Titanium extraction

The process used to extract titanium is called the Kroll process and is named after William J. Kroll, who invented the method in the 1930s. It is slow and has at least two steps. First the titanium oxide ore is reacted with chlorine to make titanium chloride.

1. Balance this equation to show the reaction between titanium oxide and chlorine:

\[ \text{TiO}_2 + \text{Cl}_2 \rightarrow \text{TiCl}_4 + \text{O}_2 \]

The titanium chloride is reduced using either magnesium or sodium to form titanium metal. The magnesium is put into a steel reactor and titanium chloride is pumped in. The reactor is welded shut and then heated to 1200 °C. As titanium is very reactive, oxygen must be kept out of the reaction vessel so the reaction is done in an atmosphere of argon.

2. Why is an atmosphere of argon used for this reaction?

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3. Suggest another gas which could be used instead.

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After two or three days the vessel is broken open and the titanium removed. The whole process can take up to 17 days and can produce unpleasant waste gases. The largest reactors only produce about 1 tonne of titanium per day. (A Blast Furnace produces about 10 000 tonnes of iron in a day.)

4. Explain why titanium is an expensive metal.

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The equation for the reduction of titanium chloride with magnesium is:

\[ 2\text{Mg}(l) + \text{TiCl}_4(l) \rightarrow 2\text{MgCl}_2(l) + \text{Ti}(s) \]

5. Calculate the atom economy of the process used to extract titanium. The guide below may help you.

Work out the total mass of reactants using the table

<table>
<thead>
<tr>
<th>Atom</th>
<th>Number</th>
<th>Atomic mass</th>
<th>Number x atomic mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg</td>
<td>2</td>
<td>24</td>
<td>48</td>
</tr>
</tbody>
</table>

Total mass of reactants = ___________ g

Total mass of desired products: ____________ g

Atom economy = \[ \frac{\text{mass of desired products}}{\text{total mass of reactants}} \times 100 \% \] = ____________ x 100%

The atom economy of the Kroll process is ________%.

6. The Kroll process is a two-step process.
   Will the atom economy of the whole process be higher, lower or the same as the value you have calculated? Explain your answer.

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William Kroll knew that his process was expensive and inefficient. In the 1950s he predicted that within 15 years an electrolytic process would replace his method. However, the Kroll process is still the main method used today and there have been many failed attempts at electrolysis. Scientists have tried using both titanium oxide and titanium chloride dissolved in other salts as the electrolyte. They have also experimented with various metals and carbon as the electrodes but none of the combinations they have tried have worked. Titanium has remained difficult to extract and expensive, although it offers properties that interest the designers of a wide variety of products.