## SECTION B

*Answer* **all** *questions*

Read the following article carefully.

### A Brief History of Particle Physics

Freely adapted from http://www.particleadventure.org/other/history/quantumt.html

Paragraph

The story starts a long time ago (~400BC) in ancient Greece. Democritus, Leucippus and Epicurus developed the theory that *the universe consists of empty space and an (almost) infinite number of invisible particles* which differ from each other in *form, position, and arrangement.* All matter is made of indivisible particles called atoms. 1

It could be argued that very little happened for another 2000 years until in 1654 Otto von Guericke invented a vacuum pump. You will probably have heard about one use he made of this vacuum pump – the Magdeburg hemispheres. Two metal hemispheres with a vacuum between them could not be separated by teams of horses pulling them apart. 2

Otto von Guericke also invented an electrostatic generator – electron accelerators were born and lightning discharge could be produced artificially. 3

In 1705, it was noted that by combining both inventions of Otto von Guericke, lightning discharge can go between electrodes in a gas and can go further at low pressures. 4

In 1838, Michael Faraday noted a strange glow from low pressure gases in glass tubes when the gas was conducting electricity. Some 40 years later Eugen Goldstein noted so-called "cathode rays" in these gases. In 1898, Joseph (JJ) Thomson identified these cathode rays as streams of negatively charged particles and made measurements on the properties of these electrons. He then put forth his "plum-pudding" model of the atom. In this model, the atom is a slightly positive sphere with small, raisin-like negative electrons inside – he obviously didn't know that radioactivity, researched by Marie Curie, was a nuclear phenomenon. Hardly surprising since the nucleus hadn't been discovered yet…. 5

The early 20$^{th}$ century saw Hans Geiger and Ernest Marsden, under the supervision of Ernest Rutherford, scatter 4.7 MeV alpha particles off a gold foil and observe large angles of scattering. This put an end to the plum-pudding model and suggested that atoms have a small, dense, positively charged nucleus of diameter around $10^{-14}$ m surrounded by electrons orbiting at a distance of around $10^{-10}$ m. 6

Paragraph

Shortly afterwards, Niels Bohr succeeded in constructing a theory of atomic structure based on quantum physics. Then, in 1924, Louis de Broglie proposed that matter had wave-like properties. 7

Strangely enough, de Broglie's wave particle duality led to JJ Thomson's son (George Paget Thomson) obtaining one of the very first electron diffraction patterns for crystals. Whereas his dad obtained a Nobel prize for identifying the electron as a particle, he obtained the prize for its wave properties. 8

The first evidence for a proton was found by Ernest Rutherford in 1919 and, in 1921, James Chadwick and E.S. Bieler concluded that some strong force holds the nucleus together. 9

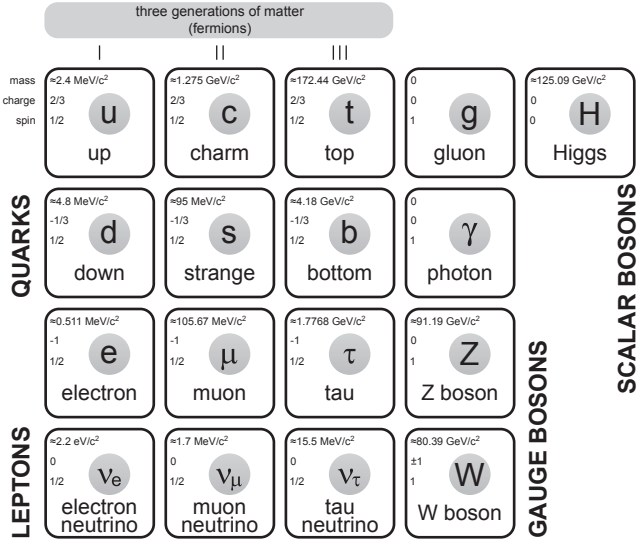
Paul Dirac realised that the positively charged particles required by his equation were new objects (he called them "positrons"). They are exactly like electrons, but positively charged – the first example of antiparticles. James Chadwick discovered the neutron. Both these developments took place in 1931. 10

Enrico Fermi put forth a theory of beta decay that introduced the weak interaction. This is the first theory to explicitly use neutrinos and particle flavour changes (1933-34). 11

In 1947, a meson that interacts strongly was found in cosmic rays, and was determined to be the pion. A year later, the Berkeley synchro-cyclotron produced the first artificial pions. 12

Some 20 years later, in the late 1960s, electron scattering experiments were carried out using the Stanford Linear Accelerator. High speed electrons were scattered off protons and the electrons appeared to be bouncing off multiple small hard cores inside the proton. James Bjorken and Richard Feynman analysed this data in terms of a model of constituent particles inside the proton. 13

**Standard Model of Elemental Particles**




In a summary talk for a conference, John Iliopoulos presented, for the first time in a single report, the view of physics now called the Standard Model – this was 1974. 14

After eighteen years of searching with many accelerators, experiments at the Fermilab near Chicago discovered the top quark at the unexpected mass of 172 GeV. No one understands why the mass is so different from the other five quarks. 15

Almost half a century after Peter Higgs predicted a Higgs boson as part of a mechanism (invented by a number of theorists) by which fundamental particles gain mass, the ATLAS and CMS experiments at the CERN lab discovered the Higgs boson (2012). 16

Some two and a half millennia after the commencement of particle physics it seems we are a lot closer to understanding the Universe but there are still many questions to be answered. Some of the most fundamental questions to be answered are: What is dark matter? What is dark energy and do either of these exist? How does quantum gravity work? For the answers to all these questions, and any others, please consult your physics teacher. 17