2001

Question 30 — From Quanta to Quarks (25 marks)

(a)(i) Define *nucleon*. **1**

(ii) Contrast ONE property of nucleons. **2**

(b) The table shows the quantum numbers of the four lowest states of the hydrogen atom, together with the energies of those states.

Quantum number, n	*Energy* (joule)
1 (Ground state)	0
2	1.63×10^{-18}
3	1.94×10^{-18}
4	2.04×10^{-18}

(i) What is the energy of the photon emitted when an electron in the $n = 4$ level makes a transition to the $n = 3$ level? **1**

(ii) Use the data to draw the energy level diagram for hydrogen, and indicate on this diagram where the energy levels lie for quantum numbers greater than 4. **3**

(c) Describe how you carried out a first-hand investigation to determine the penetrating power of alpha, beta and gamma radiation on a range of materials. **4**

(d) The Manhattan Project is the codename given to the development of atomic (nuclear fission) bombs during World War II. **6**

Discuss the significance of this project for society.

(e) Analyse how Chadwick's and Fermi's work resulted in a greater understanding of the atom. **8**

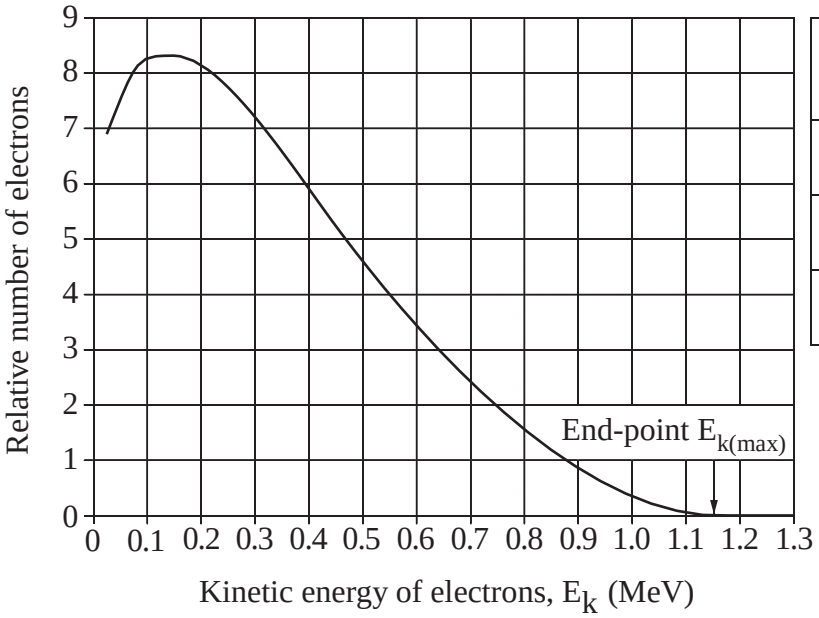
2002

Question 31 — From Quanta to Quarks (25 marks)

(a) (i) Describe Davisson and Germer's experiment that confirmed the de Broglie hypothesis of wave-particle duality. **2**

(ii) Explain the stability of the electron orbits in the Bohr atom, using de Broglie's hypothesis. **4**

(b) The diagram shows the kinetic energy distribution of the electrons emitted in the β-decay of $^{210}_{83}Bi$ into $^{210}_{84}Po$. The energy released during β-decay depends on the mass defect in the transmutation, as it does in nuclear fission.



Nucleus or particle	*Mass* (amu)
^{210}Bi	209.938 57
^{210}Po	209.936 78
e	0.000 55

(i) Identify the scientist who suggested that the existence of the neutrino relates to the need to account for the energy distribution of electrons emitted in β-decay. **1**

(ii) Use the data to calculate the mass defect in the β-decay of $^{210}_{83}Bi$. (Assume that the neutrino is a massless particle.) **2**

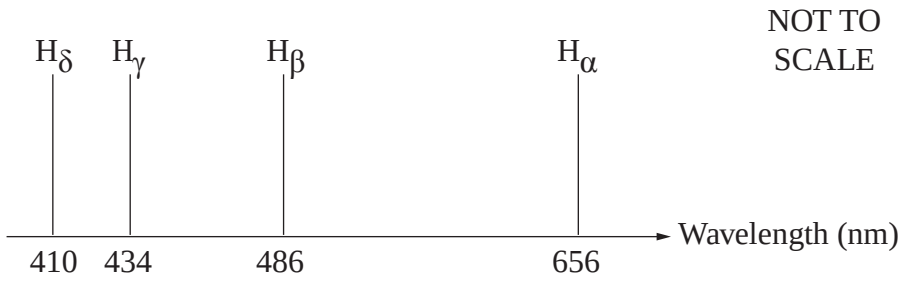
(iii) Account for the energy distribution of electrons emitted in this β-decay. **3**

Question 31 continues on page 35

Marks

Question 31 (continued)

(c) The diagram represents the four spectral lines in the visible region of the hydrogen spectrum known as the Balmer Series.



Explain how the Balmer Series provides strong experimental evidence in support of Bohr's model of the hydrogen atom (3 marks)

support of Bohr's model of the hydrogen at(d) Discuss how neutron scattering and ONE other process have been used to increase our understanding of the structure of matter. **7**

2003

Question 31 — From Quanta to Quarks (25 marks)

(a) (i) Identify the structure of the Rutherford model of the atom. **1**

(ii) Describe how Bohr refined Rutherford's model of the hydrogen atom. **2**

(b) The table below shows the different types of quarks and their charge. **3**

Quark	*Charge*
Up	$+\frac{2}{3}e$
Down	$-\frac{1}{3}e$
Strange	$-\frac{1}{3}e$
Charm	$+\frac{2}{3}e$
Bottom	$-\frac{1}{3}e$
Top	$+\frac{2}{3}e$

The standard model of matter says that protons and neutrons are composed of up and down quarks. There are three quarks in each particle. Compare protons and neutrons in terms of their quark composition.(c) The equations shown below describe three different types of transmutation reactions involving uranium.

(1) $^{238}_{92}\mathrm{U} + {}^{1}_{0}n \rightarrow {}^{239}_{92}\mathrm{U}$

(2) $^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$

(3) $^{235}_{92}\mathrm{U} + {}^{1}_{0}n \rightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}n$

(i) Identify which reaction is naturally occurring, and justify your answer. **2**

(ii) Identify ONE transmutation reaction above that has a practical application, and describe the application. **3**

(d) The two graphs below show the gravitational and electrostatic forces acting between two protons in the nucleus of an atom.

(i) If the distance between protons in a nucleus is 1.0×10^{-15} m, determine both the gravitational and the electrostatic force at this distance. **2**

(ii) Explain why these two forces cannot explain the stability of the nucleus, and why there is a need for the strong nuclear force. **2**

(iii) Describe TWO properties of the strong nuclear force. **2**

(e) Describe the requirements for a nuclear fission explosion, and describe how these are controlled in a nuclear reactor. **8**

2004

Question 31 — From Quanta to Quarks (25 marks)

(a) (i) Identify TWO features of the strong nuclear force that binds the nucleons together within the nucleus of an atom. **2**

(ii) When Chadwick discovered the neutron he estimated its mass as 1.15 times the mass of the proton, quite close to its true value. **2**

State the TWO laws of physics he used to make this estimate.

(b) (i) The table below lists the first generation of quarks and antiquarks.

Quarks			*Antiquarks*		
Name	*Symbol*	*Charge*	*Name*	*Symbol*	*Charge*
Up	u	$+\frac{2}{3}e$	Antiup	$\bar{u}$	$-\frac{2}{3}e$
Down	d	$-\frac{1}{3}e$	Antidown	$\bar{d}$	$+\frac{1}{3}e$

The Standard Model of matter states that baryons, like protons and neutrons, are comprised of three quarks, while mesons, like the pions □□ and □□, are comprised of one quark and one antiquark.

Using the table above, state the quark compositin of the neutron and the negative pion.

(ii) The first atomic bomb was a simple uranium-235 fission device. One mode of fission for uranium-235 is given below. **4**

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{139}_{54}Xe + {}^{94}_{38}Sr + 3\,{}^{1}_{0}n$$

Calculate the mass defect and the energy released per ^{235}U atom, given the following nuclear masses and other data.

$^{235}_{92}U = 234.9934$ u $\quad$ $^{139}_{54}Xe = 138.8883$ u

$^{94}_{38}Sr = 93.8945$ u $\quad$ $^{1}_{0}n = 1.00867$ u

$1\text{ u} = 1.66 \times 10^{-27}$ kg $\quad$ $c = 3.00 \times 10^{8}$ ms^{-1}

u = atomic mass unit

(c) One cannot understand the [particle] physics of the past several decades without understanding the nature of the accelerator . . . the dominant tool in the field for the past forty

years. By understanding the accelerator, one also learns much of the physics principles that physicists have laboured centuries to perfect.

Leon Lederman and Dick Teresi, *The God Particle*, 1993

Describe how the key features and components of the standard model of matter have been developed using accelerators as a probe.

(d) (i) During your study of From Quanta to Quarks you carried out a first-hand investigation to observe the visible components of the hydrogen spectrum. **2**

Identify the equipment you used to observe this spectrum.

(ii) During your physics course you examined first hand the emission spectrum of atomic hydrogen. The four coloured lines are listed in the table below. **4**

Colour of the emission line	*Name of the emission line*	*Electron transition*
Red	$H_{\square}$	$n \square 3$ to $n \square 2$
Green	$H_{\square}$	$n \square 4$ to $n \square 2$
Blue	$H_{\square}$	$n \square 5$ to $n \square 2$
Violet	$H_{\square}$	$n \square 6$ to $n \square 2$

Calculate the wavelength of the $H_{\square}$ spectral line, and hence determine the energy of the emitted photon.

(iii) Describe TWO limitations of Bohr's model of the hydrogen atom. **2**

2005

Question 31- From quanta to quarks (25 marks)

(a) During your study of From Quanta to Quarks you either performed a first-hand investigation, or you gathered information to observe nuclear radiation using a Wilson cloud chamber, or similar detection device.

Below is a true-size photograph in this type of device showing the tracks made by α-particles.

(i) Explain the appearance of these tracks in terms of properties of α-particles. **2**

(ii) Name another type of nuclear radiation, and describe differences in the tracks it would make. **2**

(b) Naturally occurring uranium-238 spontaneously disintegrates according to the equation

$$\square\!\square U \rightarrow \square\!\square Th + \square\!\square$$

The thorium radionuclide undergoes further decay according to the equation

$$\square\!\square Th \rightarrow \square\!\square Q + \square\!\square + \square\!\square \bar{\nu}$$

(i) Identify the mass number of the thorium radionuclide. **1**

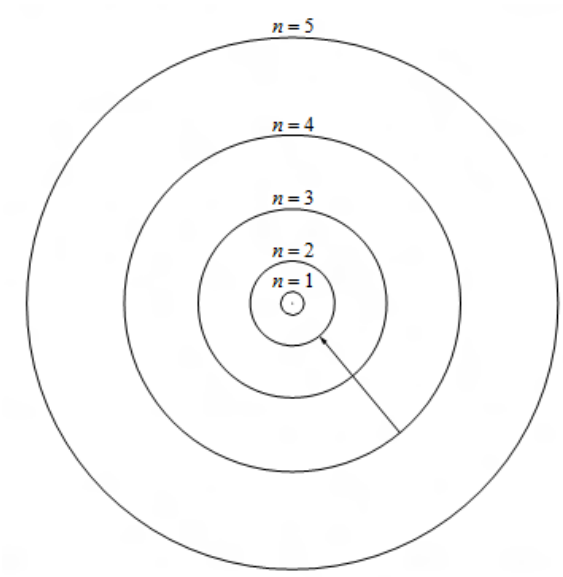
(ii) Identify the nuclide *Q*, stating its mass number. **2**

(iii) Describe Wolfgang Pauli's contribution to Enrico Fermi's explanation of beta decay. **3**

(c) An understanding of the nucleus led to the Manhattan Project, which was based in laboratories in Los Alamos between 1942 and 1945. **7**

Describe the technologies developed from this project, and assess the significance to science and society of their applications.

(d) The diagram below shows the first five circular Bohr orbits or 'stationary states' for the electron orbiting the nucleus of the hydrogen atom.



(i) For the electron transition shown on the diagram, calculate the wavelength of the emitted photon. **2**

(ii) State de Broglie's hypothesis, and calculate the wavelength of the electron in the first stationary state if its speed is 2.188 □ 10^6 m s^{-1}. **3**

(iii) Describe how de Broglie's hypothesis extended the work of Bohr in explaining the stability of electron orbits in the hydrogen atom. **3**

2006

(a) The Bohr picture of the atom explains the energy of the photons emitted when an electron falls from an initial orbit n_i to find an orbit of n_f.

The various energies depend upon the quantity $\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ and the values for this term are given in the table.

Table of values of $\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ for values of n_i and n_f from 1 to 6

n_f \ n_i	1	2	3	4	5	6
1	–	0.7500	0.8889	0.9375	0.9600	0.9722
2	–	–	0.1389	0.1875	0.2100	0.2222
3	–	–	–	0.0486	0.0711	0.0833
4	–	–	–	–	0.0225	0.0347
5	–	–	–	–	–	0.0122
6	–	–	–	–	–	–

(i) Identify the physical reason for about one-half of the table appearing blank. **1**

(ii) Calculate the energy of the photon emitted when an electron falls from $n_i = 4$ to $n_f = 3$. **4**

(b) You have gathered, processed and analysed information related to the development of atomic theory.

(i) Describe how you ensured that the information you gathered was reliable. **2**

(ii) The atomic theory changed as a result of the contributions of both Heisenberg and Pauli. **4**

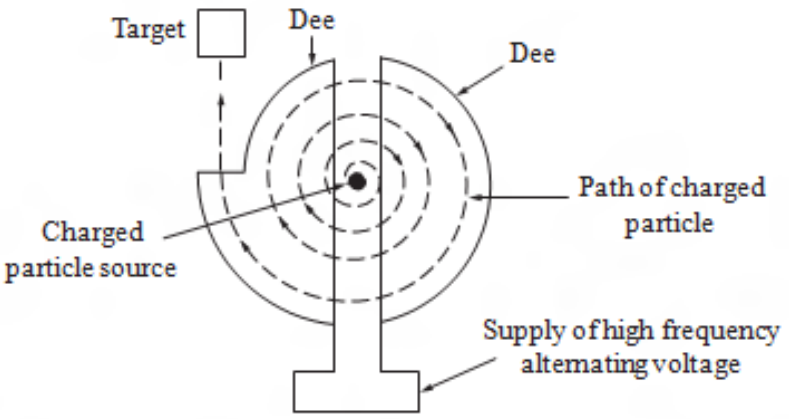
Analyse how the work of both scientists modified the atomic theory at that time.

(c) Australia has a large supply of uranium which may be used in fission reactors to create energy. The equation describes the relevant transmutation reaction: **7**

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3{}^{1}_{0}n$$

Analyse how the process described in this equation has been developed into a technology which produces a sustained and controlled amount of energy.

(d) The cyclotron, invented in 1932, accelerates charged particles to a very high speed. The diagram shows the basic design of a cyclotron. The Dees provide a strong magnetic field into the plane of the page.



(i) Explain the physical principles involved in the design of the cyclotron. **3**

(ii) Account for the use of the cyclotron (or other accelerator) in the development of our understanding of matter. **2**

(iii) Quarks are an important part of the Standard Model of Matter. The table shows the six types of quark and their charge (in units of *e*, the charge on an electron). **2**

Quark	Up	Down	Strange	Charm	Bottom	Top
Charge	$+\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	$+\frac{2}{3}$	$-\frac{1}{3}$	$+\frac{2}{3}$

Identify the quark composition of the proton and the neutron.

2007

(a) The Bohr model of the atom describes a nucleus with electron shells surrounding it.

(i) Calculate the wavelength of the electromagnetic radiation required to remove an electron from the second shell of a hydrogen atom. **2**

(ii) Outline atomic spectral features that cannot be completely explained by the Rutherford-Bohr model. **3**

(b) In your study of Quanta to Quarks you have performed an investigation to observe radiation emitted from a nucleus using a Wilson Cloud Chamber or a similar detection device.

(i) Describe how you carried out your investigation. **2**

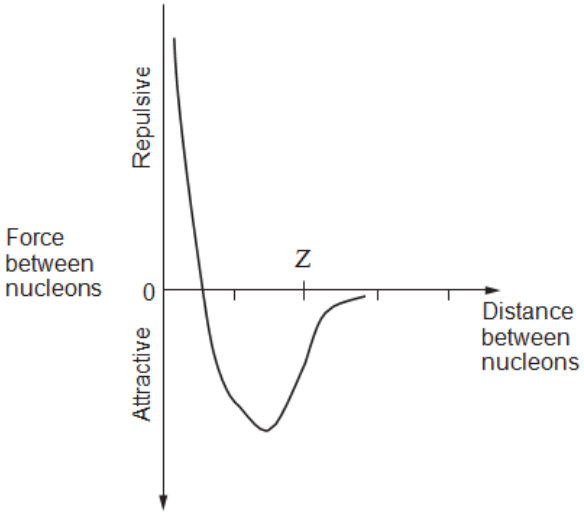
(ii) Isotopes can be used in medicine, agriculture and engineering. **4**

Choose TWO of these areas and nominate a different isotope for use in each area.

For each isotope, explain how the properties of the isotope are related to its use.

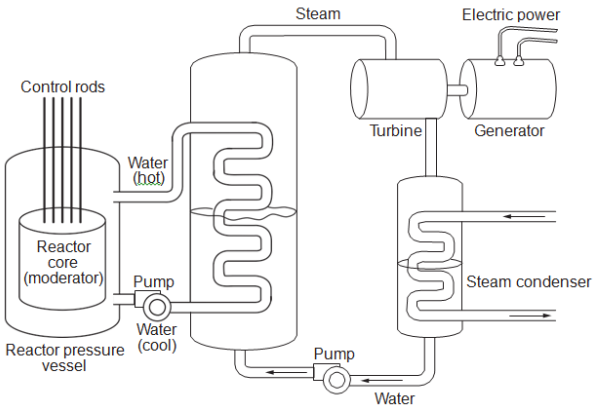
(c) Analyse how de Broglie's proposal and supporting experimental evidence led to the move from classical physics to quantum physics. **7**

(d) (i) The graph shows the force between nucleons as a function of the distance between them. **2**



Explain what would happen if two nucleons were separated by the distance indicated as Z on the graph.

The figure shows the basic features of a nuclear fission reactor.



(ii) Which part of a nuclear reactor regulates the rate of fission reaction taking place? Justify your answer. **2**

(iii) Neutron beams can be extracted from nuclear reactors. **3**

Describe how the neutrons can be used as a probe for investigating the properties of matter.

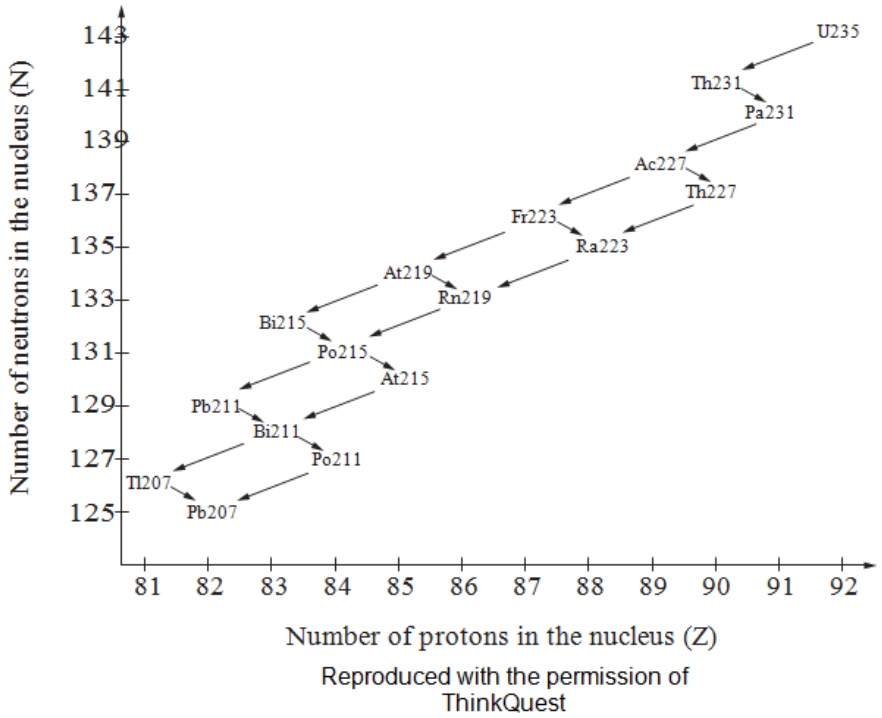
2008

(a) (i) Outline how you would conduct a first-hand investigation to observe the visible components of the hydrogen emission spectrum. **2**

(ii) How would the results from this investigation support Bohr's model of the atom? **2**

(iii) Outline ONE feature of atomic emission spectra that cannot be explained by Bohr's model. **2**

(b) Nuclear transmutations caused by natural radioactivity can be represented in diagrams such as the one shown. Each symbol represents a radioactive element and each arrow represents a transmutation.



Reproduced with the permission of ThinkQuest

(i) How many protons and how many neutrons are there in the nucleus of a Thorium-227 atom? **1**

(ii) Write the equation for the α-decay of Francium-223. **2**

(c) (i) An atom of Carbon-12 has 6 protons and 6 neutrons in its nucleus. The mass of a Carbon-12 atom is 12.000 atomic mass unit. Show that the mass defect of one Carbon-12 atom is 0.097 atomic mass unit. **3**

(ii) How much energy is this mass defect equivalent to? **1**

(d) (i) Use a diagram to outline one way in which physicists obtain particles with the appropriate energy to investigate the structure of matter. **2**

(ii) Describe the key features and components of the standard model of matter. **4**

(e) Use the work of TWO physicists to explain how the combination of ideas led to new directions in scientific thinking about atomic structure. **6**

2009

(a) Marsden and Geiger conducted an experiment in which they fired alpha particles at a thin gold foil. Most of the particles passed straight through.

(i) Describe how Rutherford's model of the atom explained these results. **(2 marks)**

(ii)Describe TWO problems associated with Rutherford's model and how these were explained by Bohr's model of the hydrogen atom. **(4 marks)**

(b)

(i)Describe de Broglie's proposal that a particle can exhibit both wave and particle properties. **(2 marks)**

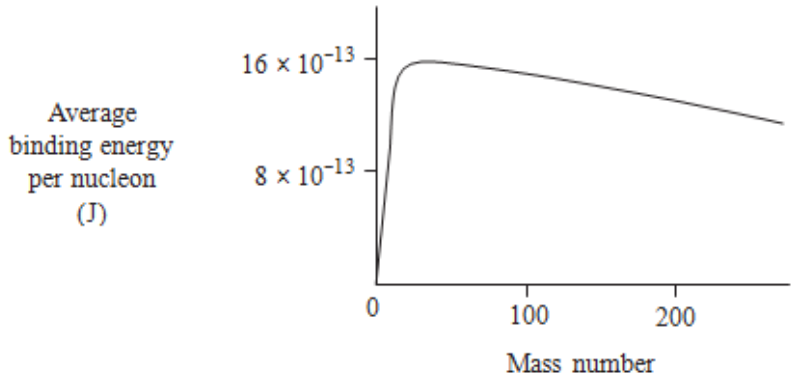
(ii)Explain how Davisson and Germer were able to confirm de Broglie's proposal. **(3 marks)**

(iii)Calculate the velocity of an electron that has a wavelength of 3.33×10^{-10} m. **(2 marks)**

(c) (i) Define *mass defect*. **1**

(ii) The energy required to separate all the nucleons within a nucleus is the binding energy. The average binding energy per nucleon is a measure of the stability of a nucleus. **2**

The graph shows how average binding energy per nucleon varies with mass number.



Use the graph to compare the stability of a nucleus of mass number 200 with a nucleus of mass number 50.

(d) In 1920, Rutherford suggested the existence of an undiscovered nuclear particle. **3**

Explain how Chadwick confirmed Rutherford's prediction using conservation laws.

(e) Theories and experiments not only help increase our understanding but also generate new questions. **6**

Use the standard model of matter to support this statement.

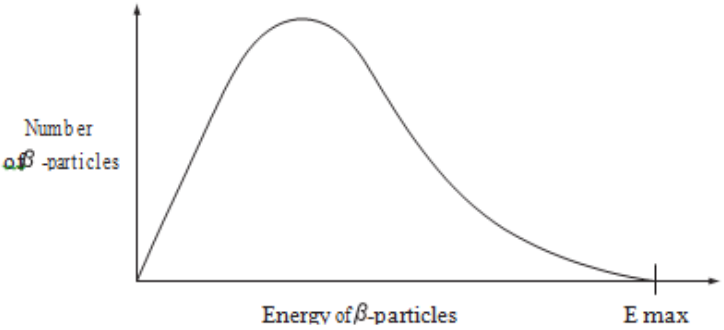
2010

Answer parts (a)–(d) in a writing booklet.

(a) Outline the relationship between Bohr's atomic model and Planck's equation $E = hf$. **3**

(b) Calculate the wavelength of a photon which is emitted when an electron in a hydrogen atom moves from energy level n = 4 to n = 2. **2**

(c) How did Louis de Broglie explain the stability of electron orbits in hydrogen atoms? **3**



How did Pauli account for the distribution of energies in the β-decay curve? **2**

Answer parts (e)–(g) in a SEPARATE writing booklet.

(e) (i) James Chadwick discovered the neutron in 1932. How did Chadwick apply conservation laws? **3**

(ii) Outline how the properties of neutrons make them useful in scattering experiments. **2**

(f) Account for the existence of stable isotopes, referring to the forces which act within the atomic nucleus. **3**

(g) 'Important fundamental discoveries in physics often lead to applications which have a significant effect on society.' **7**

Evaluate this statement, with reference to the contributions of Rutherford, Einstein and Fermi to the development of the atomic bomb.

2011

Question 34 — From Quanta to Quarks (25 marks)

Answer parts (a)–(c) in Section II Answer Booklet 1.

(a) Name a radioisotope used in agriculture and describe its use. **2**

(b) (i) Explain how the reaction rate in a nuclear reactor can be increased or decreased. **4**

(ii) $^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{140}_{56}Ba + {}^{92}_{36}Kr + 4\,{}^{1}_{0}n$ Explain why energy is released in this reaction. (2 marks)

(c) Copy and complete in your booklet the following table comparing forces in the atomic nucleus. **3**

Forces in atomic nucleus

	Gravitational	*Electrostatic*	*Strong*
Strength	Low		
Direction	Attractive		
Range	Infinite		

Answer parts (d)–(g) in Section II Answer Booklet 2.

(d) A cricket ball has a mass of 156 g and a velocity of 20 m s^{-1}. Calculate its de Broglie wavelength. **2**

(e) Identify the types and number of quarks and leptons in a tritium ($^{3}_{1}H$) atom. **2**

(f) Outline the main contributions of Heisenberg and Pauli to the development of atomic theory. **4**

(g) *Mathematical models, validated by experimental evidence, have improved our understanding of the atom.* **6**

Justify this statement, focusing on the models developed by Bohr and de Broglie.