TAP 510-2: Range of gamma radiation

Penetrating electromagnetic radiation

Gamma radiation is emitted by a nucleus in order to drop from an excited state to a more stable one. Gamma rays are high-frequency members of the electromagnetic spectrum. In this activity you will assess the penetrating power of gamma rays and also the way in which their intensity changes with distance.

You will need

- ✓ gamma source and holder
- ✓ set of absorbers: various thicknesses of lead
- ✓ a Geiger–Müller tube and associated power supply
- ✓ suitable means for mounting the GM tube a fixed measurable distance from the source
- ✓ forceps or tweezers for handling the radioactive source
- ✓ stop clock
- ✓ metre rule
- ✓ micrometer screw gauge or vernier calliper for making thickness measurements
- ✓ set square

⚠☢	**Radioactive sources** Follow the local rules for using radioactive sources, in particular do not handle radioactive sources without a tool or place them in close proximity to your body.

Making measurements

1. Set up the GM tube and counter to take a background reading. This background value will need to be subtracted from each subsequent reading you take when using the gamma source.

2. Fix the gamma source 10–15 cm from the front window of the GM tube (do not remove any plastic cap that is protecting it). The separation of the source and counter and the orientation of the source must be fixed – not too hard to see why so take care. (Because we are investigating absorption, we want a fixed geometry so that the results are not confused by the inverse square law effect investigated later.)

3. Take a reading of the number of gamma photons over a sensible time period and convert this to a rate of arrival per second.

4. Insert one of your lead sheets between the tube and source close to the GM tube, finding the new count rate for each absorber thickness. Be sensible – a short preliminary experiment using a very thin absorber and a very thick one in order to get a feeling for the range of count rates that you will encounter will save you time later. You can also plot as you go (count rate against thickness of lead), looking for patterns and anomalies.

Analysis

5. Try to find the thickness of lead for which half the incident gamma radiation is absorbed. Is the pattern exponential? Can you check?

Comparisons with beta particles

(To be done if your class has carried out the activity dealing with the range of beta particles. TAP episode 511-2)

6. Do the gamma rays penetrate further into the lead than beta particles? Which are the better ionisers?

7. Plot a graph of corrected count rate against thickness. Draw a smooth curve through the points.

8. If you have carried out the 'more sophisticated analysis' for beta particles you might like to repeat the logarithmic plot here too.

The inverse square law – a fresh start

Theory predicts that electromagnetic radiation should vary with distance according to an inverse square rule. With a little care, you can test this.

1. Remove the lead sheets – they are not needed again – and move the gamma source closer to the tube. This starting distance must not be so close that your GM tube is overwhelmed by counts and misses some out. Some trial and error may be needed.

2. Measure the distance from the thin window of the GM tube to the front of the source. A possible way to do this is to use a set square to transfer the measurement to a metre rule taped to the bench.

3. Obtain the average count rate for this distance.

4. Repeat the experiment over a wide range of distances, taking care with the alignment of the sources.

5. Does the inverse square law describe your results?

A more careful analysis

You measured a distance from the window of the GM tube to the front of the source. This leads to two problems: the source itself is on a foil and lies a few millimetres behind the wire mesh of its holder and the average detection point is somewhere inside the GM tube.

Theory predicts that the intensity of the gamma rays varies with the inverse square of the distance:

$$y \propto \frac{1}{x^2}$$

which can be rewritten as

$$y = \frac{k}{x^2}$$

However, the two problems mean that the true value of x is unknown and that it should be written as $x + c$ where c is a correction that converts your (inaccurate) measurement of distance x into the correct value.

So the equation becomes

$$y = \frac{1}{(x+c)^2}$$

and a plot of y against x^2 will not be a straight line.

The trick is to take square roots of both sides:

$$y^{\frac{1}{2}} = \frac{1}{(x+c)}$$

leading to

$$\frac{1}{y^{\frac{1}{2}}} = x + c$$

So if the gamma rays obey an inverse square law, a plot of $1/y^{1/2}$ against x ought to be a straight line. The intercept on the x-axis will give you an estimate of c, the error in the distance determination.

Plot your data in this way and decide if they verify the inverse square law.

You have seen that

1. Gamma radiation is very penetrating. It will go through metres of lead and concrete. Gammas are poor ionisers. Half thicknesses can be measured, to characterise absorbers.

2. Gamma rays, like all electromagnetic radiation, obey the inverse square law. Double your distance from the source and you reduce the intensity by four times.

Practical advice

Students will need to take care with the measurements, particularly with alignments. You may choose to make up apparatus to allow this to be easily controlled. The more careful analysis is only for mathematically competent students. It can be omitted without loss.

Be safe

Follow local rules for using radioactive sources.

Social and human context

Nuclear reactors and other nuclear machines are surrounded by huge amounts of concrete or lead to prevent the radiation emitted during the reactions causing a hazard to us. (When would you choose concrete and when lead? When there is room for lots of concrete, it is used because it is much cheaper than lead.)

External reference

This activity is taken from Advancing Physics chapter 18, 110E