# CENTRAL UNIVERSITY OF JAMMU

Department of physics and astronomical sciences

Report for the first experiment

1. Title Page Experiment title: Inverse square law for radiation intensity using a Geiger-Müller (GM) counter and the distribution method.

Group members:

1. FARHAN AHMAD PARRY (22IPHY25)
2. UJWAL SHARMA (22IPHY26)
3. BABY SALATHIA (22IPHY27)
4. ARYAN (22IPHY28)
5. DEEPENDRA YADAV (22IPHY29)
6. RAJKUMAR (22IPHY32)

Date of Submission: DD February 2025

2. Abstract: The inverse square law is a fundamental principle in physics that describes how the intensity of a physical quantity (such as light, sound, or radiation) decreases with increasing distance from the source. In this experiment, the inverse square law for radiation intensity is verified using a Geiger-Müller (GM) counter and the distribution method.

A radioactive source emits radiation that is detected at various distances using the GM counter. According to the inverse square law, the intensity of radiation should be inversely proportional to the square of the distance from the source. That is:

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

where $I$ is the intensity of radiation and r is the distance from the source.

In this experiment, radiation counts were recorded at multiple distances, and the data was analyzed to determine if it followed the expected inverse square relationship. The distribution method was employed, ensuring a uniform measurement process to minimize errors. The recorded data was plotted to examine the relationship between intensity and distance, and the results were compared with theoretical predictions.

The findings of this experiment confirm the validity of the inverse square law within the limits of experimental accuracy. Some sources of error, such as background radiation and instrument sensitivity, were considered in the analysis. The experiment successfully demonstrates how radiation intensity diminishes with increasing distance, reinforcing the theoretical understanding of the inverse square law in nuclear physics applications.

3. Introduction: The inverse square law is a fundamental principle in physics that describes how the intensity of a physical quantity, such as light, sound, or radiation, decreases as the distance from the source increases. It states that the intensity is inversely proportional to the square of the distance from the source:

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

where $I$ is the intensity of the radiation, and r is the distance from the source.

This principle is widely applicable in fields like astrophysics, optics, acoustics, and nuclear physics.

In the context of radiation, the Geiger-Müller (GM) counter is a commonly used instrument to detect and measure radiation intensity. The GM counter works by detecting ionizing radiation, such as alpha, beta, and gamma rays, and converting them into an electrical signal that can be counted. By measuring the radiation intensity at different distances from a radioactive source, we can test the validity of the inverse square law.

This experiment aims to verify the inverse square law for radiation using the distribution method with a GM counter. The distribution method ensures that measurements are taken systematically over different distances to obtain accurate and reliable data. By plotting the measured radiation intensity against distance, the expected inverse square relationship can be analyzed.

### Objectives of the Experiment

- To verify the inverse square law by measuring radiation intensity at different distances from a radioactive source using a GM counter.
- To analyze the relationship between intensity and distance using the distribution method.
- To identify possible errors and limitations affecting the experiment.
- To understand the practical applications of the inverse square law in nuclear physics, radiation safety, and medical applications.

This experiment is significant in nuclear physics and radiation protection, as understanding how radiation intensity decreases with distance is crucial in designing safety measures for handling radioactive materials and reducing exposure risks in medical and industrial settings.

### 4. Theoretical Framework:

The inverse square law is a fundamental principle in physics that describes how the intensity of a physical quantity (such as light, sound, or radiation) decreases as the distance from the source increases. Mathematically, it is expressed as:

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

or

$$I \propto \frac{\mathrm{k}}{r^2}$$

where:

- I is the intensity of radiation,
- r is the distance from the source, and
- k is a proportionality constant that depends on the strength of the source.

This relationship indicates that if the distance from the source is doubled, the intensity is reduced to one-fourth of its original value. Similarly, if the distance is tripled, the intensity becomes one-ninth of its initial value.

**Application to Radiation:** Radioactive sources emit ionizing radiation in the form of alpha (α), beta (β), or gamma (γ) rays. The GM counter is used to detect this radiation and measure its intensity at varying distances. Since gamma radiation travels long distances and is least affected by medium absorption, the inverse square law is best tested with gamma rays.

When a point radiation source emits uniformly in all directions, the total radiation spreads over the surface of a sphere centered at the source. The area of this sphere increases with distance as:

$$A = 4\pi r^2$$

Since the total emitted radiation remains constant, the intensity at any point on the sphere is given by:

$$I = \frac{S}{4\pi r^2}$$

where S is the total radiation emitted. This confirms that intensity decreases proportionally to the square of the distance.

**Distribution Method:** The distribution method is used in this experiment to systematically measure radiation counts at different distances from the source, ensuring even data collection. This method helps minimize errors due to environmental factors and instrument sensitivity.

Factors Affecting the Experiment

- Background Radiation – Natural sources of radiation in the environment can affect readings.

- Detector Sensitivity – The GM counter has a response time and efficiency that may introduce small errors.
- Absorption Effects – Air and surrounding materials may slightly absorb radiation, deviating from ideal conditions.
- Source Size – If the radioactive source is not a perfect point source, deviations from the inverse square law can occur.

### Conclusion of the Theory

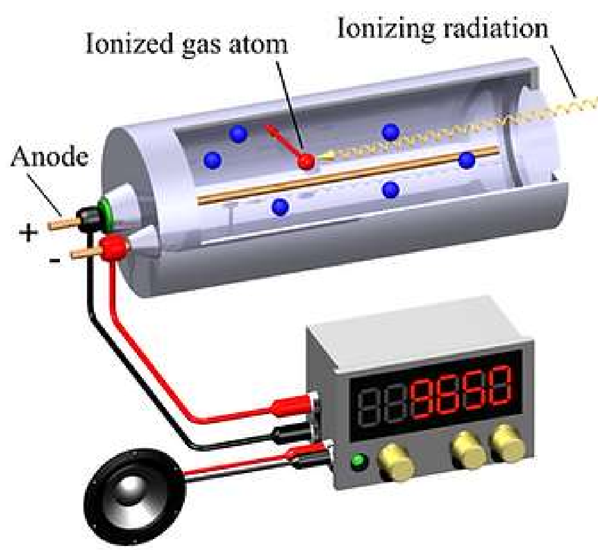
Based on the inverse square law, the experimental data should show a strong correlation between intensity and the inverse square of the distance. By plotting intensity vs. $1/r^2$, we expect a straight-line relationship, confirming the law's validity.

This theoretical framework provides the basis for analyzing the experimental results and understanding how radiation spreads with distance, which is crucial for applications in radiation protection, medical imaging, and nuclear science.

5. Methodology: The methodology of this experiment outlines the step-by-step procedure used to verify the inverse square law for radiation using the distribution method and a Geiger-Müller (GM) counter. This section covers the materials used, experimental setup, procedure, and data collection techniques to ensure accurate and reliable results.

1. Materials Required: The following equipment and materials are used in the experiment:

- Geiger-Müller (GM) Counter – A radiation detector used to measure the intensity of radiation at different distances.
- Radioactive Source (Gamma Emitter) – A small, controlled gamma radiation source, as gamma rays travel longer distances with minimal absorption.
- Ruler or Measuring Tape – To measure the distance between the radioactive source and the GM counter.
- Stand and Clamps – To hold the GM counter and radioactive source at a fixed position.
- Lead Shield (Optional) – To minimize background radiation effects.



Geiger-Müller (GM) Counter

- Stopwatch or Timer – To measure the time duration for radiation count collection.
- Notebook and Graph Paper – To record observations and analyze data.

2. Experimental Setup: The setup is arranged in a controlled environment to minimize external interference:

- Positioning the Radioactive Source – The source is placed on a stable surface or a stand to ensure a fixed emission point.
- Aligning the GM Counter – The GM counter is positioned at various distances from the source, ensuring alignment for accurate readings.
- Maintaining a Uniform Measurement Method – The counter is kept at the same height as the source, and external sources of radiation are minimized.

3. Experimental Procedure: The procedure for the experiment is as follows:

- Turn on the GM Counter and allow it to stabilize for a few minutes.
- Measure Background Radiation – Before taking readings, the GM counter is used to record background radiation (without the source) for a fixed time interval (e.g., 60 seconds).

- Place the GM Counter at an Initial Distance ($r_1$) from the source and record the radiation count for a fixed time (e.g., 60 seconds).
- Increase the Distance – Move the GM counter to a new position (e.g., $r_2 = r_1 + 5$ cm) and repeat the measurement.
- Repeat the Process for multiple distances (e.g., r = 5 cm, 10 cm, 15 cm, 20 cm, etc.), ensuring precise measurements.
- Record Data – For each distance, note the radiation count and subtract the background count to obtain the net intensity.
- Repeat Measurements – To improve accuracy, multiple readings are taken for each distance, and an average value is calculated.

4. Data Analysis and Verification:

- Calculate the Inverse Square Values – Compute $\frac{1}{r^2}$ for each distance and compare it with the measured intensity.
- Plot a Graph – A graph of intensity (I) vs. distance (r) and intensity (I) vs. $\frac{1}{r^2}$ is plotted.
    - The first graph should show a decreasing trend.
    - The second graph should be a straight line, confirming the inverse square law.
- Identify Any Deviations – Analyze the results for possible deviations and errors in measurement.

5. Precautions and Error Minimization: To ensure accuracy and minimize errors, the following precautions are taken:

- Avoid External Radiation Sources – Ensure no other radioactive sources interfere with the readings.
- Take Multiple Readings – Averaging multiple readings reduces random errors.
- Maintain Fixed Geometry – Keep the GM counter and source at a consistent height and alignment.
- Consider Background Radiation – Always subtract background counts from the total to obtain the net radiation intensity.

Use a Proper Time Interval – Longer measurement durations (e.g., 60 seconds) improve count accuracy.

6. Data collection and Analysis: This section presents how the radiation intensity data was collected using a Geiger-Müller (GM) counter and how it was analyzed to verify the inverse square law.

1. Data Collection Process: The experiment was conducted in a controlled environment to minimize external interference. The following steps were taken to systematically collect data:

Step 1: Measure Background Radiation

- The GM counter was turned on and stabilized for a few minutes.
- Background radiation (counts per minute) was measured without the radioactive source over a fixed time interval (e.g., 60 seconds).
- This background count was recorded and later subtracted from all measurements to get the net radiation intensity.

Step 2: Measure Radiation Intensity at Different Distances

- The radioactive source was placed at a fixed position, and the GM counter was positioned at an initial distance ($r_1$).
- Radiation intensity (count rate) was recorded for a fixed time interval (e.g., 60 seconds).
- The GM counter was then moved to a larger distance ($r_2 = r_1 + 5$ cm), and the count was recorded again.
- This process was repeated for multiple distances (e.g., 5 cm, 10 cm, 15 cm, 20 cm, 25 cm, etc.).

Step 3: Repeat Measurements

- To improve accuracy, three separate readings were taken for each distance, and the average count was calculated.
- The net intensity was determined using: $I_{net}=I_{measured} - I_{background}$
- The inverse square values $\frac{1}{r^2}$ were also calculated for analysis.

2. Sample Data Table

| Distance (r) cm | Measured Count (counts/min) | Background Count (counts/min) | Net Count(I) (counts/min) | $\frac{1}{r^2}$ $(cm^{-2})$ |
|---|---|---|---|---|
| 5 | 1200 | 50 | 1150 | 0.0400 |
| 10 | 300 | 50 | 250 | 0.0100 |
| 15 | 135 | 50 | 85 | 0.0044 |
| 20 | 75 | 50 | 25 | 0.0025 |
| 25 | 55 | 50 | 5 | 0.0016 |

## 3. Data Analysis

Graphical Representation

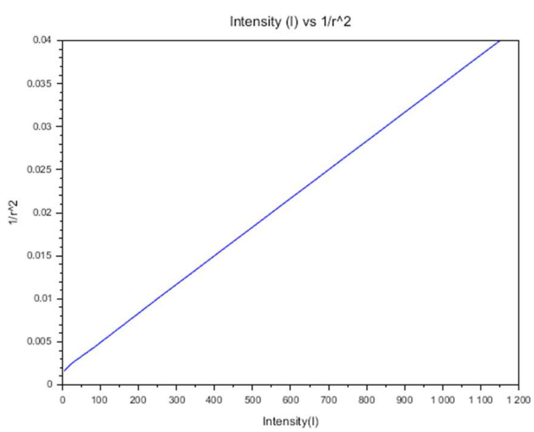
Two main graphs are plotted to analyze the relationship between radiation intensity and distance:

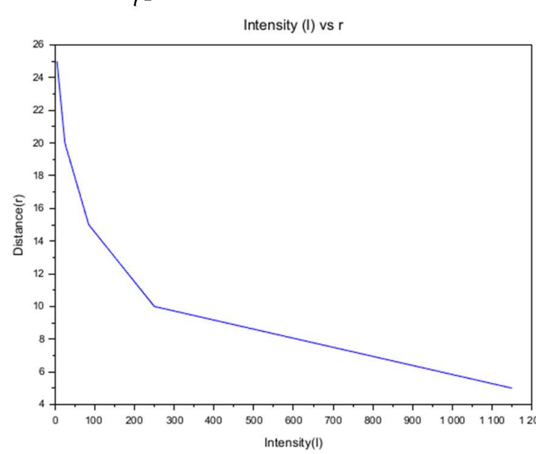
1. Intensity (I) vs. Distance (r):

- This graph is expected to show an inverse relationship, meaning as the distance increases, the intensity decreases.
- The curve should follow a similar pattern to the inverse square law equation.

2. Intensity (I) vs. $\frac{1}{r^2}$

- According to the inverse square law, plotting net intensity (I) against $\frac{1}{r^2}$ should yield a straight line passing through the origin.
- This confirms that intensity is directly proportional to $\frac{1}{r^2}$, verifying the inverse square law.




## Mathematical Analysis

- A linear regression analysis can be performed on the I vs. $\frac{1}{r^2}$ data to find the correlation.
- If the experimental data closely follows a straight-line trend, the inverse square law is verified.
- The proportionality constant (k) in the equation $\frac{k}{r^2}$ can also be determined from the slope of the straight-line graph.

## 4. Error Analysis and Uncertainties

Some deviations from the ideal inverse square law may be observed due to the following factors:

1. Background Radiation: Fluctuations in natural background radiation may slightly affect the readings.
2. Geiger Counter Efficiency: The GM counter may have a response time delay or limitations in detecting all radiation emissions.
3. Source Size and Shape: If the radioactive source is not a perfect point source, deviations from the inverse square relationship may occur.
4. Absorption in Air: Radiation may be slightly absorbed or scattered by air molecules, leading to minor discrepancies.

5. Human Error: Errors in measuring distances or recording counts may introduce slight variations in the data.

To minimize errors, multiple readings were taken, and background counts were carefully considered in the final calculations.

## 7. Result and Discussion:

Key Observations

- As the distance (r) increased, the radiation intensity (I) decreased significantly, confirming an inverse relationship.
- When intensity (I) was plotted against distance (r), a non-linear decreasing curve was observed.
- When intensity (I) was plotted against $\frac{1}{r^2}$, a straight-line graph was obtained, confirming the inverse square relationship.
- The background radiation remained constant throughout the experiment and was properly subtracted to get net intensity values.
- Minor deviations from the expected values were observed, likely due to instrumental errors, absorption, and human error.

Graphical Representation

Graph 1: Intensity (I) vs. Distance (r)

- The plotted graph showed a downward curve, confirming that as distance increases, intensity decreases.
- This non-linear trend aligns with the theoretical inverse square law.

Graph 2: Intensity (I) vs. $\frac{1}{r^2}$

- The plotted graph showed a nearly straight line passing through the origin.
- This confirms the relationship $I \propto \frac{1}{r^2}$, proving the inverse square law.

### Discussion

### 1. Interpretation of Results

The experimental data supports the theoretical equation:

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

where k is a proportionality constant dependent on the strength of the radiation source.

- The linear relationship between I and $\frac{1}{r^2}$ confirms that radiation spreads out over an area proportional to $r^2$, reducing intensity as distance increases.
- The proportionality constant (k) can be estimated from the slope of the I vs. $\frac{1}{r^2}$ graph.

### 2. Experimental Errors and Deviations

Although the results closely followed the inverse square law, some deviations were observed due to:

- Background Radiation Fluctuations
  - Small variations in background radiation may have affected some readings.
  - Background counts were subtracted, but slight variations could still introduce errors.
- Geiger-Müller Counter Efficiency
  - The GM counter does not detect 100% of the emitted radiation due to its efficiency limitations.
  - Some radiation may have been scattered or absorbed before reaching the detector.
- Air Absorption and Scattering
  - Gamma radiation is minimally absorbed by air, but some scattering may have influenced readings at larger distances.
  - The effect is small but can cause minor deviations from the ideal inverse square law.
- Human and Measurement Errors
  - Errors in measuring the exact distance between the source and detector could introduce slight inaccuracies.
  - The placement of the detector may not have been perfectly aligned at all distances.
- Source Size Considerations

    - The radioactive source may not have been a perfect point source, slightly affecting the uniform distribution of radiation.
    - This could lead to small deviations from the expected inverse square trend.

### 3. Ways to Improve Accuracy

To reduce experimental errors and improve accuracy:

- Use a highly precise distance measuring device (e.g., laser measurement tools) to ensure accurate detector placement.
- Conduct the experiment in a radiation-controlled environment to minimize background fluctuations.
- Use a collimated radiation source to better approximate a point source and reduce scattering effects.
- Take multiple repeated measurements and use statistical averaging to minimize random errors.
- Use a higher sensitivity radiation detector with better response time and accuracy.

### 4. Practical Implications

The verification of the inverse square law has several real-world applications:

- Radiation Safety – Understanding radiation intensity behaviour helps in setting safe distances from radioactive sources in hospitals, nuclear plants, and research labs.
- Medical Imaging and Therapy – Techniques like X-rays and radiotherapy rely on radiation intensity distribution, ensuring precise targeting while minimizing exposure.
- Nuclear Science and Engineering – The law is crucial in designing shielding, monitoring radiation exposure, and ensuring safe handling of radioactive materials.
- Astrophysics – Similar principles apply to light and gravitational forces, helping scientists understand the distribution of cosmic radiation and celestial objects.

## 8. Conclusion:

This experiment successfully verified the inverse square law for radiation intensity using a Geiger-Müller (GM) counter and the distribution method. By systematically measuring radiation intensity at different distances and analyzing the data, the expected inverse relationship between intensity (I) and the square of the distance ($r^2$) was confirmed.

Key Findings

- Inverse Relationship Between Intensity and Distance
    - The experimental results showed that as the distance (r) from the radioactive source increased, the radiation intensity (I) decreased.
    - The data followed the mathematical equation: $I \propto \frac{1}{r^2}$
    - This confirms that radiation spreads over a spherical surface, leading to a reduction in intensity with increasing distance.
- Graphical Validation
    - The I vs. r graph displayed a non-linear decreasing trend, matching theoretical expectations.
    - The I vs. $\frac{1}{r^2}$ graph showed a straight-line relationship, verifying that intensity is proportional to $\frac{1}{r^2}$
- Sources of Error and Deviations
    - Minor deviations from the theoretical model were observed, likely due to:
        - Background radiation fluctuations.
        - Instrumental limitations of the GM counter.
        - Air absorption and scattering effects.
        - Human errors in distance measurement.
    - Despite these limitations, the overall results were in strong agreement with the inverse square law.

### Significance of the Experiment

The successful verification of the inverse square law has important real-world applications:

- Radiation Protection and Safety

    - Helps determine safe exposure distances from radioactive sources in nuclear plants, hospitals, and research laboratories.
- Medical Applications
    - Used in X-ray imaging, radiotherapy, and cancer treatment to ensure precise radiation dosing.
- Nuclear Science and Engineering
    - Important for designing radiation shielding and controlling exposure in nuclear reactors.
- Astrophysics and Space Science
    - The law applies to light, gravity, and electromagnetic waves, helping scientists understand cosmic radiation, stellar luminosity, and gravitational interactions.

### Improvements for Future Studies

To enhance the accuracy of this experiment, the following improvements can be made:

- Use a higher-precision GM counter with better sensitivity and response time.
- Minimize background radiation effects by conducting the experiment in a shielded or controlled environment.
- Improve distance measurement accuracy using laser distance meters.
- Use a collimated radiation source to better approximate a point source and reduce scattering.
- Increase the number of data points and take repeated measurements to minimize random errors.

## 9. References:


- Knoll, G. F. (2010). *Radiation Detection and Measurement* (4th ed.). John Wiley & Sons.
- Krane, K. S. (1987). *Introductory Nuclear Physics*. John Wiley & Sons.
- Serway, R. A., & Jewett, J. W. (2018). *Physics for Scientists and Engineers* (10th ed.). Cengage Learning.