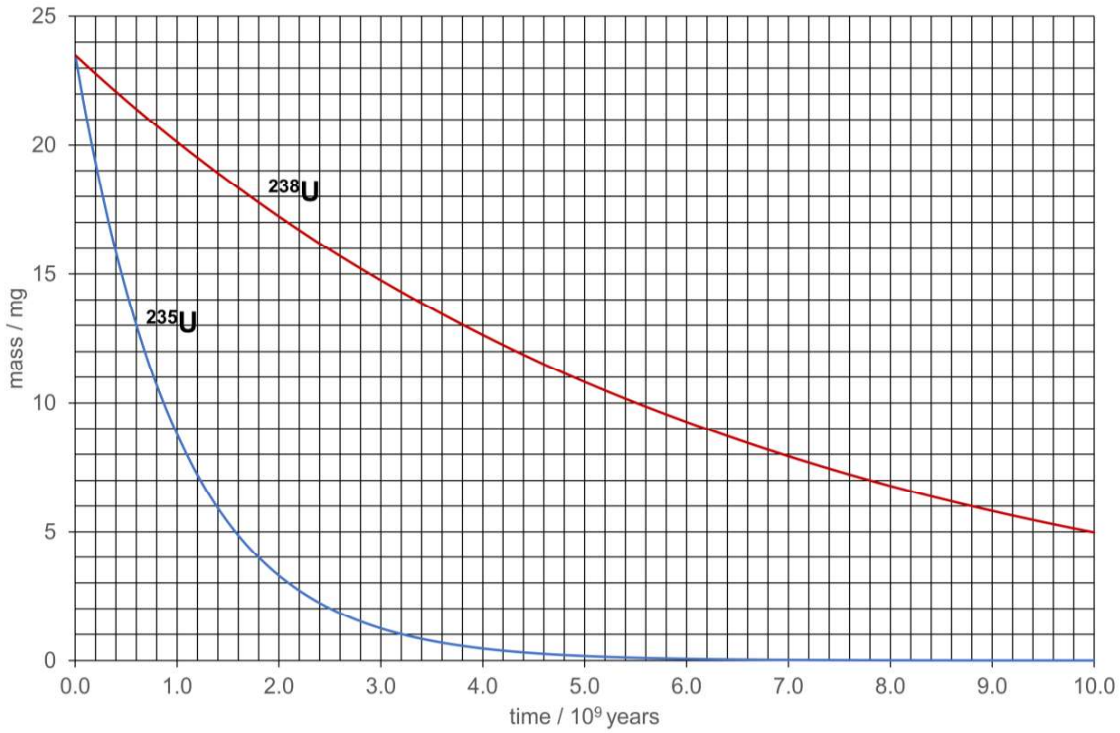
Uranium is a radioactive element. Both ^{235}U and ^{238}U isotopes undergo alpha decay. The uranium atom is converted into an atom of a different element with the loss of an alpha particle. An alpha particle is the nucleus of a helium atom.

(i) Write radioactive decay equations for the radioactive decays of ^{235}U and ^{238}U, giving the mass number of any new element formed.

^{235}U decays much faster than ^{238}U. This means that a naturally occurring sample of uranium cannot be used to make a bomb without enriching it first.

The rate of radioactive decay of an isotope can be measured in terms of the radioactive half-life, $t_{½}$. The graph below shows how the amount of the two isotopes of uranium falls over time.



(j) Using the graph, give the half-life in years of

(i) ^{235}U **(ii)** ^{238}U

The following equation relates the number of radioactive atoms, N, remaining after a time t, to the number initially present, N_0.

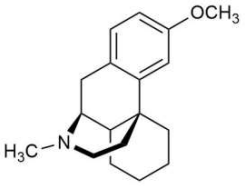
$$N = N_0 e^{-\lambda t} \quad \text{where} \quad \lambda = \frac{\ln 2}{t_{½}}$$

It is assumed that when the Earth was formed, the number of atoms of ^{235}U and ^{238}U was the same.

(k) Estimate the age of the Earth using your answers to earlier parts of the question.

4. This question is about cough suppressants

In September 2017, the UK Prime Minister, Theresa May, had a bad cough during her speech at the Conservative Party Conference. The cough suppressant drug dextromethorphan, which is present in cough remedies such as Benylin®, could have helped her out. This question is about the synthesis of dextromethorphan. The synthesis involves the formation of some strong bonds and some stable carbocations.



dextromethorphan

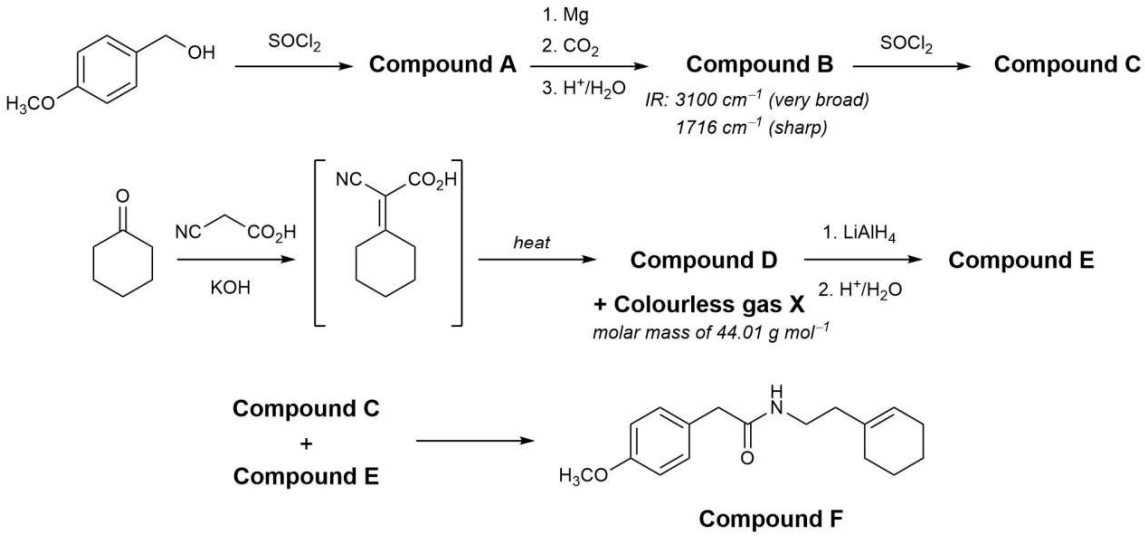
Dextromethorphan is often administered as the hydrobromide monohydrate salt.

(a) In the answer book, circle the atom in dextromethorphan that is protonated in the salt.

(b) Determine the molecular formula of dextromethorphan and hence calculate the molar mass of the dextromethorphan hydrobromide monohydrate salt.

The synthesis of dextromethorphan takes a number of steps. Please note that in the schemes describing the synthesis, by-products of the reactions are not always shown.

The synthesis of dextromethorphan begins with the synthesis of compound **F**.



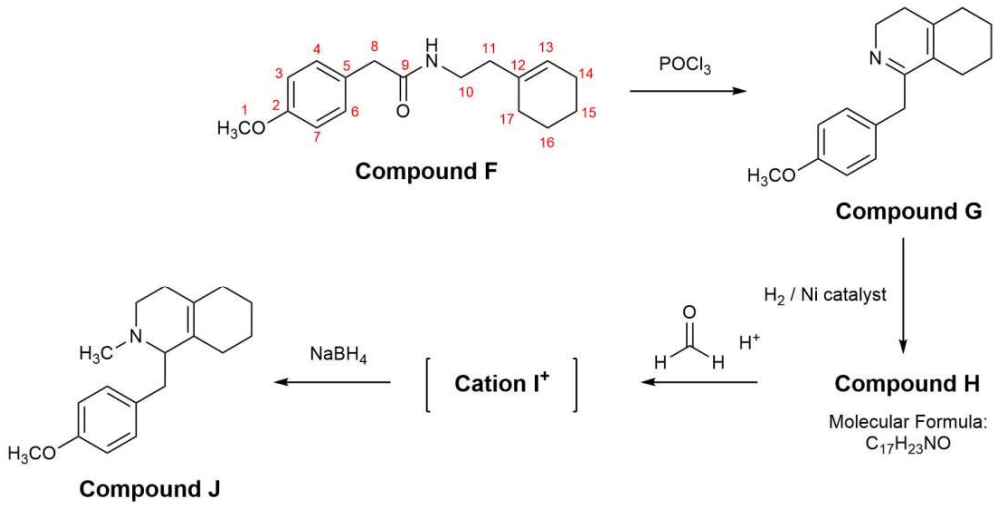
(c) Draw the stuctures of compounds **A**, **B**, **C**, **D**, **E** and gas **X**.

In the reaction to make compound **D**, the cyanoacetic acid can be deprotonated twice by the potassium hydroxide.

(d) **(i)** Draw a structure for anion $\mathbf{Z^-}$.

(ii) Draw a structure for dianion $\mathbf{Z^{2-}}$.

The synthesis continues with the conversion of compound **F** to compound **J**.



(e) Write down the numbers of the two carbon atoms in compound **F** that are connected in the reaction to synthesise compound **G**.

(f) Draw the structures of compound **H** and cation $\mathbf{I^+}$.