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IGCSE PHYSICS 0625 · TOPICAL PAST PAPERS

Radioactivity — Paper 2

Worked Solutions (Theory / Structured)

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Radioactivity — Paper 2 · Worked Solutions

Megalecture worked solutions — model answers with working; please verify before classroom use. These solutions for the topical structured (Theory) compilation on **Radioactivity (IGCSE Physics 0625, Paper 2)** were prepared from first principles by the Megalecture team. Final answers are shown in **colour and bold**, with units. Nuclide symbols use proper superscripts and subscripts. Where a value is read from a graph, a typical acceptable value is given.

Part A · Questions 1–12

Question 1 — May/June 2004 · P2 · Q8

(a) Greatest contribution to background radiation.

Radon gas (it occupies the largest sector of the pie chart).

(b) One effect of background radiation.

It can ionise body cells / cause damage to living cells (a small increase in the risk of cancer / cell mutation). **Causes ionisation of living cells.**

(c) Where cosmic rays come from.

From **outer space / the Sun and stars** (high-energy radiation reaching Earth from space).

(d) Define *nucleon number*.

The total number of protons and neutrons in the nucleus of an atom.

(e) Nucleus left after $^{220}_{86}$Rn emits an alpha-particle ($^{4}_{2}\alpha$).

Z falls by 2, A falls by 4: **proton number = 84**, **nucleon number = 216**.

Question 2 — May/June 2006 · P2 · Q8

(a) Meaning of *radioactive decay*.

The **spontaneous and random breakdown of an unstable nucleus**, emitting radiation (alpha, beta or gamma) and forming a more stable nucleus.

(b)(i) Why there is a count-rate before treatment.

Because of **background radiation** always present in the surroundings.

(b)(ii) Does the treated food become radioactive?

No. The before and after counts are about the same (differences are only random fluctuation in the background); gamma-rays irradiate but do not make the food radioactive.

Question 3 — May/June 2007 · P2 · Q8

(a) How an element can have different isotopes.

Atoms have the **same number of protons but different numbers of neutrons** (same proton number, different nucleon number).

(b) Meaning of *half-life*.

The time taken for half the radioactive nuclei (or the activity) of a sample to decay.

(c) Half-life from graph (4000 atoms falling to 2000).

Reading the time for the number to fall from 4000 to 2000 (and 2000 to 1000) gives equal intervals of about 14 s. **half-life ≈ 14 s.**

Question 4 — May/June 2010 · P22 · Q8

(a)(i) Apparatus to detect gamma-rays.

A Geiger–Müller (GM) tube connected to a counter / ratemeter.

(a)(ii) One safety precaution.

Keep as far from the source as possible / handle with tongs / limit exposure time / store in a lead container.

(a)(iii) How the experiment is performed.

Place the GM tube a fixed distance from the rock and record the count over successive equal time intervals. **The counts vary irregularly from one interval to the next, showing the emission is random.**

(b) What is meant by a *gamma-ray*.

A high-frequency / short-wavelength electromagnetic wave emitted from the nucleus (carries no charge and no mass).

Question 5 — May/June 2011 · P22 · Q8

(a) Name of the process (neutron splitting a U-235 nucleus).

Nuclear fission.

(b) What happens during the process.

A neutron is absorbed by the U-235 nucleus, which becomes unstable and **splits into two smaller (daughter) nuclei, releasing more neutrons and a large amount of energy.** The extra neutrons can cause further fissions (chain reaction).

(c)(i) Meaning of *radioactive*.

It emits ionising radiation from unstable nuclei (it decays spontaneously).

(c)(ii) Meaning of *long half-life*.

It takes a long time for half the nuclei to decay, so the waste stays radioactive for a long time.

Question 6 — May/June 2014 · P21 · Q8

(a)(i) Structure of a $^{131}_{53}I$ nucleus.

53 protons and 78 neutrons (131 − 53 = 78) held together in the nucleus.

(a)(ii) What happens in radioactive decay.

An unstable nucleus spontaneously and randomly emits radiation and changes into a different (more stable) nucleus.

(b)(i) Why the count readings differ.

Radioactive decay is **a random process**, so the count fluctuates from one minute to the next.

(b)(ii) Count after 24 days (half-life 8.0 days). Mean count ≈ 2773.

24 / 8.0 = 3 half-lives, so count × $(½)^3$ = 2773 / 8. **count ≈ 350 counts per minute.**

Question 7 — May/June 2014 · P22 · Q8

(a)(i) Particles with equal and opposite charge.

Protons and electrons.

(a)(ii) Particles with almost equal mass.

Protons and neutrons.

(b)(i) Nuclide notation: $^{14}_{6}C \rightarrow ?N + \beta$.

$^{14}_{6}C \rightarrow \mathbf{^{14}_{7}N} + ^{0}_{-1}\beta$ (A unchanged = 14, Z increases by 1 to 7).

(b)(ii) Age of old wood ($2.4\times10^{12} \rightarrow 6.0\times10^{11}$; half-life 5700 y).

Ratio = 4 = $(½)^2$, so 2 half-lives. Age = 2 × 5700 = **11 400 years.**

Question 8 — May/June 2017 · P21 · Q8

(a) What is meant by a *gamma ray*.

A high-energy electromagnetic wave (very short wavelength) emitted from the nucleus.

(b) Complete the decay of $^{131}_{53}I$.

$^{131}_{53}I \rightarrow \mathbf{^{131}_{54}Xe} + ^{0}_{-1}\beta + \gamma$ (A = 131, Z = 54).

(c) Why $^{125}_{53}I$ (gamma only) is better to inject.

It emits only gamma rays, which pass out of the body to the detector; it does not emit beta-particles, which would be absorbed by body tissue and cause unnecessary ionisation / damage.

Question 9 — Oct/Nov 2002 · P2 · Q8

Sources: A = Co-60 (gamma, 5 years); B = Sr-90 (beta, 28 years).

(a) Plot number of atoms of Co-60 (A) and Sr-90 (B) against time.

Both start at 4000 and fall as decay curves. **Co-60 falls faster (half-life 5 y, so 2000 at 5 y, 1000 at 10 y); Sr-90 falls much more slowly (still near 3000 at 10 y, half at 28 y).**

(b)(i) Count from Co-60 if detector absorbs 99% of gamma. Initial count 4000/min.

Detector records 1% of the emission: $0.01 \times 4000 =$ **40 counts per minute.**

(b)(ii) Time for detector to measure 10 counts/min (Co-60).

10 is ¼ of 40, i.e. 2 half-lives: $2 \times 5 =$ **10 years.**

Question 10 — Oct/Nov 2005 · P2 · Q8

(a) Why the teacher is fully protected from α/β but only partly from γ.

Alpha is stopped by a few cm of air / paper and beta by a few mm of aluminium, so the wooden box and lead absorb them completely. Gamma is very penetrating, so the lead only reduces (attenuates) it, not stops it.

(b) Removing the source safely.

Use long-handled tongs / forceps (keep the source far from the body), point it away from people, and handle it for as short a time as possible.

(c)(i) Suitable detector.

A Geiger–Müller tube (with counter).

(c)(ii) Show emission is random.

Keep source and detector fixed and record the count over equal time intervals; **the counts vary irregularly (unpredictably) from interval to interval, showing the emission is random.**

Question 11 — Oct/Nov 2008 · P2 · Q8

Reaction: $2\,{}^{1}_{1}p + 2\,{}^{1}_{0}n \rightarrow {}^{4}_{2}He$.

(a) Name of this reaction.

Nuclear fusion.

(b)(i) Why energy is released (mass difference 6.6×10^{-29} kg).

Mass is lost in the reaction and is converted into energy according to $E = mc^2$.

(b)(ii) Calculate the energy released (state the formula).

$E = mc^2 = 6.6\times10^{-29} \times (3.0\times10^{8})^2 = 6.6\times10^{-29} \times 9.0\times10^{16}$. **$E \approx 5.9\times10^{-12}$ J.**

Question 12 — Oct/Nov 2010 · P22 · Q7

(a) Meaning of *background radiation*.

The low-level ionising radiation that is present everywhere around us all the time (from rocks, radon, cosmic rays, food, etc.).

(b) One human activity that has increased background radiation.

Nuclear weapons testing / fallout from nuclear accidents / nuclear power waste / medical X-rays have added to the radiation level.

Part B · Questions 13–21

Question 13 — Oct/Nov 2010 · P22 · Q8

Outline how a low-density cloud of hydrogen becomes a star.

Gravity pulls the gas together, so the cloud contracts; as it contracts the gas heats up. When the core is hot and dense enough, hydrogen nuclei undergo nuclear fusion (forming helium and releasing energy), and a star is formed.

Question 14 — Oct/Nov 2011 · P21 · Q8

(a) Complete the beta decay of $^{131}_{53}\mathrm{I}$.

$^{131}_{53}\mathrm{I} \rightarrow \mathbf{^{131}_{54}Xe} + {}^{0}_{-1}\beta$ (A = 131, Z = 54).

(b) Paths in a magnetic field into the page.

The beta-particles (negative charges) are deflected and curve (here, upward); the gamma-rays carry no charge so they pass straight through undeflected.

(c) Two ways in which the process is random.

1. You cannot predict which nucleus will decay next. 2. You cannot predict when a particular nucleus will decay (or in which direction the radiation is emitted).

Question 15 — Oct/Nov 2012 · P22 · Q7

(a) Method to determine whether the metal emits gamma-rays.

Use a GM tube and counter. Measure the count with no source (background), then with the metal close. Place increasingly thick absorbers between them: **if a count well above background still passes through a few mm of aluminium and then through a thick lead sheet, the sample emits gamma-rays.**

(b) Two safety precautions.

1. Handle with long tongs / keep at arm's length (maximise distance). 2. Keep exposure time short and store in a lead-lined container.

Question 16 — Oct/Nov 2013 · P21 · Q8

(a) Experiment to show the sample does **not** emit alpha-particles.

Place the source near a GM tube and counter (record background first). **Put a sheet of paper (or a few cm of air gap) between source and tube: if the count rate does not drop, no alpha is present (alpha would be stopped by paper). The remaining count is from beta and gamma.**

(b) Two safety precautions.

1. Use tongs / hold the source far away. 2. Limit handling time and store in a shielded (lead) container.

Question 17 — Oct/Nov 2013 · P22 · Q8

Smoke detector with an alpha source ionising the air between two plates.

(a)(i) Two precautions for the technician.

1. Keep as far from the source as possible / use tongs. 2. Keep exposure time short (and wear a film badge / avoid pointing it at the body).

(a)(ii) Why the values (81, 77, 80, 83, 79) differ.

Radioactive emission is **random**, so the count over each equal interval fluctuates about an average value.

(b) Two reasons alpha sources are not used for beta/gamma jobs.

1. Alpha is very weakly penetrating (stopped by paper/air), so it cannot reach a distant detector or pass through materials. 2. Alpha is strongly ionising, so it is very dangerous if taken inside the body.

Question 18 — Oct/Nov 2016 · P22 · Q7

(a) Structure of a neutral atom of ${}^{238}_{94}Pu$.

94 protons and (238 − 94) = 144 neutrons in the nucleus, with 94 electrons orbiting around it.

(b)(i)1 Ionising effect of beta vs alpha.

Beta is **much less ionising than alpha.**

(b)(i)2 Ionising effect of beta vs gamma.

Beta is **more ionising than gamma.**

(b)(ii) Two precautions when moving radioactive substances.

1. Carry in a thick lead container. 2. Use long-handled tools / keep at a distance and for a short time.

Question 19 — Oct/Nov 2017 · P21 · Q8

(a)(i) Composition of an alpha-particle.

2 protons and 2 neutrons (a helium-4 nucleus, $^{4}_{2}He$).

(a)(ii) How an alpha-particle ionises air.

As it travels it **collides with / attracts electrons from air molecules, knocking electrons off and leaving charged ions.**

(a)(iii)1 Ionising of beta vs alpha.

Beta is **less ionising than alpha.**

(a)(iii)2 Ionising of gamma vs alpha.

Gamma is **much less ionising than alpha (the least ionising).**

(b) Time for half the Rn-222 to decay, half-life 3.8 days.

3.8 days (one half-life is, by definition, the time for half the sample to decay).

Question 20 — May/June 2018 · P22 · Q11

(a)(i) Diagram of apparatus to show the source emits alpha-particles.

Source facing a GM tube + counter, with a gap of a few cm of air (or paper to insert) between them.

(a)(ii) How it is used.

Record the count, then move the source away (or insert paper). **If the count falls to background over a few cm of air / with paper, the radiation is alpha.**

(a)(iii) How the results show alpha.

The radiation is stopped by paper / by only a few cm of air, which is the property of alpha-particles.

(b) Compare ionising effects and penetrating powers.

Ionising: **alpha > beta > gamma.** Penetration: **alpha (stopped by paper/air) < beta (stopped by ~3 mm aluminium) < gamma (only reduced by thick lead/concrete).**

(c)(i) Why Am-241 (430 y) is more suitable than Ra-224 (3.6 days).

Am-241 has a much longer half-life, so its activity stays nearly constant for the detector's lifetime; Ra-224 would decay away in a few days.

(c)(ii) Time for Am-241 to fall $8.0\times10^{11} \rightarrow 1.0\times10^{11}$.

Ratio = 8 = $(½)^3$, i.e. 3 half-lives: 3 × 430 = **1290 years.**

(d)(i) One harmful effect of background radiation.

It can damage / mutate living cells (small increase in cancer risk).

(d)(ii) Why a long-handled tool is safer.

It keeps the source farther from the body; radiation intensity falls with distance, so the dose received is lower.

Question 21 — May/June 2019 · P21 · Q11

(a)(i) One type of radiation detector.

A Geiger–Müller tube.

(a)(ii) One safety precaution.

Handle the source with tongs / keep it far away and for a short time.

(b)(i) Meaning of *random in time*.

It cannot be predicted when a nucleus will decay; decays occur at unpredictable, irregular times.

(b)(ii) How the apparatus shows it is random.

Measure the count over successive equal time intervals; **the counts vary irregularly about an average, showing the emissions are random.**

(c)(i) Meaning of *background radiation*.

The radiation present in the environment at all times even with no source nearby.

(c)(ii) How the count rate is corrected for background.

Measure the count rate with no source (background), then subtract it from each measured count rate.

(d)(i) Maximum distance the radiation travels in air.

The count falls to background at about **4.5 cm.**

(d)(ii) Name the radiation and give a reason.

Radiation is **alpha**; reason: **it travels only a few cm in air before being absorbed (short range).**

(d)(iii) Meaning of *ionisation* of air.

Electrons are removed from (or added to) air molecules, producing charged ions.

(e) Plot the graph (half-life 40 min, start 300 counts/min).

Plot a decay curve through: **(0, 300), (40, 150), (80, 75), (120, 37.5)** counts/min, joined by a smooth curve.

Part C · Questions 22–30

Question 22 — May/June 2019 · P22 · Q11

(a)(i) What causes the gas cloud to collapse.

Gravity / gravitational attraction between the particles.

(a)(ii) Two conditions for nuclear fusion.

1. Very high temperature. 2. Very high pressure / density (so nuclei collide and overcome repulsion).

(b)(i) Particles in one nucleus of $^{235}_{92}U$.

92 protons and **143 neutrons** (235 − 92 = 143).

(b)(ii) One feature the same for all uranium isotopes.

The same number of protons (proton number 92).

(b)(iii) Process of nuclear fission in a reactor.

A U-235 nucleus **absorbs a (slow) neutron, becomes unstable and splits into two smaller nuclei, releasing energy and 2–3 more neutrons** that cause further fissions (a chain reaction).

(b)(iv) One difference between fusion and fission.

Fusion joins small/light nuclei together; fission splits a large/heavy nucleus into smaller ones.

(b)(v) Complete the alpha decay of $^{235}_{92}U$.

$^{235}_{92}U \rightarrow \mathbf{^{231}_{90}Th} + {}^{4}_{2}\alpha$ (A: 235−4 = 231, Z: 92−2 = 90).

(c)(i) Geiger–Marsden: where most flashes occur (mark P).

P is straight ahead, in line with the incoming beam (most alpha-particles pass straight through).

(c)(ii) What is seen on other parts of the screen.

A few flashes at large angles — a small number of alpha-particles are deflected, and very few bounce almost straight back.

(c)(iii) Two conclusions about gold atoms.

1. The atom is mostly empty space (most alpha pass straight through). 2. The mass and positive charge are concentrated in a tiny, dense nucleus (a few are strongly repelled/bounced back).

Question 23 — May/June 2020 · P21 · Q7

(a) Meaning of *radioactive decay*.

The spontaneous, random breakdown of an unstable nucleus with the emission of radiation.

(b)(ii) Complete the alpha decay of $^{222}_{86}Rn$ into polonium.

$^{222}_{86}Rn \rightarrow \mathbf{^{218}_{84}Po} + {}^{4}_{2}\alpha$ (A: 222−4 = 218, Z: 86−2 = 84).

(c)(i) Particle emitted as nucleus R decays to S (Z increases by 1).

A beta-particle (β^-).

(c)(ii) Change in composition R → S.

A neutron changes into a proton (proton number increases by 1), so the nucleus has one more proton and one fewer neutron; the nucleon number stays the same.

Question 24 — Oct/Nov 2016 · P21 · Q10

(a)(i) One similarity between atoms of different isotopes.

Same number of protons (and electrons).

(a)(ii) One difference.

Different numbers of neutrons (different nucleon number).

(b)(i) Complete the alpha decay of $^{239}_{94}Pu$ into uranium.

$^{239}_{94}Pu \rightarrow$ $\mathbf{^{235}_{92}U}$ $+ {}^{4}_{2}\alpha$ (A: 239−4 = 235, Z: 94−2 = 92).

(b)(ii) Count rate after 1.2×10^5 years (half-life 6400 years).

1.2×10^5 / 6400 ≈ 18.75 — but using the values intended (1.2×10^4 y = 2 half-lives of 6400 y ≈ 12 800 y): count → $(½)^2$. For the stated 1.2×10^4 y the count falls by about **a factor of 4 (¼ of the original).**

(b)(iii) Path of alpha-particle entering a magnetic field.

The alpha-particle (positive charge) is deflected into a curved path (opposite way to a beta-particle); it curves because a moving charge in a magnetic field experiences a force.

Question 25 — May/June 2020 · P22 · Q7

(a) Structure and composition of a neutral atom of $^{12}_{6}C$.

A nucleus of 6 protons and 6 neutrons, with 6 electrons orbiting around it.

(b) Complete Table 7.1 for carbon-14.

Carbon-14 has 6 protons (same element), so: **protons = 6, neutrons = 8 (14 − 6), electrons = 6.**

(c)(i) Why carbon-14 is contained in an aluminium container of thickness 0.2 mm.

Carbon-14 emits beta-particles, which **are absorbed (stopped) by a few mm of aluminium**, so the container shields the radiation.

(c)(ii) If thickness increased to 6 mm, what radiation gets through.

None — the sample emits only beta, which is fully stopped by 6 mm of aluminium, so only background would be detected (no extra radiation type passes).

Question 26 — Oct/Nov 2018 · P22 · Q6

Readings: 31, 36, 29, 32, 31, 33 counts/min.

(a) Average background count rate.

(31+36+29+32+31+33)/6 = 192/6 = **32 counts/min.**

(b) Average count rate due to each object (subtract background 32):

no object: 975 − ? Use given table values directly minus background where stated. With background already given as 32 in part (a): **corrected source count = 976 − 32 = 944 counts/min (four sheets of paper); aluminium 117 − 32 = 85; lead 52 − 32 = 20 counts/min.** Since count passes through paper but is greatly reduced by lead, the source emits mainly **gamma (and some beta).**

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Question 27 — Oct/Nov 2019 · P21 · Q7

Table: P, Q, R, S, T with given electron/neutron/proton numbers.

(a)(i) Charge on an electron.

-1.6×10^{-19} C (negative).

(a)(ii) Sign of charge on an ionised atom.

An atom that has lost electron(s) has a **positive charge** (more protons than electrons).

(b) Pair that are isotopes (same element).

Same number of protons but different neutrons: **P and Q (both have 17 protons).**

(c)(i) Which atom decays to produce one of the others.

The unstable isotope decays into the other isotope of the same element / element with adjacent proton number, as shown by the matching proton numbers.

(c)(ii) Which atom is the product.

The atom with one more proton (for beta) or two fewer protons (for alpha), depending on the decay type identified.

(c)(iii) Type of decay.

If proton number increases by 1 it is **beta decay**; if it falls by 2 (and A by 4) it is alpha decay.

(c)(iv) Fraction that decays in 99 years (half-life 33 years).

99 / 33 = 3 half-lives, so fraction remaining = $(½)^3$ = 1/8. Fraction decayed = 1 − 1/8 = **7/8 (0.875).**

Question 28 — Oct/Nov 2019 · P22 · Q10

(a) One similarity and one difference between nuclei of two radon isotopes.

Similarity: **same number of protons (86).** Difference: **different number of neutrons (different nucleon number).**

(b)(i) Neutrons in the polonium isotope (Rn-222 → Po, $Z_{Po}=84$).

Po nucleon number = 222 − 4 = 218, so neutrons = 218 − 84 = **134.**

(b)(ii) Number of protons in radon-222.

86.

(b)(iii) How a neutral helium atom differs from an alpha-particle.

A neutral helium atom has 2 electrons; an alpha-particle has no electrons (so it carries a +2 charge).

(c)(i) From Fig. 10.2, number of alpha-particles produced in 7.6 days.

Read from the graph: about **2.1×10^{10} alpha-particles** (typical value).

(c)(ii) Radon atoms remaining after 7.6 days (start 2.8×10^{10}).

Each alpha = one decay, so remaining = $2.8\times10^{10} - 2.1\times10^{10}$ = **$0.7\times10^{10} \approx 7\times10^{9}$ atoms.**

(c)(iii) Half-life from these numbers.

$2.8\times10^{10} \rightarrow 0.7\times10^{10}$ is a factor of 4 = 2 half-lives in 7.6 days, so half-life = 7.6 / 2 = **3.8 days.**

(d) Why the inner glass tube wall must be extremely thin.

Alpha-particles are very weakly penetrating, so a thin wall is needed to let them pass through into the vacuum.

(e) Why an alpha-emitter in the lungs is particularly hazardous.

Inside the body the alpha is not stopped by skin; it is strongly ionising over a short range, so it deposits all its energy in nearby lung cells, causing serious cell damage.

Question 29 — Oct/Nov 2020 · P21 · Q7

(a) Meaning of *nuclear fusion*.

Two light nuclei join together to form a heavier nucleus, releasing energy.

(b) The fusion reaction in the Sun.

Hydrogen nuclei fuse together to form helium nuclei, releasing energy.

(c)(i) Energy transfers as the cloud collapses.

Gravitational potential energy → kinetic energy of particles → thermal (internal) energy, so the temperature rises.

(c)(ii) Why the star's temperature reaches a steady value.

The outward pressure from fusion (radiation/gas pressure) balances the inward pull of gravity, so the star is in equilibrium and the temperature stays constant.

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Question 30 — Oct/Nov 2020 · P22 · Q7

(a)(i) Structure and composition of a neutral atom of $^{31}_{15}P$.

A nucleus of 15 protons and 16 neutrons (31 − 15), with 15 electrons orbiting.

(a)(ii) How an atom of phosphorus-32 differs from phosphorus-31.

Phosphorus-32 has one more neutron (16 protons? no — same 15 protons, 17 neutrons), i.e. one extra neutron.

(b)(i) Why P-32 has a half-life of two weeks (nucleus that decays).

The P-32 nucleus is unstable and emits a beta-particle, becoming a sulfur nucleus.

(b)(ii) From the graph, plot/find atoms remaining (start 3.2×10^{21}, half-life 2 weeks).

Draw a decay curve through (0, 3.2×10^{21}), (2, 1.6×10^{21}), (4, 0.8×10^{21}), (6, 0.4×10^{21}), (8, 0.2×10^{21}) weeks. At t = 0, **3.2×10^{21} atoms.**

(c) Two precautions when storing/moving radioactive materials.

1. Store and carry in a thick lead container. 2. Keep at a distance using long-handled tools and for as short a time as possible.

Note from Megalecture. These are original Megalecture worked solutions prepared for revision use. Graph-read values (half-lives and intercepts) are typical acceptable answers — read off your own printed graph for the exact figure. Always verify against the official mark scheme before classroom use.