Counter tube characteristics

Physics | Modern Physics | Production & use of X-rays

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

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General information

Application

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Setup

Most applications of X rays are based on their ability to pass through matter. Since this ability is dependent on the density of the matter, imaging of the interior of objects and even peaple becomes possible. This has wide usage in fields such as medicine or security.

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Other information (1/2)

Prior knowledge

The prior knowledge for this experiment is found in the Theory section.

Main principle

The counter tube uses the ionising effect of high-energy radiation in order to measure the intensity of the radiation. The counter tube characteristics describe its working range, i.e. the voltage range in which it reliably counts the incoming particles.

Other information (2/2)

Learning objective

The goal of this experiment is to learn the principle behind a counter tube.

Tasks

1. Determine the counter tube characteristics of the type B counter tube that is used.

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Theory (1/4)

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Counter tube layout

A counter tube consists of a thin-walled metal tube that is filled with a gas mixture under reduced pressure. A thin, insulated metal wire runs through its axis. The metal tube and the wire thereby form a cylindrical capacitor that is connected to the voltage source via a high-ohmic resistance R. Figure 1 shows a schematic circuit diagram. The metal of the housing is so thin that gamma radiation can pass through it. In order to be able to also detect alpha and beta radiation as well as Xradiation, there is a mica window at one end of the tube. It is very sensitive with regard to mechanical stress and should be protected with the aid of the supplied cap. The axial counting wire of the counter tube is connected to the central conductor via a 10 MΩ-resistor, while the counter tube jacket is connected to the phase conductor of the BNC cable. Voltage is applied between the counting wire and counter tube jacket. In order to void point discharges on the metal wire, it is fused onto a ball.

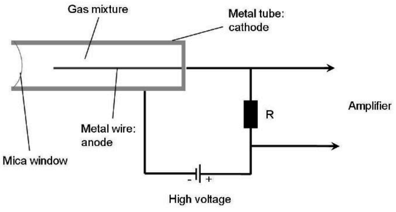

Fig. 1: Schematic circuit diagram of a GM counter tube

Theory (2/4)

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Measuring principle

The counter tube uses the ionising effect of highenergy radiation: When X-rays enter the counter tube, they ionise the gas particles, creating positively charged ions and free electrons, the primary electrons. The latter are accelerated towards the positively charged counting wire, thereby gaining sufficient energy to ionise further gas particles. Due to this socalled gas multiplication, an avalanche of electrons reaches the anode. This, in turn, results in a flow of current between the counter tube wall and the counting wire and, thereby, to a voltage drop that is detected. The resulting current flow can be converted into a voltage signal with the aid of the resistor. In the case of portable Geiger-Müller counter tubes, this signal is electronically amplified and then output either visually or audibly. The inside of the counter tube is filled with a gas mixture that mainly consists of an inert gas. Since, however, the ionised gas particles can release secondary electrons from the counter tube wall, which would distort the measurement result, they must be intercepted by a quenching gas, in this case a halogen. It will be consumed by the reaction with the ionised gas particles. This is why the service life of a counter tube is limited. The characteristics of a counter tube describe its working range, i.e. the voltage range in which it reliably counts the incoming particles.

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Theory (3/4)

If ionising radiation passes through the counter tube, the gas particles are ionised and primary electrons are released. They are accelerated towards the counting wire. However, they only reach the counting wire if they do not recombine with the gas particles on their way. If the counter tube voltage is too low some of the pulses are lost on their way, and the resulting signal will not be conclusive (recombination range). When the voltage is increased, all of the primarily released electrons impinge on the anode as of a certain level. As of this moment, the measured current is proportional to the energy of the entering radiation. When the voltage is further increased, the primary electrons take up so much energy that they ionise additional gas particles. The measured current, however, is still proportional to the energy of the incident radiation (proportional range). If the counter tube voltage is further increased, then the intensity of the ionisation current remains constant within a certain voltage interval. Every particle that enters the counter tube generates the same current pulse, since the incident part initiates a complete gas discharge. This interval is also known as the Geiger-Müller plateau or Geiger-Müller region (Fig. 2). It should be as long as possible and show only a slight gradient. If a counter tube is operated in this voltage range, it is also called a release counter tube. A further increase of the counter tube voltage will then cause a self-maintained gas discharge that will destroy the counter tube.

Theory (4/4)

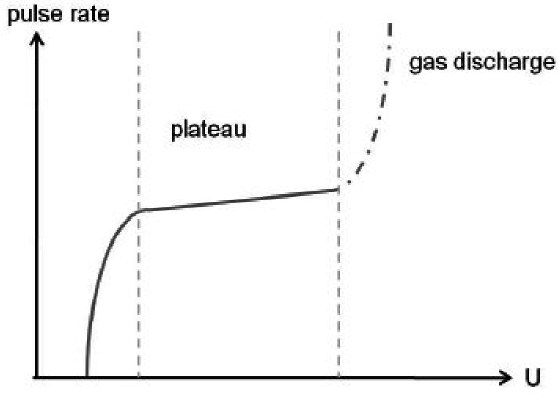

Fig. 2: Schematic course of the characteristic counter tube curve

Dead time

Immediately after a gas discharge, the counter tube is not able to detect new particles for approximately 100 μs. This is the so-called dead time. During this time, the positively charged ions shield the anode from the electric field. It is not until the gas ions have moved to the cathode and the halogen additive has quenched the counter tube discharge that the counter tube is ready again.

If τ($\tau \approx 90\ \mu s$) is the dead time of the Geiger-Müller counter tube and N_0 the measured pulse rate, the true pulse rate N is:

$$N = \frac{N_0}{1 - \tau \cdot N_0}$$

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Equipment

Position	Material	Item No.	Quantity
1	XR 4.0 expert unit, 35 kV	09057-99	1
2	XR4 X-ray Plug-in Cu tube	09057-51	1
3	XR 4.0 X-ray solid state physics upgrade set	09125-88	1

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Setup and Procedure

Setup

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Position the counter tube directly in the primary beam either with the aid of the counter tube holder or with the goniometer. Insert the diaphragm tube with a diameter of 1 mm into the beam outlet of the tube plug-in unit for the collimation of the X-rays. In doing so, you shield off a large part of the radiation. Alternatively, the counter tube can also be moved out of the primary beam.
Connect the counter tube via the BNC cable to the MultiLINK.

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Procedure (1/3)

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Procedure without a computer

- Set the anode voltage and current in the “X-ray parameters” menu. Select a voltage of 35 kV and a current intensity of 0.02 mA. This results in a counting rate of approximately 1,500 pulses per second, which is sufficient for the measurement without wearing down the counter tube.
- Under “Menu”, select “Settings” on the display.
- In the next window, select “GM voltage” and adjust the desired value with the aid of the arrow keys.
- The time for averaging the pulses/second must be set under “Menu”, “Settings”, “Gate time”. We recommend setting a gate time of approximately 10 seconds in order to avoid statistical deviations.
- Note down the counting rate at a counter tube voltage between 300 and 600 V in steps of 10 V. At the point of inflection, use smaller steps (1 V).

Procedure (2/3)

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Computer-assisted procedure

- Connect the X-ray unit via USB cable to the USB port of your computer (the correct port of the X-ray unit is marked in Fig. 3).
- You can control the X-ray unit by clicking the various features on and under the virtual X-ray unit. Alternatively, you can also change the parameters at the real X-ray unit. The program will automatically adopt the settings. If you click the display of the virtual X-ray unit (see the red marking in Figure 4), you can change the parameters of the experiments (Fig. 5). Click the X-ray tube in order to change the voltage and current of the X-ray tube. Select the settings as shown in Figure 6.
- Note down the counting rate at a counter tube voltage between 300 and 600 V in steps of 10 V. At the point of inflection, use smaller steps (1 V).

Fig. 3: Connection of the computer

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Procedure (3/3)

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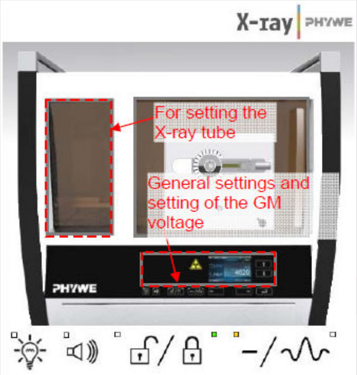

Fig. 4: Part of the user interface of the software

Fig. 5: GM voltage settings

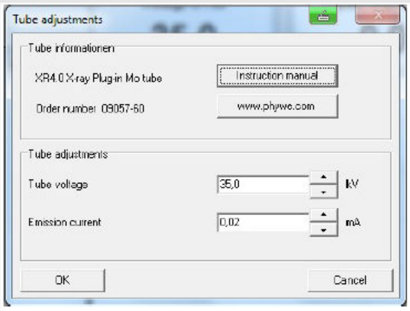

Fig. 6: Voltage and current settings

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Evaluation

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Task 1

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GM voltage/V	Pulses/s
300	0
325	0
330	0
331	0
332	0
333	25
334	911
335	1174
336	1174
337	1152
338	1154
350	1150
400	1147
450	1151
500	1150
550	1148
600	1150

Table 1: Values

The position of the plateau varies from counter tube to counter tube.

The following result is an example and, therefore, the actual measurement values may be different.

The measured values are shown in Table 1 and the result is represented in graphical form in Figure 7. It is not until a voltage of 336 V that the pulses reach the anode. This is followed by the plateau. Since anything in excess of the plateau voltage would damage the counter tube, it is not intended (and also not possible) to apply a voltage > 600 V.

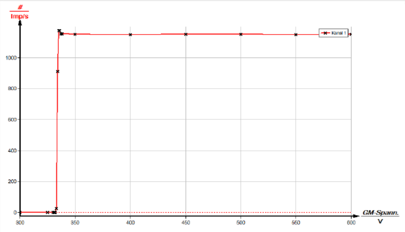

Fig. 7: Pulse rate as a function of the counter tube voltage

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