

## Detecting x-rays using an ionization chamber

### Objects of the experiment

- To detect x-radiation using an air-filled ionization chamber and measuring the ionization current  $I_C$ .
- To investigate the relationship between the ionization current  $I_C$  and the capacitor voltage  $U_C$  and verifying the saturation characteristic
- To investigate the relationship between the saturation ionization current and the emission current  $I$  of the x-ray tube at a constant tube high voltage  $U$ .
- To investigate the relationship between the saturation ionization current and the tube high voltage  $U$  at a constant emission current  $I$ .

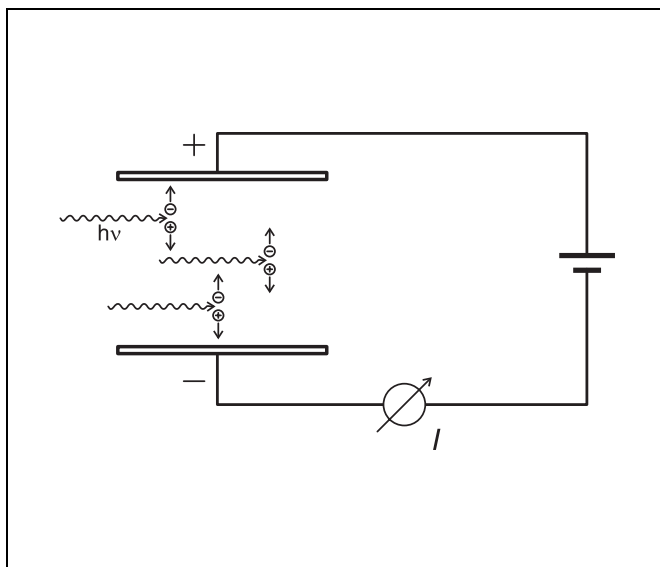
### Principles

X-radiation is detectable on account of its physical effects. For example, x-rays fog film stock and cause air and other gases to become electrically conductive, the photoeffect is observed at the surfaces of metals, and some fluorescent substances show luminescence. All these phenomena are caused by ionization of atoms or molecules of the transilluminated matter.

In the quantitative detection of x-rays, we can exploit this ionizing effect, e.g. by measuring the ionization current in a plate capacitor filled with air or another gas. Due the way it is designed and built, this type of arrangement is called an ionization chamber.

In the detection of x-rays, an x-ray beam passes through a diaphragm and strikes a plate capacitor in such a way that it does not directly fall on the plates. This prevents falsification of the measurement results due to the photoeffect at the capacitor plates. The x-rays ionize a part of the gas volume in the capacitor. When we apply a voltage  $U_C$  to the capacitor, the charge carriers, electrons or ions, are collected at the capacitor plates. The current generated at the capacitor in this way corresponds to an ionization current  $I_C$  in the outer circuit that can be measured using a measuring amplifier.

At low voltages  $U_C$ , fewer and fewer charge carriers recombine in the gas volume as  $U_C$  increases, and more and more charge carriers are collected at the capacitor plates. Thus, the ionization current  $I_C$  increases with the voltage  $U_C$ . When  $U_C$  is increased beyond a certain point,  $I_C$  ultimately reaches a saturation value, as all charge carriers formed by the incident radiation per unit of time are captured (except for negligible recombination losses). This saturation value is an indicator for the intensity of the incident x-radiation.



**Apparatus**

1 X-ray apparatus . . . . .	554 811
or	
1 X-ray apparatus . . . . .	554 812
1 Plate capacitor x-ray . . . . .	554 840
1 Power supply 450 V DC . . . . .	522 27
1 Electrometer amplifier . . . . .	532 14
1 STE resistor 1 G $\Omega$ , 0.5 W, . . . . .	577 02
1 Voltmeter, $U \leq 300$ V DC, input resistance $\geq 10$ M $\Omega$ . . . . . e.g.	531 100
1 Voltmeter, $U \leq 10$ V DC . . . . . e.g.	531 100
1 Screened cable BNC/4 mm . . . . .	575 24
Connecting leads	

- Lift the plate capacitor into the experiment chamber of the x-ray apparatus and insert the mounting plugs in the mounting sockets. Check to make sure that the capacitor plates are aligned parallel to the base plate of the x-ray apparatus, and correct as necessary.
- Feed the two cables into the free channel until they reappear on the right side of the x-ray apparatus

**Electrical assembly:**

- Connect the connecting lead to the positive pole of the 450 V DC power supply and connect the adapter cable BNC/4 mm to the electrometer amplifier fitted with the 1 G $\Omega$  resistor.
- Ground the electrometer amplifier to the negative terminal of the 450 V DC amplifier.
- Use one voltmeter each to measure the capacitor voltage  $U_C$  and the output voltage of the electrometer amplifier  $U_E$ .
- Plug in the x-ray apparatus to the mains power and switch it on.

**Setup**

Set up the experiment as shown in Fig. 1. Fig. 2 shows the electrical connections of the plate capacitor and the electrometer amplifier for determining the ionization current.

**Mechanical setup:**

- If necessary, demount the collimator of the x-ray apparatus and remove any experiment equipment from the chamber of the x-ray apparatus.
- Connect the adapter cable BNC/4 mm to the bottom capacitor plate (BNC socket) with the BNC plug and connect the connecting lead to the top capacitor plate (safety socket) of the plate capacitor x-ray.

**Safety notes**

The x-ray apparatus fulfills all regulations governing an x-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807/97 Rö).

The built-in protection and screening measures reduce the local dose rate outside of the x-ray apparatus to less than 1  $\mu$ Sv/h, a value which is on the order of magnitude of the natural background radiation.

- Before putting the x-ray apparatus into operation inspect it for damage and to make sure that the high voltage is shut off when the sliding doors are opened (see Instruction Sheet for x-ray apparatus).
- Keep the x-ray apparatus secure from access by unauthorized persons.

Do not allow the anode of the x-ray tube Mo to overheat.

- When switching on the x-ray apparatus, check to make sure that the ventilator in the tube chamber is turning.

**Carrying out the experiment****a) Ionization current  $I_C$  as a function of the capacitor voltage  $U_C$ :**

- Set the emission current  $I = 1.0$  mA.
- Set the tube high voltage  $U = 15$  kV and switch on the high voltage using the key HV on/off.
- To record a measurement series, increase the capacitor voltage  $U_C$  in steps from 0 V to 300 V and determine the ionization current  $I_C$  for each step from the voltage  $U_E$  at the output of the electrometer amplifier:

$$I_C = \frac{U_E}{1 \text{ G}\Omega}$$

- Write down your measurement results.
- Increase the tube high voltage  $U$  in steps from 5 kV to 35 kV, repeat the measurement series for each step and write down your measuring results (see table 1).

**b) Saturation ionization current  $I_C$  as a function of the emission current  $I$ :**

- Set the tube high voltage to  $U = 35$  kV.
- Set the capacitor voltage  $U_C \geq 140$  V, so that the saturation value of the ionization current  $I_C$  is reached (cf. measured values for a)).
- Increase the emission current  $I$  in steps from 0 mA to 1 mA and determine the corresponding ionization current  $I_C$ .
- Write down your measurement results.

**c) Saturation ionization current  $I_C$  as a function of the tube high voltage  $U$ :**

- Set the emission current  $I = 1.0$  mA.
- Set the capacitor voltage  $U_C \geq 140$  V.
- Increase the tube high voltage  $U$  in steps from 5 kV to 35 kV and determine the corresponding ionization current  $I_C$ .
- Write down your measurement results.

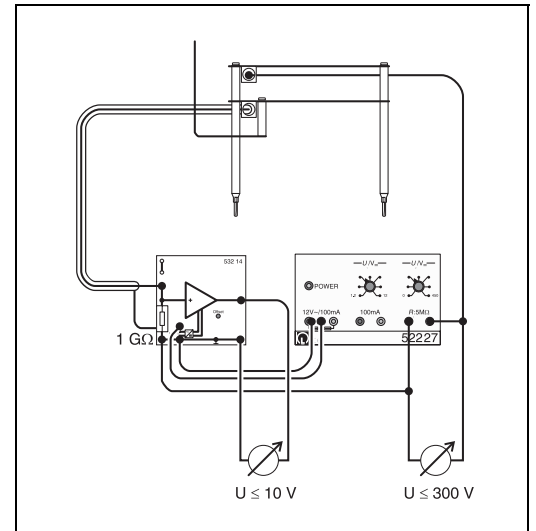
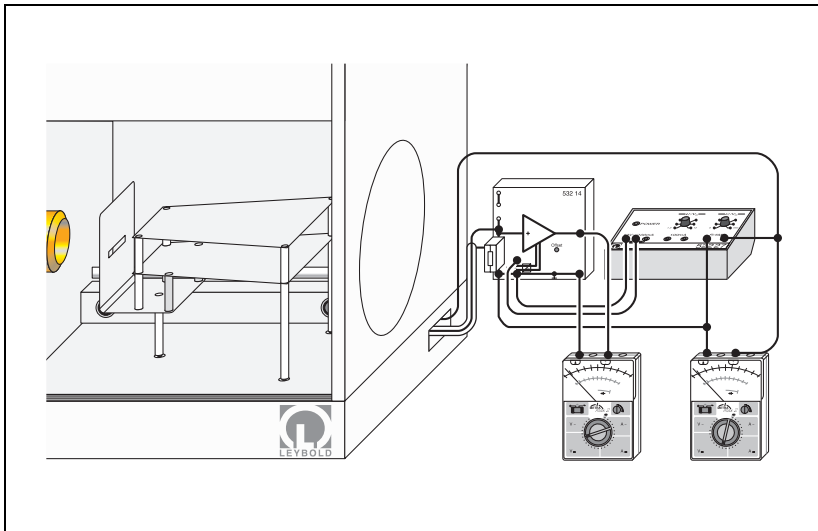


Fig. 1 Experiment setup for measuring the ionization current in a plate capacitor

Fig. 2 Connecting the plate capacitor and the electrometer amplifier for determining the ionization current

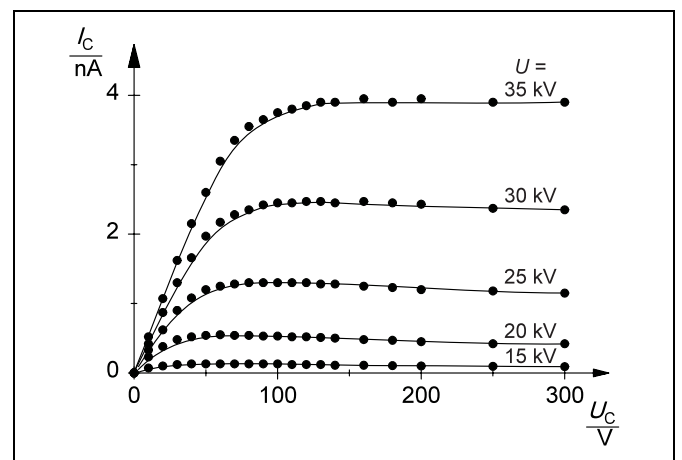
**Measuring example**

a) Ionization current  $I_C$  as a function of the capacitor voltage  $U_C$ :

Tab. 1: Ionization current  $I_C$  as a function of the capacitor voltage  $U_C$ , tube high voltages  $U_1 = 15$  kV,  $U_2 = 20$  kV,  $U_3 = 25$  kV,  $U_4 = 30$  kV and  $U_5 = 35$  kV, emission current  $I = 1.0$  mA

$U_C$ V	$I_C(U_1)$ nA	$I_C(U_2)$ nA	$I_C(U_3)$ nA	$I_C(U_4)$ nA	$I_C(U_5)$ nA
0	0.00	0.00	0.00	0.00	0.00
10	0.07	0.23	0.33	0.42	0.52
20	0.10	0.38	0.62	0.87	1.07
30	0.12	0.48	0.90	1.30	1.62
40	0.13	0.52	1.08	1.66	2.15
50	0.13	0.54	1.20	1.97	2.60
60	0.13	0.55	1.25	2.17	3.05
70	0.13	0.54	1.28	2.28	3.35
80	0.13	0.54	1.30	2.35	3.55
90	0.13	0.53	1.30	2.42	3.65
100	0.13	0.53	1.30	2.45	3.75
110	0.12	0.52	1.30	2.45	3.80
120	0.12	0.52	1.30	2.47	3.85
130	0.12	0.51	1.28	2.47	3.90
140	0.11	0.50	1.28	2.45	3.90
160	0.11	0.48	1.25	2.47	3.95
180	0.11	0.47	1.23	2.45	3.90
200	0.10	0.45	1.20	2.43	3.95
250	0.095	0.42	1.18	2.37	3.90
300	0.090	0.42	1.15	2.35	3.90

Fig. 3 Ionization current  $I_C$  as a function of the capacitor voltage  $U_C$



**b) Saturation ionization current  $I_C$  as a function of the emission current  $I$ :**

Tab. 2: Saturation value of ionization current  $I_C$  as a function of the emission current  $I$  of the x-ray tube, tube high voltage  $U = 35$  kV

$\frac{I}{\text{mA}}$	$\frac{I_C}{\text{nA}}$	$\frac{I}{\text{mA}}$	$\frac{I_C}{\text{nA}}$
0.0	0.02	0.5	2.10
0.1	0.48	0.6	2.45
0.2	0.92	0.7	2.80
0.3	1.30	0.8	3.20
0.4	1.72	0.9	3.55
		1.0	3.90

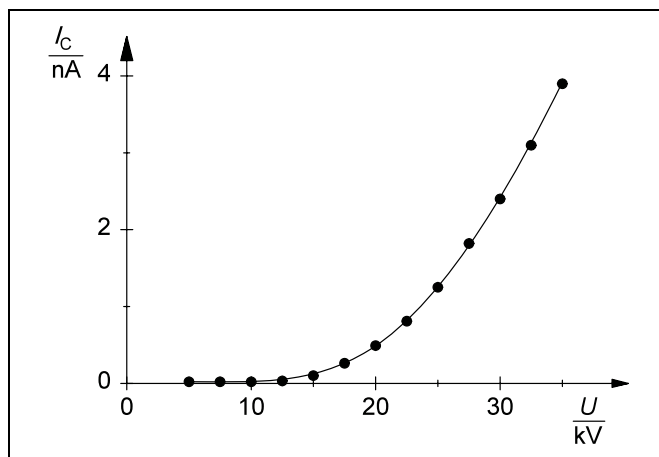


Fig. 5 Saturation value of ionization current  $I_C$  as a function of the tube high voltage  $U$

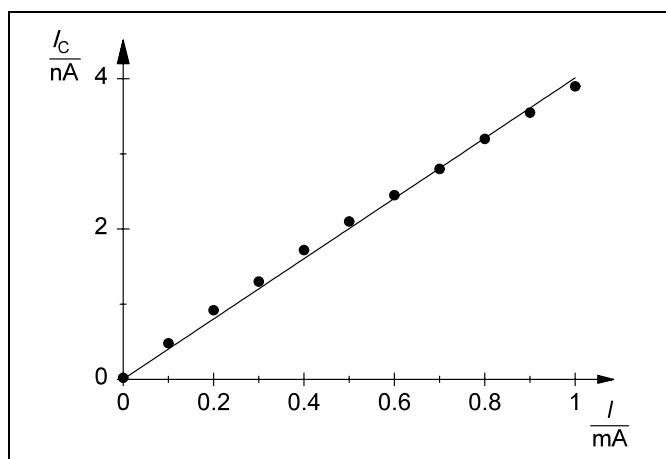


Fig. 4 Saturation value of ionization current  $I_C$  as a function of the emission current  $I$  of the x-ray tube

**c) Saturation ionization current  $I_C$  as a function of the tube high voltage  $U$ :**

Tab. 3: Saturation value of ionization current  $I_C$  as a function of the tube high voltage  $U$ , emission current  $I = 1.0$  mA

$\frac{U}{\text{kV}}$	$\frac{I_C}{\text{nA}}$	$\frac{U}{\text{kV}}$	$\frac{I_C}{\text{nA}}$
5.0	0.02	20.0	0.49
7.5	0.02	22.5	0.81
10.0	0.02	25.0	1.25
12.5	0.03	27.5	1.82
15.0	0.10	30.0	2.40
17.5	0.26	32.5	3.10
		35.0	3.90

**Evaluation**

**a) Ionization current  $I_C$  as a function of the capacitor voltage  $U_C$ :**

At a constant tube high voltage  $U$  and constant emission current  $I$ , the ionization current  $I_C$  initially increases proportionally with the capacitor voltage  $U_C$  (see Fig. 3). It subsequently increases less and less as  $U_C$  rises and ultimately reaches a saturation value (plateau). The saturation value is higher, the greater the tube high voltage  $U$  is. The capacitor voltage  $U_C$  at which the saturation value is reached also increases with  $U$ .

**b) Saturation ionization current  $I_C$  as a function of the emission current  $I$ :**

At a constant tube high voltage  $U$ , the saturation value of the ionization current  $I_C$  is in close approximation proportional to the emission current  $I$  (see Fig. 4) and thus to the intensity of the incident x-radiation.

**c) Saturation ionization current  $I_C$  as a function of the tube high voltage  $U$ :**

The ionization current  $I_C$  increases disproportionately with the tube high voltage  $U$ , as more and more energy quanta are available to ionize the air in the plate capacitor (see experiment P6.3.3.2).

**Results**

The ionization current of an ionization chamber shows a saturation characteristic. The saturation value of the ionization current can be used to quantify the ionizing effect, and thus the intensity of the x-radiation.

At a constant high voltage of the x-ray tube, the saturation value of the ionization current is proportional to the intensity of the x-radiation. The saturation value of the ionization current increases disproportionately with the tube high voltage.