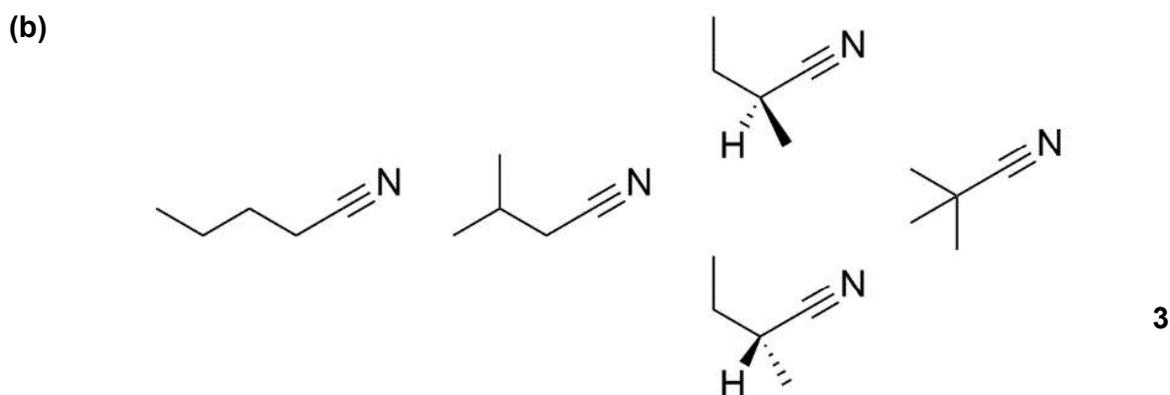


2. This question is about detecting molecules in space



Butanenitrile 1/2

Allow 1-Butanenitrile. 1/2 mark for structure, 1/2 mark for name.



All five structures correct scores 3 marks. Four correct structures scores 2 marks (it is thought that most students will draw only one of the two enantiomers). Three correct structures scores 1 mark. Two correct structures scores 1/2 mark. One correct structure scores 0 marks. Incorrect or duplicated structures should be penalised at minus 1 mark each, down to a minimum of 0 marks.



(d) (i) Energy of transition from $(J+1)^{th}$ level to J^{th} level (an emission)

$$= h \times B \times (J + 1) (J + 2) - h \times B \times J (J + 1)$$

$$= h \times B \times [(J^2 + 3J + 2) - (J^2 + J)]$$

$$= h \times B \times 2(J + 1) = h \times f$$

$$B = f / 2(J + 1)$$

$$B = 13186.853 \text{ MHz} / 2(38 + 1)$$

$$B = 169.0622179 \text{ MHz}$$

2

Correct answer scores full marks. General formula does not have to be derived, but is worth a credit of 1 mark and very useful for remainder of question.

(ii) $h \times f = h \times B \times 2(J + 1)$ (from part (d)(i))

$$f = B \times 2(J + 1)$$

$$f = 169.0622179 \text{ MHz} \times 2(37 + 1)$$

$$f = 12848.72856 \text{ MHz}$$

2

Correct answer scores full marks. General formula does not have to be derived, but is worth a credit of 1 mark. Allow error carried forward from (d)(i). Answer should be answer to (d)(i) multiplied by 76.

(e) Mass of one atom of $^{12}\text{C} = 12.00 \text{ g mol}^{-1} / 6.02 \times 10^{23} \text{ mol}^{-1}$
 $= 1.993 \times 10^{-23} \text{ g} = 1.993 \times 10^{-26} \text{ kg}$

1

Mass of one atom of $^{16}\text{O} = 16.00 \text{ g mol}^{-1} / 6.02 \times 10^{23} \text{ mol}^{-1}$
 $= 2.658 \times 10^{-23} \text{ g} = 2.658 \times 10^{-26} \text{ kg}$

(f) $\mu = 1.993 \times 10^{-26} \text{ kg} \times 2.658 \times 10^{-26} \text{ kg} / (1.993 \times 10^{-26} + 2.658 \times 10^{-26}) \text{ kg}$
 $= 1.139 \times 10^{-26} \text{ kg}$

1

Allow error carried forward from part (e)

(g) (i) $f = B \times 2(J + 1)$

$$f = B \times 2(0 + 1)$$

$$f = 2B$$

$$B = 57,636 \text{ MHz}$$

$$r^2 = \frac{h}{8\pi^2\mu B}$$

$$r^2 = \frac{6.626 \times 10^{-34} \text{ kg m s}^{-2} \text{ s}}{8 \times \pi^2 \times 1.139 \times 10^{-26} \text{ kg} \times 5.7635 \times 10^{10} \text{ s}^{-1}}$$

$$r^2 = 1.2783 \times 10^{-20} \text{ m}^2$$

$$r = 1.13 \times 10^{-10} \text{ m}$$

3

Correct answer scores 3 marks. Statement $f = 2B$ scores 1 mark, correct calculation of B is worth the second mark. The third mark is for the correct answer. Penalise 1 mark for incorrect or missing units, or if out by power(s) of 10 due to mix up with cm/m etc.

(ii) $f = B \times 2(J + 1)$

$$806651.719 \text{ MHz} = 57635 \text{ MHz} \times 2(J + 1)$$

$$2(J + 1) = 14$$

$$(J + 1) = 7$$

$$J = 6$$

Transition is from Level $J = 7$ to $J = 6$

2

Correct answer scores 2 marks. If they have calculated the correct value of J but have labelled the transition the wrong way round i.e. J = 6 to J = 7 then award only 1 mark. If J has not been calculated numerically correctly then 0 marks. Error carried forward is not credited here.

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