ESAT Physics Prep

Week 7 – Radioactivity

ANSWERS

Week 1 – Electricity

Week 2 – Magnetism

Week 3 – Mechanics

Week 4 – Thermal physics

Week 5 – Matter

Week 6 – Waves

Week 7 – Radioactivity

There is one sample ESAT test – note that they use the same questions from NSAA 2020 specimen paper. Past NSAA & ENGAA questions are the most relevant.

There are no calculators in the ESAT.

Radioactivity spec

P7. Radioactivity

P7.1 Atomic structure:

a. Understand the atom in terms of protons, neutrons and electrons.
b. Know and be able to apply the nuclear model of atomic structure.
c. Know the relative charges and masses of protons, neutrons and electrons.
d. Understand and be able to use the terms *atomic number* and *mass number*.
e. Know and understand the term *isotope*.
f. Know and understand the term *nuclide*, and use nuclide notation.
g. Understand that ionisation is caused by the gain/loss of electrons.

P7.2 Radioactive decay:

a. Know and understand that emissions arise from an unstable nucleus.
b. Know and understand the random nature of emissions.
c. Know and understand the differences between alpha, beta and gamma emission.
d. Know and understand the nature of alpha and beta particles, and gamma radiation.
e. Be able to use and interpret nuclear equations.
f. Know the effect of decay on atomic number and mass number.

P7.3 Ionising radiation:

a. Know the relative penetrating abilities of alpha, beta and gamma radiation.
b. Know the relative ionising abilities of alpha, beta and gamma radiation.
c. Understand qualitatively the deflection of alpha, beta and gamma radiation in electric or magnetic fields.
d. Know and appreciate the existence of background radiation.
e. Understand the applications and hazards of ionising radiation.

P7.4 Half-life:

a. Be able to interpret graphical representations of radioactive decay (including consideration of decay products).
b. Understand the meaning of the term *half-life*.
c. Understand and be able to apply half-life calculations.

$\lambda_x = \frac{\ln 2}{T_{\frac{1}{2}}} = \frac{\ln 2}{2}$ $\lambda_y = \frac{\ln 2}{3}$

Q10 ENGAA 2023

10 Two samples of pure radioactive isotopes X and Y decay with half-lives of 2 days and 3 days, respectively.

Both X and Y decay in a single step into different stable isotopes.

Initially the number of atoms of X is twice the number of atoms of Y.

After how many days are the expected numbers of atoms of X and Y equal to each other?

A The expected numbers of atoms of X and Y are never equal.

B 2 days

C 3 days

D 4 days

E 6 days

F 12 days

$2N e^{-(\frac{\ln 2}{2})t} = N e^{-(\frac{\ln 2}{3})t}$

$\ln 2 - \frac{\ln 2}{2} t = -\frac{\ln 2}{3} t$

$1 - \frac{1}{2}t = -\frac{1}{3}t \Rightarrow \frac{1}{6}t = 1$

$t = 6$ days

Q27 NSAA 2023

27 The nuclide symbol for helium-3 is ${}^{3}_{2}\mathrm{He}$.

${}^{12}_{4}X$

A nuclide of element X has double the nuclear charge and four times the mass of helium-3.

This nuclide of X decays by a single beta (β^-) emission to form a nuclide of element Z.

What is the nuclide symbol for this nuclide of Z?

A ${}^{8}_{2}Z$

B ${}^{8}_{4}Z$

C ${}^{12}_{4}Z$

D ${}^{8}_{5}Z$

E ${}^{12}_{5}Z$

F ${}^{16}_{5}Z$

G ${}^{7}_{8}Z$

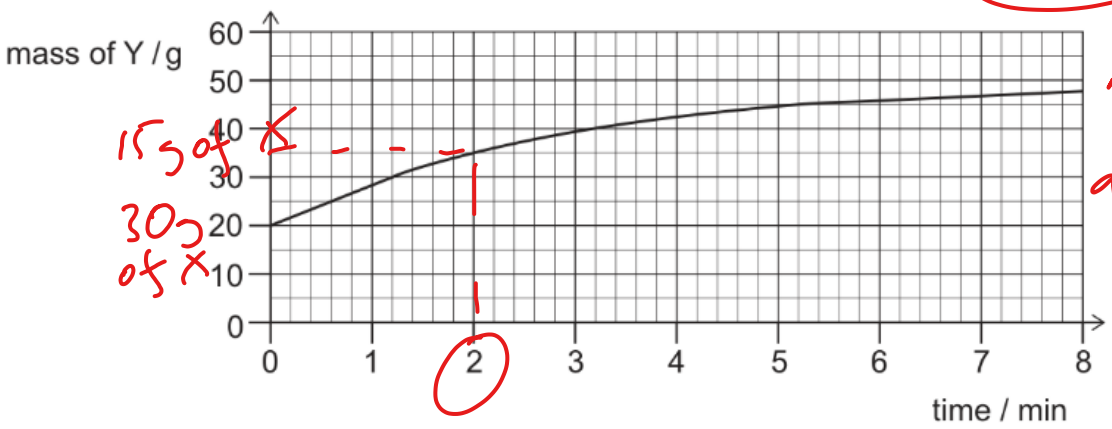
H ${}^{16}_{8}Z$

${}^{12}_{4}X \rightarrow {}^{12}_{5}Z + {}^{0}_{-1}\beta$

Q34 NSAA 2022

34 Radioactive isotope X undergoes a single beta (β^-) decay to form the stable isotope Y.

A sample consists only of X and Y. The graph shows how the mass of Y present in the sample varies with time. After a long time, the mass of Y in the sample becomes a constant 50 g.



What is the half-life of X?

A 0.6 minutes

B 1.2 minutes

C 2.0 minutes

D 3.2 minutes

E 4.0 minutes

F 5.2 minutes

Q16 ENGAA 2021

16 A radioactive nuclide X decays in a single stage to a stable nuclide R.

A radioactive nuclide Y decays in a single stage to a stable nuclide S.

When a rock formed it contained equal numbers of atoms of all four nuclides X, Y, R and S.

The half-life of X is T years and the half-life of Y is $2T$ years.

What is the value of $\frac{\text{number of atoms of R}}{\text{number of atoms of S}}$ at a time $4T$ years after the rock has formed?

(Assume that no other processes add or remove X, Y, R or S from the rock during this time.)

A $\frac{1}{4}$

B $\frac{17}{20}$

C $\frac{31}{28}$

D $\frac{6}{5}$

E $\frac{5}{4}$

F 2

$\frac{1}{16}$ left

$\frac{1}{4}$ left

$\frac{R}{S} = \frac{1+\frac{15}{16}}{1+\frac{3}{4}} = \frac{\frac{31}{16}}{\frac{7}{4}}$

$= \frac{31}{16} \times \frac{4}{7} = \frac{31}{4} \times \frac{1}{7} = \frac{31}{28}$

Q4 ENGAA 2020

4 Uranium-238 $\left(^{238}_{92}\text{U}\right)$ decays by a series of alpha and beta (β^-) emissions to become the stable isotope lead-206 $\left(^{206}_{82}\text{Pb}\right)$.

$238 - 206 = 32 = 8\alpha$

How many beta (β^-) particles are emitted in the decay of one uranium-238 nucleus to lead-206?

atomic no. goes down by 10
would be 16 from α alone
$\therefore$ 6 β^-

A 6

B 8

C 10

D 12

E 14

F 16

Q36 NSAA 2020

36 A sample contains only one radioactive isotope. This isotope decays in a single step with a half-life of 120 minutes to a stable isotope.

The sample is placed near to a radiation detector which measures the count rate. The count rate reading is 910 counts per minute (cpm). $C + b = 910 \Rightarrow C = 910 - b$

After 240 minutes the measurement is repeated. The count rate reading is now 238 cpm. $\frac{C}{4} + b = 238$

After a further 360 minutes have elapsed, a third measurement of the count rate is made. ↳ 5 T½ in total

What is the count rate due to background radiation and what is the expected reading in the third measurement?

	background count rate / cpm	*third measurement* / cpm
A	224 ✗	148
B	224 ✗	226
C	142 ✗	28
D	142 ✗	148
E	142 ✗	154
F	14 ✓	14
G	14 ✓	28
H	14 ✓	42 ✓

$\frac{910 - b}{4} + b = 238$

$910 + 3b = 952$

$3b = 42$

$b = 14$

$C = 910 - 14$

$= 896$

$\frac{C}{32} + b = \frac{896}{32} + 14$

$= 42$

$\beta: n \rightarrow p + e^- + \bar{\nu}_e$

Q12 ENGAA 2019

12 The radioactive isotope X becomes the stable isotope Y after a succession of decays involving only the emission of alpha and beta (β^-) particles.

During the decay of one nucleus from X to Y, a total of seven particles are emitted. It is known that more of these particles are alpha particles than beta particles.

The atomic number of X is Z and the mass number of X is A.

Which row in the table could give the atomic number and the mass number of Y?

	atomic number of Y	*mass number of* Y
A	$Z - 2$	$A - 12$
B	$Z - 5$	$A - 8$
C	$Z - 8$	$A - 20$
D	$Z - 10$	$A - 24$
E	$Z - 11$	$A - 16$

$4\alpha, 3\beta: Z-5, A-16$

$5\alpha, 2\beta: Z-8, A-20$

$6\alpha, 1\beta: Z-11, A-24$

Q20 ENGAA 2019

$X:Y \Rightarrow X:X$

20 A sample initially contains equal numbers of atoms of a radioactive isotope X and a stable isotope Y.

Isotope X has a half-life of 3 years and decays in a single stage to the stable isotope Y.

What is the ratio

number of atoms of X : *number of atoms of* Y

in the sample 6 years later?

6 years later

$\frac{X}{4} : \frac{7X}{4}$

A The sample contains only isotope Y.

B 1 : 7

C 1 : 4

D 1 : 3

E 7 : 4

Q2 ENGAA 2018

$\beta: n \rightarrow p + e^- + \bar{\nu}e$

2 An unstable nucleus X becomes a stable nucleus Y after a succession of decays, during which a total of 5 alpha particles and 2 beta (β^-) particles are emitted.

How many fewer protons does nucleus Y contain than nucleus X?

$\rightarrow -10p \qquad \rightarrow +2p$

A 6

B 8

C 10

D 12

E 14

F 16

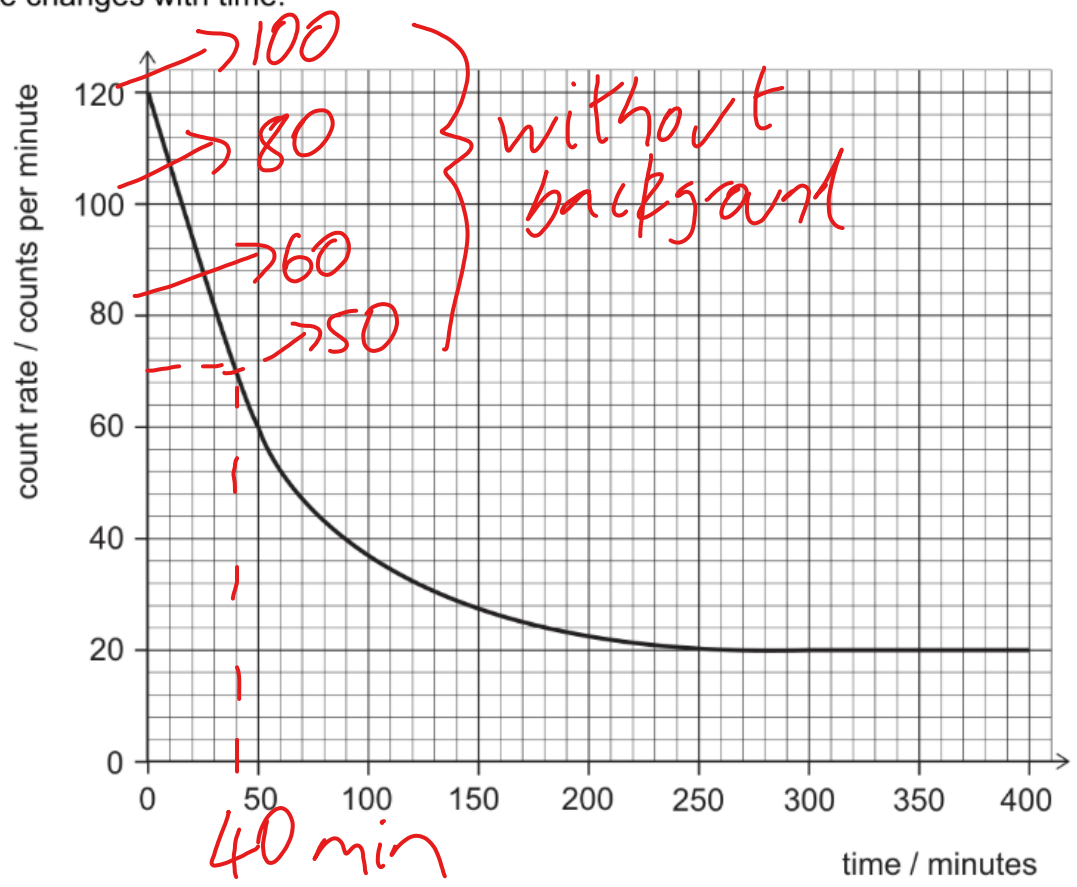
G 18

H 20

Q14 ENGAA 2018

14 A radioactive isotope decays in a single step to a stable isotope.

A radiation detector is placed very near to a sample of the radioactive isotope in a laboratory. The count rate on the detector changes as time elapses. The graph shows how the measured count rate changes with time.



What is the background count rate and what is the half-life of the isotope?

	background count rate / counts per minute	*half-life of isotope* / minutes
A	20	40
B	20	50
C	20	60
D	20	65
E	120	40
F	120	50
G	120	60
H	120	65

Q24 ENGAA 2018

24 A neutron is absorbed by a uranium-235 ($^{235}_{92}U$) nuclide.

The resulting nuclide undergoes fission to produce a bromine-88 ($^{88}_{35}Br$) nuclide, a lanthanum-145 nuclide and some neutrons.

The lanthanum-145 nuclide is radioactive and emits a beta (β^-) particle.

How many neutrons are emitted in the fission reaction and how many protons are there in the nuclide formed by the decay of lanthanum-145?

	neutrons	*protons*
A	2	55
B	2	56
C	2	57
D	2	58
E	3	55
F	3	56
G	3	57
H	3	58

Q10 ENGAA 2017

10 When a plutonium-239 nucleus absorbs a neutron it undergoes nuclear fission. One particular fission reaction results in the creation of xenon and zirconium as daughter nuclei. The nuclear equation for this reaction is shown but with some non-zero integers replaced by the letters w, x, y and z.

$$^{1}_{0}n + {}^{239}_{94}Pu \rightarrow {}^{w}_{54}Xe + {}^{y}_{x}Zr + z\,{}^{1}_{0}n$$

Which equation is correct?

A $w + y = 240$

B $z = 240 - (w + y)$

C $x = 40 - z$

D $94 = 54 + x + 1$

E $240 = 54 + x$

F $94 = w + y + 1$

$\beta: n \rightarrow p + e^- + \bar{\nu}_e$

Q14 ENGAA 2017

14 The nuclide ${}^{P}_{Q}X$ decays to the stable nuclide Y. During this process four particles are emitted: an α-particle and three β^- particles.

Which of the following is **not** a nuclide that could be formed at any stage during this process?

nuclide	*atomic mass*	*atomic number*
A	P	Q − 1
B	P	Q + 1
C	P	Q + 2
D	P	Q + 3
E	P − 4	Q − 2
F	P − 4	Q − 1
G	P − 4	Q
H	P − 4	Q + 1

× can never lose one proton (+ same mass no.)

Q2 ENGAA 2016

1 α

2 A nuclide ${}^{214}_{82}Pb$ changes by radioactive decay into the nuclide ${}^{210}_{82}Pb$.

Which combination of emissions produces this change?

$\beta: n \rightarrow p + e^- + \bar{\nu}_e$

A 3 alpha

B 2 alpha and 1 beta

C 2 alpha and 2 beta

D 1 alpha and 2 beta

E 3 beta

Q6 ENGAA 2016

6 A uranium-235 nucleus can undergo fission to produce two smaller nuclei.

Which of the diagrams, if any, could represent this process?

diagram 1

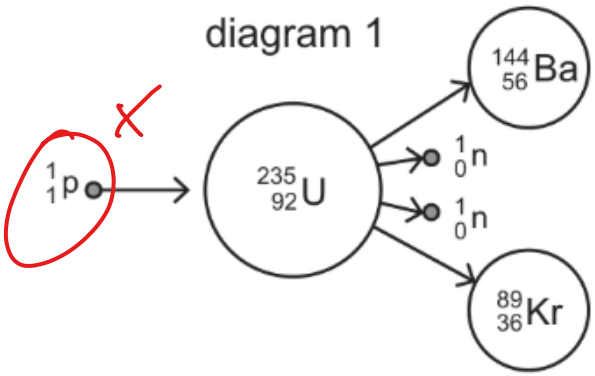


diagram 2

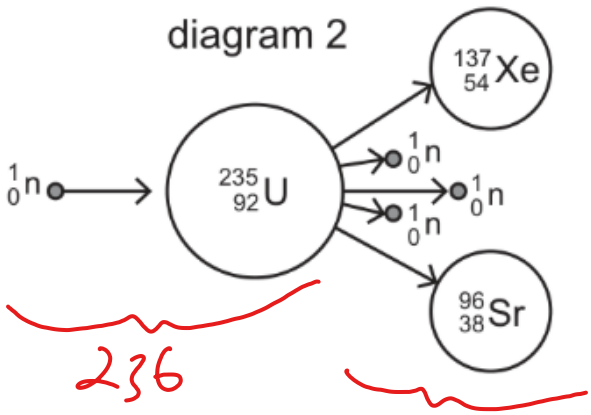
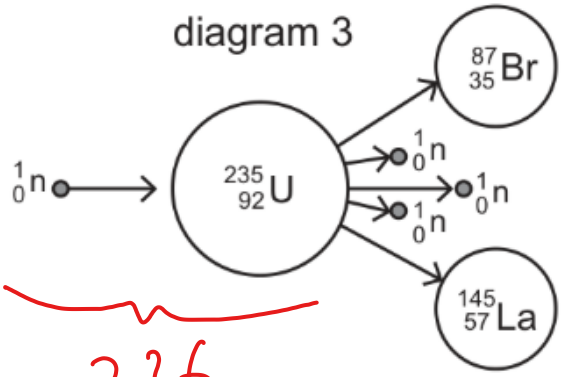


diagram 3



A none of them

B 1 only

C 2 only

D 3 only

E 1 and 2 only

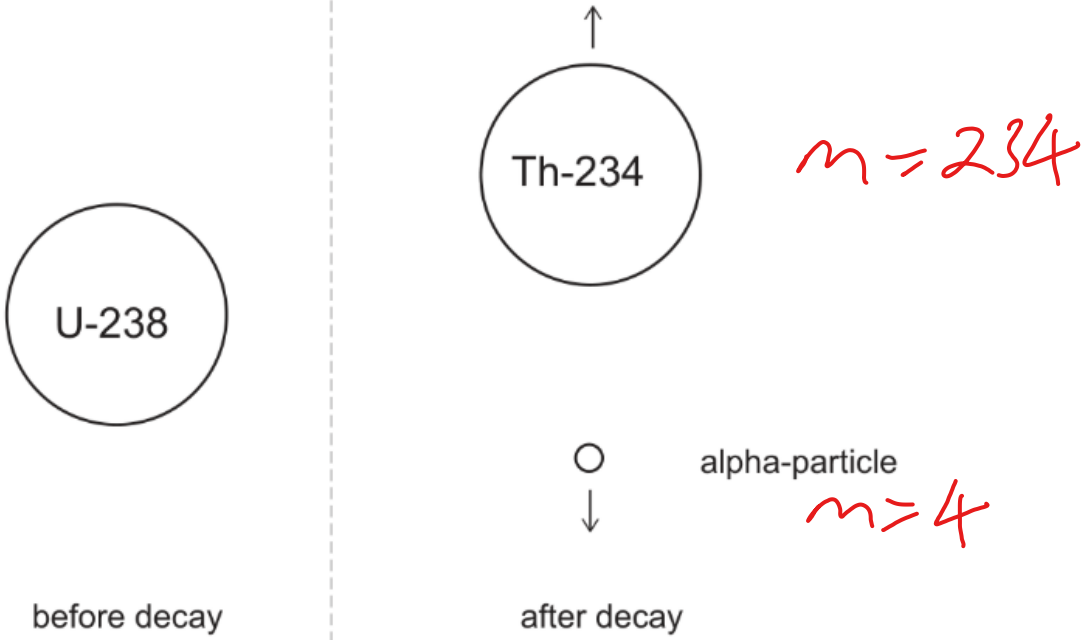
F 1 and 3 only

G 2 and 3 only

H 1, 2 and 3

Q26 ENGAA 2016

26 When a stationary uranium-238 nucleus decays by alpha emission it forms a nucleus of thorium-234. The total kinetic energy produced by the decay is E.



$m = 234$

$m = 4$

What is the kinetic energy of the alpha particle?

A $\frac{4E}{238}$

B $\frac{4E}{234}$

C $\frac{E}{2}$

D $\frac{234E}{238}$

E E

Mom conserved:

$m_{Th} v_{Th} = m_\alpha v_\alpha$

$234 v_{TH} = 4 v_\alpha$

$v_{TH} = \frac{4}{234} v_\alpha$

Total KE = E

$E = \frac{1}{2} \times 4 \times v_\alpha^2 + \frac{1}{2} \times 234 \times v_{TH}^2$

$= 2 v_\alpha^2 + \frac{1}{2} \times 234 \times \left(\frac{4}{234}\right)^2 v_\alpha^2$

$= 2 v_\alpha^2 + \frac{1}{2} \times \frac{16}{234} v_\alpha^2$

$= 2 v_\alpha^2 + \frac{8}{234} v_\alpha^2$

Overwhelming majority is KE of α

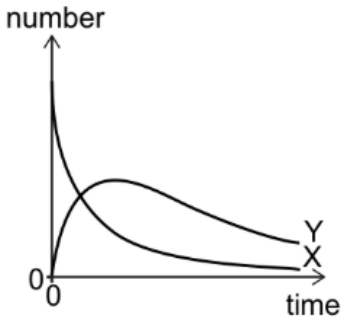
Q33 NSAA 2016

33 A sample of a radioactive isotope X decays to one other radioactive isotope Y. Y has a half-life that is double that of X. Initially only X is present.

Which graph could represent how the numbers of nuclei of X and Y that are present in the sample vary with time?

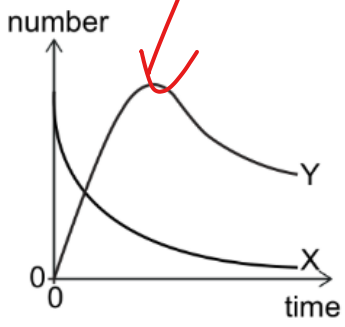
(All graphs cover the same period of time.)

A



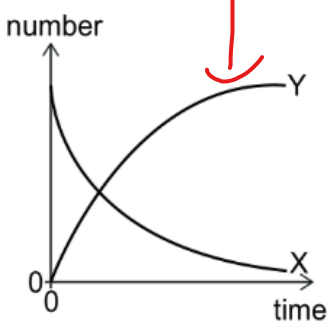
B

too high

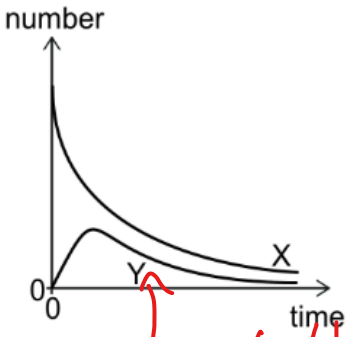


C

not decaying



D



same half life as X

E

should start at 0.