Ion chambers and flux measurements

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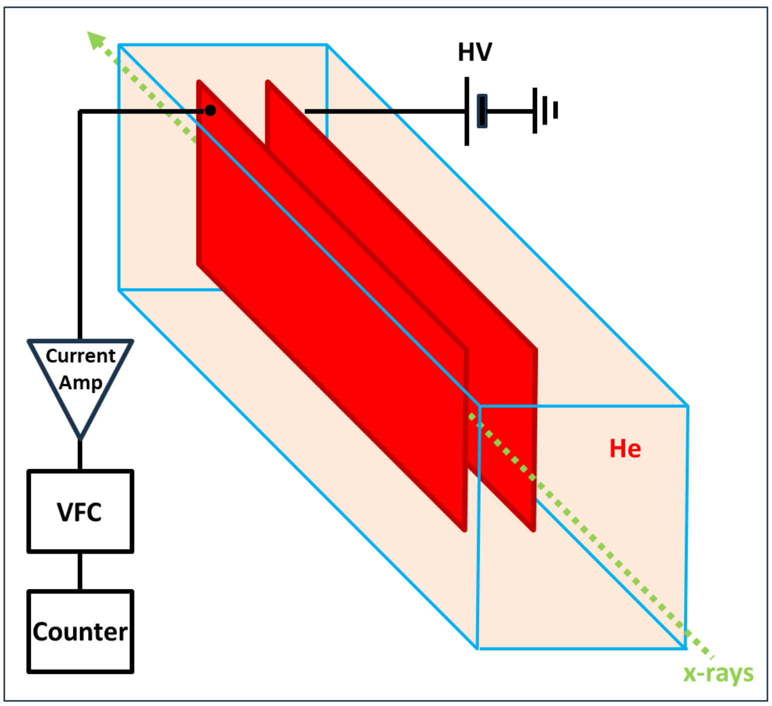
Schematic, Measured Current

Below is a coarse schematic of the ion chamber. When x-rays travel between the two electrodes a small fraction are absorbed, ionizing the counting gas (He) and resulting in e-/H+ pairs. Driven by the external high voltage (HV) a small current is generated between the electrodes which is measured by a current amplifier at a gain G and converted to a proportional voltage. The voltage is then converted to a frequency by a voltage-to-frequency converter (VFC) and sent to a counter. The measured current is given by

$$\mathrm{i0} = \frac{\mathrm{N_{abs}} \times \mathrm{G}}{\mathrm{VFC}}$$

where N_{abs} is the number of photons incident into the ion chamber.



Conversion of Measured Current to Absorbed Photons

Calculate photons absorbed, N_{abs}, by ion chamber electrodes

Converting the measured current i0 to photons absorbed by the electrodes requires knowing how many e-/H+ pairs are created by one x-ray photon of energy E_o. This number is given by

$$\mathrm{n_e} = \frac{\mathrm{E_o}}{\mathrm{W}}$$

where W is the “Energy Dissipation per Ion Pair”. Values for W for various gases can be found in ref. 1. For He, W = 41.3 eV.

The ion chamber current, i0, is composed of (i0/e) electrons (e = elementary electronic charge). Thus, the number of absorbed photons is

$$N_{abs} = \frac{i0/e}{n_e}$$

Conversion to Transmitted Photons, N_{trans}

If the fraction, f, of absorbed photon is known, the number of transmitted photons N_{trans} can be determined.

With

$$N_{total} = N_{trans} + N_{abs}$$
$$N_{abs} = fN_{total}$$

it follows that

$$N_{trans} = \frac{1-f}{f} N_{abs}$$

f can be calculated from absorption data (NIST) and the length of the ion chamber. More conveniently, there are various absorption calculators available such as the one in Ref 2.

General / 27-ID Specifics

e = 1.60217653 10^{-19} C
Current Amplifier Gain: G= 70 nA/V (typical for i0, but not for i2)
Voltage-to-Frequency Conversion: VFC = 100,000 Hz/V
Length of the i0 Ion Chamber: 100 mm

Sample Calculation

E_o = 8.0 keV
N = 100,000 Hz

$$i0 = \frac{N \times G}{VFC} = \frac{1e6\ Hz \times 70nA/V}{1e6\ Hz/V} = 70nA = 70 \times 10^{-9}A$$

and

$$n_e = \frac{E_o}{W} = \frac{8.0\ keV}{41.3 \times 10^{-3}\ keV} = 193.7$$

That is, one 8 keV photon creates 193.7 electrons.

$$N_{abs} = \frac{i0/e}{n_e} = \frac{70 \times 10^{-9}A/1.60217653 \times 10^{-19}C}{193.7} = 2.255 \times 10^{9}Hz$$

Using He at 1 atm (760 Torr), f = 3.3x10^{-4} (from ref. 2). Thus

$$N_{trans} = \frac{1-f}{f} N_{abs} = \frac{1-3.3 \times 10^{-4}}{3.3 \times 10^{-4}} 2.255 \times 10^{9}Hz = 6.8 \times 10^{12}Hz$$

Note that

The weak point of this scheme is the fraction f. A small fluctuation in f will cause a big change in N_{trans}. That's why the ion chamber yields at best an estimation of photon flux. To do better a photon-counting detector would need to be used, but that can only be done at lower fluxes.

Reference

ref. 1: Glenn F. Knoll: “Radiation Detection and Measurement” John Wiley & Sons, Inc, pg. 129 ff
ref. 2: https://henke.lbl.gov/optical_constants/gastrn2.html
ref. 3: https : // web - docs . gsi . de/~stoe_exp/web_programs/x_ray _absorption/index . php