

Radioactive decay and nuclear binding energy

Physics grades 11-12 (A Level · IB · Class 11-12) · Lab answers

The model answers use the sample table. Your own counts will differ because the dice are random, but the half-life of the model should come out within about 10 % of 3.8 throws, and the graph of $\ln N$ against n should be close to a straight line sloping downwards.

Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB E.3-E.5

Question 1 Why results vary

Whether any one die shows a six is random, so the number removed changes from run to run. In a real sample each nucleus decays at random too, so the number decaying in a short time fluctuates around the average. **The average behaviour is predictable even though each event is random.**

Question 2 Expected values

Expected $N = 120 \times (5/6)^{10} = 120 \times 0.1615 = \mathbf{19.4}$. The measured 22 is 14 % above the expected value, which is acceptable for such small numbers.

Question 3 Half-life from the graph

Half of 120 is 60. N is 61 at $n = 4$ and 48 at $n = 5$, so by interpolation $n = 4 + (61 - 60) / (61 - 48) = \mathbf{4.08}$ throws.

Question 4 Straight-line plot

The values of $\ln N$ are: 4.79, 4.62, 4.50, 4.30, 4.11, 3.87, 3.66, 3.56, 3.50, 3.30, 3.09. A least-squares line gives a gradient of $\mathbf{-0.17}$ per throw. The gradient equals $-\lambda$, where λ is the decay constant of the model, so $\lambda = 0.17$ per throw.

Question 5 Half-life from the gradient

$T_{1/2} = \ln 2 / \lambda = 0.693 / 0.17 = \mathbf{4.07}$ throws. This agrees with the graph value of 4.08 throws to within a few percent.

Question 6 Prediction from probability

$N = N_0 (5/6)^n = N_0 e^{-\lambda n}$, so $\lambda = -\ln(5/6) = \ln(6/5) = 0.182$ per throw. $T_{1/2} = 0.693 / 0.182 = \mathbf{3.80}$ throws. The measured value from the gradient, 4.07 throws, is 6.9 % different.

Question 7 Improving the reliability

Random counts fluctuate by about $\sqrt{N}$, so for $N = 22$ the fluctuation is about $\sqrt{22} = 4.7$, which is 21 % of the count. The smaller N becomes, the bigger the fractional uncertainty.

Use more dice (for example 500) or repeat the run several times and average N at each throw.