INKPHYSICS FLASHCARDS

Nuclear physics

Year 13 · 24 cards · fronts and backs

Print double-sided, flipping on the long edge, and each answer lands behind its question. Cut along the card borders.

Definitions in mark-scheme wording, the equations that are not on the data sheet, each lesson's check question, and the misconceptions that lose marks. The same cards run on the website with spaced-repetition scheduling, at inkphysics.co.uk/flashcards.

CHECK YOURSELF

A gamma source gives a corrected count rate of 1440 counts per minute at 0.50 m. Predict the corrected count rate at 1.50 m, and explain why the background was subtracted before either reading was used.

Hint: How many times further than 1.50 m is the new distance, and what does the square of that factor do?

RUTHERFORD SCATTERING AND THE NUCLEAR ATOM

SPOT THE ERROR

Say what is wrong with this claim:

An atom is a tiny solid ball, packed with matter all the way through.

RUTHERFORD SCATTERING AND THE NUCLEAR ATOM

DEFINITION

Define: Half-life.

RADIOACTIVE DECAY AND HALF-LIFE

DEFINITION

Define: Activity.

RADIOACTIVE DECAY AND HALF-LIFE

DEFINITION

Define: Decay constant.

RADIOACTIVE DECAY AND HALF-LIFE

EQUATION — NOT ON THE DATA SHEET

Activity falling with time:

A = ?

RADIOACTIVE DECAY AND HALF-LIFE

CHECK YOURSELF

Caesium-137 has a half-life of 30 years. A sealed source contains 3.0 μg of caesium-137 (molar mass 137 g mol^{-1}). Find the decay constant and the activity of the source. Take 1 year = 3.15×10^7 s.

Hint: Half-life to λ first; then mass to moles to nuclei; then $A = \lambda N$.

RADIOACTIVE DECAY AND HALF-LIFE

SPOT THE ERROR

Say what is wrong with this claim:

After two half-lives, a sample has all gone.

RADIOACTIVE DECAY AND HALF-LIFE

SPOT THE ERROR

Most alpha particles passed straight through the gold foil: an atom is almost entirely empty space. The rare large rebounds revealed the truth — nearly all the mass and all the positive charge sit in a nucleus ten thousand times smaller than the atom.

RUTHERFORD SCATTERING AND THE NUCLEAR ATOM

CHECK YOURSELF

The distance is 3 times greater, so the intensity falls by a factor of $3^2 = 9$.

1440 / 9 = 160 counts per minute.

The inverse-square law applies to the source's own photons; background counts come from everywhere and do not fall with x, so they must be removed first.

RUTHERFORD SCATTERING AND THE NUCLEAR ATOM

DEFINITION

The number of nuclei in a sample decaying per second: $A = \lambda N$, in becquerels.

RADIOACTIVE DECAY AND HALF-LIFE

DEFINITION

The time taken for the number of undecayed nuclei in a sample, and so its activity, to halve.

RADIOACTIVE DECAY AND HALF-LIFE

EQUATION — NOT ON THE DATA SHEET

$\mathbf{A = A_0 e^{-\lambda t}}$

RADIOACTIVE DECAY AND HALF-LIFE

DEFINITION

The probability per unit time that a given nucleus decays: λ, in s^{-1}.

RADIOACTIVE DECAY AND HALF-LIFE

SPOT THE ERROR

Each half-life halves what remains — it does not remove the whole. After two half-lives a quarter is still undecayed, after three an eighth: the sample dwindles by fractions forever and never cleanly reaches zero.

RADIOACTIVE DECAY AND HALF-LIFE

CHECK YOURSELF

$T_{½} = 30 \times 3.15 \times 10^7 = 9.45 \times 10^8$ s, so $\lambda = \ln 2 / (9.45 \times 10^8) = 7.3 \times 10^{-10}\ s^{-1}$.

$N = (3.0 \times 10^{-6} / 137) \times 6.02 \times 10^{23} = 1.3 \times 10^{16}$ nuclei.

$A = \lambda N = 7.3 \times 10^{-10} \times 1.3 \times 10^{16} = 9.7 \times 10^6$ Bq: ten million decays a second from three millionths of a gram.

RADIOACTIVE DECAY AND HALF-LIFE

EQUATION — NOT ON THE DATA SHEET

Closest approach: the alpha's kinetic energy:

E_k = ?

NUCLEAR RADIUS AND DENSITY

EQUATION — NOT ON THE DATA SHEET

Nuclear density from R_0:

ρ = ?

NUCLEAR RADIUS AND DENSITY

CHECK YOURSELF

Take R_0 = 1.2 fm. Find the radius of an iron-56 nucleus, and then its density, given the atomic mass unit u = 1.661 × 10^{-27} kg. Comment on how the density would differ for gold-197.

Hint: Radius first from the cube-root law; then mass over the volume of a sphere.

NUCLEAR RADIUS AND DENSITY

SPOT THE ERROR

Say what is wrong with this claim:

Bigger nuclei are packed tighter, so heavy elements have denser nuclei.

NUCLEAR RADIUS AND DENSITY

DEFINITION

Define: Binding energy.

MASS-ENERGY AND BINDING ENERGY

DEFINITION

Define: Mass defect.

MASS-ENERGY AND BINDING ENERGY

CHECK YOURSELF

The nuclear mass of iron-56 is 55.92066 u. Using m_p = 1.00728 u and m_n = 1.00867 u, find the mass difference, the binding energy, and the binding energy per nucleon.

Hint: Iron-56 has 26 protons and 30 neutrons; parts minus whole first.

MASS-ENERGY AND BINDING ENERGY

SPOT THE ERROR

Say what is wrong with this claim:

Mass is always conserved.

MASS-ENERGY AND BINDING ENERGY

EQUATION — NOT ON THE DATA SHEET

$\rho = (3u)/(4\pi R_0^3)$

NUCLEAR RADIUS AND DENSITY

EQUATION — NOT ON THE DATA SHEET

$E_k = (Qq)/(4\pi\varepsilon_0 r_{min})$

NUCLEAR RADIUS AND DENSITY

SPOT THE ERROR

Nuclear volume grows in exact proportion to nucleon number — $R = R_0A^{(1/3)}$ cubed gives $V \propto A$ — so every nucleus from hydrogen to uranium shares essentially one density, a staggering 2×10^{17} kg m^{-3}.

NUCLEAR RADIUS AND DENSITY

CHECK YOURSELF

$R = R_0A^{1/3} = 1.2 \times 56^{1/3} = 1.2 \times 3.83 = 4.6$ fm.

Mass = 56u = 9.3×10^{-26} kg; volume = $(4/3)\pi(4.59 \times 10^{-15})^3 = 4.1 \times 10^{-43}$ m^3.

$\rho = 9.3 \times 10^{-26} / 4.1 \times 10^{-43} = 2.3 \times 10^{17}$ kg m^{-3}, and gold's comes out the same: A cancels, so every nucleus shares this density.

NUCLEAR RADIUS AND DENSITY

DEFINITION

The difference between the mass of a nucleus and the total mass of its separate nucleons.

MASS-ENERGY AND BINDING ENERGY

DEFINITION

The energy needed to separate a nucleus into its constituent nucleons, equal to the mass defect times c^2.

MASS-ENERGY AND BINDING ENERGY

SPOT THE ERROR

Mass alone is not conserved: a bound nucleus weighs measurably less than its separated parts. The missing mass was released as energy when the nucleus formed — via $E = mc^2$ — and that same energy, the binding energy, would have to be paid to pull it apart. What nature conserves is total mass-energy.

MASS-ENERGY AND BINDING ENERGY

CHECK YOURSELF

Separate parts: $26 \times 1.00728 + 30 \times 1.00867 = 56.44938$ u, so $\Delta m = 56.44938 - 55.92066 = 0.52872$ u.

Binding energy = $0.52872 \times 931.5 = 492$ MeV.

Per nucleon: $492 / 56 = 8.8$ MeV: the very top of the curve, which is why iron is where both fusion and fission run out of road.

MASS-ENERGY AND BINDING ENERGY

DEFINITION

Define: Critical mass.

FISSION AND FUSION

DEFINITION

Define: Induced fission.

FISSION AND FUSION

CHECK YOURSELF

Deuterium (2.01355 u) and tritium (3.01550 u) fuse to form helium-4 (4.00150 u) and a neutron (1.00867 u), masses given as nuclear masses. Find the energy released.

Hint: Total mass before, total after, difference times 931.5.

FISSION AND FUSION

SPOT THE ERROR

Say what is wrong with this claim:

Splitting any atom releases energy.

FISSION AND FUSION

DEFINITION

Define: Moderator.

NUCLEAR REACTORS AND SAFETY

EQUATION — NOT ON THE DATA SHEET

Neutron energy kept in an elastic moderator collision:

fraction kept = ?

NUCLEAR REACTORS AND SAFETY

CHECK YOURSELF

In a head-on elastic collision with a stationary nucleus of mass M, a neutron of mass m keeps the fraction $((M - m)/(M + m))^2$ of its kinetic energy. Compare a collision with hydrogen ($M = m$) and with carbon-12 ($M = 12m$), and hence explain why water moderates in fewer collisions than graphite.

Hint: Substitute the two masses; then think about what the fractions mean per bounce.

NUCLEAR REACTORS AND SAFETY

SPOT THE ERROR

Say what is wrong with this claim:

A nuclear reactor can explode like a nuclear bomb.

NUCLEAR REACTORS AND SAFETY

DEFINITION

A heavy nucleus splitting into two smaller nuclei after absorbing a neutron, releasing energy and further neutrons.

FISSION AND FUSION

DEFINITION

The minimum mass of fissile material in which, on average, one neutron per fission goes on to cause another fission.

FISSION AND FUSION

SPOT THE ERROR

Energy is only released moving TOWARDS iron, the most tightly bound nucleus. Splitting nuclei heavier than iron pays out; splitting lighter ones would cost energy — for them, fusion is the profitable direction.

FISSION AND FUSION

CHECK YOURSELF

Before: 2.01355 + 3.01550 = 5.02905 u. After: 4.00150 + 1.00867 = 5.01017 u.

Δm = 5.02905 - 5.01017 = 0.01888 u.

E = 0.01888 × 931.5 = 17.6 MeV, carried off as kinetic energy of the helium nucleus and, mostly, the neutron.

FISSION AND FUSION

EQUATION — NOT ON THE DATA SHEET

fraction kept = $((M - m)/(M + m))^2$

NUCLEAR REACTORS AND SAFETY

DEFINITION

The reactor material that slows fission neutrons by elastic collisions to thermal speeds, at which they are more likely to cause further fission.

NUCLEAR REACTORS AND SAFETY

SPOT THE ERROR

A bomb needs a supercritical mass of highly enriched fuel; a reactor's low-enriched fuel and control-rod feedback keep exactly one neutron per fission going on to the next. The worst reactor failure is a meltdown — dire, but not a nuclear explosion.

NUCLEAR REACTORS AND SAFETY

CHECK YOURSELF

Hydrogen: $(0/2m)^2 = 0$: a head-on strike hands over every joule in one collision.

Carbon-12: $(11m/13m)^2 = 121/169 = 0.72$: the neutron keeps 72%, losing only about a quarter per head-on bounce.

Real collisions are rarely head-on, so several are always needed, but hydrogen-rich water still thermalises neutrons in far fewer collisions than graphite: the lighter the target, the bigger each bite.

NUCLEAR REACTORS AND SAFETY