Questions

Module 8: From the Universe to the Atom

8.5 Deep Inside the Atom

Multiple-choice questions: 1 mark each

1. **The Standard Model of matter was developed by physicists to describe all matter in the Universe and the forces that hold it together.**

Which of these are the three main groups of particles found in the Standard Model of matter?

(A) Quarks, leptons and bosons.

(B) Quarks, hadrons and mesons.

(C) Baryons, mesons and leptons.

(D) Bosons, quarks and fermions.

2. **Quarks can only exist as hadrons, which are further subdivided into two groups.**

Which of these are the two groups of hadrons?

(A) Baryons and leptons.

(B) Baryons and bosons.

(C) Baryons and mesons.

(D) Leptons and bosons.

3. **Protons, neutrons and electrons are sub-atomic particles. The electron is still regarded as a fundamental (or elementary) particle in the Standard Model of matter.**

However, protons and neutrons are not fundamental (or elementary) particles. Why?

(A) Protons and neutrons are made up of larger particles, called quarks.

(B) Protons and neutrons are force-carrying boson particles that act between fundamental particles.

(C) Protons and neutrons are made up of smaller particles, called quarks.

(D) Protons and neutrons are made up of even smaller particles called baryons, leptons and mesons.

4. What is a sub-atomic particle?

(A) A particle that is produced by a particle accelerator.

(B) Any particle that is smaller than an atom.

(C) The protons, neutrons and electrons within the nucleus of an atom.

(D) The boson particles within the nucleus of an atom.

5. The fundamental building blocks of matter at a sub-atomic level are called fundamental (or elementary) particles.

Which of these correctly describes fundamental particles?

(A) They cannot be broken down into smaller, simpler particles of matter and so have no internal structure.

(B) They are particles that were mathematically predicted by physicists and which have internal structure.

(C) They are made up of even smaller particles that carry positive, negative or neutral charges.

(D) They are sub-atomic particles that are composed of other particles and the forces acting between them.

6. What is the Standard Model of matter?

(A) A quantum theory describing antimatter particles and predicting the Higgs particle.

(B) A mathematical description of protons, neutrons and electrons as the smallest building blocks of atoms.

(C) A model showing how protons and neutrons are each made up of three quarks.

(D) A theory predicting the properties and behaviour of all known particles and the forces between them.

7. The Standard Model of matter is still considered to be an incomplete theory, as there are some fundamental physical phenomena in nature that it cannot explain.

Which of the following have not yet been explained by the Standard Model of matter?

(A) The existence of an antimatter equivalent for almost all the known particles.

(B) Higgs boson.

(C) Strong nuclear force and weak nuclear force.

(D) Gravity, dark matter, dark energy, and the mass of neutrinos.

8. Which row in the table below correctly shows the sub-atomic particles and whether or not they consist of quarks?

	Particle that contains quarks	*Particle that has no quarks*
(A)	Hadrons	Leptons
(B)	Baryons	Mesons
(C)	Mesons	Baryons
(D)	Leptons	Hadrons

9. There are four fundamental forces in the Universe. Of these forces, only three are in the Standard Model of matter.

Which of these statements about the fundamental forces in the Standard Model of matter is correct?

(A) The strong nuclear force acts on particles through the exchange of a quark.

(B) The forces acting between particles are mediated by other particles, called gauge bosons.

(C) Gravitational forces between particles are mediated by a boson called the gravitron.

(D) The strong nuclear force acts on particles through the exchange of photons.

10. Into which group of particles in the Standard Model of matter are electrons categorised?

(A) Leptons

(B) Fermions

(C) Bosons

(D) Baryons

11. Which of these boson particles are thought to mediate the strong nuclear force between quarks in the nucleus of an atom?

(A) Photon

(B) Gluon

(C) W and Z particles

(D) All of these particles interacting with each other.

12. Which of these fundamental forces in the Standard Model of matter provides the strongest force in the nucleus of an atom?

(A) Gravitational forces

(B) Weak nuclear forces

(C) Electromagnetic forces

(D) Strong nuclear forces

13. Once physicists knew about the existence of protons, neutrons and electrons, the quest to discover if there were any other particles at a sub-atomic level began.

Which of these technologies has not provided physicists with evidence about the existence of subatomic particles apart from the proton, neutron and electron?

(A) Particle accelerators

(B) Linear accelerators

(C) Cathode ray tubes

(D) Synchrotrons

14. What type of particles are used by all particle accelerators?

(A) Positive particles, such as protons.

(B) Negative particles, such as electrons.

(C) Uncharged particles.

(D) Charged particles.

15. In what way do electric and magnetic fields influence charged particles in a particle accelerator?

(A) The forces from electric and magnetic fields change their direction and accelerate them.

(B) The forces from electric and magnetic fields gives the particles potential energy.

(C) They decelerate particles as they approach a target, so they produce secondary particles.

(D) They cause them to travel in a circular path until they reach the target.

Short-answer questions

16. The Standard Model of matter says that baryons, such as protons and neutrons, are composed of up and down quarks. There are three quarks in each particle. The table below shows the different types of quarks and their charge (in units of e, the charge on an electron).

Quark	*Charge*
Up	$+\frac{2}{3}$e
Down	$-\frac{1}{3}$e
Strange	$-\frac{1}{3}$e
Charm	$+\frac{2}{3}$e
Bottom	$-\frac{1}{3}$e
Top	$+\frac{2}{3}$e

Using this information and your knowledge of the charge on a proton and neutron, determine the quark composition of protons and neutrons.

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Adapted 2003 HSC Q31(b) ... 2 marks

... same as 2006 Q31(d)(iii)
& similar to 2004 Q31 (b)(i)

17. Outline why gravitational forces are not included in the Standard Model of matter.

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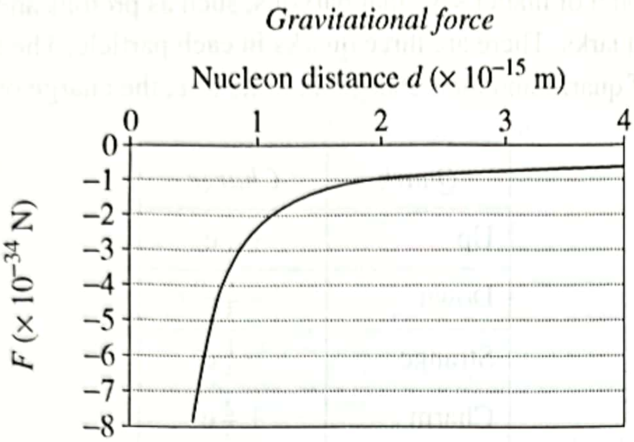
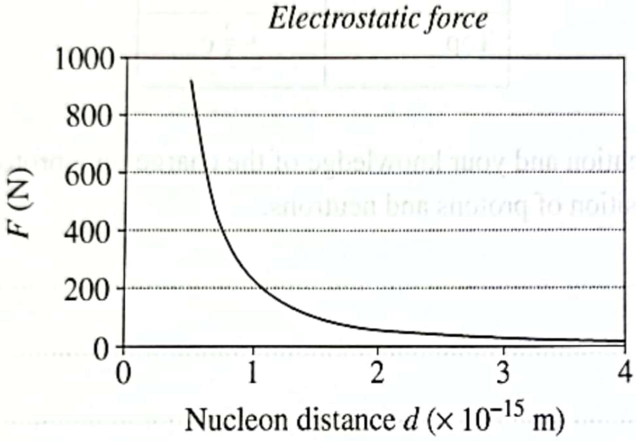
2014 HSC Q35(b)(i) ... 2 marks

18. The two graphs below show the gravitational and electrostatic forces acting between two protons in the nucleus of an atom.





(a) If the distance between protons in a nucleus is 1.0×10^{-15} m, determine both the gravitational and the electrostatic force at this distance

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(b) Explain why these two forces cannot explain the stability of the nucleus, and why there is a need for the strong nuclear force.

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2003 HSC Q31(d)(i) & (ii) ... 2 + 2 = 4 marks

19. (a) Identify the four fundamental forces in physics.

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(b) Which of these fundamental forces is not included in the Standard Model of matter?

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(c) Explain how the stability of atomic nuclei is maintained.

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Adapted 2013 HSC Q35(d) – with a new part (b)... 2 + 1 + 3 = 6 marks

20. (a) A Van de Graaff accelerator uses a single high voltage to accelerate charged particles.

Name ONE other particle accelerator and describe the method it uses to accelerate charged particles.

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(b) Vast sums of money have been spent in building and improving particle accelerators over the years.

What information does one expect to obtain from the expenditure of such money?

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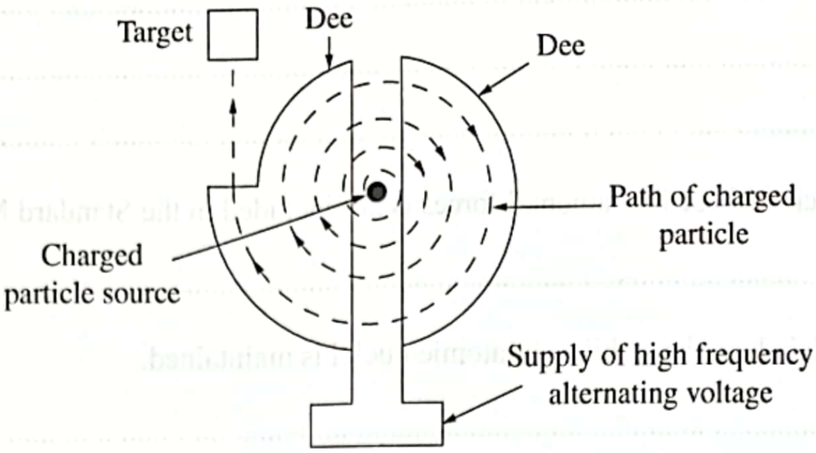
Adapted 1984 HSC Q Elective 7 (c)(i) & (ii) ... 2 + 2 = 4 marks

21. The cyclotron, invented in 1932, accelerates c[illegible] diagram shows the basic design of a cyclotron. The Dees provide a strong magnetic field into the plane of the page.



(a) Outline the physical principles involved in the design of the cyclotron.

(b) Account for the use of the cyclotron (or other accelerator) in the development of our understanding of matter.

Adapted 2006 HSC Q31(d)(i) & (ii) ... 3 + 3 = 6 marks

... (a) is similar to Q as 2008 Q31(d)(i)

22. Theories and experiments not only help increase our understanding, but also generate new questions.

To support this statement, outline the role of particle accelerators in obtaining evidence to support for the Standard Model of matter.

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Stimulus from 2009 HSC Q31(e) with new question ... 6 marks

23. Explain why electrons are classified as a fundamental particle, whereas protons and neutrons are not considered to be fundamental particles.

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24. **Outline the operation and role of particle accelerators in investigating matter.**

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... 4 marks

25. **Identify the key features and components of the Standard Model of matter.**

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Adapted 2008 Q31(d)(ii) ... 4 marks

[Note: A similar question asked for 2018 Q34(c) (7 marks) was:

'Using the Standard Model, analyse the roles of both forces and particles in the current understanding of the atom'

The first part of an answer to the 2018 question would be the same as Question 25. See the Note with the answer for Question 25 as to how you would relate the forces and particles to the current understanding of the atom.]

26. Explain how evidence from experiments involving particle accelerators and detectors has provided support for the Standard Model of matter.

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2016 HSC Q34(d) ... 4 marks

27. Describe the three fundamental forces that are currently in the Standard Model of matter.

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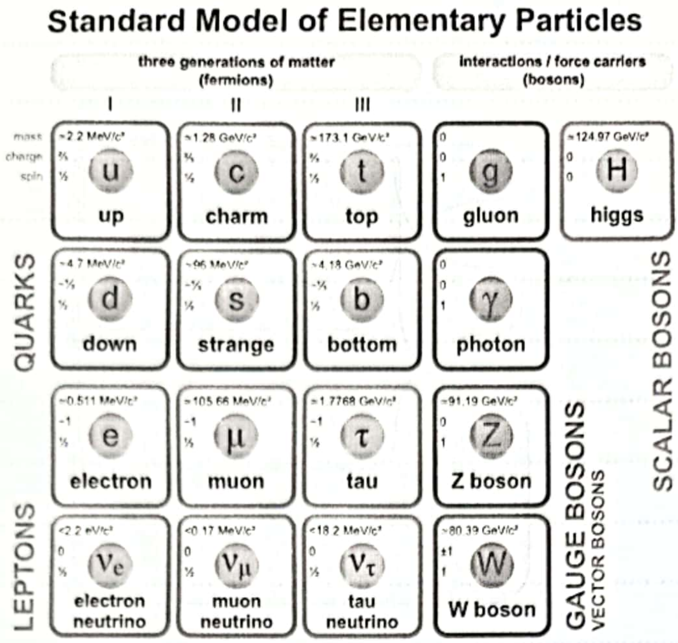
... 3 marks

28. The predicted Higgs boson was
in 2012. As shown in the diagram below, the Standard Model of matter now includes the Higgs boson, along with the 12 fundamental fermions and four other bosons.



(a) Give one reason to account for why the discovery of the Higgs boson is so special for particle physicists?

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(b) The Higgs boson has a mass of 125 GeV/c^2 – and so is about 130 times heavier than a proton. Suggest a reason as to why its high mass delayed its discovery in terms of the technology available.

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(c) Does the discovery of the Higgs bosun complete the Standard Model of matter for physicists or not? Explain.

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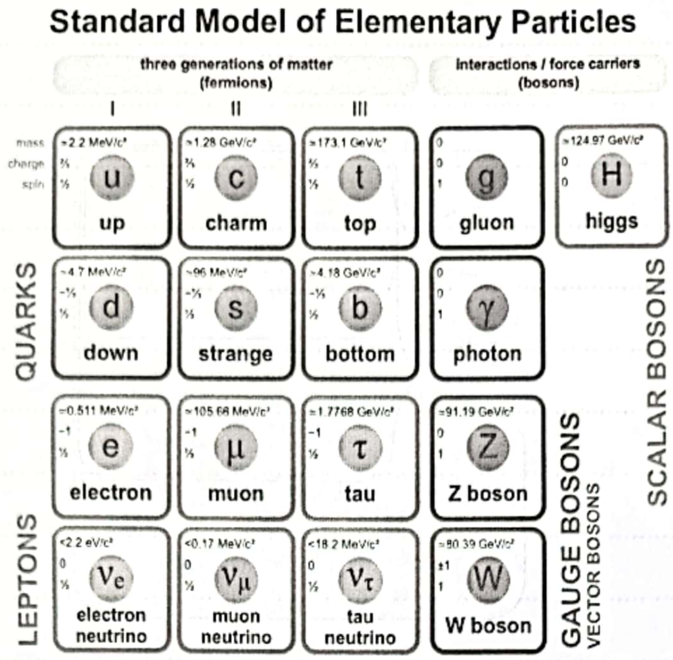
... 1 + 1 + 2 = 4 marks

28. The predicted Higgs boson was discovered using the Large Hadron Collider (LHC) at CERN in 2012. As shown in the diagram below, the Standard Model of matter now includes the Higgs boson, along with the 12 fundamental fermions and four other bosons.



(a) Give one reason to account for why the discovery of the Higgs boson is so special for particle physicists?

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(b) The Higgs boson has a mass of 125 GeV/c^2 – and so is about 130 times heavier than a proton. Suggest a reason as to why its high mass delayed its discovery in terms of the technology available.

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... 1 + 1 + 2 = 4 marks

8.5 Deep Inside the Atom

Multiple choice: 1 mark each

1. A	2. C	3. C	4. B	5. A	6. D	7. D	8. A
9. B	10. A	11. B	12. D	13. C	14. D	15. C	

Explanations:

1. **A** All matter in the Universe is made up of two elementary types of particles: fermions and bosons. Fermions are divided into quarks and leptons. Quarks only exist bonded together to form hadrons, which form two groups called baryons and mesons. Bosons are particles that mediate the forces between all the other particles. From this data, it can be seen that only (A) has the three main groups of particles, which are the quarks, leptons and bosons.

2. **C** Hadrons form two groups called baryons and mesons, as in (C). Leptons, like quarks, are a type of fermion, while bosons are particles that mediate the forces between the fundamental particles. Leptons and bosons are not hadrons. So (A), (B) and (D) are incorrect.

3. **C** Protons and neutrons were once referred to as 'fundamental particles' in classical models of the atom, as they were then considered indivisible. However, they have since been found to consist of even *smaller* particles called quarks and so are not 'fundamental particles' in the Standard Model. So (C) is the answer, and (A) is incorrect. Protons and neutrons are not force-carrying boson particles. So (B) is incorrect. Protons and neutrons belong to the hadron group called baryons – and are not made up of baryons, nor mesons, nor leptons. So (D) is incorrect.

4. **B** A sub-atomic particle is any particle that is smaller than an atom. So (B) is the answer. It is not just the particles produced by a particle accelerator, as protons, neutrons and electrons are sub-atomic particles. So (A) is incorrect. Similarly, it is not just protons, neutrons and electrons, as there are now known to many other sub-atomic particles. So (C) is incorrect. The bosons that mediate the forces between the elementary particles are just one type of sub-atomic particle in the Standard Model of matter. So (D) is incorrect.

5. **A** A fundamental particle is a sub-atomic particle that is not comprised of other smaller particles (to the best of scientific knowledge) and so has no internal structure. So (A) is the answer. Whilst the Standard Model is a mathematical description of all known particles and the three forces that act between them, the fundamental particles in this model have all been discovered using particle accelerators, and so are not just predictions. So (B) is incorrect. The fundamental particles are not fundamental if they are made up of smaller particles. So (C) is incorrect. A fundamental particle is sub-atomic, but it is not a force. So (D) is incorrect.

6. **D** The Standard Model of matter is a quantum theory that predicts the properties and behaviour of the particles in nature and the forces between these particles. So (D) is the answer. This model provides a mathematical description of these particles and forces, and not of just protons, neutrons and electrons. Also, protons, neutrons and electrons are not the smallest building blocks of atoms, as fundamental particles are smaller. So (B) is incorrect. The Standard Model covers antimatter particles and predicted the Higgs particle, and also describes how protons and neutrons are made up of quarks. But it is not just about these three things. So (A) and (C) are incorrect.

7. **D** Some of the phenomena that the Standard Model cannot adequately explain include gravity, dark matter, dark energy, and the fact that neutrinos have mass. So (D) is the answer. The existence of antimatter, i.e. particles with the same mass as known particles, but the opposite charge and magnetic moment, was predicted back in the 1920s. It has since been verified that almost every known particle has a distinct antiparticle, and this is consistent with the Standard model. So (A) is incorrect. The Higgs boson, discovered in 2012 by physicists at CERN, is now considered to be an elementary (fundamental) particle in the Standard Model – and the strong nuclear force and weak nuclear force are two of the fundamental forces in this model. So (B) and (C) is incorrect.

[Note: Another problem with the Standard Model is that it predicts that matter and antimatter should have been created after the Big Bang in equal amounts, however the Universe has much more matter than antimatter. No mechanism sufficient to explain this asymmetry exists in the Standard Model. The Standard Model is also incompatible with Einstein's general theory of relativity.]

8. **A** When quarks bond together, they form hadrons. The hadrons are divided into two groups called baryons and mesons. So, both of these groups are particles made up of quarks. Leptons do not contain quarks. Only (A) correctly shows this, and so is the answer.

9. **B** The fundamental forces acting between particles are mediated by other particles, called force-carrying particles, or gauge bosons. So (B) is the answer. The strong nuclear force acts on particles, such as quarks, through the exchange of force-carrying particles (called gauge bosons). These particular bosons are called gluons, not photons. So (A) and (D) are incorrect. Gravitational forces are not included in the Standard Model of matter as they are negligible at the sub-atomic level. Also, the proposed 'gravitron' force particle which has yet to be detected is not part of the Standard Model of matter. So (C) is incorrect.

10. **A** Electrons are a type of lepton, as in (A).

11. **B** The particles listed are all force-carrying particles, called gauge bosons (or bosons). So they are all involved in mediating the fundamental forces in the Standard Model of matter. The strong nuclear force is mediated by a gluon, as in (B). The electromagnetic forces are mediated by a photon, while the weak nuclear force is mediated by the W and Z particles. So (A), (C) and (D) are incorrect.

12. **D** The strong nuclear force is the strongest of the fundamental forces or interactions that govern the behaviour of fundamental particles in the atom, as in (D). The electromagnetic forces and weak nuclear forces are not as strong. So (B) and (C) are incorrect. The gravitational forces are so weak that they are negligible at a subatomic scale compared to the other forces –and so they are not a part of the Standard Model of matter. So (A) in incorrect.

13. **C** Cathode ray tubes (CRT) produce negatively charged particles (identified by Thomson as electrons). Canal rays, or positively charged particles were also found in CRT, flowing in the opposite direction to the cathode rays. CRT cannot accelerate these particles with high enough energy to produce fundamental particles. So (C) is the answer. Particle accelerators such as linear accelerators, cyclotrons and synchrotrons are all technologies that can accelerate particles to a very high speed to increase their energy. The collision of these high-speed particles results in breaking them into their components and so produce new sub-atomic particles apart from the proton, neutron and electron. So (A), (B) and (D) are not the answer.

14. **D** All particle accelerators require a source of charged particles – the charged particles do not have to be only positive, or only negative – they can be either positive or negative. So (D) is the answer.

15. **C** The forces from the electric and magnetic fields in a particle accelerator are used to make the charged particles accelerate and to change their direction. So (C) is the answer. In doing this, they give the particles more kinetic energy, not potential energy. So (B) is incorrect. They accelerate the particles toward the target, without any deceleration. So (C) is incorrect. They only cause particles to follow a circular path in cyclotrons and synchrotrons, not in linear accelerators. So (D) is incorrect.

Short-answer questions

16. Protons have a charge of +1, so a proton has 2 up quarks and 1 down quark

... as $(2 \times \frac{2}{3}) + (-\frac{1}{3}) = +1$

Neutrons have a charge of 0, so neutrons have 1 up quark and 2 down quarks

... as $(\frac{2}{3}) + 2 \times (-\frac{1}{3}) = 0$

17. The gravitational forces between nucleons (protons and neutrons) in the nucleus are so weak that they are negligible at a subatomic scale compared to the strong nuclear force holding the nucleons together and the electrostatic repulsion force between protons. Also, the Standard Model of matter appears to work without having to account for the effects of gravity.

[Note: Although not yet found, the 'gravitron' would be the corresponding force-carrying particle of gravity.]

18. (a) Gravitational force, $F_G = -2.2 \times 10^{-34}$ N

Electrostatic force, $F_E = 230$ N

(b) The electrostatic force of repulsion is greater than the gravitational force of attraction by a factor of 10^{36}. If these were the only two forces acting in a nucleus, the nucleus would break apart due to the electrostatic repulsion between the protons. The 'strong nuclear force' that acts between every nucleon is needed to overcome this repulsion.

19. (a)
- strong nuclear force
- electromagnetic force
- weak nuclear force
- gravity

(b) Gravity

[Note: The gravitational forces are considered negligible at a subatomic level and so are actually not included in the current Standard Model of matter.]

(c) The stability of the nucleus is related to the strength of the forces that hold the nuclear particles together. The attractive force holding the nucleons (protons and neutrons) together is the strong nuclear force. This force, which operates over very small distances, is independent of charge and much stronger than the electrostatic repulsion force between protons.

20. (a) LHC (Large Hadron Collider at CERN) – this particle accelerator generates electric fields that propel charged proton particles to very high speeds, close to the speed of light and increases their energy, while magnetic fields steer and focus them to collide with other particles travelling in the opposite direction.

[Note: The LHC also accelerates beams of lead ions, stripped of all their electrons, to similar high energies.]

(b) Analysis of the data from collisions of sub-atomic particles helps to provide evidence about nuclear structure and to determine whether models such as the Standard Model of matter are correct, or whether they need to be modified. It also helps physicists to test different theories and search for new sub-atomic particles.

21. (a) A cyclotron accelerates particles to study matter. These particles are accelerated each time they cross the electric field in the gap between the dee chambers. The applied magnetic field causes the particles to travel a circular path through the dees. As the velocity of the particles keeps increasing, so does the radius of their path. Hence the particles gain energy as they spiral around and eventually move out to the target. As they collide with the target, secondary particles are generated.

(b) Cyclotrons and other particle accelerators, have enabled physicists to give very high energy to subatomic particles, causing them to accelerate to high speeds. The collisions of these particles has provided the extra energy required to break them into their components and emit new sub-atomic particles with greater mass. This has enabled physicists to determine how some subatomic particles have internal structure, while others do not, to determine the properties of these particles and their interactions, and to understand more about the structure of the nucleus and how particles are held together.

22. Experiments with cloud chambers and bubble chambers led to the discovery or prediction of new sub-atomic particles, such as positrons and neutrinos, while experiments with modern detectors led to the discovery of many more new particles, e.g. particle accelerators led to the discovery of sub-atomic particles that had previously been theorised, e.g. quarks, etc. As scientists discovered more particles, or found that observations did not match previous results (as occurred with the discovery of muons), it posed new questions, e.g. how many more particles were awaiting discovery?

These experimental discoveries led to the Standard Model of matter with the 12 basic subatomic particles and the forces between them. However, as scientists came to know more and more about quarks and leptons and the 'force-carrier particles', it made them realise that there were still some flaws in the Standard Model of matter with a number of, as yet, unanswered questions, e.g. is there a leptoquark? a gravitron? What is dark matter? … and so on.

23. An electron cannot be broken down into smaller, simpler particles of matter and has no internal structure. Whereas protons and neutrons are made up of even smaller particles called quarks. Radioactivity experiments have revealed that both protons and neutrons have some internal structure and can be converted into each other with the emission of β^+ or β^- particles.

24. All particle accelerators operate by accelerating charged particles to very high speeds and hence very high energies. Hence high energy collisions can be produced between known particles. This causes the particles to break up and emit new sub-atomic particles, e.g. quarks and other fundamental particles. It has also led to producing more massive particles. Hence physicists have been able to investigate matter and develop the standard Model of matter.

Over time, particle accelerators have become much larger and can now accelerate particles to much higher energies than previously. Improved detectors, e.g. bubble chamber, and multi-component detectors, are used to detect the products formed. Computer analysis is an essential part of the process. As a result, physicists have used particle accelerators to infer the existence of over 200 sub-atomic particles, and the fundamental forces binding them. This has provided physicists with the experimental evidence to support and refine the Standard Model theory.

[Note: Scientists at CERN recently unveiled plans for a Future Circular Collider (FCC), four times larger than the LHC to hopefully commence operation in 2040.]

25. The Standard Model of matter describes two types of fundamental particles called quarks and leptons – these are made up of the 12 basic subatomic fundamental particles so far discovered. There are six different quarks and six different leptons, each with a corresponding antiparticle.

The fundamental particles interact through forces, which include: the electromagnetic, strong and weak forces, and their carrier particles (bosons), e.g. photons, gluons, W and Z particles, and the Higgs boson. The model explains how these forces act on all matter particles.

[Notes:

(1) Gravity is not part of the Standard Model of matter, and so there is no need to mention gravitational forces or the proposed 'gravitron' force particle, which have yet to be detected.

(2) For the 2018 question, to relate the forces and particles to the current understanding of the atom, you could add, e.g. The strong force holds nucleons (protons and neutrons) together in the nucleus, thus overcoming the electrostatic repulsion between protons. Electrons (which are leptons) are thought to orbit or are in a cloud around the nucleus. Electrons usually interact by the weak nuclear forces and electromagnetic interactions.]

26. Experiments involving the collisions of accelerated, high-energy particles with one another and with atomic nuclei in particle accelerators have led to the formation of new subatomic particles. These particles are unstable and so not able to be observed under normal conditions. Hence the need for particle accelerators. Particle detectors have been used to take measurements from which the trajectory, energy and momentum of these particles could be determined. This has enabled physicists to determine the properties of these particles and how they interact.

These discoveries have led to physicists formulating the Standard Model of matter to explain the structure and behaviour of the particles and the fundamental forces binding them. This model then predicted the existence of further sub-atomic particles. Many of these have since been discovered, thus supporting the model.

27. The three fundamental forces act between subatomic particles and determine their behaviour and interactions. These forces vary in the distance over which they act and in their strength. They work by the exchange of a force carrier particle, called a boson. These bosons include the photon (for electromagnetic forces), a gluon (for the strong nuclear forces) and W and Z particles (for the weak nuclear forces). The role of the Higgs boson in relation to these forces is still being determined, as it was only discovered in 2012 – but this bosun is thought to give all matter its mass.

[Note: (1) Bosons are also known as 'gauge bosons'. (2) The gravitational force is negligible at the subatomic level, and scientists have yet to detect this force. The Standard Model of matter works accurately without having to account for the effects of gravity. Although not yet found, the 'graviton' would be the corresponding force-carrying particle of gravity.]

28. (a) Since the mass of the Higgs boson has been calculated to be within the range predicted by the Standard Model, its discovery supports the Standard Model of matter.

OR The Higgs boson particle is important because it signals the existence of the Higgs field, an invisible energy field present throughout the universe that gives all matter its mass.

(b) Particle physicists did not have the right type of particle accelerator to produce such a heavy particle until the LHC, which can accelerate protons at up to 0.9999 times the speed of light. Hence the LHC was energetic enough to give the right type of collisions to make the discovery of the Higgs boson possible.

(c) No – its discovery is helping to develop an understanding about how fundamental particles get mass, but our understanding of matter is still very incomplete. Physicists are yet to confirm whether the properties of the Higgs bosun are as predicted by the Standard Model or not. So, the Standard Model of matter is still being validated and tested, as there are still many unanswered questions, e.g. is there a leptoquark? a gravitron? What is dark matter? … and so on.

27. 1. The Law of Conservation of Energy.
    2. The Law of Conservation of Momentum.

28. When Chadwick bombarded beryllium with α-particles, he measured the velocities of the protons and the unknown radiation released. Since he knew the mass of the target and the protons ejected and their velocities, he was able to apply the Laws of Conservation of Momentum and Energy to his measurements. He showed the protons moved off with the same momentum that the radiation had before the collision. From this, he determined that the radiation was uncharged particles (neutrons) with about the same mass as a proton.

29. Chadwick applied the Laws of Conservation of Momentum and Energy to his measurements of the three particles (alpha particles, *X* and protons) being emitted, since he knew the mass of the target and the protons ejected and their velocities. Since the protons had the same momentum as the radiation had before the collision, he determined that the mass of *X* was the same/similar to mass of a proton.

[Note: This is how Chadwick discovered that the particles at *X* were neutrons.]