

Radiophysics Lab

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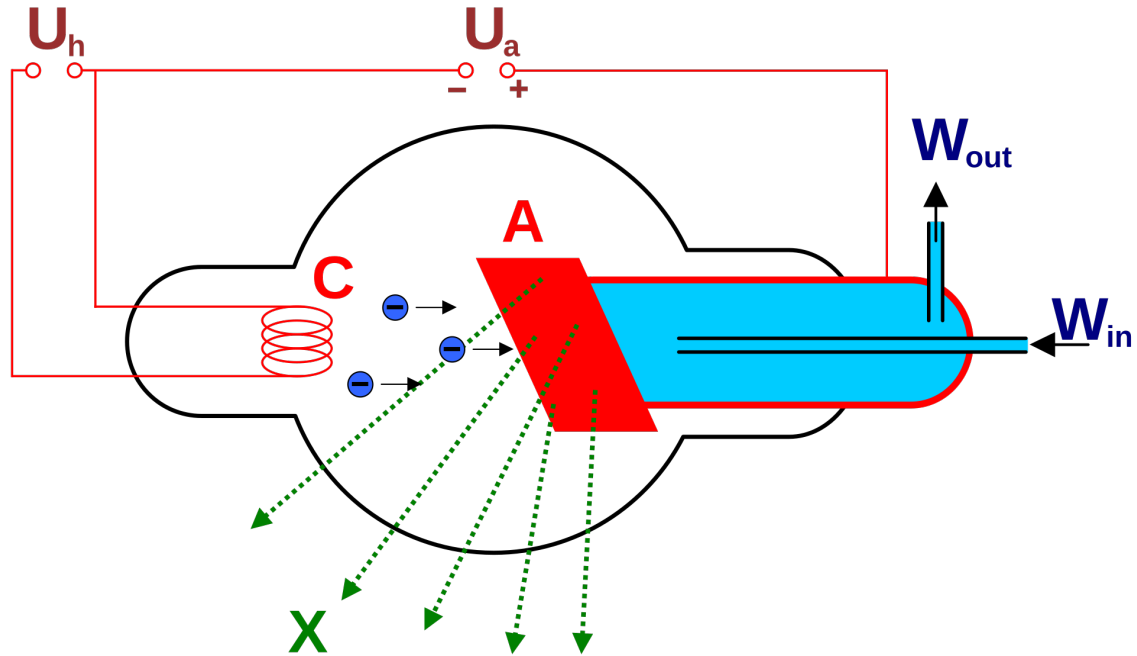
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In this Laboratory course we will learn how to work with basic radioactive sources, and how to measure and interpret data that comes about in the experiments. We will

1 X-Ray Tube



This is a sketch of a water-cooled X-Ray tube taken from Wikipedia. C is the Cathode and A is the Anode. The water cooling system won't be mentioned as it is not important in general.

We have a Potential U_h which goes through the Cathode, heating it in the process. This process emits electrons through thermionic emission. The electrons are accelerated toward the Anode via the potential U_a , such that the Anode is positively charged, attracting the electrons. The Anode is made of metal, in our case tungsten. The electrons knock out on-shell-electrons of the tungsten atoms, which leads to higher energy electrons falling into the holes left behind, producing X-Rays. Some electrons are also slowed by the Nucleuses themselves, producing Bremsstrahlung.

2 Preparatory measurements

We will be making measurements of the X-Rays liberated electrons over time, to see how an increased or decreased time affects the amount of liberated electrons. We will be measuring over 15, 30 and 45 seconds. We will keep the Area that we measure over, and the Intensity with which the electrons arrive at our area of measurement equal. We then expect a relation of

$$Q = \int dt \int dA I(r_0) = t A I(r_0), \quad Q \propto t \quad (1)$$

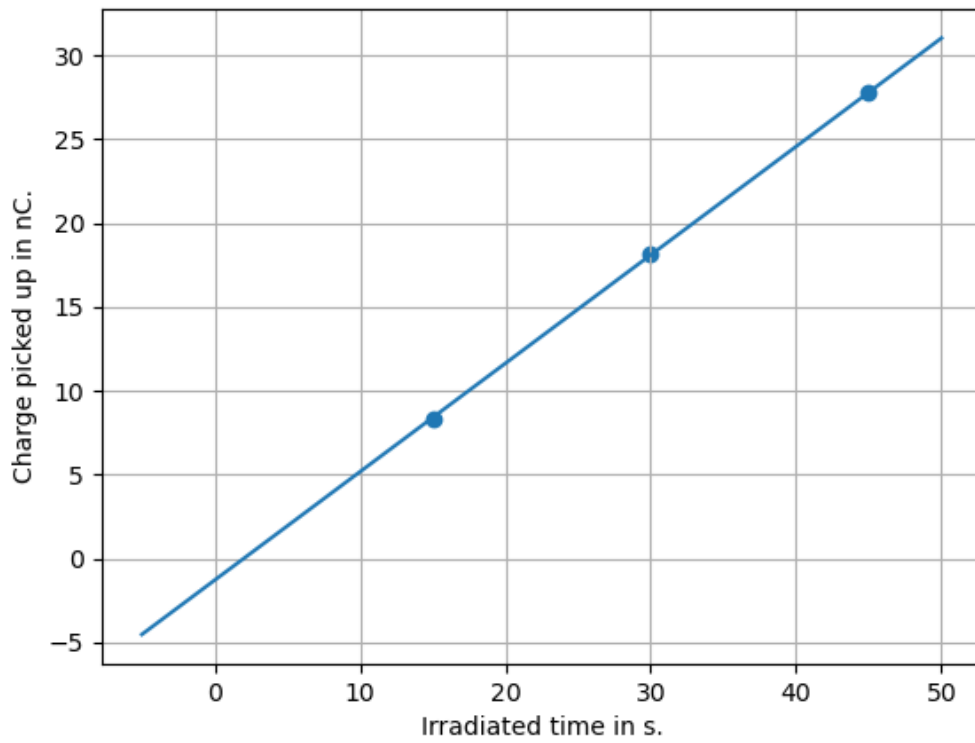
Measurement are made with 1.52mm aluminium filter. The tray is 30cm away from the source. The X-Ray tube shall be set to 120 kV and 10 mA. Measurements are in nC.

	15s	30s	45s
Measurements	8.25	18.27	28.06
	8.3	17.89	27.72
	8.44	18.14	27.97
	8.31	18.04	27.51
	8.52	18.68	27.55
Average	8.364	18.204	27.762
Average of Squared	69.966	331.458	770.778
Standard Deviation	0.097	0.269	0.222

with the average and standard deviation:

$$\langle \mu \rangle = \frac{\sum_i^n x_i}{n}, \quad \sigma = \sqrt{\langle \mu^2 \rangle - \langle \mu \rangle^2} \quad (2)$$

In relation to the Average, the Standard deviation goes down with increasing time, signifying a more accurate measurement. We also notice that there is a linear increase with time. This linear increase signifies the charge that is picked up. We can read off a slope of $0.64nC/s$.



Such that we know that the Radiator sends off $0.64nC$ of charge every second. It is notable that despite being a perfect linear fit, the fit does not coincide with $f(t) = 0$. This means that there is a loss of Charge in the first 10 seconds which is constant for all measured times. This can be

explained by a short ramp up time that the X-Ray needs to go through first before operating at the desired Voltage and Amperage.

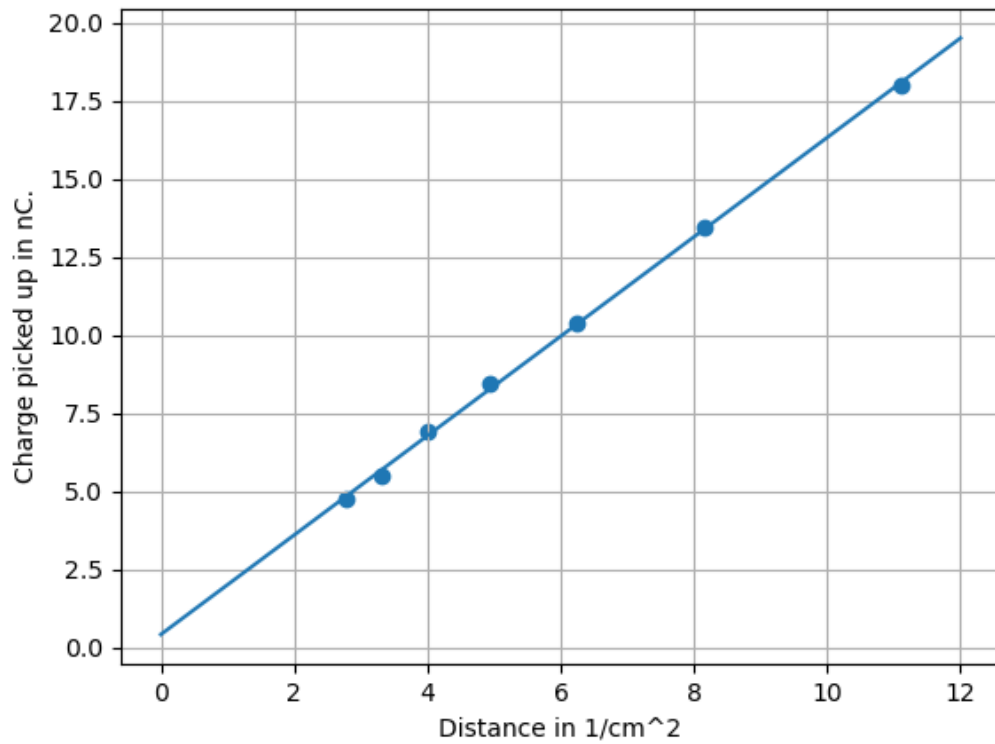
3 Inverse square law

Measuring the charge that is registered by a surface at different distances away from the source we can gather information about the relationship between Intensity of a field and distance away from the source. We assume that our findings will line up with the Inverse square law, so that $I(r) = I_0 \frac{1}{r^2}$, where r is the distance away from the center. This comes from the fact that we are measuring an Electromagnetic Wave, which is governed by $E = \frac{1}{4\pi\epsilon} \frac{Q}{r^2}$.

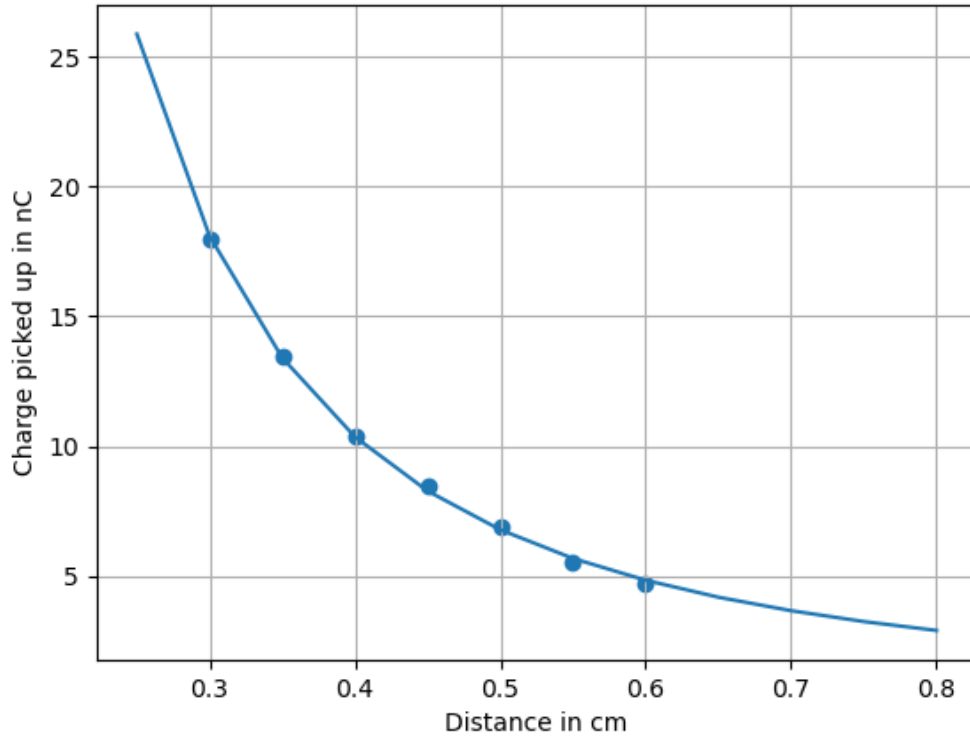
We will measure for 30s with the previous filter of 1.52mm, we will start at 30cm and end at 60cm in 5cm intervals. We use the previous measurement for 30cm.

Distance [cm]	Charge [-nC]
30	18.00
35	13.48
40	10.36
45	8.44
50	6.91
55	5.52
60	4.74

Plotting the Charge against the inverse square of the distance should give a linear plot.



So it is clear that despite small deviations stemming from measurement Errors, the inverse square law is obeyed. I also plotted the datapoints against an inverse square function, and they line up.



This shows that, as we had previously expected, that X-Rays obey the inverse square law.

4 Exponential photon attenuation

The Photon attenuation law is a law that concerns the resulting intensity when photons travel through a Medium. Mathematically we state this as

$$N_x = N_0 \exp(-\mu x) \quad (3)$$

where N_x is the amount of photons after interacting with the medium, and N_0 is the incoming amount of photons. μ is the linear attenuation coefficient, and represents how much Intensity is lost through the medium per distance, it has units $1/m$. x is the distance that the photons travel through.

We can reduce this equation to a linear equation in x , so that we can determine the coefficient μ by using the relation

$$\ln(N_x/N_0) = -\mu \cdot x \quad (4)$$

So, we will use the logarithm of Intensity that is left and graph it against the length of the medium through which it travelled. The resulting linear fit will give us a coefficient $y = mx$ with $m = \mu$.

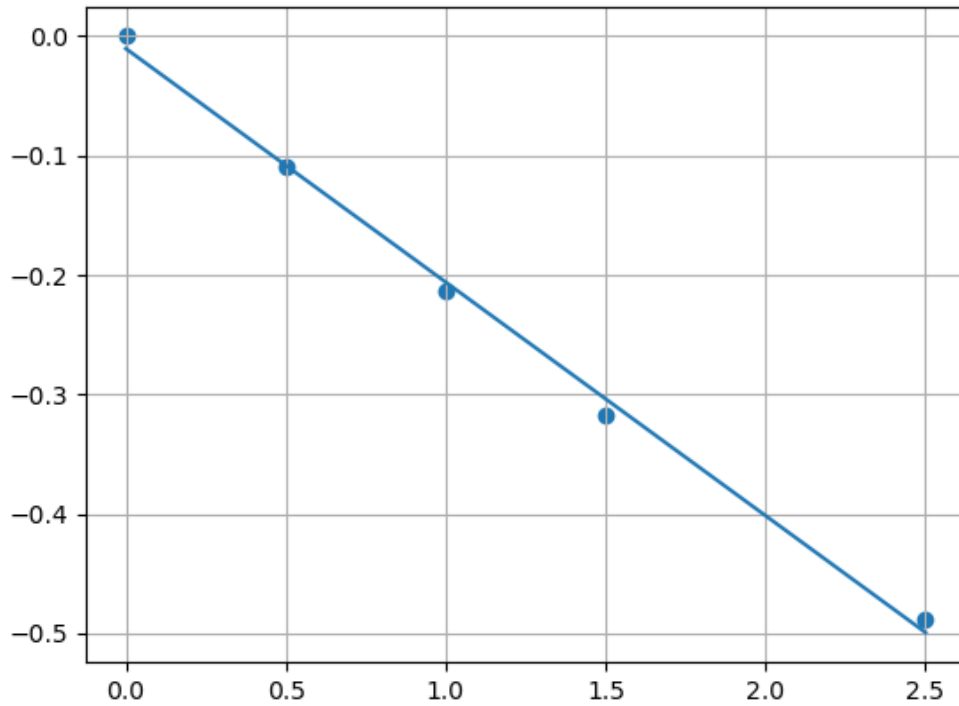
We will pick N_0 such that the first measurement of $N_x = N_0$. This will result in a linear fit where we can ignore the coefficient b in

$$\ln(N_x/N_0) = -\mu \cdot x + b \quad (5)$$

We will put the measuring device at 30cm

Material Width [mm]	Charge [-nC]
1.52	18.00
2.02	16.14
2.52	14.54
3.02	13.11
4.02	11.05

Performing a linear fit gives us the plot:



Which gives us an Attenuation Coefficient of $\mu = 0.195$.

5 Ionizations and radiation dose

We define the Radiation dose.

$$D = \frac{Q}{m} \left(\frac{W}{e} \right) = \frac{Q}{m} \cdot 34J/C \quad (6)$$

We use the Ideal gas law to calculate the mass of the Air inside the chamber.

$$pV = nRT, \quad \frac{pV}{RT} = n, \quad (7)$$

$$\frac{pV}{RT} m_{Air,mol} = m \quad (8)$$

Where we have $V = 0.65cm^3$ and $m_{Air,mol} = 28.97g/mol$. Inserting the usual Temperature and Pressure, $p = 101325Pa$ and $T = 298K$ we can calculate the mass

$$\frac{101325Pa \cdot 0.00000065m^3}{8.314J/(molK) \cdot 298K} \cdot 28.97g/mol = 0.00077g \quad (9)$$

and we have $1.6 \cdot 10^{19}$ Air molecules in the chamber. We can now calculate the radiation dose after 45 seconds of Radiation, taking the measurement of $27.7nC$ from the previous experiment.

$$\frac{27.7nC}{0.00077g} 34J/C = 1.22Sv \quad (10)$$

We will calculate the ratio of ionized molecules after an exposure of 45s. We assume that every molecule can only lose one electron, and therefore we must calculate how many electrons have a charge of $27.7nC$.

$$\frac{27.7nC}{e} = \frac{27.7nC}{1.6022 \cdot 10^{-19}nC} = 1.72 \cdot 10^{11} \quad (11)$$

We can see just from the order of magnitudes of the numbers, that the ionized molecule are a very small percentage of the total molecules. We calculate:

$$\frac{1.72 \cdot 10^{11}}{1.6 \cdot 10^{19}} = 1.075 \cdot 10^{-8} \approx 0.000001\% \quad (12)$$

So about 0.000001% of Air molecules were Ionized in those 45 seconds.

6 Conclusion

We have learned different things about X-Rays. Firstly we learned that the Energy they give off is constant if we do not change the Voltage and Amperage of the X-Ray tube. We learned that they behave as Electromagnetic waves would, following the inverse square law. We also learned that Radiation passes through material but gets weaker depending on the material, and with the thickness of the material. At last we have learned that Despite a large radiation dose (In our case $1.22Sv$) only a tiny percentage of air molecules are actually ionized in the end.