AP® CHEMISTRY
2017 SCORING GUIDELINES

Question 1

$$CS_2(g) + 3\ Cl_2(g) \rightarrow CCl_4(g) + S_2Cl_2(g)$$

Carbon tetrachloride, $CCl_4(g)$, can be synthesized according to the reaction represented above. A chemist runs the reaction at a constant temperature of 120°C in a rigid 25.0 L container.

(a) Chlorine gas, $Cl_2(g)$, is initially present in the container at a pressure of 0.40 atm.

(i) How many moles of $Cl_2(g)$ are in the container?

$n = \frac{PV}{RT} = \frac{0.40\ \text{atm} \times 25.0\ \text{L}}{0.08206\ (\text{L} \cdot \text{atm})/(\text{mol} \cdot \text{K}) \times 393\ \text{K}} = 0.31\ \text{mol}\ Cl_2(g)$	1 point is earned for the correct answer with supporting work.

(ii) How many grams of carbon disulfide, $CS_2(g)$, are needed to react completely with the $Cl_2(g)$?

$0.31\ \text{mol}\ Cl_2 \times \frac{1\ \text{mol}\ CS_2}{3\ \text{mol}\ Cl_2} \times \frac{76.13\ \text{g}\ CS_2}{1\ \text{mol}\ CS_2} = 7.9\ \text{g}\ CS_2$	1 point is earned for using the correct mole ratio (may be implicit). 1 point is earned for the mass of CS_2.

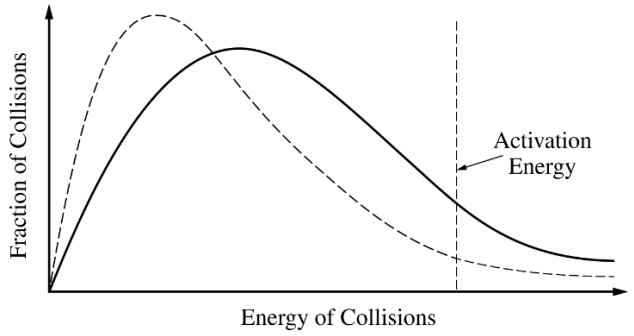
(b) At 30°C the reaction is thermodynamically favorable, but no reaction is observed to occur. However, at 120°C, the reaction occurs at an observable rate.

(i) Explain how the higher temperature affects the collisions between the reactant molecules so that the reaction occurs at an observable rate at 120°C.

At the higher temperature the particles have a greater average kinetic energy than at the lower temperature. Thus there are more collisions with sufficient energy to overcome the activation energy.	1 point is earned for an appropriate explanation that includes a reference to molecular collisions.

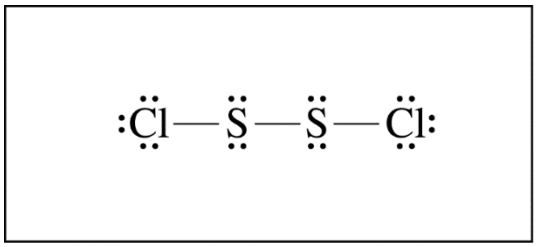
(ii) The graph below shows a distribution for the collision energies of reactant molecules at 120°C. Draw a second curve on the graph that shows the distribution for the collision energies of reactant molecules at 30°C.

Question 1 (continued)

	1 point is earned for a curve that has a peak above and to the left of the given curve. 1 point is earned for a curve that is below the given curve in the region beyond the activation energy.

(c) S_2Cl_2 is a product of the reaction.

(i) In the box below, complete the Lewis electron-dot diagram for the S_2Cl_2 molecule by drawing in all of the electron pairs.



See correct diagram above.	1 point is earned for a correctly drawn diagram.

(ii) What is the approximate value of the Cl–S–S bond angle in the S_2Cl_2 molecule that you drew in part (c)(i) ? (If the two Cl–S–S bond angles are not equal, include both angles.)

Any value between 104° and 110°	1 point is earned for an acceptable angle that is consistent with the Lewis diagram.

(d) $CCl_4(g)$ can also be produced by reacting $CHCl_3(g)$ with $Cl_2(g)$ at 400°C, as represented by the equation below.

$$CHCl_3(g) + Cl_2(g) \rightarrow CCl_4(g) + HCl(g)$$

At the completion of the reaction a chemist successfully separates the $CCl_4(g)$ from the $HCl(g)$ by cooling the mixture to 70°C, at which temperature the $CCl_4(g)$ condenses while the $HCl(g)$ remains in the gaseous state.

Question 1 (continued)

(i) Identify all types of intermolecular forces present in $HCl(l)$.

Dipole-dipole forces, London dispersion forces	1 point is earned for both types of forces.

(ii) What can be inferred about the relative strengths of the intermolecular forces in $CCl_4(l)$ and $HCl(l)$? Justify your answer in terms of the information above.

The intermolecular forces among CCl_4 molecules must be **stronger** than those among HCl molecules because the CCl_4 condenses at a higher temperature than HCl.	1 point is earned for the correct answer with a valid justification.