2. This question is about detecting molecules in space

In September 2014, the BBC announced that radio-astronomers had discovered the 'most complex molecule' to date in space. Found in 'Sagittarius-B2(N)' – the largest star-forming region in our Galaxy – this is the first molecule detected with a branched carbon chain. The systematic name for the molecule is 2-methylpropanenitrile. It was found to be approximately 0.4 times as abundant as its straight-chained isomer.

The molecule was detected from the radio signals given out as it dropped from an excited energy level to a lower one.

A nitrile is a molecule in which one of the carbons has a triple bond to nitrogen.

(a) **(i)** Draw the structure of 2-methylpropanenitrile.

(ii) Draw the structure and give the systematic name of another nitrile isomeric with 2-methylpropanenitrile.

Astronomers are now looking for the next series of nitriles with the formula C_5H_9N.

(b) Draw all the isomeric nitriles with the formula C_5H_9N.

Most of the molecules detected by radio-astronomers in less active regions of space tend to have linear structures. The largest so far detected has the unlikely-looking formula $HC_{11}N$.

(c) Draw the structure of the linear molecule with the formula $HC_{11}N$.

The signals detected in the radio wave region of the electromagnetic spectrum are due to transitions between rotational energy levels, each of which has a particular energy. Molecules have many rotational energy levels available to them, each level with a different energy being specified by the so-called rotational quantum number, J, which takes integer values from 0 upwards.

The energy (in joules) of the Jth rotational energy level, E_J, is given by the formula:

$$E_J = h \times B \times J\,(J+1)$$

where B = the rotational constant of the molecule (in Hz)
            h = Planck's constant = 6.626×10^{-34} J s.
            and light of frequency f (Hz) has energy $h \times f$ (joules)

Two signals have been detected due to $HC_{11}N$. One is due to the transition from rotational energy level ($J = 39$) to ($J = 38$), the other due to the transition from level ($J = 38$) to ($J = 37$).

(d) Given the signal from ($J = 39$) to ($J = 38$) was observed at 13186.853 MHz, calculate:

(i) the rotational constant, B, for $HC_{11}N$ (in MHz).

(ii) the frequency (in MHz) for the transition from level ($J = 38$) to ($J = 37$).

4