Investigating the Inverse Square Law

Task:

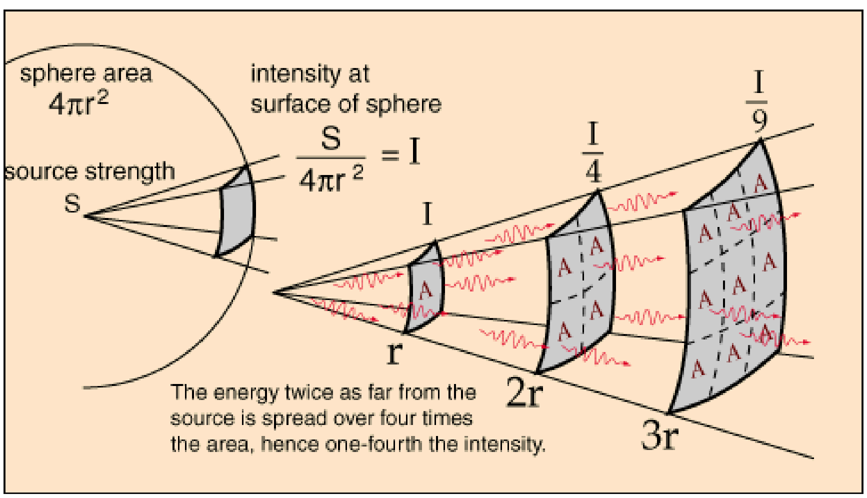
Do gamma rays from a point source obey the inverse square law?

Planning:

Sources used in research of the above task are:

- ‘Advanced Level Practical Physics’ – M Nelkon & JM Ogborn, pages 212 – 218
- ‘Essential Pre-University Physics’ – Whelan & Hodgson, page 406 + 953
- ‘Essential Principles of Physics’ – Whelan & Hodgson, pages 470 + 472
- ‘A Laboratory Manual of Physics’ – F. Tyler, page 269
- http://hyperphysics.phy-astr.gsu.edu/Hbase/forces/isq.html
- http://en.wikipedia.org/wiki/Background_radiation
- http://en.wikipedia.org/wiki/Cobalt
- http://www.imagesco.com/articles/geiger/03.html
- http://en.wikipedia.org/wiki/Geiger-M%C3%BCller_tube
- http://en.wikipedia.org/wiki/Breakdown_voltage

The Inverse Square Law states that the intensity of γ-radiation diminishes as the distance from the source increases.

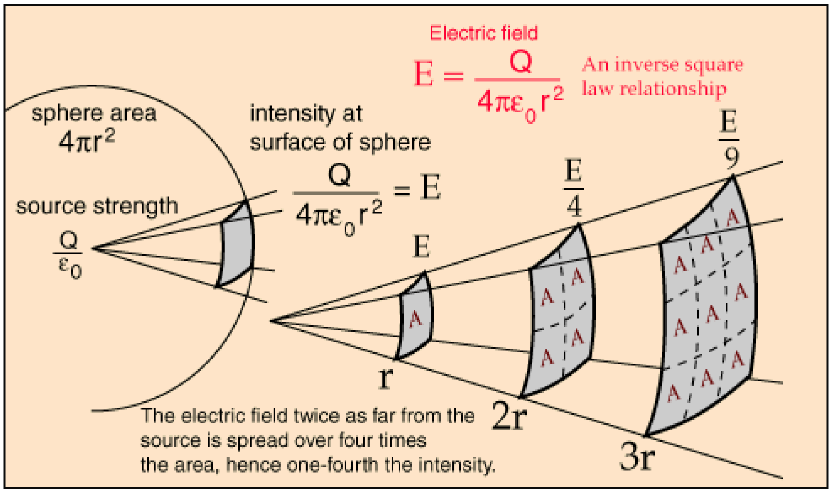


Source: http://hyperphysics.phy-astr.gsu.edu/hbase/forces/isq.html

‘The intensity of the influence at any given radius, r, is the source strength divided by the area of the sphere.’ [1]

The inverse square law can also be applied to gravity, electric fields, light and sound. In relation to electric fields, the electric force in Coulomb’s law follows the inverse square law:

[1] http://hyperphysics.phy-astr.gsu.edu/Hbase/forces/isq.html

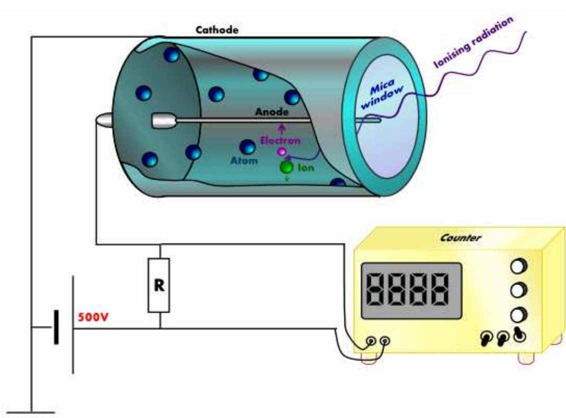


'γ-rays are [illegible] electromagnetic radiation and, [illegible] neglecting the absorption in air, the intensity, I, should vary inversely as the square of the distance between the source and the detector.' [2]

Air acts as an almost transparent medium to γ-rays, and the intensity (rate of energy arrival per unit area) of γ-rays emanating from a point source varies inversely as the square of the distance from the source. [3]

γ-rays fall into many distinct monoenergetic groups because of their variable energies which emanate from any particular emitter. The least energetic radiation will only pass through very thin foils, whereas the most energetic can penetrate up to several centimetres of lead. [4] As γ-rays tend to produce 10^{-4} times as many ion-pairs per unit length as α-particles do, measurements are usually carried out using a Geiger-Müller (G-M) tube.[5]

G-M tubes are widely used for detecting radiation and ionising particles.



[2] Essential Pre-University Physics' – Whelan & Hodgson, page 953
[3] 'Essential Principles of Physics' – Whelan & Hodgson, page 472
[4] 'Essential Principles of Physics' – Whelan & Hodgson, page 472

[5] 'Essential Principles of Physics' – Whelan & Hodgson, page 472

The anode is a central thin wire which is insulated from the surrounding cathode cylinder, which is metal or graphite coated. The anode is kept at a positive potential and the cathode is earthed. The tube may also have a thin mica end window. [6]

When radiation enters the tube, a few electrons and ions are produced in the gas. If the voltage is above the breakdown potential (The minimum *reverse* voltage to make the diode conduct in reverse) [7] of the gas, the number of electrons and ions are greatly multiplied. The electrons are attracted to the anode, and the positive ions move towards the cathode. The current flowing in the high resistance resistor (R) produces a pd which is amplified and passed to a counter which registers the passage of an ionising particle or radiation through the tube. [8]

The tube cannot be filled with air as the discharge persists for a short time after the radiation is registered. This is due to electrons being emitted from the cathode by the positive ions which arrive there. Instead, the tube is filled with argon mixed with a halogen vapour which quenches, reduces the intensity, the discharge quickly, ensuring that the registered radiation does not affect the recording of other ionising particles.

When the G-M tube is detecting one particle, if another enters the tube it will not be detected. This is known as dead time; the average maximum being approximately 90 microseconds.[9] Because this number is so small, it can justifiably be ignored for this experiment.

Background radiation must be taken into account when taking readings from the source. Background radiation primarily comes from cosmic radiation and terrestrial sources.[10] This radiation will affect the count and must be corrected. The level of this radiation varies with location and must be measured before conducting the experiment.

Since $I \propto C$:

$$C \propto \frac{1}{(d + d_0)^2}$$

Therefore: $$d + d_0 \propto \frac{1}{\sqrt{C}}$$

$$I \propto \frac{1}{r^2}$$

Where:

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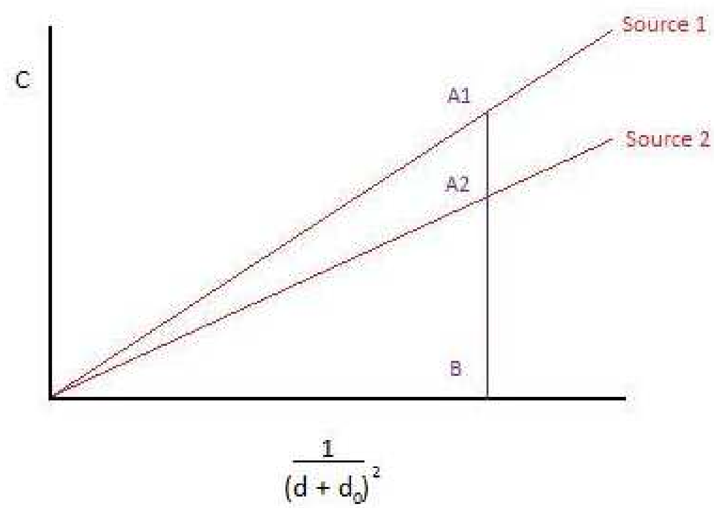
[6] http://www.imagesco.com/articles/geiger/03.html
[7] http://en.wikipedia.org/wiki/Breakdown_voltage
[8] 'Essential Pre-University Physics' – Whelan & Hodgson, page 406
[9] http://www.imagesco.com/articles/geiger/03.html
[10] http://en.wikipedia.org/wiki/Background_radiation

- d = distance
- d_0 = distance to be added to the measured distance, d, because of the reference point on the holder not coinciding with th e source, and the effective counting space inside the GM tube may not be close to the window, then $r = d + d_0$.
- I = intensity
- C = corrected count rate – the measured count rate minus the reading for background radiation[11]

Corrected count rate against $1/(d + d_0)^2$ should produce a straight-line graph, passing through the origin, if the inverse square law is followed.



Source: 'A Laboratory Manual of Physics' – F. Tyler, page 269

The gradient of the line obtained is a measure of the strength of the source used i n the experiment.[12] The strength of the source is the activity, $A = \lambda N$. The decay constant, λ, can be calculated using $\lambda = \ln 2/t_{1/2}$ where the value for the half-life of Co-60 is 5.2714 years[13].

Therefore:

$$\lambda = \ln 2/t_{1/2}$$
$$= 0.693/1.664 \times 10^{8}$$
$$= 4.175 \times 10^{-9}$$

The gradient of the straight line graph will equal $\lambda N_0 e^{-\lambda t}$ so λ = gradient/ $N_0 e^{-\lambda t}$

Safety Precautions:

[11] 'Advanced Level Practical Physics' - M Nelkon & JM Ogborn, page 218
[12] 'A Laboratory Manual of Physics' – F. Tyler, page 269
[13] http://en.wikipedia.org/wiki/Cobalt

To ensure the utmost safety before, during and after this experiment, some guidelines should be followed:

- Food and drink should not be consumed whilst in the same room as the source
- Food items should not be stored in the same room as the source
- The source should only be handled with long handled source handling tongs, and as little as possible
- Hands should be washed thoroughly after contact with the so urce
- If in contact with the source for an extended period, it is recommended that a monitoring badge is worn
- As the source will radiate in only one direction, it should not be pointed at anyone
- The source should be locked away in a lead lined box when not in use
- Open wounds should be covered securely
- Protective gloves should be warn when handling potentially contaminated items

Errors:

To reduce the possible errors within the experiment, an optical bench will be used to ensure that the G-M tube and the source are properly aligned throughout, as the source radiates in one direction, the alignment must remain standard. Also, for small distances, specifically the distance d_0 which is the distance the source is from the opening of the holder plus the distance of detection from the window in the G-M tube, vernier callipers will be used to hold as much accuracy as possible. Vernier callipers read to fractions of a millimetre, making them much more accurate than other measuring devices. Other distances, such as distance d, can be measured with a metre rule as the distances are larger which decreases the possible error in measuring.

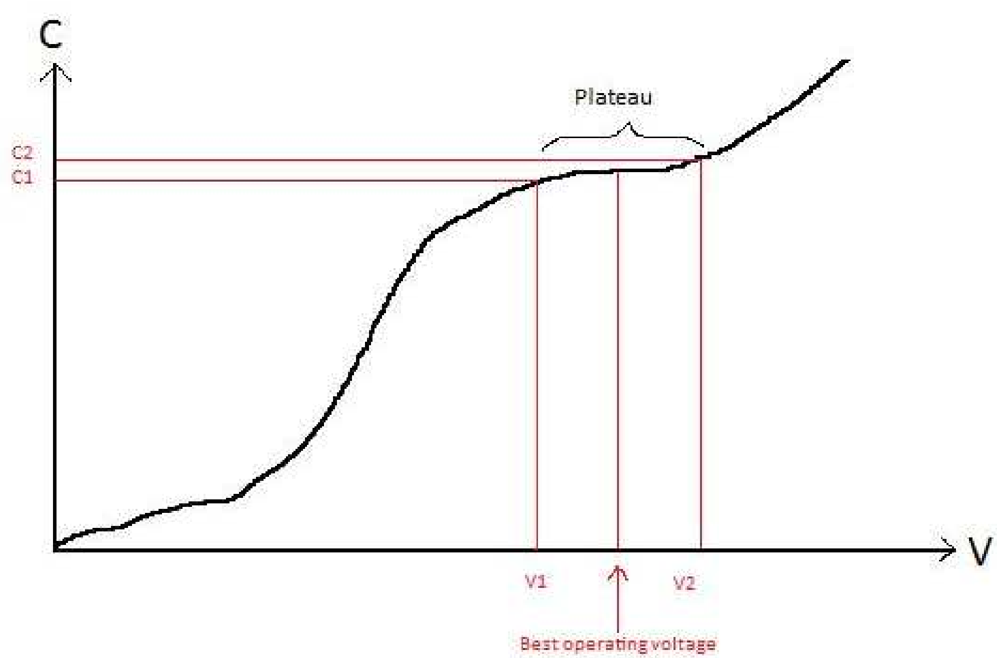
There will also be the error of human reaction times from observing the final count and pressing the stopclock. To ensure accuracy, practise using the stop-clock and count switch until reasonably consistent results can be obtained.

Preliminary Work:

To decide on an appropriate voltage to use , the G-M tube and source set-up should be tested. Place the source approximately 10 cm from the windo w of the G-M tube and increase the voltage slowly, until the count rate stops changing dramatically.

Plot a graph of the count-rate, C, against EHT voltage, V. Record the voltages V1 and V2 between which the rate of counting does not vary too much. If the rate of counting begins to rise after remaining much the same for a range of voltage **do not** raise the voltage any higher or the tube may suffer damage. [14]

- [14] 'Advanced Level Practical Physics' – M Nelkon & JM Ogborn, page 212



The optimum operating voltage will be halfway between the voltage where the plateau begins and the voltage where it ends.

To decide on the range of distances used, the source was moved close to the window of the G-M tube and was moved back slowly until the scaler could count adequately (5 cm). This is the smallest distance that will be used. To find the o ther extreme, the source was moved back until the count rate fell to a low value, but could still provide adequate results (35 cm).

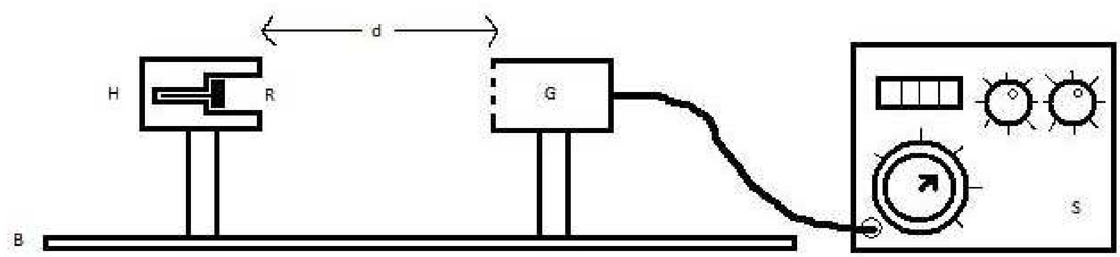
d (cm)	N	t_1 (s)	t_2 (s)	t_3 (s)	Ave. t
5.00	10,000	212	209	209	210.00
10.00	10,000	773	779	790	780.67
15.00	1000	180	220	205	201.67
20.00	1000	317	355	345	339.00
25.00	1000	457	469	437	454.33
30.00	1000	543	510	542	531.67
35.00	1000	749	720	735	734.67

From these preliminary results I have decided to time for 10,000 counts at 5 cm from the source, 5000 counts for 10cm fro m the source, and 1000 for 15 – 30cm. This is because any higher values will take considerably longer to measure. I will take three readings from each, as radioactive decay is a random process and it would be unlikely for more than three readings to be similar. An average will be calculated from the three values and the reading for the background radiation will be subtracted to find the corrected count rate.

Equipment:

- Geiger-Müller tube of β, γ sensitive type
- Decade scaler with variable EHT supply
- Sealed cobalt-60 source - [illegible]
- Long handled source handling tongs - [illegible]
- Optical bench with source holder - [illegible]
- Stop-clock, readable to at least two decimal places
- Vernier callipers – [illegible]
- Metre rule – [illegible]

Diagram:



Where:

- B is the optical bench with source holder, H
- G is the Geiger-Müller tube
- S is the decade scaler with variable EHT supply
- R is the sealed radioactive source, cobalt-60

Cobalt-60 will be used as the gamma source as it is easily produced, by exposing natural cobalt to neutrons in a reactor, and therefore easy to acquire.[15] It also produces γ-rays with energies of 1.17 MeV and 1.33 MeV.

Method:

1. Clamp the G-M tube to one end of the optical bench and attach it to the input socket of the scaler
2. Set the variable EHT voltage on the scaler at a minimum and turn it on, allowing a few minutes for the scaler to warm up
3. Change the variable EHT voltage on the scaler to the value found through preliminary work and set it to count pulses from the G-M tube

[15] http://en.wikipedia.org/wiki/Cobalt

4. Start the stopclock and measure the background radiation for an adequate length of time, e.g. 25 minutes , as background radiation is variable
5. Place the holder containing the γ -source at 5.0 cm from the window of the G - M tube
6. Start the stopclock and stop after 10,000 counts are registered. Record this value and repeat twice
7. Move the γ-source to 10.0 cm from the window of the G -M tube and repeat procedure 5, instead only counting 5000 counts
8. Move the γ-source to 15.0 cm from the window of the G -M tube and repeat procedure 5, instead counting only 1000 counts
9. Repeat procedure 7 for sets of 5.0 cm until a distance of 30.0 cm is reached
10. Tabulate these results and find the average count rate for each distance
11. Evaluate $1/(d + d_o)^2$
12. Using the recorded value for background radiation, evaluate the corrected count rate for each distance
13. Plot the graph of corrected count rate against $1/(d + d_o)^2$