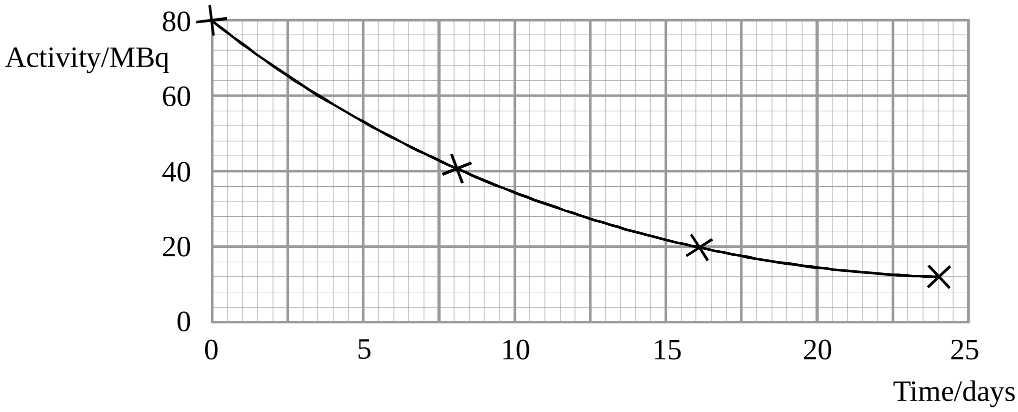
Questions on Nuclear Physics MS

1. Sketch graph:

Acceptably shaped exponential decay curve drawn **(1)**

Activity halving every 8 days **(1)** 2



Description and differences

I contains 53 protons **(1)**

and 78 neutrons **(1)**

eg. β are fast electrons/γ electromagnetic waves **(1)**

β charged; γ uncharged **(1)** 4

Explanation:

Cat emits β, γ which are hazardous to employees **(1)** 1

Calculation:

λ = ln2 / half life

= ln2 / (8 × 24 × 60 × 60) **(1)**

= 1.0×10^{-6} s^{-1} **(1)**

Use of activity = (initial activity) $e^{-\lambda t}$

So t = ln (80/50) ÷ 1.0×10^{-6}s

=4.7×10^5s **(1)** 4

(= 5.4 days)

Assumption:

Cat does not excrete any ^{131}I **(1)** 1

or daughter product not radioactive

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2. Nuclear equations

X = 2 **(1)**

Z = 2 **(1)** 2

Physics of nuclear fission and fusion

Any 5 from the following:

- either/both transform mass into energy
- products formed have greater binding energy/nucleon
- either/both reaction(s) have a mass defect
- fission – splitting nucleus; fusion joining nuclei together
- fission used in nuclear reactors; fusion reactors not yet available [or only in bombs/stars]
- fusion needs high pressure and temperature/high energy particles
- fission forms radioactive products AND fusion forms stable products
- explanation of either involving strong nuclear force Max 5

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3. Calculation of age of the Moon

Any six from:

λ = ln 2 / half-life **(1)**

= ln 2 / 1.3 × 10^9 y

5.3 × 10^{-10} y^{-1} **(1)**

Original mass of ^{40}K = 0.10 + 0.840 = 94 μ g **(1)**

Use of $N = N_0 e^{-\lambda t}$ **(1)**

So 0.10 = 0.94 $e^{-\lambda t}$ **(1)**

So ln(0.10/0.94) = – λ t **(1)**

So t = 4.2 × 109 y **(1)**

[A valid assumption may be given a mark]

[Max 6]

4. Binding energy

Energy released when separate nucleons combine to form a **nucleus (1)** 1

[OR energy required to split **nucleus** into separate nucleons]

Binding energy of a nucleus of uranium-235

Reading from graph: 7.2 ± 0.2 MeV **(1)**

Hence binding energy = $7.2 \times 10^{6} \times 235 = 1.7 \times 10^{9}$ eV **(1)** 2

[Second mark is for multiplying graph reading by 235]

Energy released

Half-sized nucleus has binding energy/nucleon = 8.2 (± 0.2) MeV **(1)**

so released energy/nucleon = $(8.2 - 7.2) \times 10^{6} \times 1.6 \times 10^{-19}$

$(=1.6 \times 10^{-13}$ J) **(1)**

Total energy released = $235 \times 1.6 \times 10^{-13}$ J $= 3.8 \times 10^{-11}$ J **(1)** 3

Energy released by fission

(2).6 × $10^{24} \times 4.0 \times 10^{-11}$J **=** 1.0×10^{14} J

[Allow e.c.f from candidate's numbers, within range] **(1)** 1

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5. Nuclear radiation which is around us

Background **(1)** 1

Source of radiation

e.g. Sun / rock (eg granite) / cosmic rays [not space] / **nuclear** power stations **(1)** 1

Why exposure greater today

Nuclear power stations/nuclear bomb tests/X–rays/
Radon from building materials **(1)** 1

Beta radiation

(i) Any two from:

- γ more difficult to shield
- β lower range (than γ)
- β more ionising (than γ) **(1) (1)**

(ii) α stopped by a few cm of air or has a short range/much
lower range (than β) / β radiation has a long range **(1)** 3

Why gamma radiation is suitable

Any two from:

· γ will pass through (metal of) wing / α and β cannot pass through the wing

· but passes more easily through cracks

· hence crack shows as darker mark on photo or increased count
on detector **(1) (1)** 2

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6. Plutonium-238

238 protons + neutrons [OR nucleons] in the (nucleus of the) atom **(1)** 1

Why plutonium source caused concern

If accident at launch, radioactive Pu would be spread around Earth **(1)** 1

Activity of plutonium source

$\lambda = \ln 2/88 \times 3.16 \times 10^7$ s $= 2.5 \times 10^{-10}$ (s^{-1}) **(1)**

Use of $dN/dt = -\lambda N$ **(1)**

$= 2.5 \times 10^{-10}\ s^{-1} \times 7.2 \times 10^{25} = 1.8 \times 10^{16}$ (Bq) **(1)** 3

Power delivered by plutonium

Use of power = activity × energy per decay **(1)**

$= 1.79 \times 10^{16}$ Bq $\times 5.6 \times 10^6 \times 1.6 \times 10^{-19}$ s

[conversion of MeV to J] **(1)**

$= 1.6 \times 10^4$ (W) **(1)** 3

[2×10^{16} Bq gives 1.79×10^4 (W)]

Whether power can be relied upon

Large number of nuclei present, so decay rate (almost) constant **(1)** 1

Percentage of power still available after 10 years

Percentage $= N/N_0 \times 100 = 100\ e^{-\lambda t}$ **(1)**

$= 100\ e^{-10 \times \ln 2/88} = 92\%$ **(1)** 2

[After 10 y, $N = N_0\ e^{-\lambda t} = 7.2 \times 10^{25} \times 0.92 = 6.65 \times 10^{25}$ **(1)**]

Why plutonium was chosen for Cassini mission

Examples:

- long (enough) half–life for duration of mission
- Power constant / no orientation problems compared with solar
- α-emitting, so energy from particles easily transferred
- availability **(1)** 1

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7. Why gamma radiation used

γ is the most/more penetrating **(1)** 1

(OR α/β **less** penetrating)

Factors controlling amount of radiation

Any 2 from:

- Strength/type of radiation source/half-life/age of source
- speed of conveyor belt/exposure time
- shape/size of food packages/surface area
- distance from radiation source **(1)** **(1)** Max 2

Suitable material for wall

Concrete/lead **(1)**

Suitable thickness

30 cm – 1 m/1 – 10 cm **(1)** 2
[thickness mark dependant on named material]

Source of natural radiation

Rocks, soil, cosmic rays, named radioactive element, sun, space, air **(1)** 1

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8. Age of part of the stalagmite

$\lambda = ln2/t_{1/2} = 1.2 \times 10^{-4}$ years^{-1} (= 3.8×10^{-12} s^{-1}) **(1)**

Use of $N = N_0 e^{-\lambda t}$ **(1)**
$1 = 256\, e^{-1.2 \times 10 - 4t}$
[allow 255 instead of 1 for this mark but do not carry forward]

t = 46 000 years (= 1.45×10^{12} s) **(1)** 3

[OR recognise 1/256 **(1)**
8 half-lives **(1)**
45 800 years **(1)**]

Carbon-14 concentration

Carbon-14 measurement would be greater **(1)** 1

Validity of radio-carbon dating

3 points, e.g.
- not valid
- twice original concentration gives greater proportion measured now
- object seems younger than it actually is
- older parts could have more carbon-14 than younger parts
- technique relies on constant levels, therefore unreliable
- mixture of old and young carbon-14 in 1 stalagmite makes dating impossible **(1) (1) (1)** 3

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9. Proton numbers:

55 and 94 **(1)** 1

Fuel for the power station:
(i) (Nuclear) fission (of ^{235}U) **(1)**
(ii) Absorption of a neutron by(^{238})U(followed by β-decay) **(1)** 2
[**not** bonding, **not** fusion, allow combining] [Any other particle mentioned in addition to neutron loses the mark]

Calculate emission rate:
Use of $\lambda = \ln 2 / t_{½}$ [allow either Cs $t_{½}$] **(1)**
See $1.5 \times 10^6.e^{-0.023 \times 20}$ [allow ecf of λ for this mark] **(1)**
Correct answer [9.5×10^5(Bq m^{-2})] **(1)**
[2040(Bq m^{-2}) scores 2/3]
OR
Work out number of half lives **(1)**
Use the power equation **(1)**
Correct answer **(1)** 3

Example of calculation:
$\lambda = \ln 2 / 30 = 0.023\ \text{yr}^{-1}$
$R = 1.5 \times 10^6.e^{-0.023 \times 20}\ \text{Bq m}^{-2}$
$R = 9.5 \times 10^5\ \text{Bq m}^{-2}$

Assumption:
the only source in the ground is ^{137}Cs / no ^{137}Cs is washed out of **(1)** 1
soil / no clean-up operation / no further contamination / reference to weather not changing the amount

Scattered isotopes:

(^{131})I and ^{134} Cs **(1)**
For either isotope: many half lives have passed / half life short compared to time passed / short half life therefore **now** low emission **(1)** 2

Comment:
Even the isotopes with a thirty year half life are still highly radioactive [eg accept strontium hasn't had a half life yet] **(1)**
Plutonium will remain radioactive for thousands of years (as the half life is very large) [accept the alpha emitting isotopes for plutonium] [accept plutonium half lives much longer than 20 years] **(1)** 2

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10. 3 **(1)**

Sum of reactant mass nos. = 236. Products must have same total mass no. **(1)** 2

Actual mass of products is slightly less (by Δm) than mass of reactants, and products have more kinetic energy (ΔE) than reactants. The two are related by

$\Delta E = c^2$ where c is the speed of light **(1)** 2

[Explanation in terms of binding energy is also acceptable]

$N/N_0 = e^{-\lambda t}$

$\lambda = \ln 2/t_{½} = 2.84 \times 10^{-5}$ years **(1)**

$\lambda t = 2.84 \times 10^{-2}$ **(1)**

$N/N_0 = e^{-(2.4 \times 10^{-2})} = 0.97$ **(1)** 3

3% **(1)** 1

The products of the decay will themselves be radioactive so will contribute to the overall activity of the sample **(1)** 1

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11. Number of protons and neutrons in isotope of cadmium

Protons: 48 **(1)**
Neutrons: (122 – 48) = 74 **(1)** 2

Process which occurs in a fission reaction

3 points, e.g.

- starts with large/heavy nucleus/atom
- nucleus captures/absorbs neutron
- (becomes) unstable

- splits into (two) smaller nuclei (and more neutrons)
- with emission of energy (from mass defect)
- increased binding energy (per nucleon) **(1) (1) (1)** 3

Calculation of change in mass

Use of $\Delta E = c^2\Delta m$ **(1)**

$\Delta m = \Delta E/c^2$

$\Delta m = 3.2 \times 10^{-11}$ J/(3 × 108 m s^{-1})^2

$= 3.6 \times 10^{-28}$ kg **(1)** 2

Calculation of number of fissions required each second

Correct use of efficiency **(1)**
e.g. fission energy required = 660 MW × 100/30 = 2200 MW

No. of fissions per second = 2200×10^6 J/3.2×10^{-11} J = 6.9×10^{19} **(1)** 2

Why it is necessary to have a lot more fuel in nuclear reactor

2 points, e.g.
- reactor needs to run for longer than 1 second
- need sustained chain reaction
- fuel must last for years
- only a small proportion of U-235 undergoes fission
- only small proportion of uranium is U-235
- greater certainty/frequency of neutron collisions **(1) (1)** 2

12. Warm river

How radioactive nuclei heat,

e.g. by decay/ionising/nuclear radiation 1

α, β and γ radiation

α helium nucleus [or equivalent] **(1)**

β (fast) electron **(1)**

γ electromagnetic wave **(1)**

[Accept an answer that fully differentiates between the types of radiation
by describing their properties] 3

Most hazardous nuclei

α emitting **(1)**

When ingested, α particles damage body cells

[e.c.f. from previous β or γ linked to penetration & damage] **(1)** 2

Source of radioactivity

e.g. rocks, Sun, cosmic radiation 1

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