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

Exemplar for Internal Achievement Standard

Physics Level 3

This exemplar supports assessment against:

91525

Demonstrate understanding of Modern 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 modern physics. This involves demonstrating understanding of connections between concepts or principles that relate to a given situation. The student connects the concepts of mass deficit and binding energy to energy release, using Einstein's equation (1), and then goes on to explain how a higher mass deficit leads to a higher energy released (2). For a more secure Excellence, the student could demonstrate more detailed understanding of connections between concepts or principles. For example, the importance of high temperatures for nuclear fusion to occur could be explained, or how the fusion process produces more energy than fission per gram of reactants.

Currently New Zealand relies on energy sources such as hydro, wind and solar. While these sources provide consistent clean energy, nuclear power sources may be able to provide energy in much greater quantities. However the New Zealand Free Zone, Disarmament and Arms Control Act of 1987 prevents any nuclear power plants from being constructed or operating in New Zealand.

With the first nuclear fusion power stations expected to be operational by 2030, many of the issues presented by nuclear fission could be addressed making it possible for New Zealand to consider a nuclear power programme. If New Zealand were to open nuclear power stations the most likely approach would be Deuterium-Tritium fusion.

Some of the benefits of nuclear Fusion are there are no CO_2 emissions as no fossil fuels are burned, there is no high-level waste generated, there is no need to import fuel as it is collected from seawater, it creates domestic job for scientists and unlike in fission reactors, there is no chance of a meltdown.

How it works

Deuterium (^2_1H) can fuse with Tritium (^3_1H) to produce Helium (^4_2He) and a neutron (^1_0n) at very high temperature. After the reaction takes place, it will be found that the combined mass of the Helium atom and the neutron is less than the combined mass of Deuterium and Tritium. This is because the constituents of Helium (2 neutrons and two protons) have more binding energy than the constituents of Deuterium and Tritium, the neutron produced is free so has no binding energy. Overall the constituent parts of the products have less energy than the constituent parts of the reactants. This energy is given off by the reaction and can be harnessed for human use.

The missing mass of the products is related to the energy produced by Einstein's formula: $E=\Delta mc^2$ which shows that mass and energy are the same thing so must be conserved. Where E is the amount of energy produced in Joules, Δm is the missing mass or $m_{reactants}$ - $m_{products}$ and c is the speed of light which is constant ($3.00 \times 10^8 ms^{-1}$). The mass lost in the reaction is called the 'mass deficit' and the greater the mass deficit, the greater the increase in total binding energy. The change in binding energy is equal to the energy released or absorbed by a reaction so a greater increase in binding energy means a greater yield of energy.

	Grade Boundary: High Merit
2.	For Merit, the student needs to demonstrate in-depth understanding of modern physics. This involves giving explanations for phenomena, concepts or principles that relate to a given situation. The student has explained how the phenomenon of coulombic repulsion can be overcome in a fusion reaction (1), and how a larger mass deficit (related to binding energy) can explain the release of more energy, using the equation $E=mc^2$ (2). To reach Excellence, the student could demonstrate comprehensive understanding by providing a clearer connection between the physics phenomena, concepts or principles. For example, the student could use actual values to explain how mass deficit, binding energy and energy released are connected.

The process of nuclear fusion is important in the future of power production in New Zealand. The fact that we need alternatives to fossil fuels and the possibilities for hydroelectricity and wind power are limited by the possible locations means another source of power will be needed. The physics behind the production of nuclear power is the fusion reaction. The most common fuel sources used are the isotopes of Hydrogen called deuterium and tritium. We can find deuterium in common sea water and tritium can be made from Lithium in the soil.

① When the two reactants fuse it gives Helium and a neutron and releases a large amount of energy. To get the two reactants to fuse the two nuclei must join however they are both positively charged. The positive charges repel each other and so the nuclei have to overcome what is called coulombic repulsion. To do this the reaction must happen at very high temperatures and high pressures. The temperatures must be millions of degrees which make some of the electrons leave the atoms, the atoms are now ionised and the electrically charged particles are called plasma. The plasma must be very dense to give the fusion reactions. *As* the particles are subjected to high temperatures the nuclei are given a lot of kinetic energy which allows the nuclei to move much faster and have more collisions which are more forceful. So they get very close to each other which allows them to overcome the coulombic repulsion and fuse together. When they are very close together the strong nuclear force is able to overcome the coulombic repulsion. The strong nuclear force then holds the new Helium nucleus together.

When the fusion reaction has occurred the mass of the product is less than the mass of the reactants. This is because some of the mass has been converted into energy.

② The equation $E = mc^2$ shows how much energy is created from a given amount of mass. The difference in the masses is called the mass deficit. Although the mass is a very small amount, the size of the value of c, the speed of light squared is very large so a small amount of mass gives a large amount of energy. Binding energy is the amount of energy required to break apart the nucleus. The binding energy is equal to the mass deficit. The more mass that is lost the greater the binding energy the nucleus has.

Each fusion event releases 17.6 MeV, compared with 200 MeV for a Uranium fission event. *A* pellet of nuclear fuel weighs approximately 6 grams but can give the energy equivalent to that generated by a metric tonne of coal, which makes it much more efficient. Nuclear energy is cleaner while generating electricity. Nuclear fission provides energy without releasing greenhouse gases such as carbon dioxide 90% of the carbon emissions from electricity generation in the United States come from coal-fired power plants. They emit pollutants such as sulfur dioxide, toxic metals, arsenic, cadmium and mercury. However, nuclear power plants generate significant amounts of radioactive waste. However the Tritium that needs to be produced only has a half-life of 12 years which is much less than Uranium and so it causes less long term dangerous waste.

	Grade Boundary: Low Merit
3.	For Merit, the student needs to demonstrate in-depth understanding of modern physics. This involves giving explanations for phenomena, concepts or principles that relate to a given situation. The student has explained how the phenomenon of coulombic repulsion in a fusion reaction can be overcome by using high temperatures (1), and the concept of mass and energy equivalence, using the equation $E=mc^2$ (2). For a more secure Merit, the student could explain, in more detail, the concept of nuclear fusion. For example, the student could compare the energy produced in nuclear fusion with other fuel options, or explain how binding energy affects energy release.

A report to the Prime Minister's Chief Science Advisor

Fusion is a process which occurs naturally within the sun and the stars. It is when two light nuclei combine to form a heavier nucleus. Not only is this new nuclei formed, but energy is released. Controlled fusion reaction have potential to produce up to 100 times the amount of energy required to start the reaction, which is why countries around the world are researching and developing methods of controlled nuclear fusion. Nuclear energy would provide the world with an almost endless supply of energy, to meet rising demand for power. This report will include physics theories relevant to nuclear fusion, as well as other information which will help to explore the possibility of nuclear fusion reactors potentially being used in New Zealand in the future. Fusion reactions to produce large amounts of energy commonly involve two dense isotopes of Hydrogen fusing to form Helium and releasing a neutron as well as a considerable amount of energy. The isotopes of Hydrogen are deuterium ($_2^1H$) and tritium ($_3^1H$). The equation for such a fusion reaction is $_2^1H + _3^1H \rightarrow _2^4He$ + 1n (+energy). The two reactants are easily accessed, as deuterium is common, found in seawater and tritium can be produced (from a fairly common element called lithium which is found is soil) by bombarding the lithium with high energy neutrons. For a nuclear fusion reaction to occur, there are specific requirements that must be achieved in order to start a reaction. These include extremely high temperatures, high pressures and densities. Since no container on Earth can hold plasma millions of degrees hot, there are two methods that are currently used to carry out controlled fusion reactions— magnetic confinement and inertial confinement.

The coulombic repulsion of atoms is a barrier to controlled nuclear fusion. Positively charged atoms repel one another due to their like charges. The temperature must be very hot In order for nuclei to overcome their force of repulsion, thus the fusion reaction is thermonuclear. The nuclei must he heated millions of degrees, in fact, over 100,000,000°C, in order for deuterium and tritium to overcome their repulsive forces and fuse to form helium. This causes the gas to become extremely hot, and electrons are removed from the nucleus (the atom hence becomes ionised.) Scientists consider this to be the form of plasma, where the matter is composed of electrically charged particles. Effectively, it is the fourth state of matter. At this extremely high temperature, atoms are within very small distances from each other, and so the strong nuclear force (a very strong force which holds nucleons together) is able to overcome the force of repulsion, allowing nuclei (deuterium and tritium) to fuse and form a new nucleus. The nuclear strong force is able to hold the nucleus (helium) together, even against the huge force of repulsion between electrons or protons. However, its short range means that atoms must be extremely close together for the nuclear strong force to have an effect. By heating the atoms :deuterium and tritium) up such a high temperature, their kinetic energy increases dramatically„ and thus they move faster and this results In more collisions between atoms, with greater force, hence more opportunities for the nuclear strong force to take hold and nuclei to fuse into a denser nucleus (helium). Therefore, a higher temperature is necessary for the columbic barrier to be overcome and fusion to occur. Therefore, deuterium and tritium are able to fuse and form helium.

② ==Energy is required to separate the nucleons from a nucleus, i.e. break apart the nucleus. This is called the binding energy. The final nuclei formed in this fusion reaction (^4_2He) is lighter in mass than its constituent parts (nucleons from deuterium and tritium). This means that some of the mass has been released as energy. According to the equation E=mc^2 energy is equivalent to the change in mass which is also known as the mass defect. (The value of c remains constant, meaning energy is proportional to mass and vice versa.) Energy and mass are interchangeable, thus the binding energy is equal to the mass defect. The equation shows that any change in mass is reflected in the energy released.== When deuterium (^1_2H) fuses with (^1_3H) tritium), they form Helium (^4_2He) which is heavier than its constituent parts. This mass is, thus, not completely lost, but released as energy. Therefore, the more mass lost, the greater the binding energy (E=mc^2). Because Helium is lighter than deuterium and tritium summed, it has a greater binding energy per nucleon (as E=mc^2) and thus it is more stable.

|	Grade Boundary: High Achieved
4.	For Achieved, the student needs to demonstrate understanding of modern physics. This involves showing awareness of how simple facets of phenomena, concepts or principles relate to a given situation. The student has described simple facets of the concept of nuclear fusion and started to explain how the phenomenon of coulombic repulsion can be overcome (1). The student has also described how a small mass of fuel produces a lot of energy, using Einstein's equation (2). To reach Merit, the student could explain the concept of nuclear fusion reaction more clearly. For example, the student could use equations and/or diagrams, explaining the mass-energy equivalence, or use calculations to compare the energy provided by nuclear fusion with other fuel options.

This report is to outline the science behind nuclear Fusion, the benefits and disadvantages of fusion and whether nuclear fusion could be used in New Zealand. (1) Nuclear fusion is the process of releasing and harnessing the energy emitted when two nuclei collide and fuse. Nuclear fusion occurs when two nuclei, usually Deuterium, tritium and/or Helium, moving at very high speeds collide. The process needs a lot of energy but when the new nucleus is created it is unstable and a neutron is ejected with a huge amount of energy. The nuclei must be travelling fast enough to overcome the Coulombic repulsion between the two nuclei. This is the attractive force that makes an electron orbit the nucleus, where an electron is negative and the nucleus are positive. This means that two nuclei would repel each other, like two magnets facing north to north however when the nuclei are moving fast enough, they can overcome this repulsion, collide and fuse. The repulsion can be overcome and the nuclei can be forced together and held by the strong nuclear force which works when the nuclei are very very close to each other. The way to overcome it is the give the nuclei enough kinetic energy to give really strong collisions and lots of the collisions which can be provided by extreme heat of around 1million degrees.

(2) When the nuclei fuse, a small amount of mass is converted into a large amount of energy. This converted mass is the mass deficit, or the change in mass, worked out by subtracting the mass of the sum of the two nuclei by the mass of the final nuclei. The Laws of Thermodynamics state matter or energy cannot be destroyed or created, only converted. This proves that the mass deficit is converted to energy during fusion. The famous physicist and scientist Albert Einstein discovered the relationship $E=mc^2$, used to calculate the amount of energy released during fusion. The energy released is equal to the mass deficit (m or Δm) multiplied by the speed of light squared (c^2). Despite the mass deficit being such a tiny amount, the speed of light squared is so great that it produces a large amount of energy.

	Grade Boundary: Low Achieved
5.	For Achieved, the student needs to demonstrate understanding of Modern physics. This involves showing awareness of how simple facets of phenomena, concepts or principles relate to a given situation. The student has described simple facets of the concept of fusion, the phenomenon of coulombic repulsion (1) and the concept of mass-energy equivalence (2). For a more secure Achieved, the student could describe the phenomenon of coulombic repulsion in more detail, or describe how a small mass difference leads to a large energy release.

(1) Nuclear fusion is where nuclei (lightweight) break free of their positively charged protons and fuse together to make a heavier nucleus. In this reaction, the fused nuclei mass is smaller than if the nuclei were individual. This relates to binding energy, the smaller the total mass of the fused nuclei the more / higher amount of energy is released to form the heavier nucleus e.g.
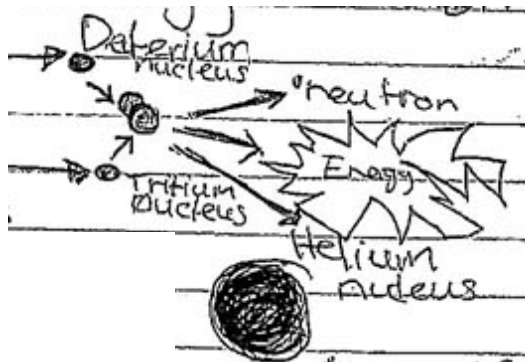
In my example, this is Deuterium and Tritium fusion. This produces the most energy and the by-product of this reaction produces helium. For this reaction to happen though, the two nucleus needs to break free of the positively charged protons. For this to happen, the nuclei need to be excited (moving really fast). The reason behind this is at this excited state the nuclei can break free of the coulombic repulsion and thus fuse together. For the nuclei to achieve this excited state it has to be heated, extremely heated. This heat is called thermonuclear. The thermonuclear reaction produces matter called plasma, plasma has free electrons and free nuclei, when these nuclei are moving at their excited speed they overcome their repulsion and fuse. The energy produced by the fused reaction of the two

(2) nuclei mass is different from the two individual mass of the nuclei without the fused reaction. The missing mass from the fused reaction of the two nuclei is the energy produced according to the Einstein's theory of $E = \Delta m c^2$ where Δm being the Δm and c = the speed of light, increasing some of the binding energy that was in the two individual nuclei, which actually reduces the net mass of the two nuclei is gone, change into energy.

	Grade Boundary: High Not Achieved
6.	For Achieved, the student needs to demonstrate understanding of Modern pwhysics. This involves showing awareness of how simple facets of phenomena, concepts or principles relate to a given situation. The student has attempted to describe simple facets of the concept of nuclear fusion (1). To reach Achieved, the student could describe in more detail the concept of nuclear fusion, or describe the concept of mass-energy equivalence using Einstein's equation.

Nuclear fusion and nuclear fission can be used to produce energy in New Zealand. Nuclear fusion takes place inside the sun, releasing the energy we know as solar radiation. Fusion reactors could be a very wise investment for New Zealand; currently New Zealand's main sources of power are wind farms and hydro power, machinery and buildings that cost a lot to build and run and produce little energy. A fusion reactor would be a similar cost to setup, and would require decent amount of start-up energy, but would be much more beneficial and "pay itself off" very quickly. The reactor would not require a large area to be built in, like conventional nuclear plants, so it could be placed in the hearts of cities to produce direct and clean energy. The only main disadvantages are the large amount of start-up energy which could be made very easily once the machine is running and the danger of the plasma of lasers overheating or destroying the reactor, currently extensive research is being done to develop ways to stop this from happening.

Nuclear fusion is when nuclei fuse to produce energy. Unfortunately it needs a lot of energy to happen which makes it expensive. This is because the nuclei have strong forces between them. This shows the reaction between Deuterium and tritium which gives the end result of Helium and a neutron.

$$^2_1H + {}^3_1H \longrightarrow {}^4_2He + {}^1_0n$$

Large amounts of energy are given off when the neutron is released. The result gives around 17.6 million electron volts (MeV) of kinetic energy through the conversion of mass to energy.