Question 1

8. A nuclear reactor is a device in which a sustained chain reaction takes place. From each nuclear fission, only one (on average) of the emitted neutrons hits another nucleus to cause another fission. The power output from a sustained nuclear reaction doesn't grow, but is constant.

Explain the underlined terms. (9)

A substance called a moderator is mixed with the fuel in a nuclear reactor. Control rods are used to control the rate of the reaction.

Give an example of a moderator.

Explain (*i*) why a moderator is needed in a nuclear reactor and (*ii*) how the control rods affect the rate of the reaction. (15)

A heat exchanger is used in a nuclear reactor.

Explain how the heat exchanger operates. Why is it necessary to use a heat exchanger? (10)

Plutonium is produced in a fission reactor when one of the neutrons released in the fission reaction converts uranium–238 into plutonium–239 with the emission of two beta-particles.

Write an equation for this nuclear reaction. (10)

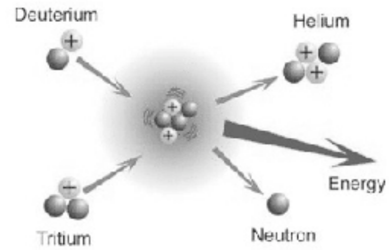
Each fission of a uranium–235 nucleus produces 202 MeV of energy. Only 35% of this energy is used to generate electricity. How many uranium–235 nuclei are required to undergo fission to generate a constant electric power of 1 GW for a day? (12)

Question 2

8. Nuclear fission reactors are used as an energy source in many parts of the world, but it is only recently that the use of nuclear fusion as a possible power source is achieving some encouraging results.
The ITER nuclear facility at Caderache in south-east France is a global collaboration that has been formed to "demonstrate that fusion is an energy source of the future". It is expected to begin testing in 2016.

Energy can be produced in a fusion reaction by combining a deuterium and a tritium nucleus as follows:

$$ {}^{2}_{1}\mathbf{H} + {}^{3}_{1}\mathbf{H} \rightarrow {}^{4}_{2}\mathbf{He} + \mathbf{n} + \mathbf{energy} $$



(i) Distinguish between nuclear fission and nuclear fusion. (12)

(ii) What are the advantages of fusion over fission in terms of fuel sources and reaction products? (12)

(iii) How much energy is produced when a deuterium nucleus (${}^{2}_{1}H$), combines with a tritium nucleus (${}^{3}_{1}H$)? (18)

(iv) Calculate the force of repulsion between a deuterium and a tritium nucleus when they are 2 nm apart in free space. (9)

(v) Fusion can only take place at very high temperatures. Explain why. (5)

Question 3

(*i*) Give one benefit of switching from fossil fuels to nuclear power for the generation of electricity. Explain your answer.

Question 4

(*b*) The following reaction occurs in a nuclear reactor:

$$ {}^{235}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{141}\text{Ba} + \text{X} + 3{}^{1}_{0}\text{n} + 202.5\ \text{MeV} $$

(i) Identify the element X. (6)

(ii) Calculate the mass difference between the reactants and the products in the reaction. (9)

(iii) What is a chain reaction?
Give one condition necessary for a chain reaction to occur. (9)

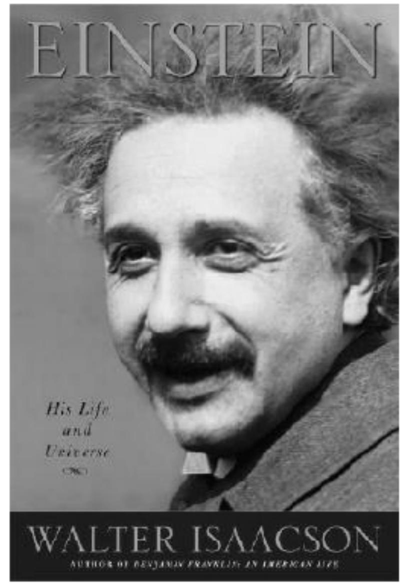
(iv) Give one environmental impact associated with a nuclear reactor. (4)

(speed of light = 3.0×10^{8} m s^{-1}; 1eV = 1.6×10^{-19} J)

Question 5

11. Read the following passage and answer the accompanying questions.

The Miracle Year: 1905



"There is nothing new to be discovered in physics now," Lord Kelvin reportedly said in 1900. He was wrong.

Isaac Newton had laid the foundations of classical physics in the late seventeenth century. He developed laws that described a mechanical universe: a falling apple and an orbiting moon governed by the same rules of gravity, mass, force and motion. In the mid-1800s, Newtonian mechanics was joined by another great advance. Michael Faraday discovered the properties of electric and magnetic fields. James Clerk Maxwell subsequently showed how changing electric and magnetic fields united to form electromagnetic radiation.

Physics was upended in the early twentieth century by Albert Einstein. In 1905 he devised a revolutionary quantum theory of light to explain the photoelectric effect, helped prove the existence of atoms, united the concepts of space and time, and produced science's best-known equation.

(Adapted from "Einstein: His Life and Universe"; Isaacson; 2007)

(*a*) The SI unit is named in honour of Lord Kelvin.
What is the temperature of the boiling point of water in kelvin? (7)

(*b*) Define the newton, the unit of force. (7)

(*c*) A force of 9 kN is applied to a golf ball by a golf club.
The ball and club are in contact for 0.6 ms.
Using Newton's laws of motion, calculate the change in momentum of the ball. (7)

(*d*) Name three different electromagnetic radiations. (7)

(*e*) What is the photoelectric effect? (7)

(*f*) Why was the quantum theory of light revolutionary? (7)

(*g*) High-energy radiation of frequency 3.3×10^{14} Hz is used in medicine.
What is the energy of a photon of this radiation? (7)

(*h*) 100 MJ of energy are released in a nuclear reaction.
Calculate the loss of mass during the reaction. (7)

(Planck constant = 6.6×10^{-34} J s; speed of light = 3.0×10^{8} m s^{-1})

Question 6

11. Read the following passage and answer the accompanying questions.

At present, nuclear fission reactors supply a sixth of the world's electricity. Along with hydroelectric stations they are the major source of 'carbon-free' energy today. Nuclear reactors have shown remarkable reliability and efficiency even though the development of nuclear technology was held back by the nuclear accidents at Chernobyl and Three Mile Island.
A nuclear revival is possible. The global reserves of uranium could support a much larger number of reactors than exist today. Nuclear power generation could increase from three hundred gigawatts today to one thousand gigawatts by the year 2050, saving the earth from 1.5 billion tonnes of carbon emissions a year. Already more than twenty gigawatts of nuclear capacity have come online since 2000. Nuclear power would significantly contribute to the stabilisation of greenhouse gas emissions.

The type of reactor that will continue to dominate for the next two decades is the light water reactor, which uses ordinary water (as opposed to heavy water, containing deuterium) as the coolant and moderator.

Solar cells, wind turbines and biofuels are becoming viable energy sources. Solar cells use semiconductor materials, such as silicon, to convert sunlight into electricity, but at the moment they provide only 0.15% of the world's energy needs. Yet sunlight could be harnessed to supply 5000 times as much energy as the world currently consumes.

(Adapted from "Scientific American; Energy's Future beyond Carbon"; September 2006)

(a) What is nuclear fission? (7)

(b) How much energy is generated worldwide every minute by nuclear power today? (7)

(c) At present, why is a fission reactor a more viable source of energy than a fusion reactor? (7)

(d) Deuterium is an isotope of hydrogen, what is an isotope? (7)

(e) What is the function of a moderator in a fission reactor? (7)

(f) Why is silicon a semiconductor? (7)

(g) A large number of solar cells are joined together in series and cover an area of 20 m^2. The efficiency of the solar cells is 20%. If the solar constant is 1400 W m^{-2}, what is the maximum power generated by the solar cells? (7)

(h) What is the source of the sun's energy? (7)

Question 7

(*c*)

In 1939 Lise Meitner discovered that the uranium isotope U–238 undergoes fission when struck by a slow neutron.
Barium–139 and krypton–97 nuclei are emitted along with three neutrons.

Write a nuclear reaction to represent the reaction. (12)

In a nuclear fission reactor, neutrons are slowed down after being emitted.
Why are the neutrons slowed down?
How are they slowed down? (9)

Fission reactors are being suggested as a partial solution to Ireland's energy needs.
Give one positive and one negative environmental impact of fission reactors. (7)

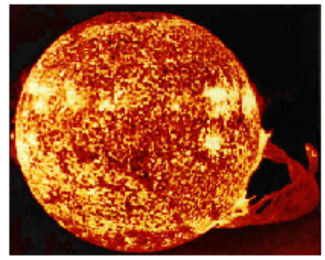
Question 8

8. Distinguish between fission and fusion. (12)

The core of our sun is extremely hot and acts as a fusion reactor. Why are large temperatures required for fusion to occur? (5)

In the sun a series of different fusion reactions take place. In one of the reactions, 2 isotopes of helium, each with a mass number of 3, combine to form another isotope of helium with the release of 2 protons.

Write an equation for this nuclear reaction. (12)



picture of sun from skylab

Controlled nuclear fusion has been achieved on earth using the following reaction.

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n$$

What condition is necessary for this reaction to take place on earth?
Calculate the energy released during this reaction. (18)

Give one benefit of a terrestrial fusion reactor under each of the following headings:
(i) fuel;
(ii) energy;
(iii) pollution. (9)

(speed of light = 2.998×10^{-8} m s^{-1}; mass of hydrogen-2 nucleus = 3.342×10^{-27} kg; mass of hydrogen-3 nucleus = 5.004×10^{-27} kg; mass of helium nucleus = 6.644×10^{-27} kg; mass of neutron = 1.674×10^{-27} kg)

Question 9

(*i*) Describe Rutherford's model of the atom.

Question 10

9. Define the becquerel. (6)

Name one device used to detect ionising radiations. (3)

Compare alpha, beta, and gamma emissions using the following headings: (*a*) penetrating ability, (*b*) deflection in a magnetic field. (9)

The photograph shows one of the nuclear reactors at Chernobyl, where there was a fire in April 1986 that released large quantities of radioactive contaminants. Among the contaminants were iodine–131 and caesium–137, which are two of the unstable isotopes formed by the fission of uranium–235.

Explain what happens during nuclear fission. (8)

Iodine–131 decays with the emission of a beta-particle and has a half-life of 8 days.
Write an equation for the beta-decay of iodine–131.
Estimate the fraction of the iodine–131 that remained after 40 days. (15)

Caesium–137 has a half-life of 30 years and it remains a significant contaminant in the region around Chernobyl. It is easily absorbed into the tissues of plants as they grow. Scientists collected a sample of berries growing near the abandoned power station. The activity of the sample was measured at 5000 Bq.

Calculate the decay constant of caesium–137. Hence calculate the number of caesium–137 atoms present in the sample. (You may assume that all of the activity was caused by caesium–137.) (15)

Question 11

(*a*) List three quantities that are conserved in nuclear reactions. (6)

Write an equation for a nucleus undergoing beta-decay.

In initial observations of beta-decay, not all three quantities appear to be conserved. What was the solution to this contradiction? (12)

List the fundamental forces of nature in increasing order of their strength.

Which fundamental force of nature is involved in beta-decay? (12)

In the Large Hadron Collider, two protons with the same energy and travelling in opposite directions collide. Two protons and two charged pi mesons are produced in the collision.

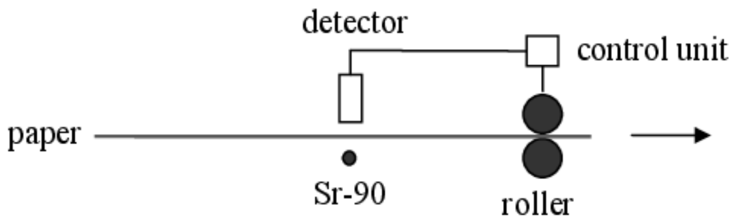
Why are new particles produced in the collision?

Write an equation to represent the collision. (12)

Show that the kinetic energy of each incident proton must be at least 140 MeV for the collision to occur. (14)

Question 12

(*d*) In the manufacture of newsprint paper, heavy rollers are used to adjust the thickness of the moving paper. The paper passes between a radioisotope and a detector, and a pair of rollers, as shown.



The radioisotope used is Sr-90 and it emits beta-particles, which are recorded by the detector. The output from the detector adjusts the gap between the rollers, so that the paper is of uniform thickness.

(i) Name a suitable detector. (6)

(ii) Describe how the reading on the detector may vary as the paper passes by. (9)

(iii) Why would the radioisotope Am-241, which emits alpha-particles, **not** be suitable for this process? (4)

(iv) Calculate the number of atoms present in a sample of Sr-90 when its activity is 4250 Bq. The half-life of Sr-90 is 28.78 years. (9)

Question 13

9. What is thermionic emission? (6)

X-rays are produced when high-energy electrons collide with a target.

Draw a labelled diagram of an X-ray tube. (12)

What are X-rays and how do they differ from light rays?

Give two uses of X-rays. (18)

When electrons hit the target in an X-ray tube, only a small percentage of their energy is converted into X-rays. What happens to the rest of their energy and how does this influence the type of target used? (9)

A potential difference (voltage) of 40 kV is applied across an X-ray tube.

Calculate:

(i) the maximum energy of an electron as it hits the target

(ii) the frequency of the most energetic X-ray produced. (11)

(Plank constant = 6.6×10^{-34} J s ; charge on electron = 1.6×10^{-19} C)

Question 14

(*d*) Smoke detectors use a very small quantity of the element americium-241. This element does not exist in nature and was discovered during the Manhattan Project in 1944.

Alpha particles are produced by the americium-241 in a smoke detector.

(i) Give the structure of an alpha particle.

(ii) How are the alpha particles produced?

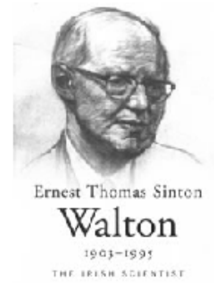
(iii) Why do these alpha particles not pose a health risk? (13)

Americium-241 has a decay constant of 5.1×10^{-11} s^{-1}.
Calculate its half life in years. (9)

Explain why americium-241 does not exist naturally. (6)

Question 15

(a) Read the following passage and answer the accompanying questions.



Ernest Walton was one of the legendary pioneers who made 1932 the *annus mirabilis* of experimental nuclear physics. In that year James Chadwick discovered the neutron; Carl Anderson discovered the positron; Fermi articulated his theory of radioactive decay; and Ernest Walton and John Cockcroft split the nucleus by artificial means. In their pioneering experiment Cockcroft and Walton bombarded lithium nuclei with high-energy protons linearly accelerated across a high potential difference (*c.* 700 kV). The subsequent disintegration of each lithium nucleus yielded two helium nuclei and energy. Their work gained them the Nobel Prize in 1951.

(Adapted from "Ernest Thomas Sinton Walton 1903 –1995 The Irish Scientist" McBrierty; 2003)

(i) Draw a labelled diagram to show how Cockcroft and Walton accelerated the protons. (6)

What is the velocity of a proton when it is accelerated from rest through a potential difference of 700 kV? (12)

Write a nuclear equation to represent the disintegration of a lithium nucleus when bombarded with a proton. (9)

Calculate the energy released in this disintegration. (12)

(ii) Compare the properties of an electron with that of a positron. (5)

What happens when an electron meets a positron? (3)

(iii) In beta decay it appeared that momentum was not conserved.

How did Fermi's theory of radioactive decay resolve this? (9)

(charge on electron = 1.6022×10^{-19} C; mass of proton = 1.6726×10^{-27} kg;
mass of lithium nucleus = 1.1646×10^{-26} kg; mass of helium nucleus = 6.6443×10^{-27} kg;
speed of light = 2.9979×10^{8} m s^{-1})

Question 16

(i) Name an instrument used to detect radioactivity.
What is the principle of operation of this instrument? (7)

Question 17

(d) Explain the term half-life. (6)

A sample of carbon is mainly carbon-12 which is not radioactive, and a small proportion of carbon-14 which is radioactive. When a tree is cut down the carbon-14 present in the wood at that time decays by beta emission.

Write a nuclear equation to represent the decay of carbon-14. (9)

An ancient wooden cup from an archaeological site has an activity of 2.1 Bq.
The corresponding activity for newly cut wood is 8.4 Bq.
If the half-life of carbon-14 is 5730 years, estimate the age of the cup. (6)

Name an instrument used to measure the activity of a sample.
What is the principle of operation of this instrument? (7)

Question 18

(i) Describe the Bohr model of the atom. (7)

Question 19

(j) Name the fundamental force of nature that holds the nucleus together.

or

Draw the truth table for an AND gate. (7)

Question 20

8. Nuclear disintegrations occur in radioactivity and in fission.

Distinguish between radioactivity and fission. (12)

Give an application of (i) radioactivity, (ii) fission. (6)

Radioactivity causes ionisation in materials. What is ionisation?

Describe an experiment to demonstrate the ionising effect of radioactivity. (15)

Cobalt–60 is a radioactive isotope with a half-life of 5.26 years and emits beta particles.

(i) Write an equation to represent the decay of cobalt–60.

(ii) Calculate the decay constant of cobalt–60.

(iii) Calculate the rate of decay of a sample of cobalt–60 when it has 2.5×10^{21} atoms. (23)

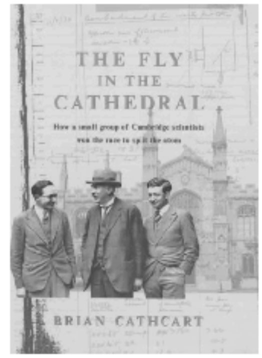
(Refer to Mathematics Tables, p. 44.)

Question 21

(a) Read the following passage and answer the accompanying questions.

Ernest Rutherford made the following point:

If the particles that come out naturally from radium are no longer adequate for my purposes in the laboratory, then maybe the time had come to look at ways of producing streams of fast particles artificially. High voltages should be employed for the task. A machine producing millions of alpha particles or protons would be required. These projectiles would be released close to a high voltage and would reel away at high speed. It would be an artificial particle accelerator. Potentially such apparatus might allow physicists to break up all atomic nuclei at will.



(Adapted from "The Fly in the Cathedral" Brian Cathcart; 2004)

(i) What is the structure of an alpha particle? (7)

(ii) Rutherford had bombarded gold foil with alpha particles. What conclusion did he form about the structure of the atom? (7)

(iii) High voltages can be used to accelerate alpha particles and protons but not neutrons. Explain why. (7)

(iv) Cockcroft and Walton, under the guidance of Rutherford, used a linear particle accelerator to artificially split a lithium nucleus by bombarding it with high-speed protons. Copy and complete the following nuclear equation for this reaction. (7)

$$^{7}_{3}Li + ^{1}_{1}H \longrightarrow$$

(v) Circular particle accelerators were later developed. Give an advantage of circular accelerators over linear accelerators. (7)

(vi) In an accelerator, two high-speed protons collide and a series of new particles are produced, in addition to the two original protons. Explain why new particles are produced. (7)

(vii) A huge collection of new particles was produced using circular accelerators. The quark model was proposed to put order on the new particles. List the six flavours of quark. (7)

(viii) Give the quark composition of the proton. (7)

(Refer to Mathematics Tables, p. 44.)