HL Paper 3 Section A Experimental work (8) with worked answers

A class of students wanted to find a possible mechanism for the reaction between propanone and iodine in the presence of an acid catalyst.

Three different burettes were set up in the laboratory. One contained an aqueous solution of 2.0 mol dm^{-3} propanone, CH_3COCH_3, another contained an aqueous solution of 0.010 mol dm^{-3} iodine, $I_2(aq)$, and the third contained 2.0 mol dm^{-3} hydrochloric acid solution, HCl(aq).

Students were instructed to place the required volumes of the propanone and iodine solution in a test-tube together with the required volume of water. They then added the specified volume of hydrochloric acid, mixed the contents and timed how long it took for the yellow colour of the iodine to disappear.

Table showing volumes to be added

Experiment	Volume of 2.0 mol dm^{-3} $CH_3COCH_3(aq)$ / cm^3	Volume of 0.010 mol dm^{-3} $I_2(aq)$ / cm^3	Volume of water / cm^3	Volume of 2.0 mol dm^{-3} HCl(aq) / cm^3
1	4.0	2.0	10.0	4.0
2	8.0	2.0	6.0	4.0
3	4.0	1.0	11.0	4.0
4	4.0	2.0	6.0	8.0

The following results show the initial concentrations of the three reagents and the average time taken for the iodine colour to disappear.

Experiment	$[CH_3COCH_3]$ / mol dm^{-3}	$[I_2(aq)]$ / mol dm^{-3}	$[H^+(aq)]$ / mol dm^{-3}	Time for yellow colour to disappear / s
1	0.40	0.0010	0.40	800
2	0.80	0.0010	0.40	400
3	0.40	0.0005	0.40	400
4	0.40	0.0010	0.80	400

(a) Explain how the value for the initial concentration of the iodine solution in Experiment number 3 was calculated. ***[1]***

1.0 cm^3 of 0.010 $I_2(aq)$ is diluted 20 times to give a total volume of 20.0 cm^3.
Hence the concentration is one twentieth of the original concentration.
0.010 ÷ 20 = 0.0005 mol dm^{-3}. ***[1]***

(b) Explain why the colour of the iodine disappears as the reaction proceeds. ***[1]***

$I_2(aq)$ is yellow but both the products containing iodine, $I^-(aq)$ and $CH_2ICOCH_3(aq)$, are colourless. ***[1]***

(c) Determine the order of reaction with respect to iodine. ***[1]***

Zero order.
When half the amount of iodine is placed in the reaction tube, the time taken for the colour of the iodine to disappear is halved, so the rate is the same, i.e. the rate does not depend upon the concentration of iodine. ***[1]***

(d) Determine the rate equation for the reaction. ***[1]***

Order with respect to $[CH_3COCH_3] = 1$
Order with respect to $[H^+] = 1$
Rate = $k[CH_3COCH_3(aq)][H^+(aq)]$ where k is the rate constant. ***[1]***

(e) State what can be deduced about the slow step of the reaction in terms of the reactants. ***[1]***

The slow step of the reaction does not involve iodine.
It does involve propanone and hydrogen ions. ***[1]***

(f) Use your knowledge of chemistry to suggest a possible first step in the mechanism of the reaction if it is assumed that the first step is the slowest step. ***[1]***

The first step is likely to be the protonation of propanone. The carbonyl oxygen atom will have a small negative charge as oxygen is more electronegative than carbon so it is likely to attract the proton to form $CH_3–CO^+H–CH_3$ as a reactive intermediate. ***[1]***