Name	Date started	Target end date

GCE AS / A LEVEL — PARTICLES & NUCLEAR STRUCTURE QUESTION PACK

Legacy PH2 · New spec Unit 1 Topic 7 · AS unit, 20% of A-level

REVISE
.wales

PHYSICS — UNIT 1 · PARTICLES & NUCLEAR STRUCTURE

1.7 Particles & nuclear structure — hadrons, leptons and the four forces

Quark content of mesons and baryons, conservation of baryon and lepton number, identifying strong / weak / electromagnetic interactions, and quark-flavour change in beta decay.

NEW 2015 SPEC · UNIT 1 TOPIC 7

Estimated time for entire question pack: ~1 h 52 min

Derived from the legacy PH2 paper's pace of 80 marks in 1¼ hours.

*You are advised to **not** attempt to complete all of this in one sitting.*

ABOUT THIS QUESTION PACK

This is a **comprehensive practice question pack**, not a single mock paper. It contains every question from the legacy WJEC PH2 papers (2008 modular spec) that maps onto new-spec Unit 1 Topic 7 (1.7).

Questions are ordered chronologically within each section.

INSTRUCTIONS

Use black ink or black ball-point pen. Answer all questions in the spaces provided.

The number of marks is given in brackets at the end of each question or part-question. A calculator is required. The Data Booklet is allowed.

For Examiner's use only

Q	Source	Max	Mark
1	Jun 11 Q6	9	
2	Jan 12 Q7	10	
3	Jun 12 Q9	8	
4	Jan 13 Q7	9	
5	Jun 13 Q8	8	

Q	Source	Max	Mark
6	Jan 14 Q8	10	
7	Jun 14 Q8	9	
8	Jun 15 Q8	8	
9	Jun 16 Q7	9	
Total		**80**	

Particles & Nuclear Structure — what the new spec asks

WJEC GCE AS / A Level Physics (from 2015) · Unit 1: Motion, Energy & Matter · Topic 1.7.

Hadrons & quarks A

- Hadrons split into baryons (qqq) and mesons ($q\bar{q}$).
- First-generation quarks: up (charge $+\frac{2}{3}e$), down ($-\frac{1}{3}e$).
- Antiquarks have opposite charge; identify quark content of π^+, π^-, K^+, p, n.

Leptons A

- Electron, muon and their neutrinos as first/second generation leptons.
- Lepton number conserved in every interaction.

Conservation laws A

- Charge, baryon number, lepton number — conserved in all interactions.
- Use to identify missing particles in interaction equations.

Fundamental forces A

- Strong, weak, electromagnetic and gravitational interactions.
- Identify interaction type from particles and timescale.
- Beta decay at the quark level: $d \rightarrow u + e^- + \bar{\nu}_e$ (weak interaction).

Crib sheet »

Particles & Nuclear Structure in one page

Quick-reference notes — revisit before each section.

Hadrons

Baryons: 3 quarks (qqq); examples p (uud), n (udd).

Mesons: quark + antiquark ($q\bar{q}$); examples π^+ ($u\bar{d}$), π^- ($\bar{u}d$), K^+ ($u\bar{s}$).

Charge of a particle = sum of quark charges.

First-gen quarks

u quark: charge $+\frac{2}{3}$ e.

d quark: charge $-\frac{1}{3}$ e.

$\bar{u}$ = $-\frac{2}{3}$ e; $\bar{d}$ = $+\frac{1}{3}$ e.

Leptons

Charged: e^-, μ^- (and their +ve antis).

Neutral: ν_e, ν_μ (and antineutrinos).

Lepton number L: +1 for particles, -1 for antiparticles.

Conservation laws

Charge.

Baryon number B.

Lepton number L (per generation).

Energy & momentum.

The four forces

Strong: gluons; binds quarks in hadrons; range $\approx 10^{-15}$ m.

Electromagnetic: photons; infinite range; acts on charge.

Weak: $W^\pm$, Z^0; very short range; quark / lepton flavour change.

Gravitational: graviton (hypothetical); infinite range.

β decay at quark level

β^-: $d \rightarrow u + e^- + \bar{\nu}_e$.

β^+: $u \rightarrow d + e^+ + \nu_e$.

Quark flavour changes ⇒ weak; characteristic timescales 10^{-10} s or longer.

Section index

Use this index to jump straight to the section you need.

Examiner only

6. *(a)* (i) What is a *meson*? [1]

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(ii) A π^+ particle is a (first generation) meson with a positive charge. Explain why its quark make-up must be $u\bar{d}$. [1]

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(b) An interaction sometimes observed at high energies is

$$\pi^+ + {}^{2}_{1}\mathrm{H} \longrightarrow \mathrm{p} + \mathrm{p}$$

[${}^{2}_{1}\mathrm{H}$ symbolises here the **nucleus** of a ${}^{2}_{1}\mathrm{H}$ atom.]

(i) Determine whether or not

(I) u quark number is conserved. [1]

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(II) d quark number is conserved. [1]

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(ii) Discuss which force is likely to be responsible for this interaction. [2]

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(c) A similar interaction can be observed between a π^+ particle and a ${}^{7}_{3}\mathrm{Li}$ nucleus.

$$\pi^+ + {}^{7}_{3}\mathrm{Li} \longrightarrow {}^{A}_{Z}\mathrm{X} + \mathrm{p}$$

(i) Determine A and Z. [2]

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(ii) What is in common between the nuclei ${}^{A}_{Z}\mathrm{X}$ and ${}^{7}_{3}\mathrm{Li}$? [1]

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Examiner only

7. *(a)* (i) State **three** ways in which the properties of down-quarks and electrons differ. [3]

(ii) The Δ^- ('delta-minus') particle has the quark make-up ddd. Deduce its charge. [1]

(b) The Δ^- particle decays in a typical time of 6×10^{-24} s into a neutron and a pion (π meson).

$$\Delta^- \rightarrow n + \pi^-$$

State **two** features of the decay which point to it being a *strong* interaction. [2]

(c) The neutron and the pion formed in the decay are themselves unstable. The neutron decays thus:

$$n \rightarrow p + x + y$$

in which p is a proton and x is a charged (first generation) lepton.

(i) Use the laws of conservation of charge and of lepton number to identify x and y, setting out your reasoning clearly. [3]

(ii) Which force is responsible for this decay? [1]

THERE ARE NO MORE QUESTIONS IN THE EXAMINATION.

Examiner only

Examiner only

9. *(a)* An electron and a positron can annihilate (destroy) each other, in this interaction:

$$e^- + e^+ \longrightarrow \gamma + \gamma$$

(i) Explain how *lepton number* is conserved in this interaction. [2]

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(ii) State which force (strong, weak or electromagnetic) is involved in this interaction, giving a reason for your answer. [1]

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(b) A proton and an antiproton can annihilate each other, in this **strong** interaction:

$$p + \bar{p} \longrightarrow \pi^+ + x$$

By applying conservation rules, suggest the identity of particle x. [2]

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(c) The π^+ is unstable. It can decay, thus:

$$\pi^+ \longrightarrow y + \nu_e$$

(i) Identify y. [1]

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(ii) Which force is involved? [1]

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(d) Show below, as an equation, how the π^- might decay. [1]

..... $\longrightarrow$ ..... + ...

THERE ARE NO MORE QUESTIONS IN THE EXAMINATION.

Examiner only

Examiner only

7. *(a)* A law of Physics is that the baryon number is always conserved.

[Baryon number = number of baryons – number of antibaryons.]

Name one antibaryon, giving its quark make-up. [2]

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(b) (i) A gamma ray photon of high enough energy can interact with a proton to produce a neutron and a particle x in the following interaction:

$$p + \gamma \rightarrow n + e^{+} + x$$

Identify x, giving your reasoning. [2]

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(ii) Another possible interaction is:

$$p + \gamma \rightarrow n + y$$

Identify y, giving your reasoning. [3]

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(iii) For each of the above interactions (*(b)*(i) and *(b)*(ii)) discuss whether the *weak force* is involved. [2]

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Examiner only

8. *(a)* Discuss why neutrinos and antineutrinos are difficult to detect. [2]

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(b) In a special laboratory in Canada neutrinos from the Sun are detected by looking for electrons released in the interaction

$$\nu_e + {}^{2}_{1}\mathrm{H} \rightarrow \mathrm{p} + \mathrm{p} + \mathrm{e}^{-}$$

The ${}^{2}_{1}\mathrm{H}$ is a deuterium nucleus.

(i) A proton (p) is a baryon. State what is meant by a baryon. [1]

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(ii) Explain how *lepton number* and *charge* are conserved in this interaction. [2]

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(iii) The quarks in ${}^{2}_{1}\mathrm{H}$ and p occur in two 'flavours', u and d. Determine whether any quark *changes* its flavour in the interaction above. [2]

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(iv) Explain why the interaction below is considered to be impossible. [1]

$$\nu_e + {}^{2}_{1}\mathrm{H} \rightarrow \mathrm{p} + \mathrm{p} + \pi^{-}$$

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END OF PAPER

Examiner only

8. *(a)* The particles in the table below are either first generation leptons or combinations of first generation quarks (and/or antiquarks). Complete the table. [3]

Symbol	Quark make-up (leave blank if no quarks)	Charge / e	Lepton number
p	uud	+1	0
Δ^{++}	uuu		
π^-			
ν_e			

(b) A sequence of interactions is given.

[Stage 1] $p + p \rightarrow {}^{2}_{1}H + e^{+} + \nu_e$

[Stage 2] ${}^{2}_{1}H + p \rightarrow {}^{3}_{2}He + \gamma$

[Stage 3] ${}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + p + p$

(i) Where do these interactions take place naturally? ..... [1]

(ii) Stage 2 takes place by means of the strong force, but another force is also involved. Identify this force, giving a reason for your answer. [1]

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(iii) Explain briefly how lepton conservation applies in **each** stage. [2]

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(iv) u and d are the two flavours of first generation quarks.

(I) Show clearly that there is a change in quark flavour in stage 1. [2]

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(II) Explain in terms of the interactions involved why you would not expect a change in quark flavour in stage 2 or stage 3. [1]

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Examiner only

8. *(a)* When two protons collide at high kinetic energies, the interaction below sometimes occurs.

$$p + p \longrightarrow p + n + \pi^+$$

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(i) **Write** the quark make-up of each particle in the spaces provided above. [2]

(ii) Explain how this interaction conforms to *baryon number conservation.* [Note that baryon numbers are assigned thus: baryon: 1, antibaryon: –1, non-baryons: 0.] [1]

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(iii) State what type of interaction (strong, weak or electromagnetic) this is likely to be, giving a reason for your choice. [1]

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(iv) State **one** quantity, other than *baryon number* or *lepton number,* which is conserved in this interaction. [1]

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(b) Another interaction which can occur when two protons collide at high energies is:

$$p + p \longrightarrow {}^{2}_{1}H^+ + e^+ + \nu_e$$

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${}^{2}_{1}H^+$ represents a deuterium (heavy hydrogen) nucleus.

(i) **Write** the *lepton number* of each particle in the spaces provided above. [1]

(ii) State what type of interaction this is, and why the interaction is important to life on Earth. [3]

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Examiner only

8. *(a)* The positive pion, π^+, is a meson.

(i) Distinguish, in terms of quark make-up, between a meson and a baryon. [1]

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(ii) Show that the charge of the π^+ fits with it having the quark make-up $u\bar{d}$. [1]

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(b) The π^+ sometimes decays (typically in a time of 26 ns) in this way:

$$\pi^+ \rightarrow e^+ + \nu_e$$

(i) Show how lepton number is conserved in this decay. [1]

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(ii) Identify the type of interaction, giving a reason for your answer. [1]

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(c) The following interaction has been observed.

$$\pi^+ + {}^2_1H^+ \rightarrow p + p$$

[The ${}^2_1H^+$ is a deuterium (heavy hydrogen) nucleus.]

(i) Show how u quark number is conserved. [1]

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(ii) Before the interaction the π^+ and the ${}^2_1H^+$ are a few millimetres apart. The interaction will take place only if these charged particles are sent towards each other at high speeds. Explain why this is so. [3]

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Examiner only

7. *(a)* The charge on a proton is e and the charge on a neutron is 0. Account for these values in terms of quarks. [2]

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(b) **A**, **B** and **C** are three interactions which are from part of a sequence of interactions in a star such as the Sun. Symbols of the form ${}^{A}_{Z}\mathrm{X}$ represent nuclei.

A ${}^{3}_{2}\mathrm{He} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{7}_{4}\mathrm{Be} + \gamma$

B ${}^{7}_{4}\mathrm{Be} + \mathrm{e}^{-} \rightarrow {}^{7}_{3}\mathrm{Li} + \nu_{\mathrm{e}}$

C ${}^{7}_{3}\mathrm{Li} + {}^{1}_{1}\mathrm{H} \rightarrow 2\,{}^{4}_{2}\mathrm{He}$

(i) Baryon number (as well as energy and momentum) is conserved in all interactions. Name **two** other conserved quantities and explain how each is conserved in **B** above. [2]

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(ii) In **B** there is only one change of nucleon type, and this can be traced to a single change of quark flavour. Identify the change in nucleon type and the change in quark flavour. [2]

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(iii) Identify the change in **isotope** between the beginning and the end of the sequence **A**, **B**, **C** taken as a whole. [1]

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(iv) Interaction **A** could be described both as a *fusion interaction* and as an interaction involving the electromagnetic force. Explain why both these descriptions are correct. [2]

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9 questions · 80 marks · ~1 h 52 min
Source: WJEC PH2 (2008 modular spec)
Curated for WJEC Physics 2015 spec AS Unit 1 — Topic 7 (1.7)