

Alpha beta gamma penetration and shielding

AQA GCSE Combined Science Trilogy 8464 and Separate Physics 8463 | F/H | Paper 1

Worked answers and marking guidance | 27 parts | 46 marks

Specification points covered

8463 4.4.2.1 / 8464 6.4.2.1: radiation properties, count rate and applications

8463 4.4.2.4 / 8464 6.4.2.4: irradiation, contamination, precautions and peer review

A materials-inspection laboratory identifies three sealed sources, chooses a beam for checking plastic film and reviews shielding. Use the supplied records only. This is a data exercise, not instructions for handling radioactive sources.

Original PhysicsUK practice, not an official AQA resource. Both qualifications and both tiers use every section. Credit equivalent scientifically correct wording and consistent error carried forward. All background data are supplied; no Separate-only background-source recall or practical-completion claim is intended.

1 Reading the laboratory record

With all test sources removed, a detector records 44, 48 and 52 counts in three separate 120 s intervals. Use the mean as the background estimate throughout this worksheet.

1(a) What is meant by ionisation of an atom? **[1 mark]**

Answer / mark points: Removal of one or more electrons from an atom, forming an ion. [1] Accept loss or gain of electrons forming a charged atom.

1(b) Which one of alpha, beta and gamma radiation is electromagnetic radiation? **[1 mark]**

Answer / mark points: Gamma radiation. [1] Alpha and beta are particles.

1(c) Calculate the mean background count in 120 s from the three readings. **[1 mark]**

Answer / mark points: Mean = $(44 + 48 + 52) / 3 = 48$ counts in 120 s. [1]

1(d) Calculate the mean background count rate in counts per second. **[1 mark]**

Answer / mark points: Background count rate = $48 / 120 = 0.40$ counts s^{-1} . [1] This is a detector count rate, not the activity of one source in Bq.



2 Checking the detector arrangement

Figure 1 is a schematic of the laboratory test. The source windows allow the emitted radiation to escape. The detector can detect alpha, beta and gamma radiation. The source face is 30 mm from the detector window in air; the drawing is not to scale.

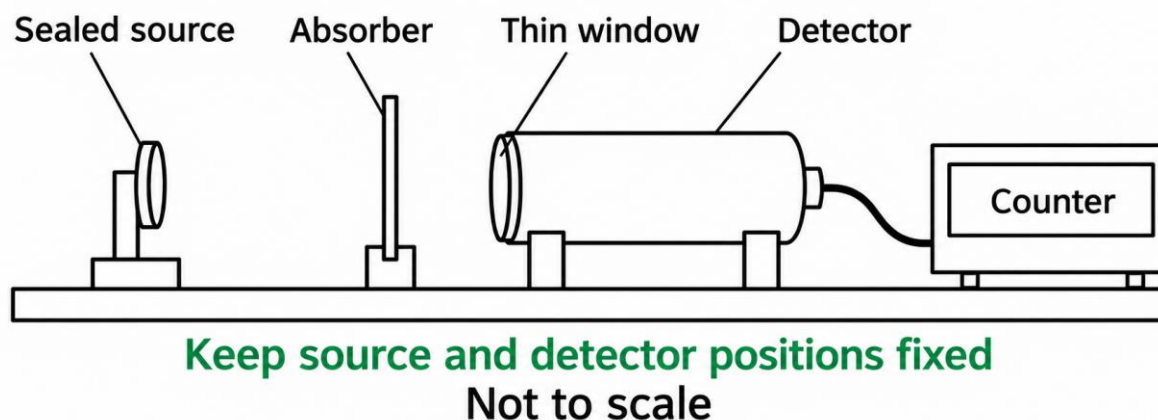


Figure 1

2(a) The technician changes only which absorber is placed in the holder. Identify the independent variable. **[1 mark]**

Answer / mark points: The choice/type of absorber (its material and specified thickness). [1] Do not give source identity or count rate.

2(b) Explain why both the counting time and the source-to-window separation must remain the same when comparing total counts for different absorbers. **[2 marks]**

Answer / mark points: A longer counting time collects more counts even without an absorber change. [1]
Changing the separation changes the radiation reaching the detector, so its effect could be confused with the absorber effect. [1]

Teacher prompt: Two linked control-variable explanations are required, not just a list of controls.

2(c) With no absorber, an alpha-emitting source gives a clear reading at 30 mm, but a reading close to background after the air gap is increased to 150 mm. Explain the change. Assume the source activity is unchanged. **[2 marks]**

Answer / mark points: Alpha radiation has only a short range in air, so it is absorbed before reaching the more distant detector. [1]
Fewer alpha particles reach the detector; the low reading does not mean the source has stopped emitting. [1] No inverse-square calculation is needed.



3 Identifying three sealed sources

Each source P, Q or R emits just ONE of alpha, beta or gamma radiation in this model. Its activity changes negligibly during these tests. Table 1 gives mean TOTAL counts in 120 s, including background. Only the absorber is changed; source and detector positions are fixed. Use 48 background counts per 120 s.

Table 1

Absorber	P / counts	Q / counts	R / counts
None	1248	2448	3648
Paper	48	2328	3528
3 mm aluminium	48	48	3288
20 mm lead	48	48	288

3(a) Identify the radiation from P. Justify your answer using the paper reading and the reading without an absorber. **[2 marks]**

Answer / mark points: P emits alpha radiation. [1] The total falls from 1248 to 48 counts when paper is inserted, leaving only the supplied background level. [1]

3(b) Identify the radiation from Q. Use both its paper and aluminium readings to justify your answer. **[2 marks]**

Answer / mark points: Q emits beta radiation. [1] It passes through paper (2328 total counts, above background) but 3 mm aluminium reduces the reading to the background level of 48. [1] Both comparisons support the identification.

3(c) Identify the radiation from R. Explain what its aluminium and lead readings show. **[2 marks]**

Answer / mark points: R emits gamma radiation. [1] It penetrates 3 mm aluminium; 20 mm lead reduces the total from 3288 to 288 counts but the result remains above the 48-count background. [1] Lead attenuates it rather than stopping it completely.

3(d) For R with 20 mm lead, calculate the background-corrected count rate in counts per second. **[2 marks]**

Answer / mark points: Corrected count = $288 - 48 = 240$ counts in 120 s. [1]
Corrected rate = $240 / 120 = 2.0$ counts s^{-1} . [1]

3(e) A trainee says that inserting paper has switched off source P because the detector now reads background only. Explain why this is wrong. **[2 marks]**

Answer / mark points: The source continues to undergo radioactive decay/emit radiation; paper does not switch off the nuclei. [1]
Paper absorbs the alpha particles before they reach the detector, so the detected source count falls to background. [1]

Teacher prompt: Distinguish what happens at the source from what reaches the detector.



4 Choosing a beam to check plastic film

The laboratory tests a gauge that measures plastic-film thickness by placing film between a source and detector. Table 2 gives background-corrected count rates for three possible sources at fixed positions. The desired film thickness is 0.40 mm. Source activities stay unchanged. For beta and gamma, count rate decreases as thickness increases over the tested range.

Table 2

Film thickness / mm	Alpha / counts s ⁻¹	Beta / counts s ⁻¹	Gamma / counts s ⁻¹
0.20	0	16	24.0
0.40	0	10	23.9
0.60	0	4	23.8

4(a) Choose the most useful radiation type for monitoring changes around 0.40 mm thickness. Justify your choice using the pattern in Table 2. **[2 marks]**

Answer / mark points: Choose beta. [1] Its count rate changes substantially with thickness while radiation still reaches the detector: 16, 10 and 4 counts s⁻¹. [1] Gamma changes much less, so it is less sensitive in this stated test. No universal claim about all gamma gauges is intended.

4(b) Use Table 2 to explain why alpha radiation cannot distinguish the three film thicknesses. **[1 mark]**

Answer / mark points: All three corrected alpha readings are zero: the film absorbs the alpha radiation at every tested thickness, so there is no changing signal. [1]

4(c) Using the beta source, the gauge records 15 counts s⁻¹ after background correction. Is the film thinner or thicker than the desired 0.40 mm? Explain using the evidence. **[2 marks]**

Answer / mark points: Thinner than 0.40 mm. [1] Its 15 counts s⁻¹ exceeds the target-thickness reading of 10, so less beta radiation has been absorbed. [1] Do not infer an exact thickness from only these discrete data.

4(d) Later the corrected beta reading is 5 counts s⁻¹. Explain whether the film is now thinner or thicker than 0.40 mm. **[2 marks]**

Answer / mark points: Thicker than 0.40 mm. [1] Only 5 counts s⁻¹ are detected rather than 10 at the target thickness, because the thicker film absorbs more beta radiation. [1] Do not say that the source has become less active.



5 Choosing a gamma shield

A separate design test uses source R. Table 3 gives mean TOTAL counts in 120 s for different lead thicknesses; background is still 48 counts per 120 s. The test criterion is a background-corrected rate of at most 5.0 counts s^{-1} . This criterion alone is not a complete safety assessment.

Table 3

Lead thickness / mm	Total counts in 120 s
0	3648
5	1848
10	1008
20	288

5(a) For 10 mm lead in Table 3, calculate the background-corrected count rate in counts per second. **[2 marks]**

Answer / mark points: Corrected count = $1008 - 48 = 960$ counts. [1]
Corrected rate = $960 / 120 = 8.0$ counts s^{-1} . [1]

5(b) Choose the smallest TESTED lead thickness that meets the 5.0 counts s^{-1} criterion. Justify your choice using the corrected rates for 10 mm and 20 mm lead. **[2 marks]**

Answer / mark points: 20 mm: its corrected rate is 2.0 counts s^{-1} , at or below the 5.0 maximum. [1]
10 mm gives 8.0 counts s^{-1} , above the maximum; the thinner tested shields also give higher readings. [1] The table does not establish the minimum thickness between 10 and 20 mm.

5(c) A report says that 20 mm lead stops all gamma radiation. Use the data to correct this statement. **[2 marks]**

Answer / mark points: 20 mm lead reduces/attenuates the gamma radiation but does not stop it all. [1]
288 total counts exceeds the 48-count background, or the corrected rate is still 2.0 counts s^{-1} . [1]

5(d) Repeated 120 s measurements with the same 20 mm shield give 276, 288 and 312 total counts. Why need the readings not be identical? **[1 mark]**

Answer / mark points: Radioactive decay, and therefore the recorded number of events in each interval, is random. [1] The changing counts alone do not show a changing mean activity.

5(e) Describe one change to the measurements that would make the estimated mean count rate more reliable. Explain why it helps. **[2 marks]**

Answer / mark points: Repeat the same-duration measurement more times and calculate the mean. [1] This reduces the influence of random fluctuations on the estimated mean. [1]
Alternatively count for a longer total time and divide by that time [1], reducing the relative effect of random fluctuations [1]. Keep the geometry and absorber fixed. Do not claim random variation is eliminated.



6 Reviewing exposure and contamination

A robot moves test products through a closed inspection cabinet. Normally its radioactive source is sealed and no radioactive material is transferred to the products. The laboratory also considers what would happen if a damaged source released radioactive dust.

6(a) Which event is contamination: only radiation passing into a product, or radioactive dust settling on the product? **[1 mark]**

Answer / mark points: Radioactive dust settling on the product. [1] Contamination involves the unwanted radioactive material, not merely radiation passing through.

6(b) A product leaves the cabinet after irradiation by the intact sealed source. Explain why the product does not become a radioactive source in this situation. **[2 marks]**

Answer / mark points: No radioactive material is transferred from the intact sealed source to the product. [1]

Irradiation exposes it to radiation but does not make it radioactive. [1] Do not confuse this with a claim that irradiation cannot damage cells.

6(c) In the damage scenario, radioactive dust remains on a product after the cabinet shutter closes. Explain why the product can still present a radiation hazard. **[2 marks]**

Answer / mark points: The deposited radioactive atoms continue to decay and emit ionising radiation. [1]

Closing the original source shutter does not remove or shield the contamination already on the product. [1]

6(d) The dust emits alpha radiation. Compare its ionising power with gamma radiation and explain why breathing in the dust can damage cells despite alpha's short range. **[2 marks]**

Answer / mark points: Inside the body, the alpha emitter is close to cells, so the short range does not protect them. [1]

Alpha radiation is more strongly ionising than gamma, transferring energy over a short distance and potentially damaging cells/DNA. [1] Do not call alpha radiation harmless because it cannot penetrate intact skin.

6(e) The system is controlled remotely from behind shielding, and its source shutter closes between inspections. Explain how each feature reduces the operator's exposure. **[2 marks]**

Answer / mark points: Remote operation increases distance and/or puts absorbing shielding between source and operator, reducing radiation reaching the operator. [1]

Closing the shutter between inspections reduces the time during which radiation reaches the operator. [1] These are design principles, not permission for pupils to handle sources.

6(f) The laboratory publishes a study of its shielding results. State the name of the process in which other scientists check the work, and explain why this check matters. **[2 marks]**

Answer / mark points: Peer review. [1] Other scientists examine the method, evidence and conclusions to identify errors or assess whether the conclusions are supported. [1] Checking does not guarantee that a study is correct.

Review and improve

Reinforce: an absorber reduces detected radiation, not nuclear decay. Penetration is not ionising power; an irradiated object need not contain radioactive atoms. Timing is estimated and untrials.

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