A2 Level Physics

Chapter 8 – Nuclear and Particle Physics

8.2.2 Fundamental Particles

Worked Examples

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Fundamental Particles

Exam Style Question 1

(a) The diameter of a nucleus is about $10^{-14}\ m$.

(i) Complete the sentence below.

The diameter of a nucleus is .... times smaller than the diameter of an atom.

(ii) Very high-energy electrons are diffracted by the nucleus when they have a wavelength similar to the nuclear diameter.

(1) Estimate the momentum of an electron with a de Broglie wavelength equal to the diameter of a nucleus.

(2) Suggest why the speed of these electrons cannot be calculated by dividing the answer to (ii)1 by the mass $9.11 \times 10^{-31}\ kg$.

(b) The table of Fig. 5.1 shows some of the isotopes of phosphorus and, where they are unstable, the type of decay.

Isotope	$^{29}_{15}P$	$^{30}_{15}P$	$^{31}_{15}P$	$^{32}_{15}P$	$^{33}_{15}P$
Type of decay	β^+	β^+	stable	β^-	β^-

Fig. 5.1

(i) State the difference between each of the isotopes shown in the table.

(ii) Describe the structure of the proton in terms of up (u) and down (d) quarks.

(iii) Describe what happens in a beta-plus (β^+) decay using a quark model.

(iv) State two quantities conserved in a beta decay.

(v) Examine the table of isotopes in Fig. 5.1 and suggest what determines whether an isotope emits β^+ or β^-.

Fundamental Particles

Exam Style Question 1

(a)The diameter of a nucleus is about $10^{-14}\ m$.

(i) Complete the sentence below.

Remember the below:

$$diameter\ of\ nucleus \approx 10^{-15}m\ to\ 10^{-14}m$$
$$diameter\ of\ atom \approx 10^{-10}m$$

Therefore:

The diameter of a nucleus is $\mathbf{10^5\ to\ 10^4}$ times smaller than the diameter of an atom.

(ii) (1) Estimate the momentum of an electron with a de Broglie wavelength equal to the diameter of a nucleus.

Use $\lambda = \frac{h}{mv}$ and $momentum = \rho = mv$

$$\therefore \lambda = \frac{h}{\rho}$$

We know that the de Broglie wavelength is equal to the diameter therefore:

$$\lambda = 10^{-14}\ m$$
$$\therefore 10^{-14}m = \frac{6.63 \times 10^{-34}\ J\ s}{\rho}$$

Rearrange for ρ:

$$\rho = \frac{6.63 \times 10^{-34}\ J\ s}{10^{-14}\ m}$$
$$\rho = 6.6 \times 10^{-20}\ kg\ m\ s^{-1}\ (2\ s.f.)$$

(ii) (2) Suggest why the speed of these electrons cannot be calculated by dividing the answer to (ii)1 by the mass $9.11 \times 10^{-31}\ kg$.

Dividing the momentum from (ii)(1) by the mass of an electron gives a speed greater than the speed of light ($c = 3 \times 10^8\ m\ s^{-1}$), which is impossible. Therefore, you cannot simply divide momentum by the mass of an electron.

Fundamental Particles

Exam Style Question 1

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(iv) State two quantities conserved in a beta decay.

(v) Examine the table of isotopes in Fig. 5.1 and suggest what determines whether an isotope emits β^+ or β^-.

Fundamental Particles

Exam Style Question 1

(b) The table of Fig. 5.1 shows some of the isotopes of phosphorus and, where they are unstable, the type of decay.

(i) State the difference between each of the isotopes shown in the table.

Different number of neutrons.

(ii) Describe the structure of the proton in terms of up (u) and down (d) quarks.

$$p = uud$$

(iii) Describe what happens in a beta-plus (β^+) decay using a quark model.

Particle equation: $p^+ \rightarrow n^0 + e^+ + v_e$

Quark equation: $uud \rightarrow udd + e^+ + v_e$

Which simplifies to: $\mathbf{u} \rightarrow \boldsymbol{d} + \boldsymbol{e}^+ + \boldsymbol{v}_e$

(iv) State two quantities conserved in a beta decay.

- Charge or proton number
- Momentum
- Nucleon number
- Lepton number
- Strangeness
- Baryon number

(v) Examine the table of isotopes in Fig. 5.1 and suggest what determines whether an isotope emits $\boldsymbol{\beta}^+$ or $\boldsymbol{\beta}^-$.

β^+ is emitted when there are fewer neutrons and β^- when there are more neutrons.

Fundamental Particles

Exam Style Question 2

There are two types of beta decay, beta-plus and beta-minus. An isotope of carbon ${}^{15}_{6}C$ decays by beta emission into an isotope of nitrogen ${}^{15}_{7}N$. An isotope of phosphorus ${}^{30}_{15}P$ decays by beta emission into an isotope of silicon ${}^{30}_{14}Si$.

(a) Complete the following decay equations for the carbon and phosphorus isotopes.

(i) Carbon decay

$${}^{15}_{6}C \rightarrow {}^{\cdots}_{\cdots}e + {}^{\cdots}_{\cdots}N + \ldots\ldots$$

(ii) Phosphorus decay

$${}^{30}_{15}P \rightarrow {}^{\cdots}_{\cdots}e + {}^{\cdots}_{\cdots}Si + \ldots\ldots$$

(b) State the two beta decays in terms of a quark model of the nucleons.

(i) Beta-plus decay

(ii) Beta-minus decay

(c) Name the force responsible for beta decay.

Fundamental Particles

Exam Style Question 2

(a)Complete the following decay equations for the carbon and phosphorus isotopes.

(i) Carbon decay

$${}^{15}_{6}C \rightarrow {}^{0}_{-1}e + {}^{15}_{7}N + \overline{v_e}$$

(ii) Phosphorus decay

$${}^{30}_{15}P \rightarrow {}^{0}_{+1}e + {}^{30}_{14}Si + v_e$$

(b) State the two beta decays in terms of a quark model of the nucleons.

(i) Beta-plus decay

Particle equation: $p^+ \rightarrow n^0 + e^+ + v_e$

Quark equation: $uud \rightarrow udd + e^+ + v_e$

Which simplifies to: $\mathrm{u} \rightarrow d + e^+ + v_e$

(ii) Beta-minus decay

Particle equation: $n^0 \rightarrow p^+ + e^- + \overline{v_e}$

Quark equation: $udd \rightarrow uud + e^- + \overline{v_e}$

Which simplifies to: $d \rightarrow u + e^- + \overline{v_e}$

(c) Name the force responsible for beta decay.

Weak nuclear force.

Fundamental Particles

Exam Style Question 3

(a) (i) Complete Fig. 9.1 to show the quark composition and charge for neutrons and protons.

	Quark Composition	Charge
Neutron		
Proton		

(ii) Complete Fig. 9.2 to show the composition of quarks

Quark	Charge	Baryon Number	Strangeness
Up		+1/3	
Down			0

(b) When a neutron decays it can produce particles that include an electron.

(i) Complete the decay equation below for a neutron.

$$^{1}_{0}n \rightarrow$$

(ii) Name the interaction responsible for the decay of the neutron.

(iii) Electrons and neutrons belong to different groups of particles. Name the group of particles to which each belongs.

electrons ....

neutrons ....

Fundamental Particles

Exam Style Question 3

(a)(i) Complete Fig. 9.1 to show the quark composition and charge for neutrons and protons.

	Quark Composition	Charge
Neutron	$u\ d\ d$	0
Proton	$u\ u\ d$	+1

(ii) Complete Fig. 9.2 to show the composition of quarks

Quark	Charge	Baryon Number	Strangeness
Up	+2/3	(+1/3)	0
Down	-1/3	+1/3	(0)

(b) When a neutron decays it can produce particles that include an electron.

(i) Complete the decay equation below for a neutron.

$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \overline{\nu_e}$$

(ii) Name the interaction responsible for the decay of the neutron.

Weak nuclear

(iii) Electrons and neutrons belong to different groups of particles. Name the group of particles to which each belongs.

Electrons are leptons

Neutrons are hadrons/baryons.

Fundamental Particles

Exam Style Question 4

The equation represents the collision of a neutral kaon with a proton, resulting in the production of a neutron and a positive pion.

$$K^0 + p \rightarrow n + \pi^+$$

(a) Show that this collision obeys three conservation laws in addition to energy and momentum.

(b) The neutral kaon has a strangeness of +1. Write down the quark structure of the following particles:

K^0 ………………

π^+ ………………

p …………………

Fundamental Particles

Exam Style Question 4

(a)Show that this collision obeys three conservation laws in addition to energy and momentum.

Baryon number: 0 + 1 = 1 + 0
Lepton number: 0 + 0 = 0 + 0
Charge: 0 + 1 = 0 + 1

(b) The neutral kaon has a strangeness of +1. Write down the quark structure of the following particles:

$K^0 = \bar{s}d$
$\pi^+ = \mathrm{u}\bar{d}$
$p = uud$

Fundamental Particles

Exam Style Question 5

(a) The table gives information about some fundamental particles.

Complete the table by filling in the missing information.

particle	quark structure	charge	strangene	baryon number
	uud		0	
Sigma $^+$	uus	+ 1		
	$u\bar{d}$		0	0

(b) Each of the particles in the table has an antiparticle.

(i) Give one example of a baryon particle and its corresponding antiparticle.

particle ....

antiparticle ....

(ii) State the quark structure of an antibaryon.

(iii) Give one property of an antiparticle that is the same for its corresponding particle and one property that is different.

Fundamental Particles

Exam Style Question 5

(a) Complete the table by filling in the missing information.

particle	quark structure	charge	strangene	baryon number
Proton	uud	$+1$	0	1
Sigma $^+$	uus	+ 1	-1	1
π^+	$u\bar{d}$	$+1$	0	0

(b) Each of the particles in the table has an antiparticle.

(i) Give one example of a baryon particle and its corresponding antiparticle.

particle = proton

antiparticle = antiproton

(ii) State the quark structure of an antibaryon.

Consists of 3 antiquarks.

(iii) Give one property of an antiparticle that is the same for its corresponding particle and one property that is different.

Same: same mass

Difference: baryon number/charge

Fundamental Particles

Exam Style Question 6

(a) (i) Name two baryons.

(ii) State the quark structure of the pion π^+.

(b) (i) The K^+ kaon is a strange particle. Give one characteristic of a strange particle that makes it different from a particle that is not strange.

(ii) One of the following equations represent a possible decay of the K^+ kaon.

$$K^+ \rightarrow \pi^+ + \pi^0$$
$$K^+ \rightarrow \mu^+ + \overline{\nu_\mu}$$

State, with a reason, which one of these decays is not possible.

(c) Another strange particle, X, decays in the following way:

$$X \rightarrow \pi^- + p$$

(i) State what interaction is involved in this decay.

(ii) Show that X must be a neutral particle.

(iii) Deduce whether X is a meson, baryon or lepton, explaining how you arrive at your answer.

(iv) Which particle in this interaction is the most stable?

Fundamental Particles

Exam Style Question 6

(a)(i) Name two baryons.
Proton and neutron.

(a) (ii) State the quark structure of the pion π^+.

$$u\bar{d}$$

(b) (i) Give one characteristic of a strange particle that makes it different from a particle that is not strange.
Contains a strange quark.
Longer half life than expected.
Decays by weak interaction.

(b) (ii) State, with a reason, which one of these decays is not possible.
The second one is not possible because the lepton number is no conserved.

(c) (i) State what interaction is involved in this decay.
Weak interaction.

(c) (ii) Show that X must be a neutral particle.
Because charge must be conserved.

$$0 = -1 + 1$$

(c) (iii) Deduce whether X is a meson, baryon or lepton, explaining how you arrive at your answer.
X must be a baryon.
The baryon number on the right hand side is +1.

(c) (iv) Which particle in this interaction is the most stable?
Proton.

Fundamental Particles

Exam Style Question 7

(a) Hadrons are a group of particles composed of quarks. Hadrons can either be baryons or mesons.

(i) What property defines a hadron?

(ii) What is the quark structure of a baryon?

(iii) What is the quark structure of a meson?

(b) State one similarity and one difference between a particle and its antiparticle.

(c) Complete the table below which lists properties of the antiproton.

	charge / C	baryon number	quark structure
antiproton			

(d) The K^- is an example of a meson with strangeness – 1. The K^- decays in the following way:

$$K^- \rightarrow \mu^- + \overline{\nu_u}$$

(i) State, with a reason, what interaction is responsible for this decay.

(ii) State two properties, other than energy and momentum, that are conserved in this decay.

Fundamental Particles

Exam Style Question 7

(a)Hadrons are a group of particles composed of quarks. Hadrons can either be baryons or mesons.

(i) What property defines a hadron?

Particles that experience the strong nuclear force.

(ii) What is the quark structure of a baryon?

Particles composed of three quarks.

(iii) What is the quark structure of a meson?

Particles composed of a quark and an antiquark.

(b) State one similarity and one difference between a particle and its antiparticle.

Similarity: the same rest mass.

Difference: Opposite quantum states e.g. charge.

(c) Complete the table below which lists properties of the antiproton.

	charge/C	baryon number	quark structure
antiproton	-1.6×10^{-19}	–1	$\overline{u}\overline{u}\overline{d}$

(d) The K^- is an example of a meson with strangeness – 1. The K^- decays in the following way:

$$K^- \rightarrow \mu^- + \overline{\nu_u}$$

(i) State, with a reason, what interaction is responsible for this decay.

Weak interaction.

(ii) State two properties, other than energy and momentum, that are conserved in this decay.

- Charge
- Baryon number
- Lepton number

Fundamental Particles

Exam Style Question 8

Use the laws of conservation of charge and baryon number to decide whether the following reactions are possible or not possible. In each case show how you applied the laws. Pions (π^+ , π^- and π^0) are mesons.

(i) $\pi^- + p \rightarrow n + \pi^- + \pi^+ + \pi^0$

(ii) $p + p \rightarrow p + p + p + \bar{p}$

Fundamental Particles

Exam Style Question 8

(i) $\boldsymbol{\pi^- + p \rightarrow n + \pi^- + \pi^+ + \pi^0}$

Charge: $(-1) + (+1) = (0) + (-1) + (+1) + (0)$
Baryon number: $(0) + (+1) = (+1) + (0) + (0) + (0)$
Charge and baryon number are conserved so possible.

(ii) $\boldsymbol{p + p \rightarrow p + p + p + \bar{p}}$

Charge: $(+1) + (+1) = (+1) + (+1) + (+1) + (-1)$
Baryon number: $(+1) + (+1) = (+1) + (+1) + (+1) + (-1)$
Charge and baryon number are conserved so possible.

Please see '8.2.1 Fundamental Particles notes' pack for revision notes.

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