National Certificate of Educational Achievement
TAUMATA MĀTAURANGA Ā-MOTU KUA TAEA

Exemplar for Internal Achievement Standard

91172 Level 2

This exemplar supports assessment against:

Achievement Standard 91172

Demonstrate understanding of atomic and nuclear physics

An annotated exemplar is an extract of student evidence, with a commentary, to explain key aspects of the standard. It assists teachers to make assessment judgements at the grade boundaries.

New Zealand Qualifications Authority

To support internal assessment

	Grade Boundary: Low Excellence
1.	For Excellence, the student needs to demonstrate comprehensive understanding of atomic and nuclear physics. This involves writing statements that demonstrate understanding of connections between concepts. The student has explained the concept of half-life and demonstrated understanding of how it is connected to the quantity of radioactive substance remaining after a period of time (1). The student has also attempted to link the creation of a new substance by radioactive decay to the concept of atomic number (2). An explanation is provided for ionisation ability (3). The student has attempted to explain how the energy that is created in a nuclear reaction is linked to mass / energy equivalence (4). For a more secure Excellence, the student could further demonstrate comprehensive understanding by: • giving a more detailed explanation for how radioactive decay produces a new substance, for example by giving an equation for each type of decay to illustrate the concept of conservation of charge and mass number • giving a more accurate explanation of mass/energy equivalence by showing understanding that energy is measured as mass, not changed from mass.

Student 1: Low Excellence

Note: This student evidence comes from student work related to the task FAQs. The following is a snippet of the complete report that was written by the student.

Sometimes you hear that radioactive substances have been used in medicine. Why don't they cause cancer in patients?

If a radioactive substance is to be used inside the body for imaging (eg PET scanning) or for diagnosis (like some thyroid treatments) it always has a short half-life so that the body is exposed to radiation for as short a time as possible. Half-life is the time it takes for a mass of radioactive substance to decay to half. Because radioactive substances have an exponential decay, after 5 half-lives, the mass will have decayed to $\frac{1}{2^5}$, which is $\frac{1}{32}$ of what it was at the start. A small as possible mass is used in the first place so after 5 half-lives there is not much left to cause any damage. [1] However, you have to have a half-life that gives enough time to do the treatment, if it was only a few seconds you wouldn't even get it to the patient before it was all decayed out. A half-life of a few hours seems to be the best.

When a radioactive atom decays it produces either an electron (beta decay) or an alpha particle (alpha decay). In both, the atomic number of the atom changes because charge will have been lost from the atom. If the new atom has a different atomic number it must be a different substance. [2] It is important that this new substance is not radioactive too, otherwise the danger will still continue.

What does ionising ability mean?

For a particle to ionise an atom it needs to supply the atom with sufficient energy to overcome the energy holding the electron in the atom. This can be done by either knocking it out or by "eliminating" an electron from the shells around the atom. This is ionising radiation. Alpha particles, because of their relatively high (+2) charge and their relatively high physical mass (2 × proton + 2 × neutron) and therefore size, can very easily knock out and absorb an electron from an atom and so ionise the atom. A beta particle (an electron) is about 8000 times smaller than an alpha particle but it travels a lot faster. It will still ionise as it is charged and has a reasonably high energy but will not ionise as well as an alpha particle. A gamma ray has no mass (rest mass), is not charged and has a velocity of the speed of light. The chances of it interacting with an atom are reduced but possible. If gamma radiation hits an outer electron of an atom sometimes the electron gains enough energy from the gamma photon to be removed from the atom and so the atom becomes ionised. Therefore gamma rays have high penetration ability but little ionising ability compared to alpha and beta particles [3]

How do the radioactive decays cause the reactor to heat up and make electricity?

When there is a nuclear reaction heat is produced. One of the reactions that might happen is:

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{137}_{55}Cs + {}^{95}_{37}Rb + 3{}^{1}_{0}n + energy$$

If you calculate the total rest mass of the reactants you will find it is more than the total rest mass of the products. Einstein said that the mass of the nucleons in a nucleus can be changed into energy and vice versa ($E = mc^2$) and so when a nucleus is split into two other nuclei some mass is changed into energy or energy into mass. In this case mass is lost so the lost mass has been changed into energy that has been released. Part of the energy will be e/m radiation but there will also be a lot of heat released.[4] The heat from fission reactions is used to heat up water to make the water pumped through the reactor into steam a little bit like the radiator of a car removes the heat from the chemical reactions in the engine. The hot steam goes through turbines connected to electric generators to create electricity. If for some reason the water cannot flow to remove heat then the reactor will melt.

	Grade Boundary: High Merit
2.	For Merit, the student needs to demonstrate in-depth understanding of atomic and nuclear physics. This involves writing statements that give reasons why phenomena, concepts or principles relate to a described situation. The student has given reasons for why Thompson developed his model of the atom (1). The student has also given reasons for how the results of the Gold Foil experiment led to the Rutherford's development of the structure of the nucleus of an atom (2). Reasons are also given for why alpha particles have a low penetration ability and has attempted to explain the difference between the penetration power of alpha and beta particles (3). To reach Excellence, the student could demonstrate comprehensive understanding with statements that show connections beween concepts, such as: • explaining how Thomson's experiment led to the discovery of the electron • explaining how the results of the Gold Foil experiment indicated which type of charge the nucleus has, and explaining the presence and distribution of the electrons in the atom • comparing the sizes of alpha and beta particles to give a more comprehensive explanation for the difference in their penetration ability, and explaining why gamma rays have the least penetration ability.

Student 2: High Merit

Note: This student evidence comes from student work related to the task FAQs. The following is a snippet of the complete report that was written by the student.

What was Thomson's original model of the atom?
Thomson's model was called the plum pudding model and was made as a result of his discovery of the electron. At the time the concept of the neutral atom was accepted widely but Thomson knew from his experiments that all atoms contained electrons, which he also knew were negatively charged. To solve this problem he proposed that an atom consisted of positively charged matter (the pudding) in which electrons were randomly scattered (the plums). The amount of positive charge in the 'pudding' was exactly balanced by the total negative charge on the electron 'plums'. [1]

What was Rutherford's model of the atom?
Rutherford proposed his model in 1911. He proposed it from the results of his famous Gold foil experiment. In this experiment alpha particles were fired at a very thin gold foil. Geiger, Marsden and Rutherford found that most alpha particles went straight through. They had expected them to get deviated because they would be bumping against the gold atoms, but as they weren't, they concluded that the atom was mainly empty space. A few alpha particles did get deviated but only by a small amount – from this they concluded that there must be a small, charged particle in the atom (it was later called the nucleus). It had to be small because only a few alpha particles came close enough to be affected and it had to be charged otherwise it wouldn't have had any effect on the alpha particle. They also found that a very few alpha particles were deflected so much that they turned back on themselves – a bit like reflection. They thought that this reflection must have happened off the nucleus and so the nucleus must be very dense otherwise the alpha particle would have just pushed the nucleus out of the way. [2]

What are the penetration abilities of the three major types of radiation?
Alpha particles have a very low penetrating ability and can be stopped by something as thin as cigarette paper. This is because they are relatively large and so more likely to bump into the molecules of whatever they are penetrating. At each collision they lose energy so very quickly stop. Beta particles have a stronger penetrating capability because they are smaller and can pass through a few millimetres of aluminium. [3] Gamma rays, however, have the greatest penetration abilities and may only be stopped by a great chunk of lead. Alpha particles are the biggest form of radiation, and so penetrate the least, meaning that penetration ability has to do with size.

	Grade Boundary: Low Merit
3.	For Merit, the student needs to demonstrate in-depth understanding of atomic and nuclear physics. This involves writing statements that give reasons why phenomena, concepts or principles relate to a described situation. The student has attempted to give reasons why the Gold Foil experiment disproved Thomson's model (1). An attempt to explain how Rutherford was able to use the results of the Gold Foil experiment to predict the structure of the atom was alos provided (2). The student explained how carbon dating relates to radioactive decay (3). For a more secure Merit, the student could further demonstrate depth of understanding by explaining Thomson's experiment more fully: • including the role of the electron in the determination of the structure of the atom • giving reasons for why only a few of the alpha particles were scattered • giving reasons for why the density of the nucleus is important in its ability to deflect the alpha particle • explaining that the rate of decay of C-14 is the same for all living things, so the graph always starts at the same place.

Student 3: Low Merit

Note: This student evidence comes from student work related to the task FAQs. The following is a snippet of the complete report that was written by the student.

How was Thomson's Plum Pudding model disproved?
This model was disproved by the 1909 gold foil experiment, done by Ernest Rutherford. Thomson's model said that the whole of an atom was solid - the pudding. If the atom was solid, when the alpha particles were fired at the gold foil they would have bumped into the atoms and been knocked off course. They weren't – most went straight through and so the atom cannot be solid. This could only have happened if there was a lot of empty space. Rutherford's suggestion, that an atom consists of a small central nucleus surrounded by mostly empty space, explained why they went straight through. [1]

What did we learn about atoms after the gold foil experiment?
That most of the atom consisted of empty space, because most of the fired alpha particles went straight through (see above).
The atom must have a small mass that contains positively charged particles (protons). This is because some of the positively charged alpha particles were repelled and scattered away.
The atom must have a lot of mass in a very tiny area because it was able to reflect some of the fast moving alpha particles back by almost 180 degrees. [2]
The gold foil experiment proved that the nucleus of the atom was very small and contained a high positive charge. This model of the atom contradicted the plum pudding model, as it suggests that the negatively–charged "plums" were surrounded by the positively–charged "pudding".

How does carbon dating relate to radioactive decay?
All living things have some carbon-14 in them. Carbon-14 has an unstable nucleus and so it will decay over time. When living things die no more carbon-14 is produced so to find out how old a substance is, they find the amount of carbon-14 that is left in it. They can do this because they know the half-life of carbon-14 – it is about 6000 years. If a graph of amount of carbon-14 against time is drawn, the amount left in the dead substance will give the number of years it has been dead. [3] If the material has a less amount of carbon14, it is old and if it has a lot, it is young.

	Grade Boundary: High Achieved
4.	For Achieved, the student needs to demonstrate understanding of atomic and nuclear physics. This involves writing statements that show an awareness of how simple facets of phenomena, concepts or principles relate to a described situation. The student has described how a fission reaction can create the required heat energy (1). A description is given that shows an awareness of the principles of fission and fusion (2). The student has also described the function of alpha particles in smoke detectors (3). To reach Merit, the student could demonstrate in-depth understanding by giving reasons for the phenomena, concepts or principles, such as: • using the uranium fission equation to give reasons why mass deficit results in energy release • explaining how the production of 3 neutrons per fission could result in a controlled chain reaction • giving reasons why so much energy is needed to bring about a fusion reaction, and explaining the statement that the reactions are governed by the law of conservation of charge and mass • explaining how alpha particles ionise the air, and how the ionised particles are then able to allow a current to flow.

Student 4: High Achieved

Note: This student evidence comes from student work related to the task FAQs. The following is a snippet of the complete report that was written by the student.

How is Uranium used by power plants to make heat energy?

Uranium-235 can capture a neutron to form uranium-236. This uranium-236 is unstable and so will split into 2, to form 2 smaller nuclei, as well as 2 more neutrons. A possible reaction is:

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3{}^{1}_{0}n + energy$$

Notice that the reaction makes three new neutrons. These neutrons are then captured by other atoms, thus starting a chain reaction.

Part of the energy produced during the reaction is heat [1] and this is used to boil water just like coal in in an ordinary power station. The steam drives the blades of a turbine which then drives a generator to produce electric power.

What is the difference between fission and fusion?

Fission is splitting a large nucleus into two or more smaller nuclei, whereas fusion is getting small nuclei and combining them together to form a big nucleus. Fission is started by firing a small particle like a neutron into the large nucleus, making it so unstable that it splits up. Fusion can only happen if the small nuclei are given huge amounts of energy to make them bash together at high speed. It is easier to cause fission than fusion. Both of these processes are governed by the fundamental laws of conservation of charge and mass. [2]

What are alpha particles used for?

Alpha particles are used in smoke detectors. They work by ionizing the air between two small plates which are part of an electric circuit. The ionised air is then used to pass a current between the plates. Smoke between the plates reduces the amount of air, thus reduces the amount of ionised air thus reducing the current passing through, making the smoke detector sound an alarm. [3]

	Grade Boundary: Low Achieved
5.	For Achieved, the student needs to demonstrate understanding of atomic and nuclear physics. This involves writing statements that show an awareness of how simple facets of phenomena, concepts or principles relate to a described situation. This student has shown awareness of how the model of the atom was derived from Rutherford's Gold Foil experiment (1). The student has described radioactive decay (2). The student has described some of the products of nuclear reactions and has given a statement relating to their properties (3) For a more secure Achieved, the student could demonstrate further understanding by: • describing how the results of Rutherford's gold foil experiment led to the proposal that the atom contained a small nucleus • giving an example decay equation in the description of radioactive decay • describing that other elements (both radioactive and non-radioactive) are also products of nuclear reactions • describing what ionisation is, in order to show a greater awareness of the properties of radioactive particles.

Student 5: Low Achieved

Note: This student evidence comes from student work related to the task FAQs. The following is a snippet of the complete report that was written by the student.

What conclusions were made about the atom from Rutherford's gold leaf experiment?
Rutherford fired a beam of alpha particles at thin gold foil. The alpha particles were from a radioactive source, in an evacuated container. A scintillation detector then rotated around the container was used to pick up the readings. Most of the particles passed straight through it with no deviation, a very small number were deflected. Conclusions were:

- nucleus charged because some atoms deflected.
- very few particles deflected through a very large angle – all mass in nucleus
- virtually all alpha particles went straight, as atoms are mainly empty space. [1]

What is radioactive decay?
Radioactive decay is the process where atomic nuclei instantly break up by releasing alpha, beta or gamma radiation. The two principles observed is the conservation of Mass number, and the conservation atomic number. The number of protons and neutrons remain the same for conservation of Mass number. The charge remains the same, for conservation atomic number. [2]

What are the products of nuclear reactions and what are their properties?
There are three possible products of nuclear reactions, these are alpha particles, beta particles and gamma radiation. Alpha particles are strong ionisers as they are heavy and slow, but can be stopped by a sheet of paper. Beta particles are less ionizing than alpha particles, but more penetrating as they're lighter. They can be stopped by metal foil. Gamma rays are the least ionizing, but travel quickly and are the most penetrating. Material that is dense such as lead is needed to stop them. [3]

	Grade Boundary: High Not Achieved
6.	For Achieved, the student needs to demonstrate understanding of atomic and nuclear physics. This involves writing statements that show an awareness of how simple facets of phenomena, concepts or principles relate to a described situation. The student has attempted to describe nuclear fission (1). The student has also attempted to state why Rutherford's Gold Foil experiment led to the discovery of the nucleus (2). The student has stated what alpha and beta particles are and has attempted to describe why they have different penetration abilities (3). To reach Achieved, the student could demonstrate understanding by: • describing the concept of conservation of mass • describing the role of other particles such as neutrons • describing the evidence from Rutherford's Gold Foil experiment that showed that the majority of the mass of an atom is in what came to be called the nucleus.

Student 6: Not Achieved

What is nuclear fission?

Fission is a nuclear reaction in which the nucleus splits into smaller parts and at the same time it releases a large amount of energy. [1] Because of the large amounts of energy it can be used to make bombs, such as the ones dropped on Japan. It can also be used on nuclear power stations.

How did Rutherford discover the nucleus?

Rutherford conducted the gold foil experiment. To do this he fired alpha particles at a thin sheet of gold foil. He proved that the majority of the mass of an atom was in a small portion, meaning that there must be a nucleus holding the protons and neutrons. [2] The gold foil experiment proved Thomson's theory of a plum pudding wrong as there isn't a large amount of mass in the nucleus.

Why can beta particles pass through paper while alpha can't?

Beta particles have a very low mass compared to alpha particles and beta particles have a much higher speed. Beta particles are purely electrons and alpha particles are helium nucleus. [3] Because of these differences beta particles can move through paper while alpha particles can't.