

2019 SCORING GUIDELINES

Question 2

Answer the following questions relating to the chemistry of the halogens.

- (a) The molecular formulas of diatomic bromine, chlorine, fluorine, and iodine are written below. Circle the formula of the molecule that has the longest bond length. Justify your choice in terms of atomic structure.



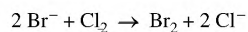
I₂ has the longest bond length because the radius of the I atom is greater than the radii of the other halogen atoms. Thus, the distance between the nuclei of atoms in I₂ is greater than it is in smaller halogens.

1 point is earned for circling I₂ and providing a valid explanation.

A chemistry teacher wants to prepare Br₂. The teacher has access to the following three reagents: NaBr(aq), Cl₂(g), and I₂(s).

Half-Reaction	E° at 25°C (V)
$\text{Br}_2 + 2 e^- \rightarrow 2 \text{Br}^-$	1.07
$\text{Cl}_2 + 2 e^- \rightarrow 2 \text{Cl}^-$	1.36
$\text{I}_2 + 2 e^- \rightarrow 2 \text{I}^-$	0.53

- (b) Using the data in the table above, write the balanced equation for the thermodynamically favorable reaction that will produce Br₂ when the teacher combines two of the reagents. Justify that the reaction is thermodynamically favorable by calculating the value of E° for the reaction.



$$E^\circ = E^\circ(\text{reduced species}) - E^\circ(\text{oxidized species}) \\ = 1.36 \text{ V} - 1.07 \text{ V} = +0.29 \text{ V}.$$

Because E° for the reaction has a positive value, the reaction is thermodynamically favorable.

1 point is earned for the correct balanced equation.

1 point is earned for the correct calculation of E° .

Br₂ and Cl₂ can react to form the compound BrCl.

- (c) The boiling point of Br₂ is 332 K, whereas the boiling point of BrCl is 278 K. Explain this difference in boiling point in terms of all the intermolecular forces present between molecules of each substance.

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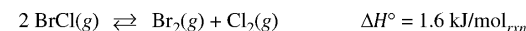
Question 2 (continued)

The only intermolecular attractions in Br₂(l) are London forces, while those in BrCl(l) include both London forces and dipole-dipole forces. However, due to the greater polarizability of the electron cloud of Br₂ compared to that of BrCl, the London forces in Br₂(l) are stronger than the combined intermolecular forces in BrCl(l). Thus, the boiling point of Br₂(l) is greater than that of BrCl(l).

1 point is earned for identifying the intermolecular forces in each substance.

1 point is earned for a valid explanation.

The compound BrCl can decompose into Br₂ and Cl₂, as represented by the balanced chemical equation below.



A 0.100 mole sample of pure BrCl(g) is placed in a previously evacuated, rigid 2.00 L container at 298 K. Eventually the system reaches equilibrium according to the equation above.

- (d) Calculate the pressure in the container before equilibrium is established.

$$P = \frac{nRT}{V} = \frac{(0.100 \text{ mol})(0.08206 \text{ L atm mol}^{-1} \text{ K}^{-1})(298 \text{ K})}{2.00 \text{ L}} = 1.22 \text{ atm}$$

1 point is earned for a correct pressure with consistent units.

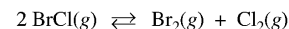
- (e) Write the expression for the equilibrium constant, K_{eq} , for the decomposition of BrCl.

$$K_{eq} = \frac{[\text{Br}_2][\text{Cl}_2]}{[\text{BrCl}]^2} \quad \text{or} \quad K_{eq} = \frac{P_{\text{Br}_2}P_{\text{Cl}_2}}{(P_{\text{BrCl}})^2}$$

1 point is earned for a correct equilibrium expression.

After the system has reached equilibrium, 42 percent of the original BrCl sample has decomposed.

- (f) Determine the value of K_{eq} for the decomposition reaction of BrCl at 298 K.



I	1.22	0	0
C	-2x	+x	+x
E	0.71	0.26	0.26

$$P_{\text{BrCl decomposed}} = (0.42)(1.22 \text{ atm}) = 0.51 \text{ atm}$$

$$2x = 0.51 \text{ atm} \Rightarrow x = 0.26 \text{ atm}$$

$$K_{eq} = \frac{(0.26)(0.26)}{(0.71)^2} = 0.13$$

Note: The solution is in terms of pressures. Solutions in terms of molar concentrations also earn full credit.

1 point is earned for correct stoichiometric values at equilibrium.

1 point is earned for a consistent value of K_{eq} .

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Question 2 (continued)

(g) Calculate the bond energy of the Br-Cl bond, in kJ/mol, using ΔH° for the reaction (1.6 kJ/mol_{rxn}) and the information in the following table.

Bond	Bond Energy (kJ/mol)
Br – Br	193
Cl – Cl	243
Br – Cl	?

$$\Delta H^\circ = \sum (\text{bond energies})_{\text{broken}} - \sum (\text{bond energies})_{\text{formed}}$$

$$1.6 \text{ kJ/mol} = 2(\text{Br-Cl bond energy}) - (193 \text{ kJ/mol} + 243 \text{ kJ/mol})$$

$$(436 + 1.6) \text{ kJ/mol} = 2(\text{Br-Cl bond energy})$$

$$\text{Br-Cl bond energy} = 219 \text{ kJ/mol}$$

1 point is earned for a correct calculation of the Br-Cl bond energy.