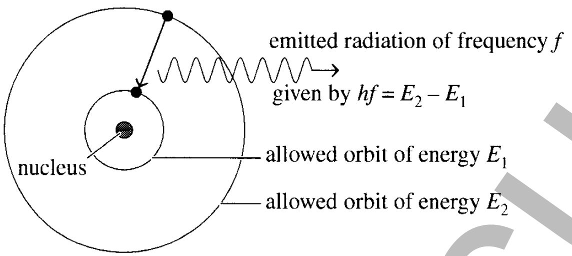
Question 31 **From Quanta to Quarks**

Sample answer	Syllabus content, course outcomes and marking guide
(a) Balmer had noticed that there was a pattern to the frequencies of the spectral lines from the discharge of hydrogen gas. His mathematical formula fitted a precise mathematical series. Bohr visualised that the electrons of atoms were in discrete orbits around the nucleus and that the energies and radii of these orbits fitted with the frequencies of the Balmer series. He suggested that when electrons make transitions between orbits they absorb or emit energy in quanta, $E = \frac{hc}{\lambda}$. The wavelengths could be calculated from $\frac{1}{\lambda} = R\frac{1}{n_f^2} - R\frac{1}{n_i^2}$. The n-values in the formula corresponded to these allowable orbits in Bohr's model. According to Bohr, each individual line in the Balmer series of the hydrogen spectrum could be matched with an electron transition. The Balmer series could be matched with a set of electron transitions from all possible higher energy states back to the state where $n = 2$, for the visible hydrogen spectrum.	9.8.1 H2, H7 • Comprehensive explanation linking Balmer's mathematical formula to Bohr's conceptual model. Includes a fully labelled diagram . . . 3 • Comprehensive explanation linking Balmer's mathematical formula to Bohr's conceptual model. Without a fully labelled diagram. OR • Partial explanation linking Balmer's mathematical formula to Bohr's conceptual model. Includes a fully labelled diagram. 2 • Some explanation linking Balmer's mathematical formula to Bohr's conceptual model. OR • Labelled diagram . . . 1



Sample answer	Syllabus content, course outcomes and marking guide
(b) (i) de Broglie.	9.8.2 H10, H13 • Correct name . . . 1
(ii) $\lambda = \frac{h}{mv}$ $v = \frac{h}{m\lambda}$ $= \frac{6.63 \times 10^{-34}}{(9.1 \times 10^{-31})(5.3 \times 10^{-11})}$ $= 1.37 \times 10^{7}$ m s^{-1} $v = f\lambda$ $f = \frac{v}{\lambda}$ $= \frac{1.37 \times 10^{7}}{5.3 \times 10^{-11}}$ $= 2.6 \times 10^{17}$ Hz	9.8.2 H10, H13 • Correct numerical answer and working shown for both wavelength and velocity . 3 • Correct numerical answer and working shown for either wavelength or velocity . 2 • Incorrect numerical answers but working shown for either wavelength or velocity . 1

Question 31 **From Quanta to Quarks** (Continued)

	Sample answer	Syllabus content, course outcomes and marking guide
(c)	(i) Neutrons have a similar mass to that of a proton. Accordingly, all nucleons should experience forces of gravitational attraction (i.e. between protons and protons, protons and neutrons and neutrons and neutrons). However, the masses involved are so very small that these gravitational forces are negligible. Protons are positively charged and neutrons possess no charge. Therefore, there will be repulsive electro-static forces between protons only.	9.8.3 H9 • Generally correct outline of both electro-static and gravitational forces . . . . 2 • Generally correct outline of either electro-static or gravitational force 1
	(ii) The strong nuclear force keeps the neutrons and protons together in the nucleus. This strong force needed to • be about 100 times stronger than Coulomb force when nucleons close together; • quickly become weak at larger distances; • become repulsive at very short distances. Its nature differs from the electro-static and gravitational forces in so far that it is an extremely short ranged force and independent of charge and mass of the nucleons. It arises from the exchange of pions between nucleons. It also acts to keep the nucleons apart. It therefore has both an attractive and repulsive nature and is responsible for the stability of the nucleus.	9.8.3 H9 • Comprehensive and detailed discussion of the nuclear force with clear description of the relationship to other forces. . . . . 4 • Reasonable discussion of the nuclear force with clear description of the relationship to other forces . . . . 3 • Some discussion of the nuclear force with brief description of the relationship to other forces . . . . 2 • Brief description of the nuclear force with some reference of the relationship to other forces 1
(d)	**Medical Sector** Radio-isotopes have found many uses within the medical sector. One such application is the use of sodium-24 for diagnosis. This radio-isotope forms sodium chloride molecules, which are very important in the working of nerve cells and the body in general. Salt containing trace amounts of the sodium-24 isotope is said to be labelled or tagged. By this means its movement throughout the body can be traced. If a patient is given some labelled salt its progress through the body can be followed by using a Geiger-Muller tube or other radiation detector. Chemically, the labelled salt behaves normally. However, the sodium-24 atoms will decay while within the body, emitting radiation which passes out of the body, allowing for its detection. By this means, doctors can determine the extent of the movement of the labelled isotope and how much salt has been absorbed. **Industrial Sector** Many industrial uses have been found for radio-isotopes. Cobalt-60 is used to check the welds in steel structures and pipelines. A large source of cobalt-60 is placed on one side of the steel structure and its emitted gamma radiation exposes photographic plates strategically placed on the other side. Since this radiation produces exposed images similar to X-rays, flaws such as a crack or a bubble inside the weld on pipelines becomes visible on the exposed film. Gamma radiation sources such as cobalt-60 may also be used in difficult to reach and remote places without the requirement of very high voltage power supplies required for X-ray production.	9.8.4 H3, H4 • Comprehensive and detailed description of two different radio-isotopes (one from each sector). . . . . 5–4 • Comprehensive and detailed description of one radio-isotope. OR • A brief description of two different radio-isotopes (one from each sector) . . . . . . 3–2 • A brief description of one radio-isotope . 1

Sample answer	Syllabus content, course outcomes and marking guide
(e) Italian physicist Enrico Fermi managed the first fission reactor, called Chicago Pile 1 (CP-1). Under the abandoned west stands of the University of Chicago, the first controlled nuclear reaction occurred. Although fission had been observed on a small scale in many laboratories, no one had carried out a controlled chain reaction. Fermi thought that he could achieve a controlled chain reaction using natural uranium. The nuclear reactor, called a pile, was composed of uranium oxide, of uranium, and of ultra-pure graphite arranged in a manner to maximise neutron propagation. In December 1942, the first controlled nuclear chain reaction was achieved when the reactor went critical; that is, it produced one neutron for every neutron absorbed by the uranium nuclei. Fermi allowed the reaction to continue for the next 27 minutes before inserting neutron-absorbing cadmium control rods. In addition to excess neutrons and energy, the pile also produced a small amount of Pu-239, the other known fissionable material. The achievement of the first sustained nuclear reaction was the beginning of a new age in nuclear physics and the study of the atom. Humankind could now use the tremendous potential energy contained in the nucleus of the atom. Einstein's theory of special relativity produced the deduction that all energy has mass and that if a body gains energy its inertia is increased by an amount of mass $\left(m = \frac{E}{c^2}\right)$. Einstein derived this relationship by assuming that all conservation laws must hold equally for all frames of reference and using the principles of conservation of momentum, mass and energy. If a nuclear fission occurs, the binding mass of the products is less than the initial binding mass of the reactants. Einstein proposed that this missing mass (the mass defect) is converted into energy $E = mc^2$. As 'c' (the speed of light) is very large, a tiny amount of mass produces a large amount of energy. A fission reaction is initiated by a high speed neutron, which is absorbed into the nucleus, making it unstable. This heavy nucleus then splits into two lighter and more stable nuclei. Two or three other neutrons are also emitted, which are capable of causing further fissions in other large nuclei. In a fission reaction energy is released when a heavy nucleus such as uranium splits into two lighter nuclei. This results in a loss of mass, which is converted into nuclear energy.	9.8.5 H1, H3, H10, H13 • A coherent response inclusive of both a detailed description of Fermi's nuclear reactor for a controlled fission reaction. AND • A comprehensive discussion of the relationship between mass and energy within nuclear fission .... 7–6 • A coherent response inclusive of both a detailed description of Fermi's nuclear reactor for a controlled fission reaction. AND • A reasonable discussion of the relationship between mass and energy within nuclear fission .... 5–4 • A reasonable response of either an adequate description of Fermi's nuclear reactor for a controlled fission reaction. OR • A brief discussion of the relationship between mass and energy within nuclear fission .... 3–2 • A general response describing a nuclear reactor for a controlled fission reaction. OR • A brief description of the relationship between mass and energy 1