GCE A LEVEL

1420U30-1

S19-1420U30-1

PHYSICS – A2 unit 3
Oscillations and Nuclei

THURSDAY, 6 JUNE 2019 – MORNING

2 hours 15 minutes

For Examiner's use only			
	Question	Maximum Mark	Mark Awarded
Section A	1.	16	
	2.	15	
	3.	15	
	4.	6	
	5.	15	
	6.	13	
Section B	7.	20	
	Total	100	

ADDITIONAL MATERIALS

In addition to this examination paper, you will require a calculator and a **Data Booklet**.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen. Do not use gel pen. Do not use correction fluid.

Write your name, centre number and candidate number in the spaces at the top of this page.

Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space use the continuation page(s) at the back of the booklet taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

This paper is in 2 sections, **A** and **B**.

Section **A**: 80 marks. Answer **all** questions. You are advised to spend about 1 hour 35 minutes on this section.

Section **B**: 20 marks. Comprehension. You are advised to spend about 40 minutes on this section.

The number of marks is given in brackets at the end of each question or part-question.

The assessment of the quality of extended response (QER) will take place in question **4**.

SECTION A

*Answer **all** questions.*

1. A student performs an experiment to estimate the Celsius temperature of absolute zero.
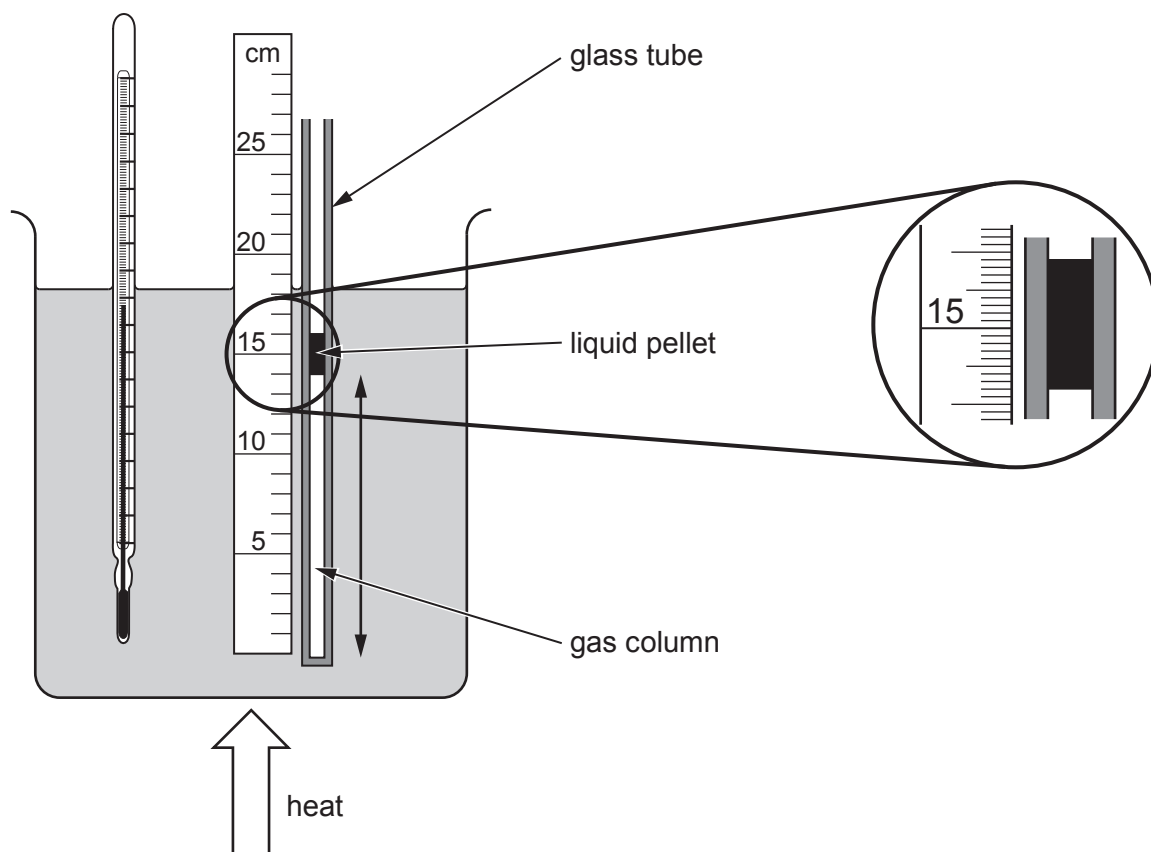
The length, l, of the gas column and its temperature, θ, are measured at atmospheric pressure, 1.01×10^5 Pa. The temperature of the water is initially 0.0 °C. It is then increased to 80.0 °C. Readings are taken at 20.0 °C intervals. The scale used to measure the length gives an uncertainty of ± 0.1 cm at the top of the column and an uncertainty of ± 0.1 cm at the bottom.

Values of θ and l are recorded in the table below.

θ / °C	l / cm
0.0	11.5
20.0	12.5
40.0	13.2
60.0	14.2
80.0	15.0

(a)   Justify the number of significant figures used to record the length, l.   [2]

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(b)   The glass tube in which the gas is trapped has an internal diameter of (1.5 ± 0.1) mm.

     (i)   Calculate the volume of the gas at 0.0 °C.   [2]

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     (ii)   Show that the percentage uncertainty in this volume, V, is approximately 15%.   [3]

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(c) The length, *l*, is plotted against the temperature, *θ*. Lines of maximum and minimum gradient consistent with the error bars have been drawn.
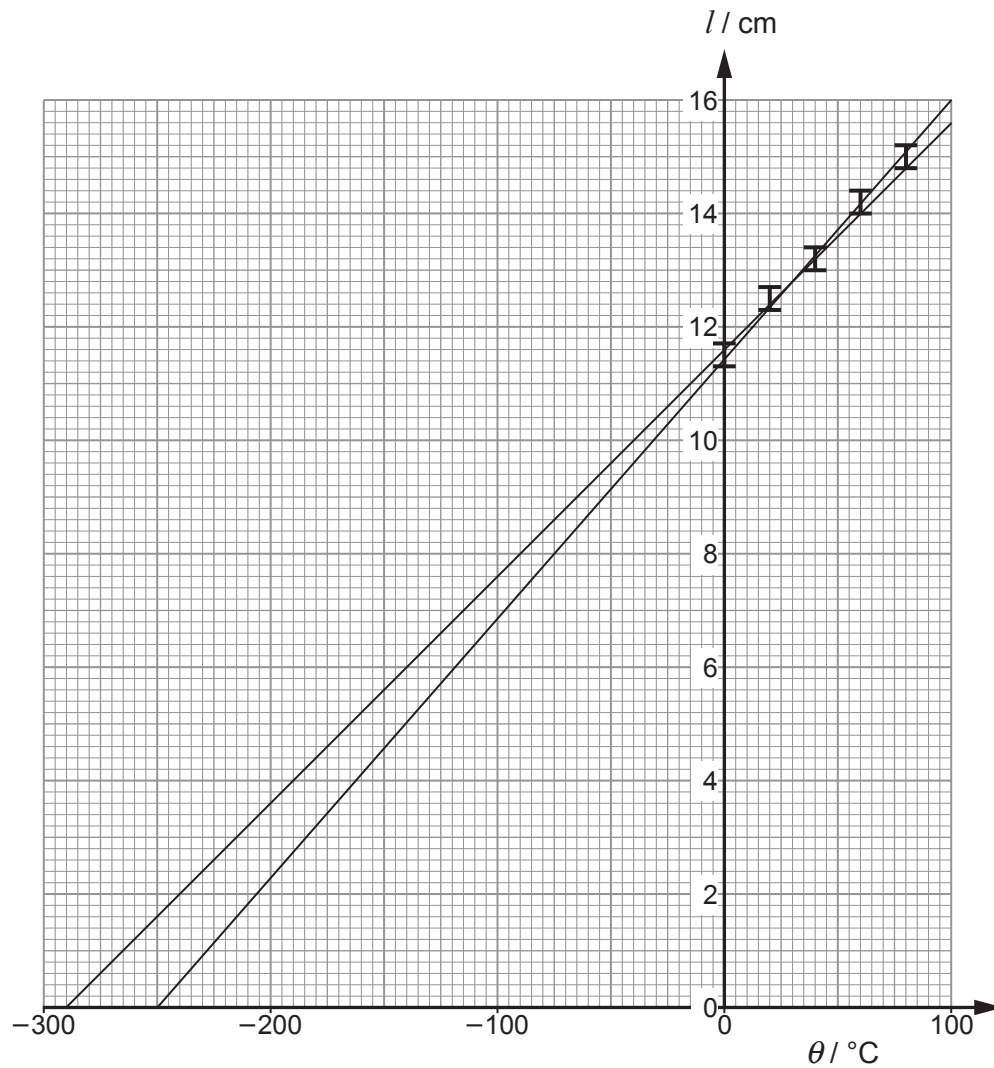
(i) Use the graph to estimate the temperature of absolute zero in °C, together with its **absolute** uncertainty. [2]

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(ii) Justify the statement that *the results are consistent with the ideal gas equation.* [4]

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(d) State what happens to the behaviour of the gas molecules as the temperature approaches absolute zero. [1]

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(e) The scale resolution of the ruler affects the final uncertainty in the value of absolute zero. Identify **two** other factors that could affect the accuracy. [2]

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2. A fairground ride consists of a large empty cylinder of radius 2.80 m with its axis of rotation vertical. A person of mass 66.2 kg walks into the cylinder and stands against its inner wall. The cylinder is rotated around the axis. When the rotation rate is 36.0 revolutions per minute the floor is lowered, but the person remains fixed in place against the wall.

This is a student's diagram.

Axis of rotation

2.8 m

F

N

W
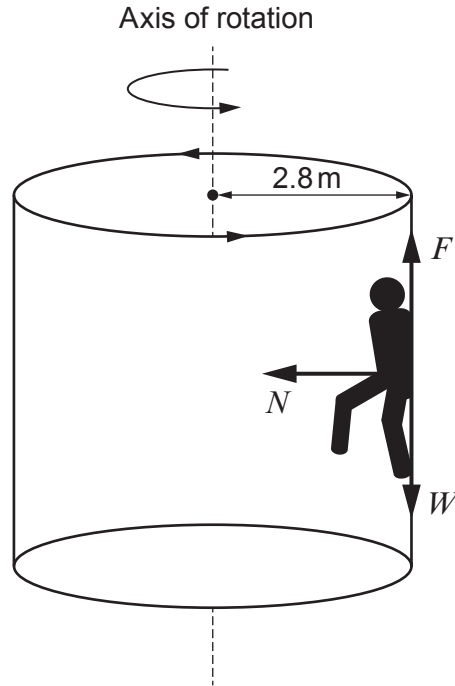
(a) Define the *radian*. [1]

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(b) Calculate:

(i) the period of rotation, T; [2]

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(ii) the speed, v, at which the person is moving in the circle. [2]

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(c) Three forces act on the person: the normal contact force from the wall, N, the weight, W, of the person, and the frictional force, F, from the wall. These are shown in the student's diagram.

Explain why the values of N and F are approximately $2\,600\,\text{N}$ and $650\,\text{N}$ respectively.

[4]

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(d) The maximum value that a frictional force can take is μN where μ is a dimensionless constant.

(i) Show that the person does not slide down the wall provided that μ is larger than approximately 0.25. [2]

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(ii) A student says that as the cylinder slows down the floor will need to be raised to support the person when the angular velocity reduces below a certain value. Justify this and determine this angular velocity if μ has a value of 0.45. [4]

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3. Simple harmonic motion (SHM) may be represented by:

$$a = -\omega^2 x$$

(a) State what quantities are represented by: [1]

a ....

ω ....

x ....

(b) If the amplitude of the oscillation of an object moving with SHM is 0.012 m and the period is 0.40 s:

(i) determine the maximum acceleration; [3]

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(ii) sketch a graph showing the variation of a with x. Insert values on the a-axis. Values are given on the x-axis. [3]

a / m s^{-2}

−0.012   0.012

x / m
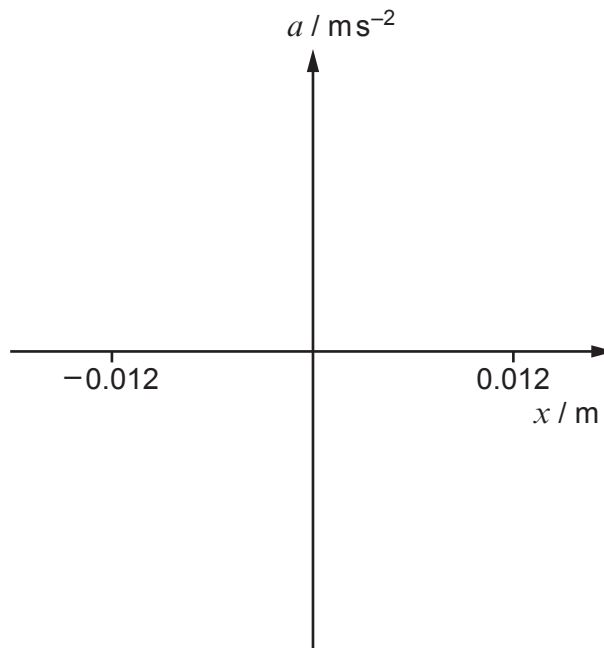
(c) The oscillating object in part *(b)* is at its centre position when $t = 0$ and moving in the positive x direction. Insert the missing values in the expression for x in metres. [3]

$$x = \boxed{} \cos(\boxed{} t + \boxed{})$$

(d) An oscillating system may be driven by an external force. Describe and explain:

   (i)   an application of forced oscillations that is useful; [2]

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   (ii) an example of forced oscillations that should be avoided. [3]

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4. Describe an experiment that uses a pendulum to determine the acceleration due to gravity with graphical analysis. [6 QER]

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5. A sealed container with a leakproof piston of cross-sectional area $0.040\,m^2$ at one end has an initial volume of $8.5 \times 10^{-3}\,m^3$. It contains oxygen gas at a pressure of $5.0 \times 10^5\,Pa$ and a temperature of $285\,K$.

(Relative molecular mass of oxygen = 32)

Volume
$= 8.5 \times 10^{-3}\,m^3$

Cross-sectional area
$= 0.040\,m^2$
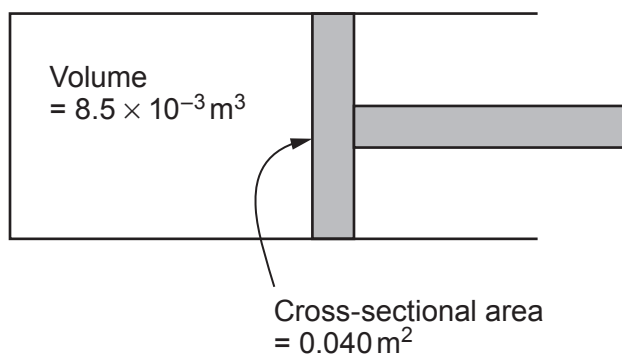
(a) Calculate:

(i) the number of moles of oxygen gas in the container; [2]

(ii) the number of molecules in the container; [1]

(iii) the rms speed of the molecules; [3]

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(iv) the force exerted by the gas on the piston. [1]

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(b) The gas is allowed to expand at a constant temperature of 285 K to a volume of $10.2 \times 10^{-3}\,\text{m}^3$.

(i) Calculate the final pressure of the gas. [2]

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(ii) During the process the gas does 773 J of work. Determine the heat flowing into the gas, explaining your reasoning. [2]

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Turn over.

(iii) Following the expansion the gas is returned to its initial state by a two-stage process:

– a decrease in volume at constant pressure;

– an increase in pressure at constant volume.

A student says that approximately 60 J of heat flows into the gas during the overall cycle (the expansion and return of the gas to its original state). Justify this. Include a sketch of the paths on a p–V diagram with values on both axes.   [4]

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p

V

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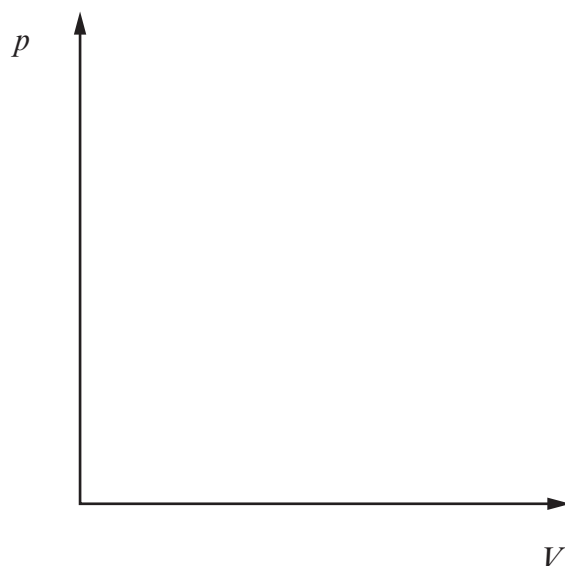
6. *(a)* Complete the following decay equations.

(i)

$$^{228}_{90}\text{Th} \longrightarrow \text{.......} \text{Ra} + \text{.......} \alpha$$

[1]

(ii)

$$^{90}_{38}\text{Sr} \longrightarrow \text{.......} \text{Y} + \text{....} \beta$$

[1]
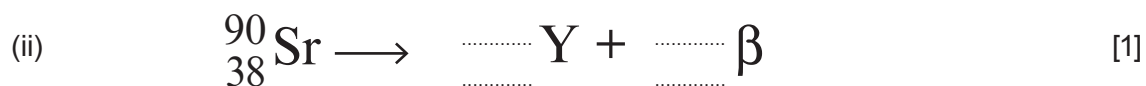
(b) Calculate the binding energy **per nucleon** for $^{90}_{38}\text{Sr}$.

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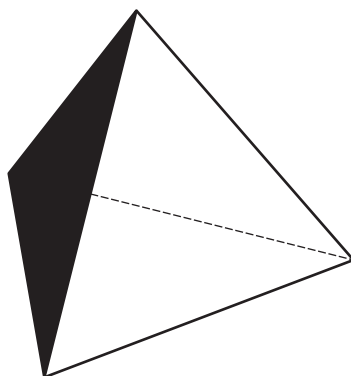
(i) If the student throws one of the dice, what is the probability of the tetrahedron landing on the black face? [1]

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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:

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

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

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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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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 2 000 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 <u>Eugen Goldstein noted so-called "cathode rays" in these gases</u>. 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 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. 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.

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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.

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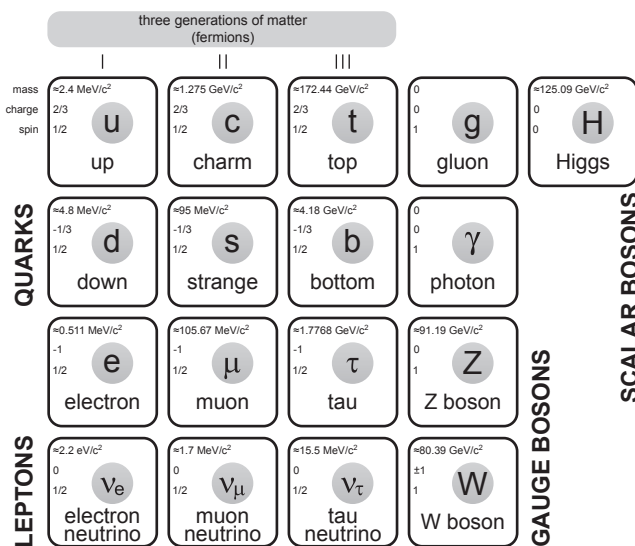
In a summary talk for a conference, John Iliopoulos presented, for the first time in a single report, the view of physics now called the Standard Model – this was 1974.

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

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Turn over.

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 $100\,000\,\text{m s}^{-1}$. When a positron annihilates an electron at room temperature, two photons of wavelength $2.43 \times 10^{-12}\,\text{m}$ 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 $1\,u \equiv 931$ MeV if required. [2]

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