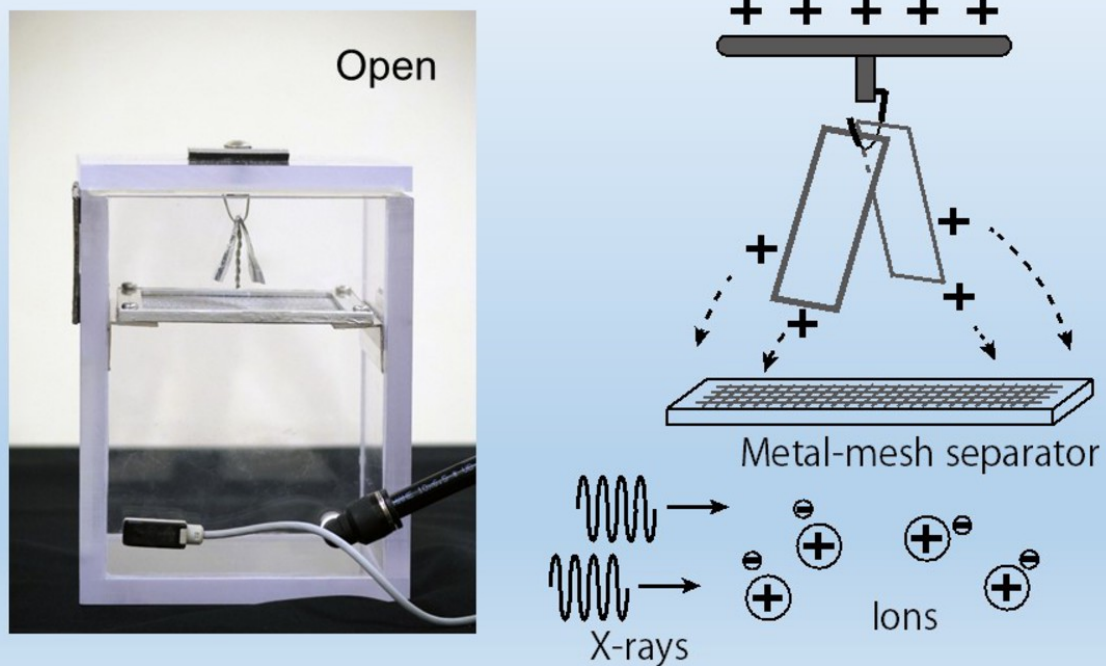


Fig. 7: Results and discussion of the experiment in which a metal-mesh separator was inserted.

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Results and discussion: 4. vacuumed

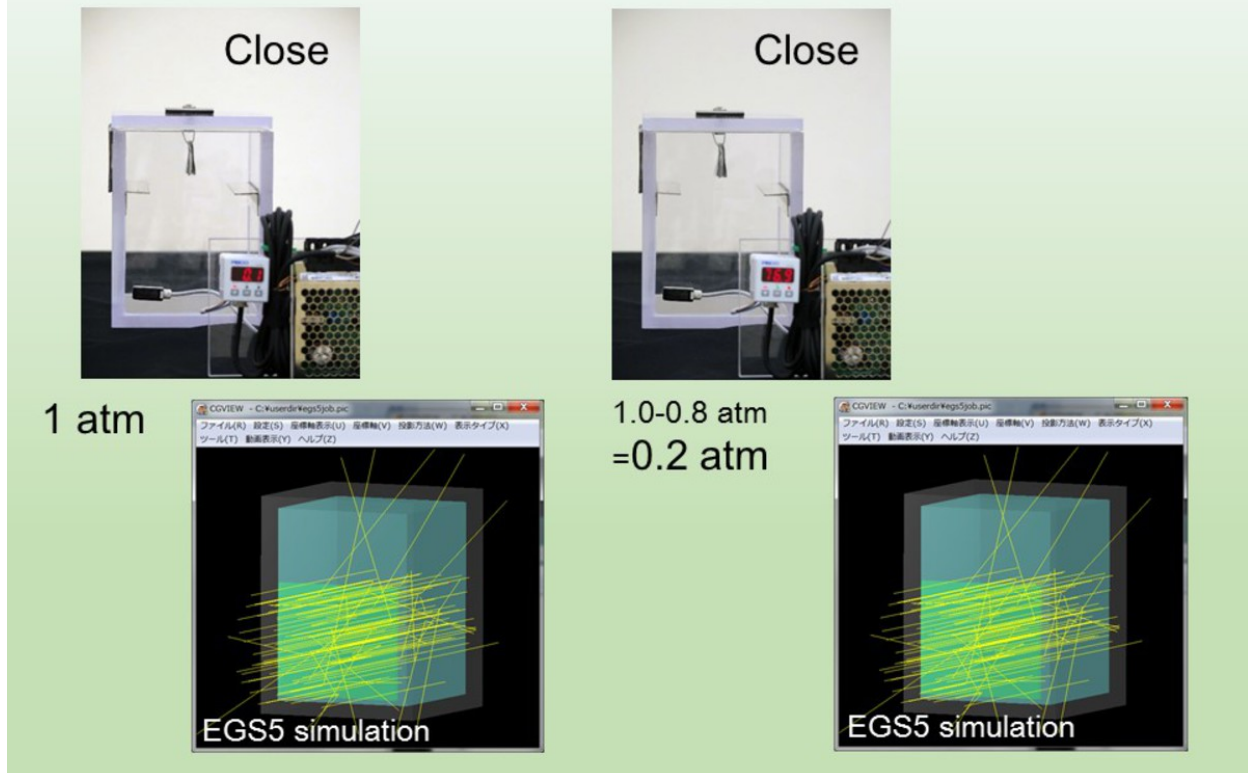


Fig. 8: Results and discussion of the experiment in which the air inside the electroscope was vacuumized.

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Conclusion

In conclusion, we developed a new leaf electroscope for educating beginners. The apparatus has two spaces; one is used for production of ions and electrons, and charged leaves are placed in the other space. By observing the conditions of "Open" and "Close" for leaves, one can easily understand the relationship between X-ray irradiations and productions of ions and electrons (ionization). The developed leaf electroscope almost works as well as we had wished, but improvement of the entrance window is necessary to reduce interactions between incident X-rays and materials in the window.

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