Laboratory exercise in FYSKJM4710 –
Low- to intermediate energy X-ray physics

Equipment: 1 Pantak HF225 X-ray generator
1 Wellhöfer FC65G ion chamber
1 Standard imaging MAX4000 electrometer
Various filters of copper and aluminum, holders

V = X-ray voltage, I = X-ray current

a) Position the ion chamber so that it's sensitive volume is placed below the center of X-ray beam, and connect the chamber to electrometer. Place a 1.5 mm aluminum filter in the filter holder. Use an X-ray beam of V=60 kV, I=5 mA. What is the ion rate (number of charges per second) shown on the electrometer? Move the chamber closer and closer towards the X-ray tube (turn off the X-ray beam in between!); in total 6-7 steps over at least 20 cm. Plot the data. How does the radiation intensity change with the distance from the source – is the decrease linear or quadratic?

b) Move the chamber back to the original position. Note the ion rate. Increase systematically the current from 5 mA to 10 mA (keep the voltage constant), and note the rate at each mA. Plot the data. Give a comment – is the result as expected?

c) Turn the current back to 5 mA. Increase the voltage from 60 kV to 200 kV (keep the current constant), and note the ion rate for each 20 kV step. Plot the data. Give a comment on the result. Use the Kramer's spectrum to explain the findings - how does the area below the X-ray spectrum increase with the voltage, what is the effect of the aluminum filter and how does the mass energy absorption coefficient in air (tabulated below) depend on photon energy?

d) Define the half-value layer, HVL, for an X-ray beam. By assuming exponential photon attenuation, how is HVL related to the attenuation coefficient μ? Use V=100 kV, I= 5 mA and a 1.5 mm aluminum primary filter. Keep the ion chamber at least 40 cm from the filter. Measure the rate without extra filters. Place 1 mm of additional aluminum. Measure the ion rate. Systematically increase the thickness of aluminum until the ion rate is reduced by at least 50 %. Make at least four measurements, e.g. ~1, 2, 4 and 6 mm. Plot the ion rate as a function of the thickness of extra aluminum (do not include the primary filter of 1.5 mm Al !). Find the HVL in aluminum. Repeat the measurements for a 220 kV beam (I=5 mA), with 1.5 mm aluminum and 0.5 mm copper as primary filters, but this time with copper as additional filter material. Perform 4-5 measurements with additional thickness of copper. Plot the logarithm of the ion rate as a function of the thickness of extra aluminum or copper. Can the data be fitted to a straight line? If not, how does the data deviate from a linear relation? Explain. Furthermore, estimate the HVLs. Use the tabulated values of photon attenuation coefficients in aluminum and copper to find the equivalent photon energy from the measured HVLs.

e) The dose to air measured by the chamber is approximately defined as Dair ≈ $M \cdot N_{D,air}$, where $N_{D,air}$ is the calibration factor and M is the electrometer readout. $N_{D,air}$ of the chamber is 43.4 mGy/nC. What is the absorbed dose rate of the 100 kV-beam (5 mA, 1.5 mm aluminum) and of the 220 kV-radiation (5 mA, 1.5 mm aluminum and 0.5 mm copper)? (use the measurements in d). Discuss shortly the difference in absorbed dose rate from what you know about the changes in the radiation spectrum with kV and filtration.

Energy (keV)	*Aluminum* μ/ρ, *cm*^{2}*/g*	*Copper* μ/ρ, *cm*^{2}*/g*
1.00E+1	2.605E+1	2.141E+2
2.00E+1	3.423E+0	3.359E+1
3.00E+1	1.131E+0	1.090E+1
4.00E+1	5.675E-1	4.854E+0
5.00E+1	3.684E-1	2.619E+0
6.00E+1	2.778E-1	1.593E+0
7.00E+1	2.302E-1	1.063E+0
8.00E+1	2.018E-1	7.631E-1
9.00E+1	1.832E-1	5.796E-1
1.00E+2	1.705E-1	4.604E-1
1.10E+2	1.607E-1	3.782E-1
1.20E+2	1.533E-1	3.216E-1
1.30E+2	1.472E-1	2.789E-1
1.40E+2	1.421E-1	2.467E-1
1.50E+2	1.378E-1	2.226E-1
1.60E+2	1.339E-1	2.032E-1
1.70E+2	1.306E-1	1.882E-1
1.80E+2	1.275E-1	1.751E-1
1.90E+2	1.246E-1	1.653E-1
2.00E+2	1.219E-1	1.560E-1
2.10E+2	1.196E-1	1.489E-1
2.20E+2	1.174E-1	1.424E-1