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

Exemplar for Internal Achievement Standard

Chemistry Level 3

This exemplar supports assessment against:

Achievement Standard 91389

Demonstrate understanding of chemical processes in the world around us

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 chemical processes in the world around us This involves an evaluation of the impact of, and issues that have arisen from, the chemical processes. This involves elaborating on, comparing and contrasting, or analysing the links between the chemical processes and their consequences. This requires the consistent integration of chemistry vocabulary, symbols, conventions, and equations. This student has used chemical equations and vocabulary to analyse the chemical process of gold extraction using cyanide (1), to discuss how the use of cyanide in the chemical process affects the environment (2), to compare some chemical processes that are used to treat cyanide by-products of the extraction process (3), and to elaborate on one process used in New Zealand (4). For a more secure Excellence, the student could compare and contrast in detail the different processes used to treat the by-products of the extraction process.

Student 1: Low Excellence

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Extraction of gold using cyanide

Gold is found in very low concentrations in the ore from which it is mined. To collect the gold from the ore it needs to be separated from the other minerals in the ore. To do this the gold needs to be made into a soluble form so that it can be separated from the other minerals as gold is insoluble. To make gold soluble sodium cyanide (NaCN) is added and the cyanide ion forms a complex ion with the gold. This complex ion, $[Au(CN)_2]^-$, is readily soluble.

Issues of gold extraction using cyanide:

Cyanide is toxic to humans and may cause death if exposed to high enough doses. Liquid or gaseous hydrogen cyanide, as well as salts of cyanide can enter the body through inhalation, ingestion or absorption through the eyes and skin.

The Absorption causes asphyxiation. This is because cyanide binds to cytochrome oxidase. This is an enzyme in the mitochondria of the cell that is involved in respiration. In other words it is involved in the conversion of oxygen to water and eventually energy. When cyanide binds to this enzyme the cell can no longer use the oxygen present in the bloodstream and asphyxiation occurs.

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Even at low concentrations convulsions, shallow breathing, irregular heartbeat, and a weaker/erratic pulse can occur.

In the environment cyanide is rapidly degrading or forming stable complexes and salts. This occurs via a number of ways.

1. Complexation: Ionic complexes between cyanide and many metals form. Most of these are much less toxic than free cyanide as in a complexed form the cyanide can no longer bind to cytochrome c. Iron cyanide complexes are especially stable and are important due to large amounts of iron in the soil. Ferro cyanide is formed in the following reactions:
    - $Fe^{2+} + 6CN^- \rightarrow [Fe(CN)_6]^{4-}$
      This can be converted to ferricyanide in the following reaction:
      $[Fe(CN)_6]^{4-} \rightleftharpoons [Fe(CN)_6]^{3-} + e^-$
      Less stable complexes with copper and zinc are unstable and can release free cyanide.
    - Volatilisation: in the form of HCN which is very volatile and forms naturally into a gas
    - Oxidation: Cyanide can be oxidised to the cyanate ion (OCN-) which is less toxic. This can occur via an oxidising agent or by micro-organisms that can promote oxidation.
    - Biodegradation: microbes can convert cyanide to ammonia.
    - Precipitation: Insoluble metal cyanide complexes can form which will not enter the waterways.
    - Absorption: Cyanide can strongly bind to organic matter in soil.

Even though some of the above processes occur rapidly and no examples of bio magnification have been found, the problem remains that cyanide is toxic to many living things at very low concentrations.

The process:

The ore is ground and crushed and any free gold is extracted by use of gravity as it may be too large to react readily with the cyanide. If the gold ore contains other metals and/or sulphide minerals it may require additional treatments prior to the leaching process.

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The treated gold then has sodium cyanide added to it and the following reaction known as Elsener's equation occurs:

$4Au + 8CN^- + O_2 + 2H_2O \rightleftharpoons 4[Au(CN)_2]^- + 4OH^-$

The oxygen is added in the form of dissolved oxygen. This oxygen is also added as it oxidises some of the possible cyanide consuming species in the slurry. By lessening the effect of these species the leach rate of gold is sped up.
The sodium cyanide has lime added to it so that the pH is about 10-11 so that the equilibrium favours the reactants side. This is due to the cyanide ion/hydrogen cyanide equilibrium shown below:
$CN^- + H_2O \rightleftharpoons HCN_{(aq)} + OH^-_{(aq)}$
Now the slurry is now treated with either activated carbon or zinc to extract the gold.
For the activated carbon process the slurry is mixed with carbon which is porous and can absorb the gold onto its surface. The activated carbon is then removed from the slurry by adding NaCN and NaOH to the mixture and heating it to 110°C. This removes the gold back into solution which goes through an electrolytic process (known as 'electrowinning') to extract the gold.
At the anode: $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$
At the cathode: $e^- + [Au(CN)_2]^- \rightarrow Au + 2CN$
Overall: $4OH^- + 4[Au(CN)_2]^- \rightarrow 4Au + 8CN^- + O_2 + 2H_2O$

For the Zinc process the slurry has Zn powder added to it and a displacement reaction occurs:
$2[Au(CN)_2]^-_{(aq)} + Zn_{(s)} \rightarrow [Zn(CN)_4]^{2-}_{(aq)} + 2Au_{(s)}$
The zinc is leached out with acids and the less reactive gold remains.
The remaining slurry after extraction of the gold has occurred is then sent for recovery or destruction. There are several different methods that can be used. Some of these are listed below:

1. Natural degradation:
    - If the pH drop below 9 most of the free cyanide is in the HCN form. HCN is volatile and readily evaporates into the air.
    - Oxidation occurs to form ammonia and bicarbonate when cyanide reacts with water and air.
    - Several species of bacteria degrade cyanide (biodegradation).
    - Photodecomposition can break down cyanide when sunlight is present.
2. Chemical degradation which involves oxidation of weaker cyanide complexes and precipitate the more stable complexes.
    - Oxidation using hydrogen peroxide.
    - Oxidation using a combination of sulphur dioxide and air.

Case study – Golden cross mine using the Cyanisorb process near Waihi.
The Golden Cross mine is close to important river fisheries on the Coromandel Peninsula. The Cyanisorb process was introduced in 1991. It recovers cyanide directly from the slurry (tailings) and uses this recovered cyanide again in the leaching process. This reduces cost and reduces the amount of cyanide entering groundwater and therefore the risk to wildlife which may access the tailings dam (storage pools for natural degradation).

The pH of the tailings is adjusted to 7.5 using sulphuric acid. This causes most of the free cyanide to be converted to HCN. This HCN is then mixed with turbulent air in a packed tower. This causes the HCN to volatise into a gaseous form. This is then redissolved in an absorber by recirculating a strong sodium hydroxide solution.

	Grade Boundary: High Merit
2.	For Merit, the student needs to demonstrate in-depth understanding of chemical processes in the world around us. This involves making and explaining links between chemical processes, and the consequences of the chemical processes for the environment or people. This requires explanations that integrate chemistry vocabulary, symbols, conventions, and equations. This student has used chemical equations and vocabulary to explain how cyanide is used in the chemical process of gold extraction (1), explain how the use of cyanide in this chemical process affects the environment (2), and explain the chemical processes that are used to treat cyanide by-products of the extraction process (3). To reach Excellence, the student could elaborate of the effects of cyanide on the environment, and compare the methods used to treat the by-products (resolve an issue).

Student 2: High Merit

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Extraction of gold using cyanide

Gold is found in very low concentrations in the ore from which it is mined. To collect the gold from the ore it needs to be separated from the other minerals in the ore. To do this the gold needs to be made into a soluble form so that it can be separated from the other minerals as gold is insoluble. To make gold soluble sodium cyanide (NaCN) is added and the cyanide ion forms a complex ion with the gold. This complex ion, $[Au(CN)_2]^-$, is readily soluble.

Issues of gold extraction using cyanide:

Cyanide is toxic to humans and may cause death if exposed to high enough doses. Liquid or gaseous hydrogen cyanide, as well as salts of cyanide can enter the body through inhalation, ingestion or absorption through the eyes and skin.

The Absorption causes asphyxiation. They affect an enzyme which means that cells within the body cannot use oxygen and so suffer cellular asphyxiation. As a result death occurs. Because of this the cyanide slurry that is left after the gold has been refined must be dealt with or else it can enter waterways where it is poisonous as described above. There are a number of ways of dealing with the cyanide tailings (slurry after it has been used and is ready to be destroyed or reused). The diagram below shows how the processes that occur when the tailings are poured into a decant pond.

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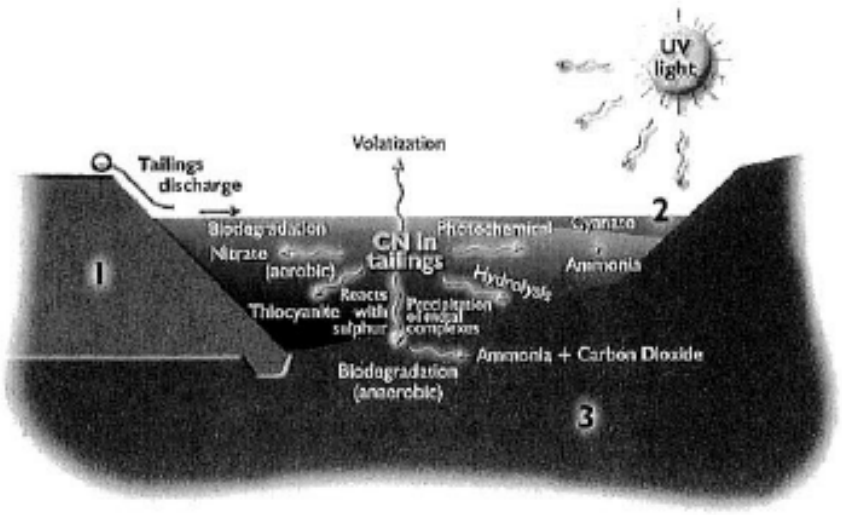

The natural processes occurring in the diagram include:

1. The cyanide ion reacts with sulphur forming thiocynate ion.
2. Bacteria breakdown the cyanide and in doing so form nitrate ions.
3. Cyanide is oxidised to form cyanate ions (OCN^-) and ammonia.
4. The cyanide forms metal complexes with iron for example. These complexes are stable and do not affect the enzyme which allows cells to use oxygen in the bloodstream.
5. Anaerobic bacteria convert the cyanide to form ammonia and carbon dioxide.
6. UV light causes iron cyano complexes to break down.
7. Hydrolysis occurs forming HCN.

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8. Volitisation occurs. If the pond is not basic the cyanide ions are converted to HCN in the equilibrium explained below. HCN is very volatile meaning that it becomes gaseous and escapes the pond. To enhance this process shallow ponds with a large surface area are used.

It has been shown by testing in the tailings under drainage that the levels of cyanide are acceptable and within acceptable safety levels.

The process:

The ore is ground and crushed and any free gold is extracted by use of gravity as it may be too large to react readily with the cyanide. If the gold ore contains other metals and/or sulphide minerals it may require additional treatments prior to the leaching process.

The treated gold then has sodium cyanide added to it and the following reaction known as Elsener's equation occurs:

$4Au + 8CN^- + O_2 + 2H_2O \rightleftharpoons 4[Au(CN)_2]^- + 4OH^-$

1 The oxygen is added in the form of dissolved oxygen. This oxygen is also added as it oxidises some of the possible cyanide consuming species in the slurry. By lessening the effect of these species the leach rate of gold is sped up.

The sodium cyanide has lime added to it so that the pH is about 10-11 so that the equilibrium favours the reactants side. This is due to the cyanide ion/hydrogen cyanide equilibrium shown below:

$CN^- + H_2O \rightleftharpoons HCN_{(aq)} + OH^-_{(aq)}$

Now the slurry is now treated with either activated carbon or zinc to extract the gold.

For the activated carbon process the slurry is mixed with carbon which is porous and can absorb the gold onto its surface. The activated carbon is then removed from the slurry by adding NaCN and NaOH to the mixture and heating it to 110°C. This removes the gold back into solution which goes through an electrolytic process (known as 'electrowinning') to extract the gold.

For the Zinc process the slurry has Zn powder added to it and a displacement reaction occurs:

$2[Au(CN)_2]^-_{(aq)} + Zn_{(s)} \rightarrow [Zn(CN)_4]^{2-}_{(aq)} + 2Au_{(s)}$

The zinc is leached out with acids and the less reactive gold remains.

The remaining slurry after extraction of the gold has occurred is then sent for recovery or destruction.

	Grade Boundary: Low Merit
3.	For Merit, the student needs to demonstrate in-depth understanding of chemical processes in the world around us. This involves making and explaining links between chemical processes, and the consequences of the chemical processes for the environment or people. This requires explanations that integrate chemistry vocabulary, symbols, conventions, and equations. This student has used chemical equations and vocabulary to explain how cyanide is used in the chemical process of gold extraction (1), explain how the use of cyanide in the chemical process affects the environment (2), and to briefly explain natural processes that are used to treat cyanide by-products of the extraction process (3). For a more secure Merit, the student could elaborate on the chemical processes for the treatment of the cyanide by-products of the extraction process (to resolve an issue).

Student 3: Low Merit

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Extraction of gold using cyanide

Gold is found in very low concentrations in the ore from which it is mined. To collect the gold from the ore it needs to be separated from the other minerals in the ore. To do this the gold needs to be made into a soluble form so that it can be separated from the other minerals as gold is insoluble. To make gold soluble sodium cyanide (NaCN) is added and the cyanide ion forms a complex ion with the gold. This complex ion, $[Au(CN)_2]^-$, is readily soluble.

Cyanide can also be found in the form of HCN (hydrogen cyanide). An equilibrium exists between the two as shown below: (1)

$CN^- + H_2O \rightleftharpoons HCN_{(aq)} + OH^-_{(aq)}$

At a high pH the equilibrium is to the left and cyanide ion predominates. As the pH lowers the equilibrium is forced to the right and hydrogen cyanide is in higher concentrations.

Issues of gold extraction using cyanide:

Cyanide is toxic to humans and may cause death if exposed to high enough doses. Liquid or gaseous hydrogen cyanide, as well as salts of cyanide can enter the body through inhalation, ingestion or absorption through the eyes and skin. (2)

It is toxic as it prevents cells using oxygen in the bloodstream.

The process:

The ore is ground and crushed and any free gold is extracted by use of gravity as it may be too large to react readily with the cyanide. If the gold ore contains other metals and/or sulphide minerals it may require additional treatments prior to the leaching process.

The treated gold then has sodium cyanide added to it and the following reaction known as Elsener's equation occurs:

$4Au + 8CN^- + O_2 + 2H_2O \rightleftharpoons 4[Au(CN)_2]^- + 4OH^-$

In this form the gold is now soluble. This process is known as leaching. One form of this is heap leaching. In this method dilute sodium cyanide is dripped into ore stacked on an impermeable pad or membrane. Because the gold is now in a soluble form it can move through the membrane whereas the rest of the ore cannot move through the membrane. (1) The sodium cyanide has lime added to it so that the pH is about 10-11 so that the equilibrium favours the reactants side. This ensures that the cyanide ion is not converted to hydrogen cyanide ion/hydrogen cyanide equilibrium. If heap leaching is not used then this process occurs in leaching tanks.

Now the slurry is now treated with either activated carbon or zinc to extract the gold. Cementation involves using a zinc electrode in carbon paste which is immersed directly into the gold cyanide solution. The following reactions occur:

Cathode: $e^- + [Au(CN)_2]^- \rightarrow Au + 2CN^-$ Gold is reduced as it is gaining electrons or decreasing in oxidation number

Anode: $Zn + 2OH^- \rightarrow Zn(OH)_2 + 2e^-$ Zinc is oxidised as it is losing electrons or increasing in oxidation number

And: $Zn(OH)_2 + 4CN^- \rightarrow Zn(CN)_4^{2-} + 2OH^-$

Note that at the anode there is an intermediate step which forms $Zn(OH)_2$.

The gold is then further purified and refined for use.

The remaining cyanide in the tailings (slurry after gold leaching) now needs to be destroyed or recycled in some way. As mentioned above cyanide is toxic and cannot be allowed into the local environment. Until the last 20 years the main process used has been natural degradation. These are natural processes that include volitisation, biodegradation, oxidation, (3)

and absorption onto the surfaces of solids. Absorption means attachment to solid soils, etc.
Volitisation occurs when cyanide ions are converted to hydrogen cyanide via the cyanide/ hydrogen cyanide equilibrium. This hydrogen cyanide the changes to a gaseous form as it is volatile. A low pH is used to promote this transformation.
More recently chemical processes that involve recycling have also been used.

	Grade Boundary: High Achieved
4.	For Achieved, the student needs to demonstrate understanding of chemical processes in the world around us. This involves processing and interpreting given information to identify, describe, and give an account of chemical processes occurring in the natural world or developed in response to an issue or need. The account given must be supported by the use of chemistry vocabulary, symbols, conventions, and equations. This student has used chemical equations and vocabulary to describe how cyanide is used in the chemical process of gold extraction (1), and to give an account of natural and chemical processes that are used to treat cyanide by-products of the extraction process (2). To reach Merit, the student could explain the links between the chemical processes and elaborate on how the process meets the needs of society or how the processes resolve an issue.

Student 4: High Achieved

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Extraction of gold using cyanide

Gold is found in very low concentrations in the ore from which it is mined. To collect the gold from the ore it needs to be separated from the other minerals in the ore. To do this the gold needs to be made into a soluble form so that it can be separated from the other minerals as gold is insoluble. To make gold soluble sodium cyanide (NaCN) is added and the cyanide ion forms a complex ion with the gold. This complex ion, $[Au(CN)2]^-$, is readily soluble.

Issues of gold extraction using cyanide:

Cyanide is toxic to animal and plant life and may cause death if exposed to high enough doses. Free cyanide is cyanide ion (CN^-) and hydrogen cyanide (HCN) which is often gaseous as it is volatile. Free cyanide causes cellular asphyxiation.

The process:

The ore is ground and crushed to make a slurry

The treated gold then has sodium cyanide added to it and the following reaction:

$Au + 2CN^- \rightarrow Au(CN)_2^-$

In this form the gold is now soluble. This process is known as leaching. This reaction is normally carried out at a pH of 10-11 as this prevents cyanide ion being converted to hydrogen cyanide which would occur if the pH was lower.

Because gold is soluble in this form it can now be separated from the rest of the ore that is insoluble. This process of dissolving the gold using cyanide is known as leaching.

Sometimes some other precious metals can also be leached along with the gold, for example silver. This process of leaching is done in leaching tanks or by heap leaching where sodium cyanide is dripped onto a heap of gold ore and left to percolate its way through the heap of gold ore.

The dissolved gold in the form of the complex now needs to be separated out and recovered. This can be done by a process called absorption. Absorption is when gaseous or dissolved species attach to a solid surface. A substance called activated carbon is used to absorb the gold. Activated carbon is formed from wood, peat, coal, etc. It is treated so that gold will absorb to its surface. The majority of the gold will absorb onto this activated carbon. The activated carbon is then washed with water or air on screen, and the gold can be further purified by electro winning which use electricity. It is then further refined until the final product is obtained

The remaining cyanide in the slurry now needs to be disposed of or recycled in some way. As mentioned above cyanide is toxic and cannot be allowed into the local environment. There are a number of natural processes that get rid of cyanide. Included in this list are:

- Volitisation – when CN^- turns into HCN at low pH's and then this becomes gaseous.
- Absorption – when CN- naturally absorbs onto solid surfaces, e.g. soil particles.
- Microbial degradation – some bacteria naturally break down cyanide.

These processes can all occur in holding pools in which the slurry after gold extraction is put into. Some chemical processes can also be used. One of these is the Cyanisorb process which is used at a mine near Waihi. This takes the slurry and reacts it at low pH forming hydrogen cyanide which can be converted back to cyanide ion for reuse later. The use of air mixed in helps this process. All of the above processes lowers the cyanide levels to within NZ safety levels and so there is no dangerous cyanide levels entering the environment.

	Grade Boundary: Low Achieved
5.	For Achieved the student needs to demonstrate understanding of chemical processes in the world around us. This involves processing and interpreting given information to identify, describe, and give an account of chemical processes occurring in the natural world or developed in response to an issue or need. The account given must be supported by the use of chemistry vocabulary, symbols, conventions, and equations. This student has used some chemistry vocabulary to describe how cyanide is used in the chemical process of gold extraction (1), and to give a brief description of a chemical process that is used to treat cyanide by-products of the extraction process (2). For a more secure Achieved, the student could use more chemistry vocabulary and equations. The student could also elaborate on the natural processes used to treat the cyanide by-products.

Student 5: Low Achieved

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Extraction of gold using cyanide

Cyanide has been used in New Zealand in gold extraction since the end of the nineteenth century. It has made the extraction of gold from gold ore much more effective and therefor more economic.

Cyanide does occur naturally. It is secreted by hundreds of species of bacteria, algae, fungi, plants and insects.

The problem with using cyanide in gold extraction is that cyanide is toxic to plant and animal life. It is toxic as it causes asphyxiation. In New Zealand there has been a case of a young girl who ingested a number of apricot kernels, after the season had ended. The girl developed signs of acute poisoning. Apricot kernels from the same batch were tested for cyanide levels and contained 0.33% levels of cyanide.

There for it is important not to let the cyanide after it has been used to get into the waterways. The companies that extract gold therefore need to put systems in place that prevent this happening or keep the levels of cyanide entering the environment acceptable according to New Zealand standards.

Cyanide consists of nitrogen and carbon joined together by a triple bond. It has a formula CN^-. Another type of cyanide that is poisonous if hydrogen cyanide which has formula HCN. It is the cyanide ion that is used in gold extraction.

The process:

The ore is ground and crushed to make a slurry. To collect the gold from the ore it needs to be separated from the other minerals in the ore. To do this the gold needs to be made into a soluble form so that it can be separated from the other minerals as gold is insoluble. To make gold soluble sodium cyanide (NaCN) is added and the cyanide ion forms a complex ion with the gold. This complex ion, $[Au(CN)_2]^-$, is readily soluble. (1)

The dissolved gold in the form of the complex now needs to be separated out and recovered. This can be done by either absorption onto activated carbon or by zinc cementation. In absorption the dissolved gold forms on the carbon and in zinc cementation zinc powder and electricity is used. It is then further refined until the final product is obtained

The slurry, known as tailings is what is left after the gold has been recovered. This slurry contains cyanide and it is this that must be dealt with so that the cyanide does not enter the environment.

At one of the mines near Waihi they have used what is known as the Cyanisorb process. Rather than trying to destroy or dispose of the cyanide it is recycled so that it can be used again in gold extraction. The slurry has sulphuric acid added to it. This converts the cyanide ion to be converted to hydrogen cyanide. This is then made into hydrogen cyanide as. This does not require high temperatures as hydrogen cyanide is volatile. Air is mixed in to help this process. Sodium hydroxide is added to reabsorb the sodium cyanide, which can now be reused for leaching the gold. After this some natural processes could occur to dispose of any leftover cyanide in the tailings. (2)

At this mine they have found that this is more economic and it reduces the amount of sodium cyanide that needs to be transported to the mine in the form of solid briquettes.

	Grade Boundary: High Not Achieved
6.	For Achieved, the student needs to demonstrate understanding of chemical processes in the world around us. This involves processing and interpreting given information to identify, describe, and give an account of chemical processes occurring in the natural world or developed in response to an issue or need. The account given must be supported by the use of chemistry vocabulary, symbols, conventions, and equations. This student has given very basic descriptions of the chemical process of gold extraction (1), and processes used to treat cyanide by-products of the chemical process (2). s To reach Achieved, the student could use correct chemistry vocabulary and equations. The student could also provide a more detailed description of the chemical processes involved in the extraction of gold.

Student 6: High Not Achieved

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Extraction of gold using cyanide

Gold is a very precious metal, and is very valuable. It has been valuable for a long time. Gold has a chemical symbol Au. It is found in what is called ore. Within this gold ore there is not too much actual gold so it needs to be separated out from this ore in an economic but safe way.

Cyanide has been used in New Zealand in gold extraction since the 1889.
Cyanide consists of nitrogen and carbon joined together by a triple bond. It is toxic to animal and plant life. Therefore it needs to be prevented from getting into the environment.

To collect the gold from the ore it needs to be separated from the other minerals in the ore. However gold is an unreactive metal and is insoluble. The gold needs to be made into a soluble form so that it can be separated from the other minerals. To make gold soluble cyanide is added in the leaching tanks. This process is done at a high pH.

1

Now that it is soluble it is separated from the rest or the ore. It now needs to be recovered. This is done by absorption onto something called activated carbon. Now that the gold has been absorbed it can be further refined and be ready for actual use.

Once the gold has been separated the cyanide left over must disposed of in some way. Processes that dispose of cyanide or recycle it are:

1. Volitisation
2. Microbial degradation
3. Absorption onto soil
4. Photochemical breakdown
5. Oxidation
6. Using electricity
7. The Cyanisorb process in which it is recycled

2

Some of these processes are natural while others are chemical.

So gold has been extracted and the cyanide left over has been safely dealt with.