4. *(a)* A fission nuclear reaction for uranium is:

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

The masses of the nuclei are:

mass of $^{235}_{92}\text{U}$ = 235.01 u

mass of $^{92}_{36}\text{Kr}$ = 91.90 u

mass of $^{141}_{56}\text{Ba}$ = 140.89 u

mass of $^{1}_{0}\text{n}$ = 1.01 u

1 u = 931 MeV

Calculate the energy released in this nuclear reaction. [2]

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(b) Explain carefully the relevance of the binding energy per nucleon curve to nuclear fission and fusion. [6 QER]

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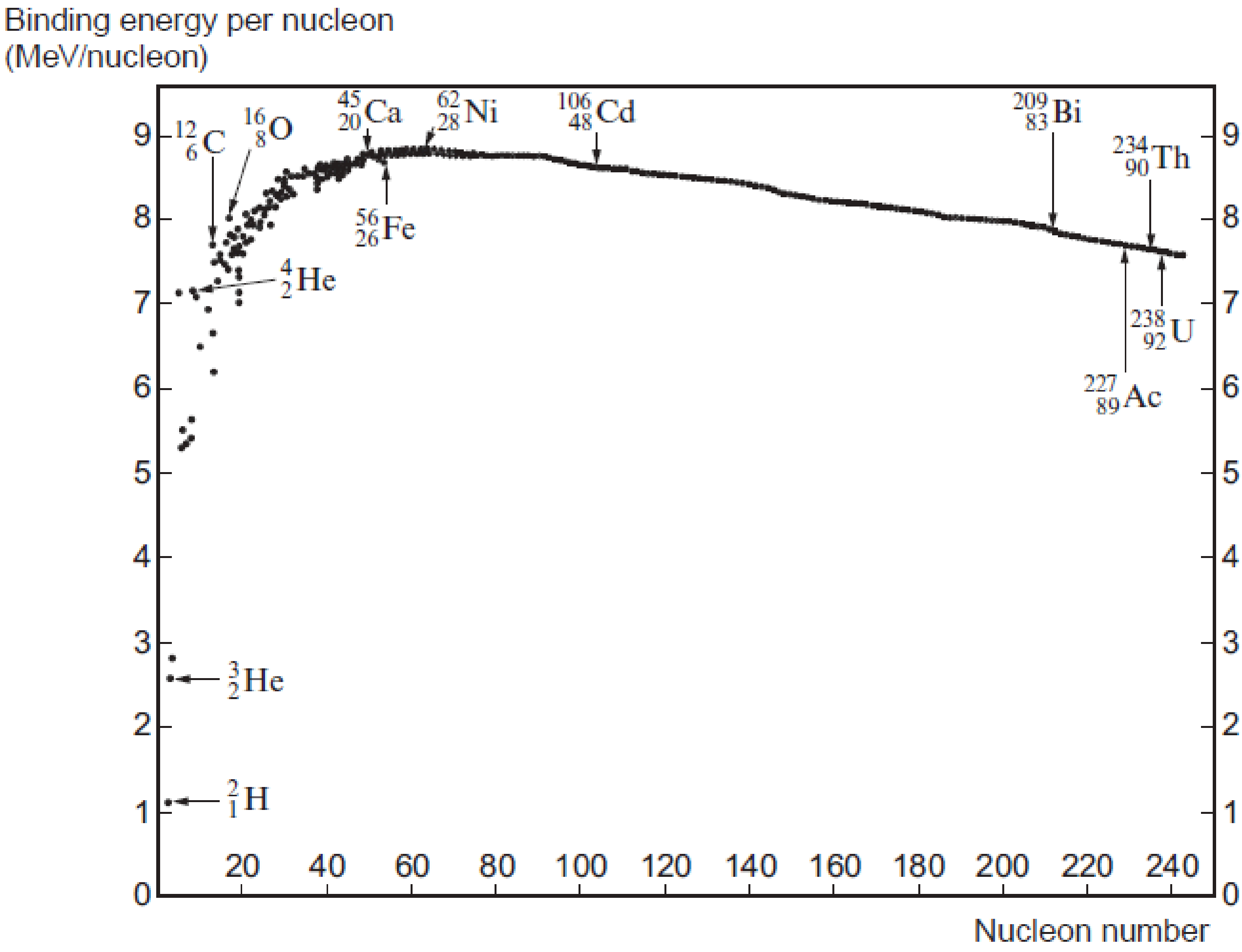
#2

(a) Nuclear energy can be released by fusion or fission. Describe these processes by considering the graph of the binding energy per nucleon plotted against the nucleon number. [4]



(b) The fusion of hydrogen to helium in the Sun may be represented by:

$$4\,{}^{1}_{1}\text{H} + 2e^{-} \rightarrow {}^{4}_{2}\text{He} + 2\,\nu_e$$

Particle	Mass / u

$^{1}_{1}H$	1.00728
$^{4}_{2}He$	4.00151
e^{-}	0.00055
ν_e	0.00000

$1\,u = 931\,MeV$

Calculate the energy released in this reaction in MeV. [3]

(c) Nuclear power has played a role in the generation of electricity in Wales. Wylfa Newydd on Anglesey may feature in further developments. Indicate a benefit and an issue that may arise from such projects and discuss their relative importance. [3]

#3

6. *(a)* Complete the following decay equations.

(i) $${}^{228}_{90}\text{Th} \longrightarrow {}^{\cdots\cdots}_{\cdots\cdots}\text{Ra} + {}^{\cdots\cdots}_{\cdots\cdots}\alpha$$ [1]

(ii) $${}^{90}_{38}\text{Sr} \longrightarrow {}^{\cdots\cdots}_{\cdots\cdots}\text{Y} + {}^{\cdots\cdots}_{\cdots\cdots}\beta$$ [1]

(b) Calculate the binding energy **per nucleon** for ${}^{90}_{38}\text{Sr}$. [4]

m_{proton} = 1.007 276 u

m_{neutron} = 1.008 664 u

m_{electron} = 0.000 549 u

atomic mass of ${}^{90}_{38}\text{Sr}$ = 89.907 738 u

1 u = 931 MeV

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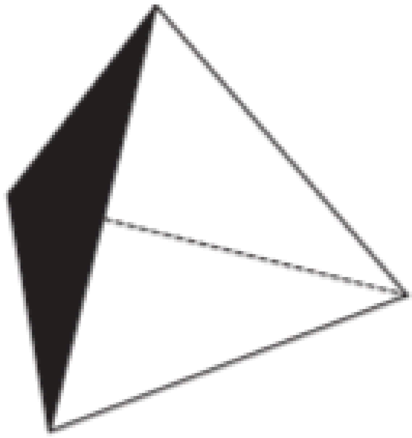
(c) Radioactive decay may be investigated in the laboratory using a dice analogy.

A student has 564 identical wooden dice. These dice are tetrahedrons, with one face painted black. A tetrahedron is a solid with four identical faces, each face being an equilateral triangle.



(i) If the student throws one of the dice, what is the probability of the tetrahedron landing on the black face? [1]

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(ii) The student then throws all dice and counts and discards those that landed on the black face. The remaining dice are thrown again and the process is repeated multiple times. The number of dice discarded after each throw is recorded in the table, and the number remaining after each throw is calculated. The results are shown in the table, which also gives the fraction of dice remaining, where:

$$\text{Fraction of dice remaining after a throw} = \frac{\text{number of dice remaining after a throw, } R}{\text{number of dice thrown in that throw, } T}$$

Throw number, n	Number of dice thrown, T	Number of dice discarded after throw	Number of dice remaining after throw, R	Fraction remaining after throw, $\frac{R}{T}$
1	564	138	426	0.76
2	426	116	310	0.73
3	310	87	223	0.72
4	223	52	171	0.77
5	171	39	132	0.77
6	132	34	98	0.74
7	98	10	88	0.90
8	88	27	61	0.69
9	61	18	43	0.70
10	43	8	35	0.81

I. Explain why the expected fraction remaining after n throws is $(0.75)^n$. [2]

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II. Hence predict the expected number remaining after 10 throws. [1]

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III. Discuss to what extent the observations agree with those expected from theory. [3]

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Question taken from WJEC examination paper 242701, June 2019

#4

Read the following article carefully.

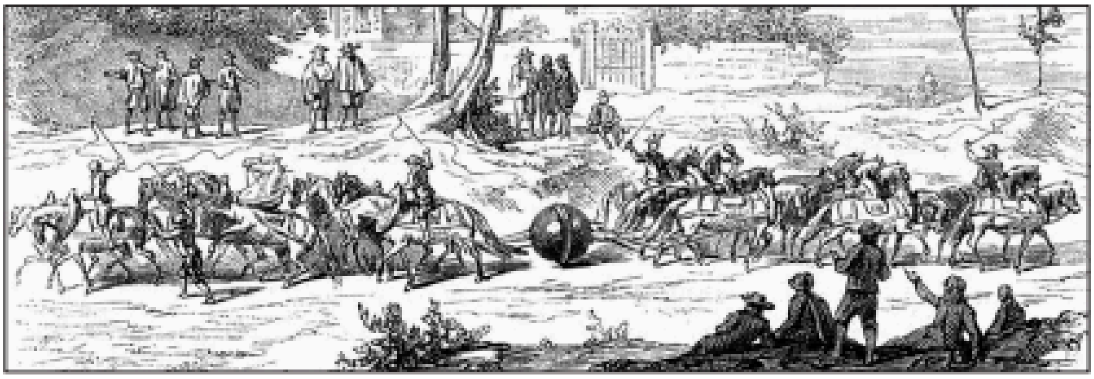
A Brief History of Particle Physics

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* 1
number of invisible particles which differ from each other in *form, position, and arrangement*.
All matter is made of indivisible particles called atoms.

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 2
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.



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

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

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 5
“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….

The early 20th 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. 6
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.

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 7
properties.

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 8
dad obtained a Nobel prize for identifying the electron as a particle, he obtained the prize for
its wave properties.

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

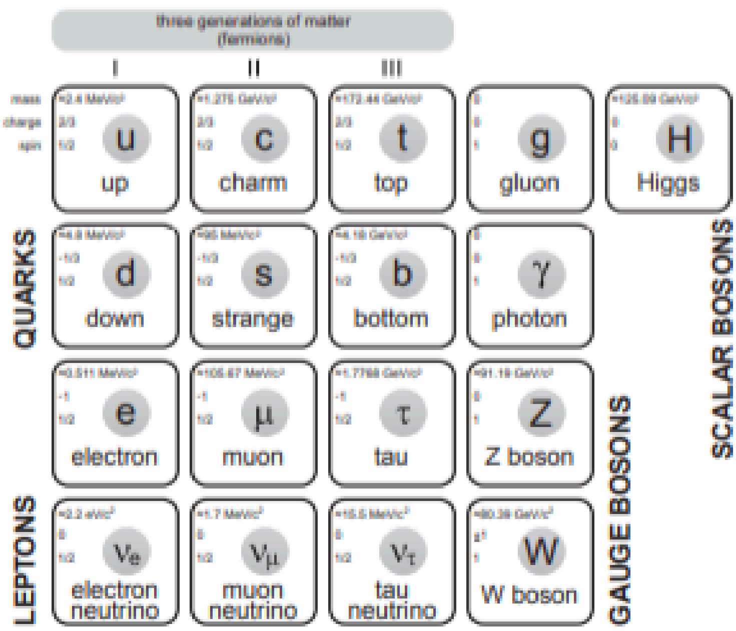
Paul Dirac realised that the positively charged particles required by his equation were new
objects (he called them "positrons"). They are exactly like electrons, but positively charged 10
– the first example of antiparticles. James Chadwick discovered the neutron. Both these
developments took place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

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 13
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.

Standard Model of Elemental Particles



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

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

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

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 17
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.

7. Answer the following questions in your own words. Extended quotes from the original article will not be awarded marks.

(a) Calculate the maximum force required to separate two Magdeburg hemispheres of radius 10 cm (atmospheric pressure = 1.01×10^5 Pa, see paragraph 2). [2]

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(b) Suggest why lightning discharge travels further at low pressures (see paragraphs 4 & 5). [2]

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(c) (i) Calculate the distance of nearest approach for a 4.7 MeV alpha particle when fired at gold foil (the charge on a gold nucleus is $+79e$, see paragraph 6). [3]

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(ii) State why your answer to *(c)*(i) and the results of the alpha particle scattering experiment contradict the "plum-pudding" model (see paragraphs 5 & 6). [2]

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(d) A student claims that a 4 keV electron is suitable for atomic diffraction experiments. Determine whether or not she is correct (see paragraphs 6 & 8). [4]

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(e) Explain why the strong nuclear force is required to hold nuclei together (see paragraphs 6 & 9). [1]

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(f) A typical thermal electron has a rms speed of approximately 100 000 $m\,s^{-1}$. When a positron annihilates an electron at room temperature, two photons of wavelength 2.43×10^{-12} m are produced. Explain, using conservation of momentum, why these photons travel in opposite directions (see paragraph 10). [3]

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(g) Explain why the quark make up of a π^- meson is $\bar{u}d$. [1]

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(h) Calculate the mass of a top quark in kg (see paragraph 15).

Note that 1 u ≡ 931 MeV if required. [2]

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