CHAPTER 6

RESULT AND DISCUSSION

6.1 Preliminary investigation of solid-solid reactions at various temperatures.

Table 6.1.1 Solid-solid reaction of the first transition series at room temperature.

R_1 \ R_2	$Cr_2(CO_3)_3$ blue	R_1 \ R_2	$Cr_2(CO_3)_3$ blue	R_1 \ R_2	Cr_2O_3 green
$Hg(NO_3)_2$ yellow	P - black time 10 hrs	NH_4I brown hygr.	P - black time 10 hrs	Ag_2SO_4 white	P - black time 10 hrs

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R_1 = 1st reactant

R_2 = 2nd reactant

P = product

P_1 = 1st product

P_m = mth product

hygr. = hygroscopic

time n hrs = after the contact n hrs

Table 6.1.1 (continued)

R_2 \ R_1	CrO_3 dark-red	R_2 \ R_1	CrO_3 dark-red	R_2 \ R_1	CrO_3 dark-red
$AlPO_4$ white	P - black time 1 hr	As_2O_3 white	P - black	As_2S_3 orange	P - Black
Ag_2SO_4 white	P - black	BaO_2 white	P - black	BaS white	P - Black
$Ca(OH)_2$ white	P - yellow time 1 hr	CaF_2 white	P - yellow time 10 hrs	CuCl green	P - black
$CuCl_2 2H_2O$ blue-green	P-dark-green	$Fe(NH_4)_2(SO_4)_2 6H_2O$ yellow	P - black	$Fe_2(C_2O_4)_3 6H_2O$ green	P - black
$K_4Fe(CN)_6$ yellow	P - dark yellow time 10 hrs	KCNO white	P -yellow time 10 hrs	$K_2C_2O_4$ white	P - black time 3mins
$MnSO_4 4H_2O$ pink	P - black	KCN white hygr.	P_1 - yellow P_2 - orange time 10 hrs	$MnC_2O_4 4H_2O$ white	P - black
$MnCl_2 4H_2O$ white	P - black	MgC_2O_4 white	P - black	$Na_2C_4H_4O_6$ white	P - black
$(NH_4)_2C_4H_4O_6$ white	P - black	PbC_2O_4 white	P - black	$TiKC_2O_4$ white	P - black

Table 6.1.1 (continued)

R_1 \ R_2	$(NH_4)_2CrO_4$ yellow	R_1 \ R_2	$(NH_4)_2CrO_4$ yellow	R_1 \ R_2	$(NH_4)_2CrO_4$ yellow
$Al(NO_3)_3 \cdot 9H_2O$ colourless hygr.	P - yellow time 15 min.	$CoF_2 2H_2O$ pink	P - black time 30 hrs	$CoCl_2 6H_2O$ red-violet hygr.	P - black time 1 hrs
$CuCl_2 2H_2O$ blue-green	P - red-brown time 3 hrs	$CrCl_3$ green hygr.	P - black time 10 hrs	$CuSO_4 5H_2O$ blue	P - red-brown time 10 hrs
$Fe(NH_4)_2-(SO_4)_2 6H_2O$ pale green	P- red brown time 30 hrs	$Fe_2(C_2O_4)_3 \cdot 5H_2O$ green	P - brown time 10 hrs	$Hg(NO_3)_2$ yellow	P_1- orange P_2- black P_3- red P_4- white
KI white hygr.	P - black time 5 hrs	KCN white hygr.	P- yellow time 10 hrs	$MnSO_4 7H_2O$ rose	P - black
$NiCl_2 6H_2O$ green	P - brown	$Ni(NO_3)_3 - 6H_2O$ green	P - brown time 10 min	NaI white hygr.	P- brown time 10 mins
$Na_2S_2O_3$ colourless	P - brown time 10 hrs	$(NH_4)_2C\ H_4O_6$ white	P - Black time30 hrs	$(NH_4)I$ yellow-brown hygr.	P - brown

Table 6.1.1 (continued)

R_1 \ R_2	$(NH_4)_2CrO_4$ yellow	R_1 \ R_2	$(NH_4)_2CrO_4$ yellow	R_1 \ R_2	K_2CrO_4 yellow
$Pb(NO_3)_2$ white	P_1- yellow P_2- brown time 30hrs.	$ZnSO_4 7H_2O$ white	P_1- yellow P_2- orange time 2 days	$AgNO_3$ white	P - black time 16 hrs

R_1 \ R_2	K_2CrO_4 yellow	R_1 \ R_2	K_2CrO_4 yellow	R_1 \ R_2	K_2CrO_4 yellow
$Cu(C_2H_3O_2)_2$ navy-blue	P - black time 22 hrs	$CoCl_2 6H_2O$ red-violet hygr.	P-dark-brown time30mins	$CuCl_2 2H_2O$ blue-green	P - brown time 1 hr.
$HgCl_2$ white	P- dark-yellow	$MnCl_2 4H_2O$ white	P- dark-brown	NH_4F white hygr.	P - orange time 1 hr.
Na_2CO_3 white	P- orange time 30 hrs	$NiCl_2 6H_2O$ green	P - red-brown time 1 hr.		

Table 6.1.1 (continued)

R_2 \ R_1	K_2CrO_4 yellow	R_2 \ R_1	K_2CrO_4 yellow	R_2 \ R_1	K_2CrO_4 yellow
$Ni(NO_3)_2 6H_2O$ green hygr.	P - red-brown time 1 hr.	$NaH_2PO_4 12H_2O$ white	P_1- red-orange time 1 hr.	$SnCl_2 2H_2O$ white	P_1- dark yellow P_2- brown P_3- green time 1 hr.
$ZnCl_2$ white	P - orange time 1 hr.	$Zn(NO_3)_2$ white	P_1- yellow P_2- orange time 20 hrs.		

R_2 \ R_1	$FeC_2O_4 2H_2O$ yellow	R_2 \ R_1	$FeC_2O_4 2H_2O$ yellow	R_2 \ R_1	$FeC_2O_4 2H_2O$ yellow
HgKCN white	P - black time 10hrs	KF white	P - black time 10hrs	$KHCO_3$ white	P - red brown time 10 hrs.
KCNO white	P - blood red time 10 hrs	$NaC_2H_3O_2$ white	P - red brown time 10 hrs.		

Table 6.1.1 (continued)

R_1 \ R_2	$Fe_2(C_2O_4)_3 5H_2O$ yellow-green	R_1 \ R_2	$Fe_2(C_2O_4)_3 5H_2O$ yellow-green	R_1 \ R_2	$Fe_2(C_2O)_{43} 5H_2O$ yellow-green
$BaBr_2 2H_2O$ colorless	P-dark yellow time 10 mins	HgKCN white	P-brown time 22hrs.	KCN white	P_1- red P_2- white time 20 hrs
KI white	P - brown time 1/2hrs	KF white hygr.	P_1- yellow P_2- white time 1 hr.	KCl white	P_1-yellow P_2-brown time 22hrs.
KCNO white	P-red brown time 1 hr.	$KC_2H_3O_2$ white	P - brown time 1 hr.	$LiC_7H_5O_3$ white	P - black time 16hrs.
$Na_2S_2O_3$ colorless hygr.	P - yellow time 10 hrs.	$NaI 2H_2O$ white hygr.	P - brown	NaCl white	P - yellow time 24 hrs
Na_2CO_3 white	P-dark brown time 22 hrs.	$NaC_2H_3O_2$ white	P - brown time 23 hrs.	NaH_2PO_4 $12H_2O$ white	P - white time 22 hrs
$(NH_4)_2CO_3$ H_2O white hygr.	P - yellow time 1 min	NH_4I yellow	P - black time 1 min.	$(NH_4)_2CrO_4$ yellow	P - brown time 20 hrs.

Table 6.1.1 (continued)

R_1 / R_2	$Fe(NH_4)_2(SO_4)_2 8H_2O$ pale green	R_1 / R_2	$Fe(NH_4)_2(SO_4)_2 8H_2O$ pale green	R_1 / R_2	$Fe(NH_4)_2(SO_4)_2 8H_2O$ pale green
$AgNO_3$ white	P - brown time 10hrs.	$BaCl_2 2H_2O$ white	pale yellow time 1 day	CrO_3 dark red	P -black
$CuCl_2 2H_2O$ blue green	P- dark-green time 10 mins	$Hg(NO_3)_2$ yellow	P-brown time 1 day	$HgCl_2$ white	P-dark brown time 20 hrs.
KCNO white	P - brown time 10 hrs	KF white	P - grey time 10 hrs	KBr white	P -yellow time 10 hrs
$KC_2H_3O_2$ white	P -black time 10 hrs	KCN white	P_1- orange P_2- yellow time 22 hrs	$KHCO_3$ white	P -yellow time 20 hrs
KCN white	P_1- yellow P_2- green time 20 hrs	$MnCl_2 4H_2O$ white	P - yellow	$MgCO_3$ white	P-pale yellow time 20 hrs.
$Mg(BO_2)_2 8H_2O$ white	P - dark yellow time 22 hrs.	$NaNO_3$ white	P- orange time 24 hrs	$NaC_2H_3O_2$ white	P-white time 10 hrs.
$NaH_2PO_4 8H_2O$ white	P - white	Na_2CO_3 white	P-dark brown time 20 hrs	$(NH_4)_2CrO_4$ yellow	P-red brown time 2 days

Table 6.1.1 (continued)

R_1 / R_2	$Fe_3(PO_4)_2 8H_2O$ white-blue	R_1 / R_2	$Fe_3(PO_4)_2 8H_2O$ white-blue	R_1 / R_2	$Fe_3(PO_4)_2 8H_2O$ white-blue
CrO_3 dark red	P - black	HgKCN white	P - brown time 1 day	KF white hygr.	P - brown time 5 mins.
KCNO white	P - brown time 1 day	NH_4I brown	P-red-brown time 1 day		

R_1 / R_2	$CoCO_3$ dark-violet	R_1 / R_2	$CoCl_2 6H_2O$ red-violet	R_1 / R_2	$CoCl_2 6H_2O$ red-violet
$NiCl_2 6H_2O$ green	P -black time 1 hr.	$AlPO_4$ white	P-pale-violet time 1 day	$Al(NO_3)_3$ $9H_2O$ colourless	P-pale-violet time 5 mins.

R_1 / R_2	$CoCl_2 6H_2O$ red-violet	R_1 / R_2	$CoCl_2 6H_2O$ red-violet	R_1 / R_2	$CoCl_2 6H_2O$ red-violet
$Ba(C_2H_3O_2)_2$ white	P - pink time 10 hrs.	$BaCl_2 2H_2O$ white	P-blue violet time 1 day	BaO_2 white	P - black time 10 mins.

Table 6.1.1 (continued)

R_2 \ R_1	$CoCl_2 6H_2O$ red-violet	R_2 \ R_1	$CoCl_2 6H_2O$ red-violet	R_2 \ R_1	$CoCl_2 6H_2O$ red-violet
Bi_2O_3 yellow	P - grey time 1 day	$CaCl_2 2H_2O$ white	P - blue	$Ca(C_2H_3O_2)_2$ white	P - black
$CaBr_2 6H_2O$ white	P - blue	CaS grey	P - brown time 1 day	CuCl green	P - brown time 1/2 hr.
$K_2Cr_2O_7$ orange	P - black time 1/2 hr	K_2CrO_4 yellow	P - black time 1/2 hr	KCNO white	P - blue time 10 mins.
KCN white	P - brown	NaI white	P_1 - black P_2 - green	$Na_2S_2O_3$ colourless	P - blue
$(NH_4)_2C_4H_4O_6$ white	P - blue time 1 hr.	$(NH_4)_2CO_3 .H_2O$ white	P - green time 1 min	$(NH_4)_2C_2O_4 .H_2O$ white	P - violet time 1 min.
NH_4I brown	P - black	$(NH_4)_2SO_4$ colourless	P - pink time 1 day	$(NH_4)_2CrO_4$ yellow	P - black time 1 min
PbO yellow	P - black time 10 hrs.	$Sr(OH)_2 2H_2O$ white	P - black time 1/2 hrs	$SrCO_3$ colourless	P - Black time 3 hrs.

Table 6.1.1 (continued)

R_1 \ R_2	$CoF_2 2H_2O$ pink	R_1 \ R_2	$CoF_2 2H_2O$ pink	R_1 \ R_2	$CoF_2 2H_2O$ pink
$Al(NO_3)_3 9H_2O$ white	P - red time 10 mins.	CaS grey	P - black	$CuCl_2 2H_2O$ blue-green	P - brown time 1 day
KCN white	P_1 - yellow P_2 - brown time 1 day	KCNO white	P - blue time 1 day	NaSCN colourless	P - blue
$(NH_4)_2CO_3H_2O$ white	P - violet time 15 min	NH_4I brown	P-dark yellow time 1 min.	$(NH_4)_2CrO_4$ yellow	P - black time 2 days.
$SrCl_2 2H_2O$ white	P_1 - red-violet P_2 - blue-violet time 1 day				

R_1 \ R_2	$CoSO_4 7H_2O$ red- orange	R_1 \ R_2	$CoSO_4 7H_2O$ red-orange	R_1 \ R_2	$CoSO_4 7H_2O$ red-orange
$BaCl_2 2H_2O$ white	P - violet time 1 day	$CaCl_2 2H_2O$ white	P - blue	HgKCN white	P - green time 1 day
KCN white	P - brown time 1 day	KCNO white	P - blue	$KC_2H_3O_2$ white	P - brown time 1 day

Table 6.1.1 (continued)

R_1 \ R_2	$CoSO_4 7H_2O$ red-orange	R_1 \ R_2	$CoSO_4 7H_2O$ red-orange	R_1 \ R_2	$CoSO_4 7H_2O$ red-orange
NaSCN colourless	P - blue	$Na_2S_2O_3$ white	P-dark blue	$NiCl_2 6H_2O$ green	P - black time 10 hrs.
$(NH_4)_2CrO_4$ yellow	P - black time 10 hrs.	$(NH_4)_2CO_3H_2O$ white	P - black time 1 day		

R_1 \ R_2	$Cu(C_2H_3O_2)_2$ navy-blue	R_1 \ R_2	$Cu(C_2H_3O_2)_2$ navy-blue	R_1 \ R_2	$Cu(C_2H_3O_2)_2$ navy-blue
KI white	P-yellow- brown time 1/2 hr.	K_2CrO_4 yellow	P - black time 1 day	$KC_2H_3O_2$ white	P - blue time 1 day
NaI white	P_1 - brown P_2 - yellow time 1 day	$Na_2S_2O_3$ colourless	P_1 - white P_2 -yellow time 10 hrs.	$(NH_4)_2CO_3H_2O$ white	P - blue time 10 hrs.
$SrBr_2$ white hygr.	P - black time 1/2 hr.				

Table 6.1.1 (continued)

R_1 \ R_2	$2CuCO_3Cu(OH)_2$ blue	R_1 \ R_2	$2CuCO_3Cu(OH)_2$ blue	R_1 \ R_2	$2CuCO_3Cu(OH)_2$ blue
$CuBr_2 6H_2O$ white	P - black	KCNO white	P - blue time 1 day	$SnCl_2 2H_2O$ white	P-dark green time 10 hrs.
KBr white	P - black time 1 day				

R_1 \ R_2	CuCl green	R_1 \ R_2	CuCl green	R_1 \ R_2	CuCl green
Ag_2SO_4 white	P - black	$AgNO_3$ white	P_1 - green P_2 - blue	$Ca_3(PO_4)_2$ white	P-dark green time 10 hrs.
$Ca(C_2H_3O_2)_2$ white	P-dark green time 10 hrs	$CaCO_3$ white	P-dark green time 10 hrs.	$CuCl_2 2H_2O$ blue-green	P-dark green time 1/2 hr.
KCNO white	P - blue time 1 day	KBr white	P - black time 1/2 hr.	$KC_2H_3O_2$ white	P - orange time 1/2 hr.
NaI white	P - grey time 1/2 hr.	NaH_2PO_4 white	P - green time 1/2 hr.	Na_2HAsO_2 white	P - blue time 10 hrs.
$NaC_2H_3O_2$ white	P - blue time 10 hrs	$Zn(CN)_2$ white	P - black		

Table 6.1.1 (continued)

R_1 / R_2	$CuCl_2 2H_2O$ blue-green	R_1 / R_2	$CuCl_2 2H_2O$ blue-green	R_1 / R_2	$CuCl_2 2H_2O$ blue-green
$AlPO_4$ white	P - pale-blue	BaO white	P- dark blue time 10 mins.	BaS white	P - black time 10 hrs.
$Ba(C_2H_3O_2)_2$ white	P - green time 1 day	$Ca(C_2H_3O_2)_2$ white	P-pale green time 5 mins	$CaBr_2 6H_2O$ white	P - black
$Ca(OH)_2$ white	P-pale green time 15 mins.	CaF_2 white	P-pale green	$CoF_2 2H_2O$ pink	P - brown time 10 hrs.
CdS orange	P - brown time 1/2 hrs.	$Fe(NH_4)_2(SO_4)_2 6H_2O$ pale green	P-pale green time 10 mins.	HgKCN white	P - black time 1 day
K_2CrO_4 yellow	P - brown time 1/2 hrs.	$K_4Fe(CN)_6$ yellow	P - black time1/2 hrs.	KCNO white	P - blue time 1 day
KCN white	P - black time 1/2 hrs.	KBr white	P - black time 1/2 hrs	$KC_2H_3O_2$ white	P- blue time 1/2 hrs.
$LiC_7H_5O_3$ white	P-yellow green time 16 hrs.	$Na_2S_2O_3$ colourless	P - black	NaI white	P - black
NaSCN colourless	P - black	PbI_2 yellow	P - black time 1/2 hr.	$SrBr_2$ white	P - black time 5 mins.
$Zn(CN)_2$ white	P-dark green time 1 day				

Table 6.1.1 (continued)

R_2 \ R_1	$CuSO_4$ pale blue	R_2 \ R_1	$CuSO_4$ pale blue	R_2 \ R_1	$CuSO_4$ pale blue
$BaCl_2 2H_2O$ white	P - green time 1 day	$CuCl_2 2H_2O$ white	P - green	$CaBr_2 2H_2O$ white hygr.	P - bla
$CoCl_2 6H_2O$ red-violet	P - green time 1 day	$Hg(NO_3)_2$ yellow	P - blue time 15 mins	KI white	P - brown time 2 mins
KCNO white	P_1 - blue P_2 - green time 1 day	NaI white	P - black	$Na_2S_2O_3$ colourless	P - yellow brown time 1 day
NaSCN colourless	P - black time 10 mins	$(NH_4)_2CO_3$ H_2O white	P - violet	NH_4F white hygr.	P - blue time 1 day
$(NH_4)_2CrO_4$ yellow	P - blue time 1 day	$SrBr_2 2H_2O$ white	P - black	$Sr(BO_2)_2$ white	P-dark brown time 1 day

R_2 \ R_1	$CuSO_4 5H_2O$ blue	R_2 \ R_1	$CuSO_4 5H_2O$ blue	R_2 \ R_1	$CuSO_4 5H_2O$ blue
$BaCl_2 2H_2O$ white	P - green time 1 day	CaC_2O_4 white	P - black time 1 day	$CoCl_2 6H_2O$ red-violet	P - green time 1 day

Table 6.1.1 (continued)

R_1 / R_2	$CuSO_4 5H_2O$ blue	R_1 / R_2	$CuSO_4 5H_2O$ blue	R_1 / R_2	$CuSO_4 5H_2O$ blue
KI white	P - green time 5 mins	KCNO white	P - blue time 1 day	KBr white	P - black time 10 hrs
NaI white	P - red-brown	NaSCN colourless	P - black time 5 mins	$(NH_4)_2CO_3 \cdot H_2O$ white	P - blue
NH_4I brown	P - red-brown	$(NH_4)_2CrO_4$ yellow	P-red brown	$SrCl_2 6H_2O$ white	P - green time 1 day

Table 6.1.2 Solid-solid reactions at the higher temperatures

R_2 \ R_1 = $CoCl_2 6H_2O$ red violet, hygr.	Temperature Celcius	Time minute	Colour of product
Cr_2O_3 green	180	60	sky-blue
$K_3Fe(CN)_6$ orange	90	10	black
$K_4Fe(CN)_6$ yellow	70	30	green
NH_4Cl white	50	30	dark-blue
$(NH_4)_2SO_4$ colourless	50	30	dark-blue

R_2 \ R_1 = $CoSO_4 7H_2O$ red-orange	Temperature Celcius	Time minute	Colour of product
K_2CrO_4 yellow	50	30	black
NH_4Cl white	80	30	blue
$(NH_4)_2SO_4$ colourless	80	30	pale-yellow

Table 6.1.2 (continued)

R_1 = $CoCO_3$ grey-violet			
R_2	Temperature Celcius	Time minute	Colour of product
K_2CrO_4 yellow	200	60	black
$(NH_4)_2CrO_4$ yellow	175	30	black

R_1 = $CuCO_3Cu(OH)_2$ green			
R_2	Temperature Celcius	Time minute	Colour of product
K_2CrO_4 yellow	200	60	black
$(NH_4)_2CrO_4$ yellow	175	30	black

R_1 = $CuCl_2 2H_2O$ blue green			
R_2	Temperature Celcius	Time minute	Colour of product
Cr_2O_3 green	90	30	brown
FeC_2O_4 yellow	175	30	brown
$Fe_2(C_2O_4)_3$ green	175	30	brown

Table 6.1.2 (continued)

R_2 \ R_1 = $CuCl_2 2H_2O$ blue-green	Temperature Celcius	Time minute	Colour of product
$K_3Fe(CN)_6$ orange	175	30	brown
NH_4Cl white	140	10	orange
$(NH_4)_2SO_4$ colourless	110	60	blue

R_2 \ R_1 = $CuSO_4$ (an) pale blue	Temperature Celcius	Time minute	Colour of product
NH_4Cl white	100 130	10 10	green brown
$(NH_4)_2SO_4$ colourless	150	30	yellow

Table 6.1.2 (continued)

R_1 = $CuSO_4 5H_2O$ blue hygr.			
R_2	Temperature Celcius	Time minute	Colour of product
K_2CrO_4 yellow	90 130	60 30	black orange
NH_4Cl white	90	30	green
$(NH_4)_2SO_4$ colourless	120	60	yellow-blue

R_1 = $FeC_2O_4H_2O$ yellow			
R_2	Temperature Celcius	Time minute	Colour of product
K_2CrO_4 yellow	150	30	brown
$(NH_4)_2CrO_4$ yellow	180	30	black
NH_4Cl white	150	10	green
$(NH_4)_2SO_4$ colourless	140	60	green

Table 6.1.2 (continued)

$R_1 = Fe_2(C_2O_4)_3 5H_2O$ green			
R_2	Temperature Celcius	Time minute	Colour of product
NH_4Cl white	110	60	brown
	150	10	black
$(NH_4)_2SO_4$ colourless	150	60	brown

$R_1 = Fe(NH_4)_2(SO_4)_2 6H_2O$ green			
R_2	Temperature Celcius	Time minute	Colour of product
K_2CrO_4 yellow	50	10	brown
NH_4Cl white	180	60	red-orange

Table 6.1.3 The comparison between reactions in solid state and aqueous solution at room temperature

R_1	R_2	Phase of reaction	Properties of product		
			Quantity	Colour	Solubility in water
$CoCl_2 6H_2O$ red-violet hygr.	NaSCN colourless	solid	1	blue	soluble
		aqueous solution	1	blue	soluble
	KSCN colourless	solid	1	blue	soluble
		aqueous solution	1	blue	soluble
	K_2CrO_4 yellow	solid	1	dark-brown	insoluble
		aqueous solution	1	black	insoluble
	$(NH_4)_2CrO_4$ yellow	solid	1	black	insoluble
		aqueous solution	1	black	insoluble
$CoSO_4 7H_2O$ red-orange hygr.	NaSCN colourless	solid	1	blue	soluble
		aqueou solution	1	blue	soluble
	KSCN colourless	solid	1	blue	soluble
		aqueous solution	1	blue	soluble
	$(NH_4)_2CrO_4$ yellow	solid	3	black	insoluble
				blue	insoluble
				orange	soluble
		aqueous solution	1	black	insoluble

Table 6.1.3 (continued)

R_1	R_2	Phase of reaction	Properties of product		
			Quantity	Colour	Solubility in water
$CoF_2 2H_2O$ pink	CaS grey	solid	1	black	insoluble
		aqueous solution	-	-	-
	NaSCN colourless	solid	1	blue	soluble
		aqueous solution	1	blue	soluble
	KSCN colourless	solid	1	blue	soluble
		aqueous solution	1	blue	soluble
$Cu(C_2H_3O_2)_2 \cdot 2H_2O$ navy-blue	K_2CrO_4 yellow	solid	1	black	insoluble
		aqueous solution	1	dark-brown	insoluble
	$Na_2S_2O_3$ colourless	solid	3	white	insoluble
				yellow	insoluble
				orange	insoluble
		aqueous solution	-	-	-
$CuCl_2 2H_2O$ blue-green	K_2CrO_4 yellow	solid	1	dark-brown	insoluble
		aqueous solution	1	yellowbrown	insoluble
	$(NH_4)_2CrO_4$ yellow	solid	1	dark-brown	insoluble
		aqueous solution	1	yellow	insoluble
	$Fe(NH_4)_2(SO_4)_2 6H_2O$ green	solid	2	black	insoluble
		aqueous solution	-	-	-

Table 6.1.3 (continued)

R_1	R_2	Phase of reaction	Properties of product		
			Quantity	Colour	Solubility in water
$CuCl_2 2H_2O$	$K_4Fe(CN)_6$	solid	2	black	insoluble
blue-green	pale-yellow	"	1	blue	soluble
		aqueous solution	1	brown	insoluble
	$(NH_4)_2CrO_4$	solid	3	dark-brown	insoluble
$CuSO_4 5H_2O$	yellow			green	insoluble
blue				orange	soluble
hygr.		aqueous solution	1	yellow	insoluble
	$(NH_4)_2CO_3$	solid	1	brown	insoluble
$Fe_2(C_2O_4)_3$	white	aqueous solution	-	-	-
$5H_2O$	$(NH_4)_2CrO_4$	solid	1	brown	insoluble
green	yellow	aqueous solution	-	-	-
$Fe(NH_4)_2$	$(NH_4)_2CrO_4$	solid	1	brown	insoluble
$(SO_4)_2 6H_2O$	yellow	aqueous solution	-	-	-
green					

A rise in temperature for solid-solid reaction increased the number of reactions from ten percents at room temperature to fifty percents at higher temperatures.

It was very rare for aqueous solution of inorganic compounds to be all the same behaviour to their solid state. However, it was found that reactions in two phases, solution and solid, between any compound of cobalt(II) and alkali thiocyanate behaved similarly and gave same blue product which was expected to be $M_2[Co(SCN)_4]$.

The aqueous solution of six pairs of reactants from the selected reactions did not show any change when they were mixed together. These were $CoF_2 2H_2O$ + CaS, $Cu(C_2H_3O_2)_2$ + $Na_2S_2O_3$, $CuCl_2 2H_2O$ + $Fe(NH_4)_2(SO_4)_2 6H_2O$, $Fe_2(C_2O_4)_3 5H_2O$ + $(NH_4)_2CO_3$, $Fe_2(C_2O_4)_3$ $5H_2O$ + $(NH_4)_2CrO_4$, $Fe(NH_4)_2(SO_4)_2 6H_2O$ + $(NH_4)_2CrO_4$.

6.2 Rate of formation of product at room temperature and higher temperatures

Table 6.2.1 . Result of growth rate of solid reaction $CoSO_4 7H_2O$ + $(NH_4)_2CrO_4$ at room temperature

Time	Thickness of (cm)				
	$CoSO_4 7H_2O$	$(NH_4)_2CrO_4$	black product	blue product	orange product
10 hrs.	1.5	1.5	line	-	-
30 hrs.	1.4	1.4	.2	line	line
3 days	1.2	1.2	.2	.2	.2
5 days	1.1	1.1	.2	.3	.3
30 days	1.1	1.1	.2	.3	.3

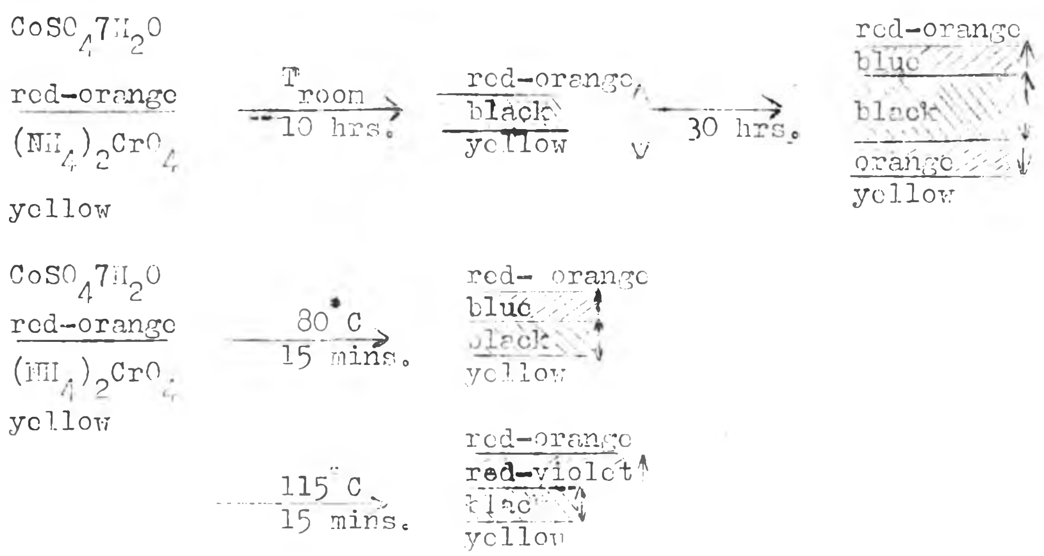


Table 6.2.2 Result of growth rate of solid reaction $CoCl_2 6H_2O + K_2CrO_4$ at room temperature

Time	Thickness of (cm)		
	$CoCl_2 6H_2O$	K_2CrO_4	black product
10 hrs.	1.475	1.475	0.05
10 days	1.475	1.425	0.1
20 days	1.475	1.375	0.25
30 days	1.475	1.325	0.3

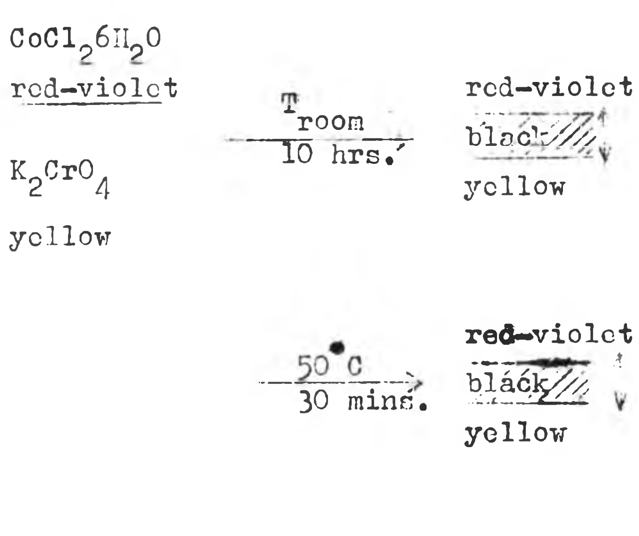


Table 6.2.3 Result of growth rate of solid reaction $CoF_2 2H_2O + CaS$ at room temperature

Time	Thickness of (cm)		
	$CoF_2 2H_2O$	CaS	black product
immediatly	1.5	1.5	line
10 hrs.	1.475	1.475	0.05
2 days	1.475	1.475	0.05
30 days	1.475	1.475	0.05

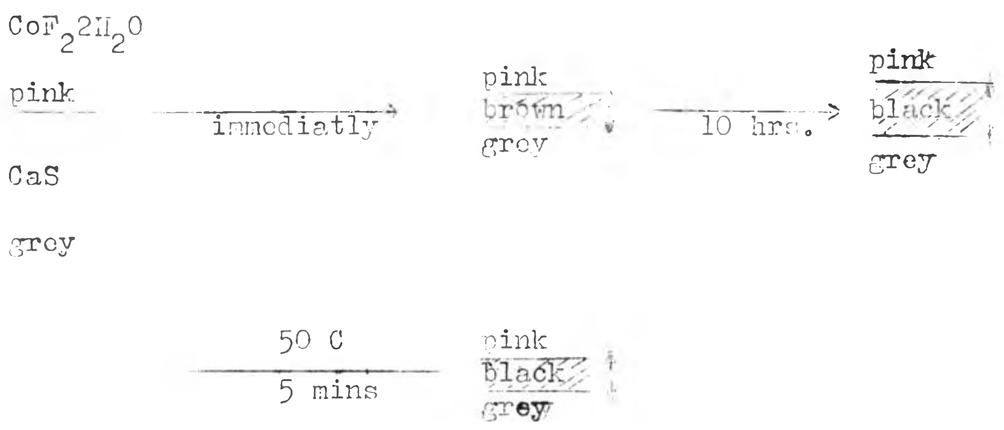


Table 6.2.4 Result of growth rate of solid reaction

$Cu(C_2H_3O_2)_2$ + $Na_2S_2O_3$ at room temperature

Time	Thickness of (cm)				
	$Cu(C_2H_3O_2)_2$	$Na_2S_2O_3$	white product	yellow product	orange product
1 hr.	1.5	1.5	line	--	--
10 hrs.	1.4	1.4	0.2	line	--
3 days	1.375	1.375	0.25	line	line
10 days	1.23	1.35	0.3	0.1	0.02

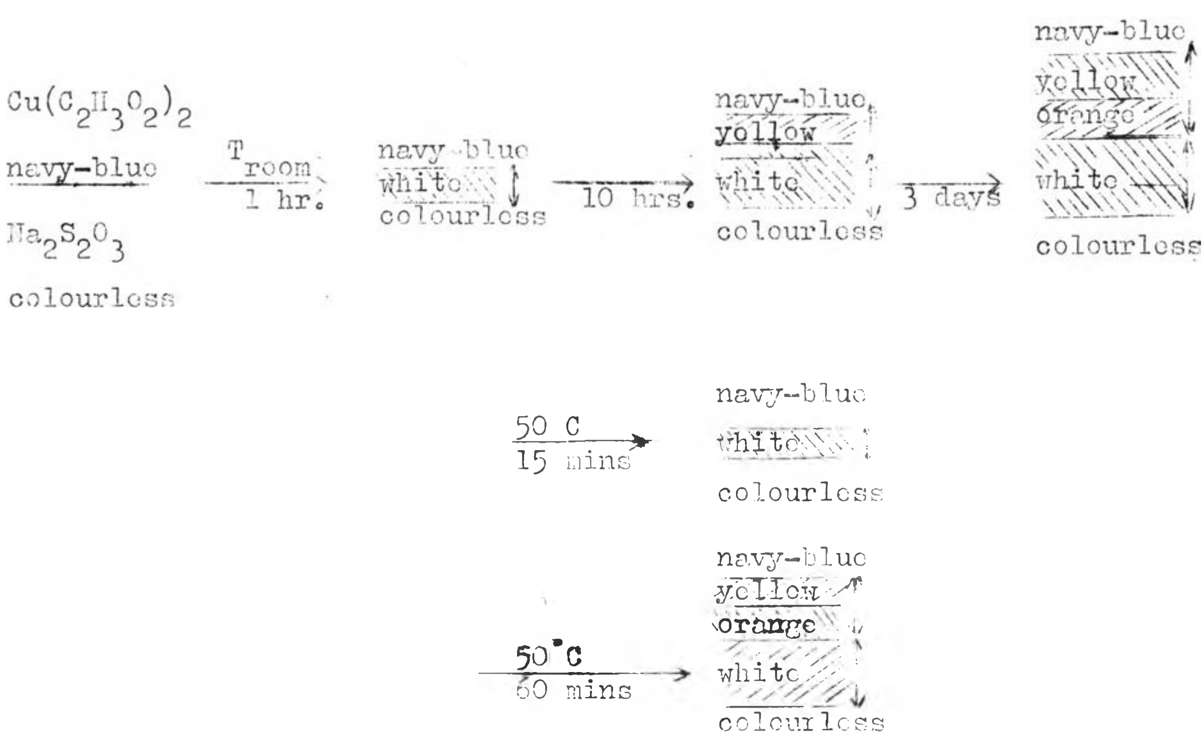
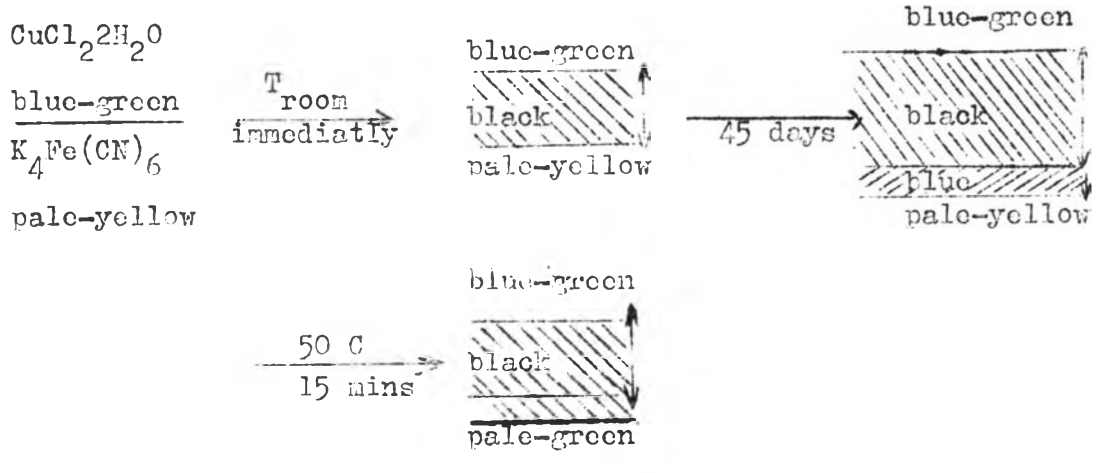


Table 6.2.5 Result of growth rate of solid reaction

$CuCl_2 2H_2O + K_4Fe(CN)_6$ at room temperature

Time	Thickness of (cm)			
	$CuCl_2 2H_2O$	$K_4Fe(CN)_6$	black product	blue product
immediatly	1.5	1.5	line	-
1 hr.	1.465	1.465	0.07	-
1 day	1.44	1.44	0.12	-
20 days	1.3	1.3	0.4	-
45 days	1.15	1.15	0.7	line



A rise in temperatures for the solid-solid reaction not only increased the rate of chemical change but also changed the colour of entities.

To study solid-solid reaction, it was able to follow up every step of process of changing which included the reaction of product-reactant or product-product. It was found that there were two types of mechanisms or processes of chemical change. In the first case, the thickness of product increased with time and it appeared to react infinitely. However, in the second one, the thin layer of product did not change any more. It seemed to be steady forever, such as the reaction of $CoF_2 2H_2O$ + CaS, the thickness of black product showed its constancy of 0.05 centimeters.

6.3 The photographs of the interesting reactions were arranged as shown in Fig 6.3.1 -6.3.10.

The interesting reactions were divided into two groups such as the fast reaction (which occured immediatly) and the slow reaction (which occured after a period of time). The example of the fast reaction, which involved the movement of pieces of reactants while the reaction was progressing, are listed as the following:-

$CoSO_4 7H_2O$ + KSCN

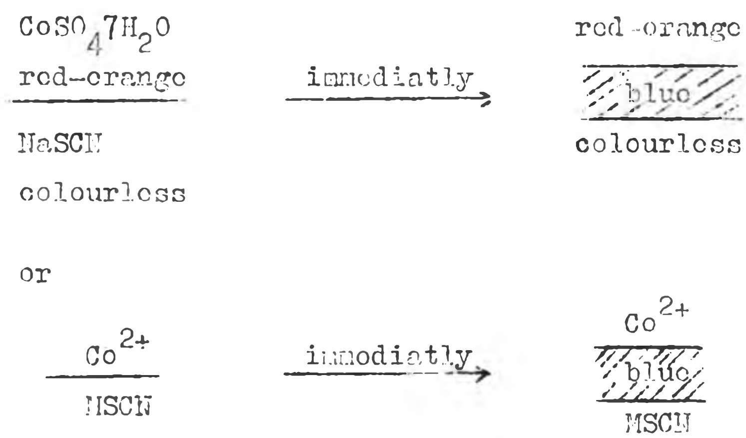
$CoSO_4 7H_2O$ + NaSCN

$CoCl_2 6H_2O$ + KSCN

$CoCl_2 6H_2O$ + NaSCN

For the case of $CoF_2 2H_2O$ and CaS, reaction took place immediatly when the large amount of reactants were used, but in a small scale such as setting in the slide for observing through microscope, it took 30 minutes after contacting between reactants.

In the figure 6.3.2 , the reaction of $CoSO_4 7H_2O$ + KSCN was observed, an overhead light source (lamp) were used in stead of light from the base of the microscope.



M = K,Na

Co^{2+} = $CoF_2 2H_2O$

$CoCl_2 6H_2O$

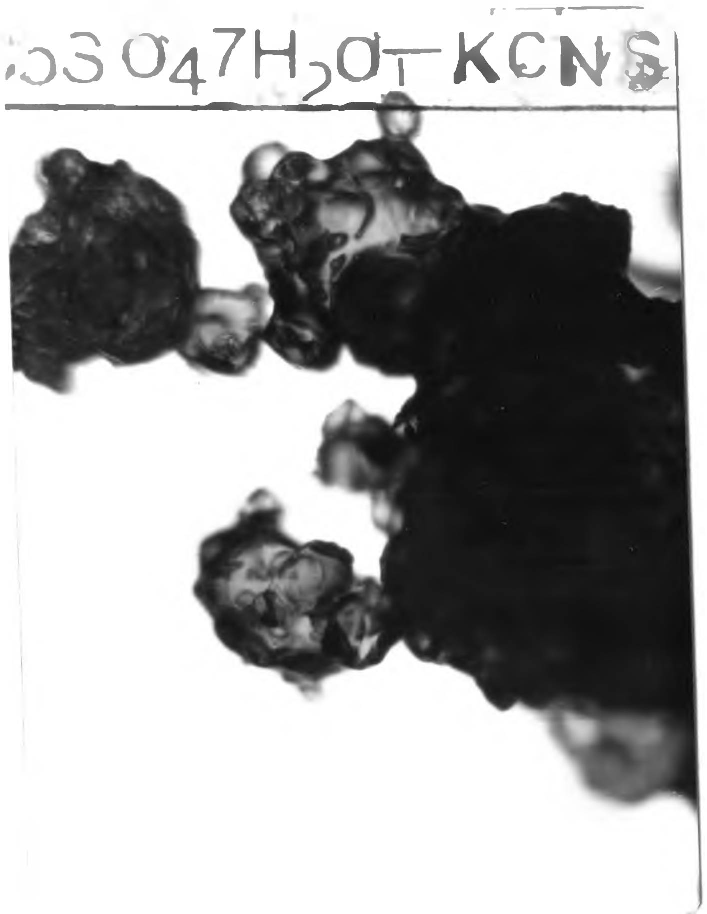
$CoSO_4 7H_2O$

The direction of formation of the product between Co^{2+} and MSCN

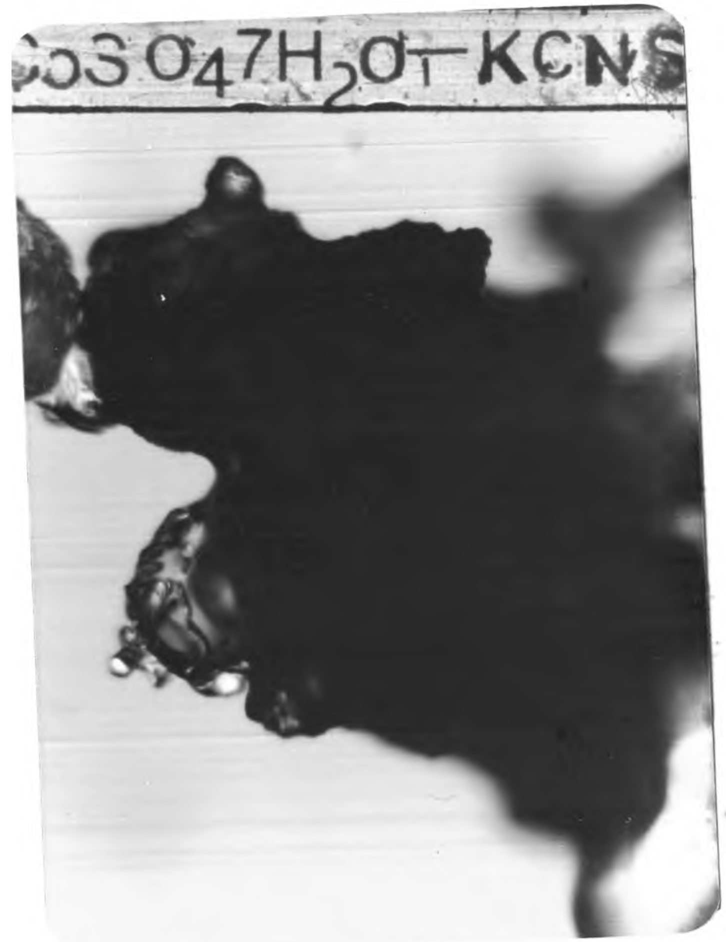
$CoSO_4 7H_2O$ (I) KCNS

$CoSO_4 7H_2O$ (II) KCNS

Fig 6.3.1 The progression of product of $CoSO_4 7H_2O$ + KSCN by microscope observation at 100 times magnification.

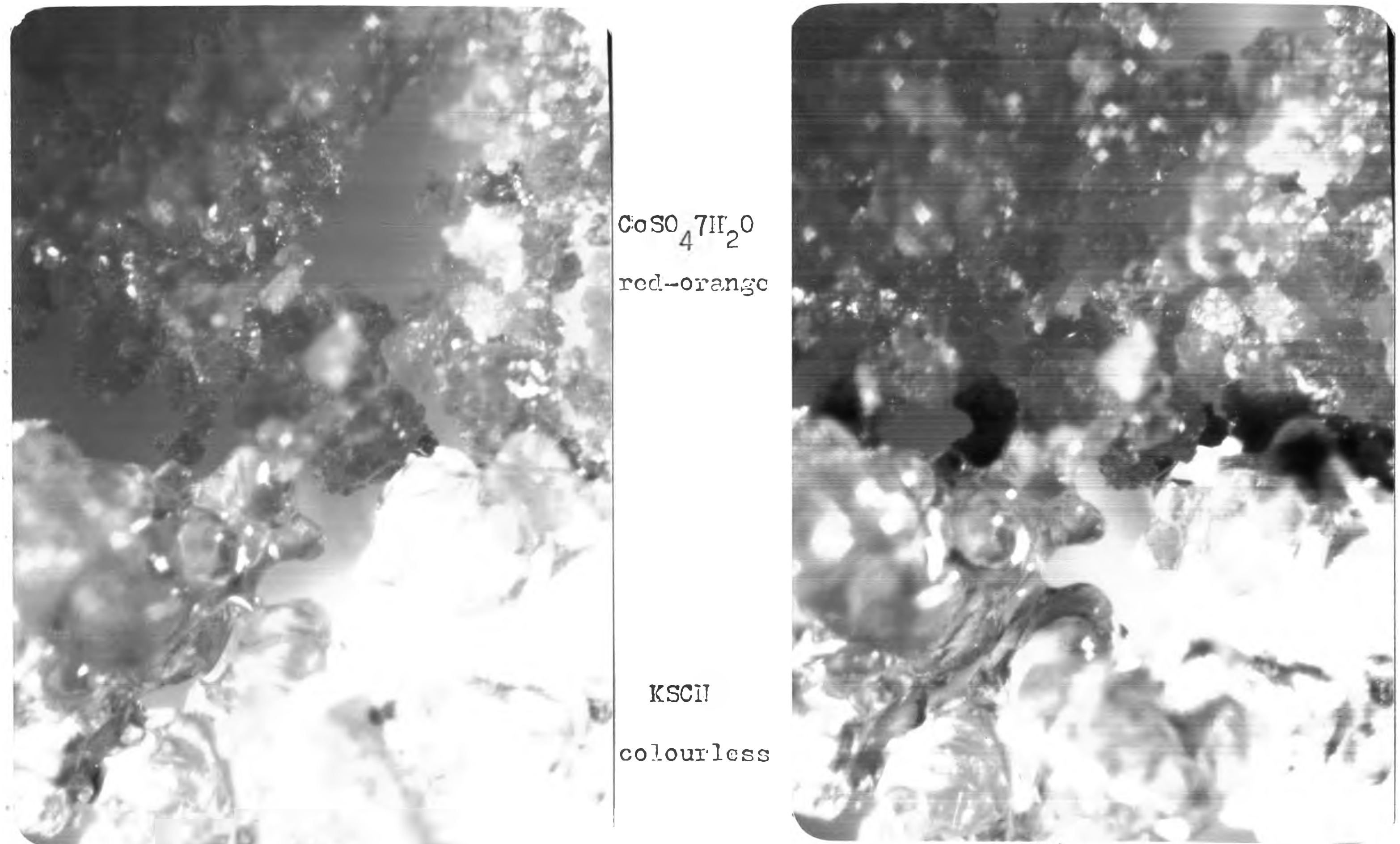


$CoSO_4 7H_2O$ (III) KSCN



$CoSO_4 7H_2O$ (IV) KSCN

Fig 6.3.1 (continued)



(I) (II)

Fig 6.3.2 The progression of blue product of $CoSO_4 7H_2O$ + KSCN by microscope observation at 100 times magnification.

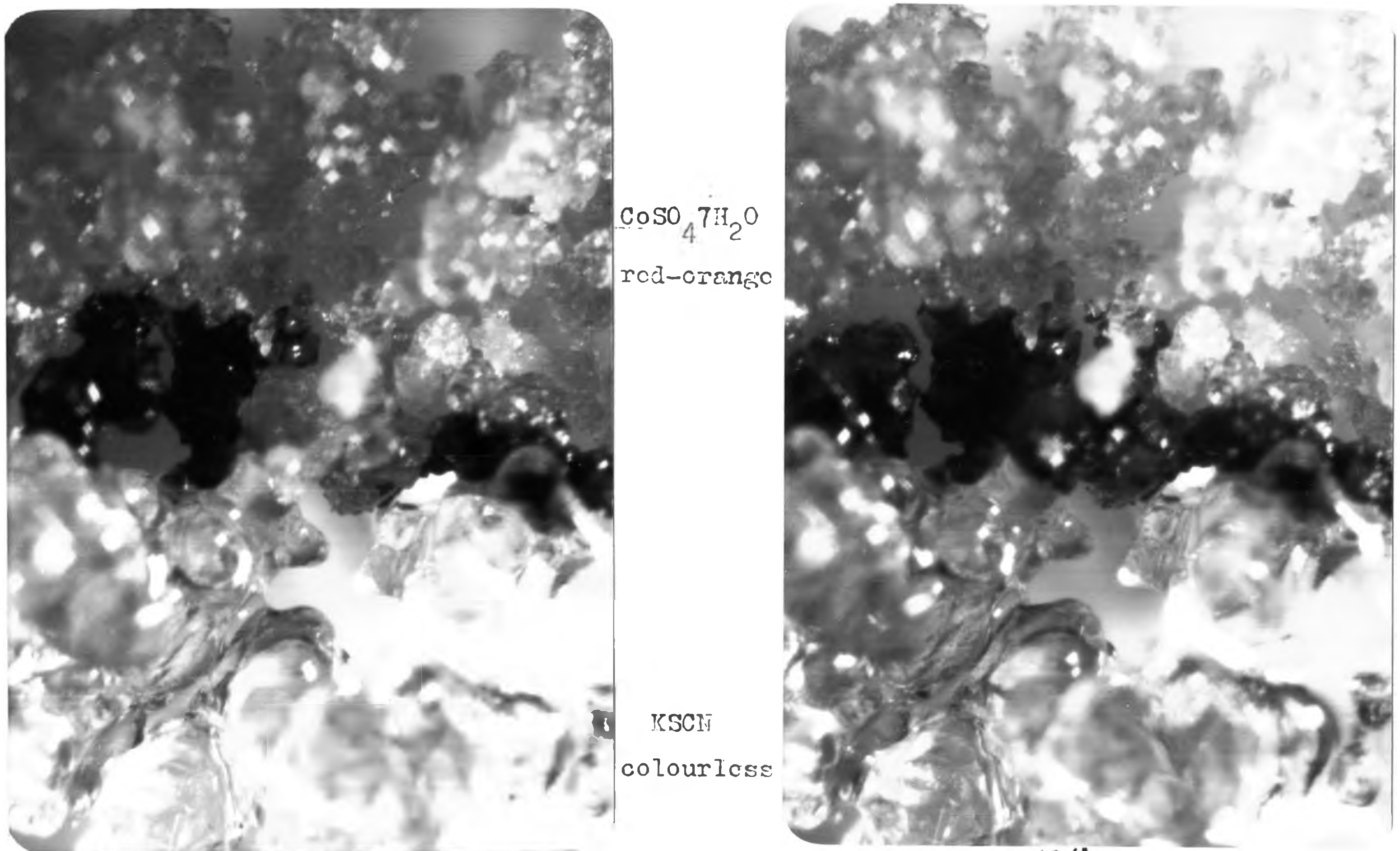
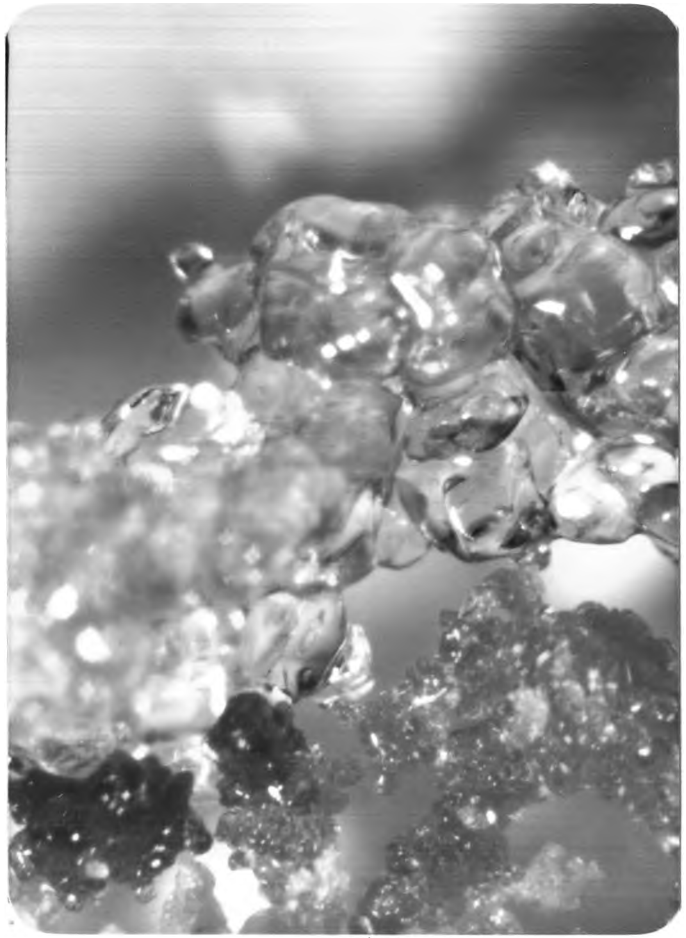


Fig 6.3.2 (continued)



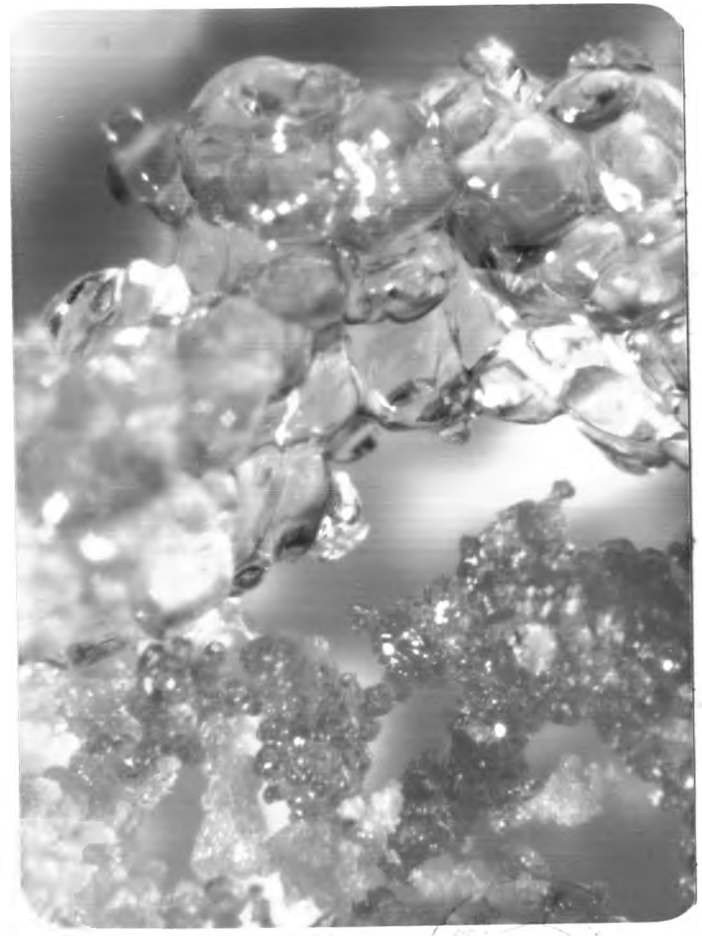
(I)

NaSCN

colourless

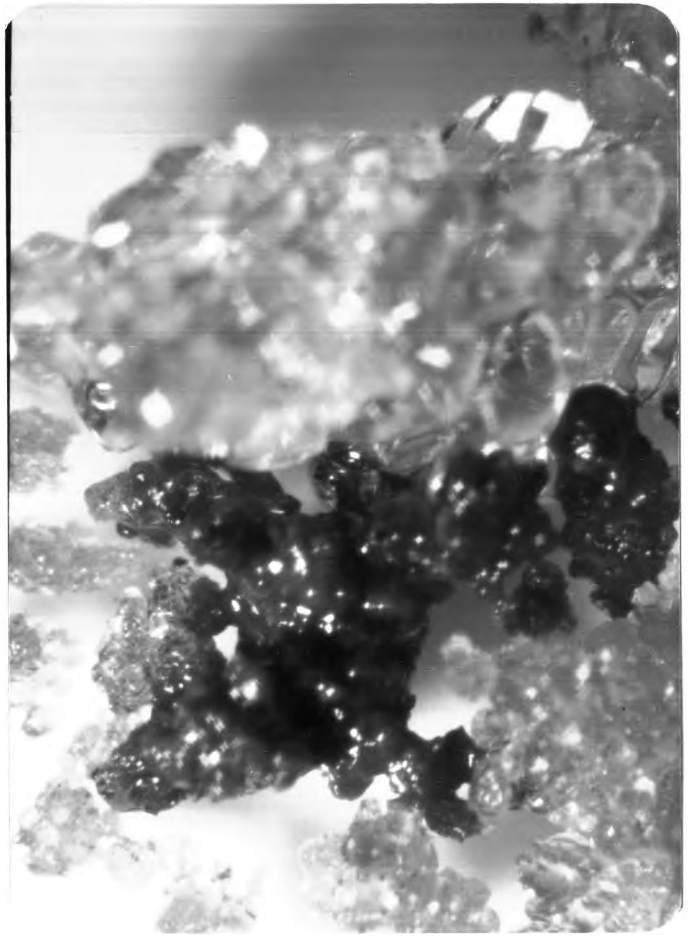
$CoSO_4 7H_2O$

red- orange



(II)

Fig 6.3.3 The progression of blue product of $CoSO_4 7H_2O$ + NaSCN by microscope observation at 100 times magnification.

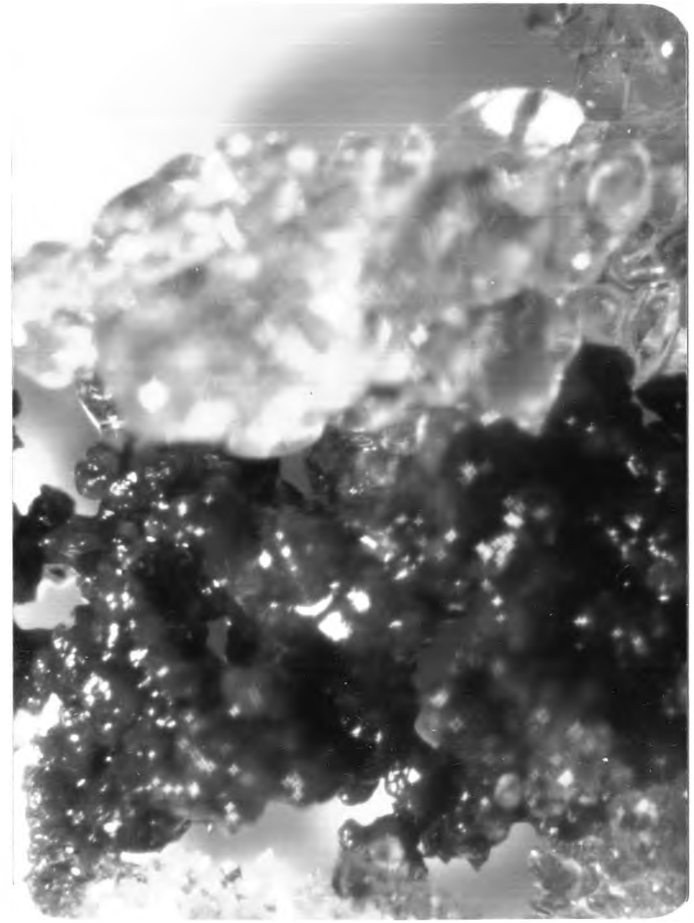


NaSCN

colourless

$CoSO_4 7H_2O$

red-orange



(III)

(IV)

Fig 6.3.3 (continued)

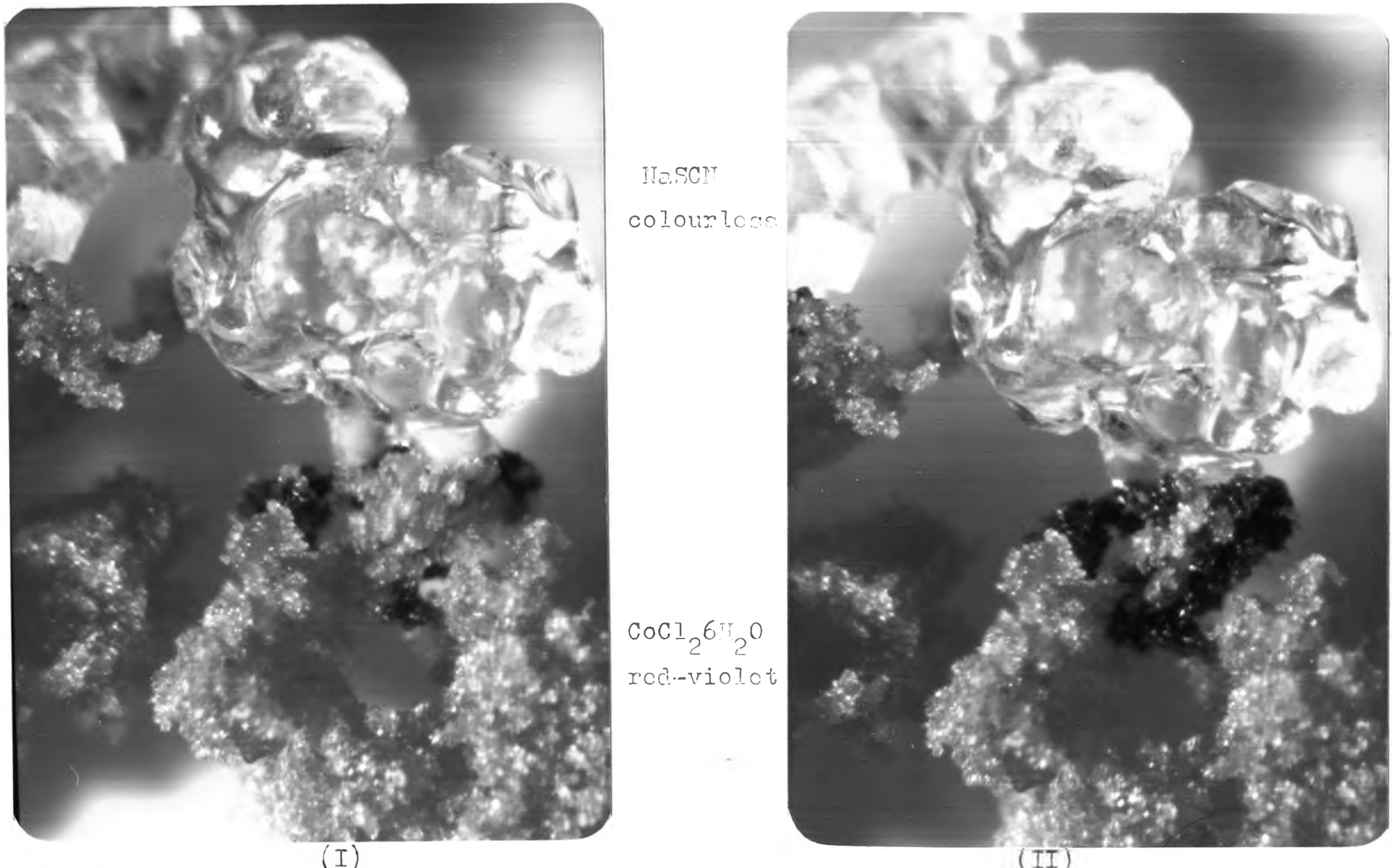
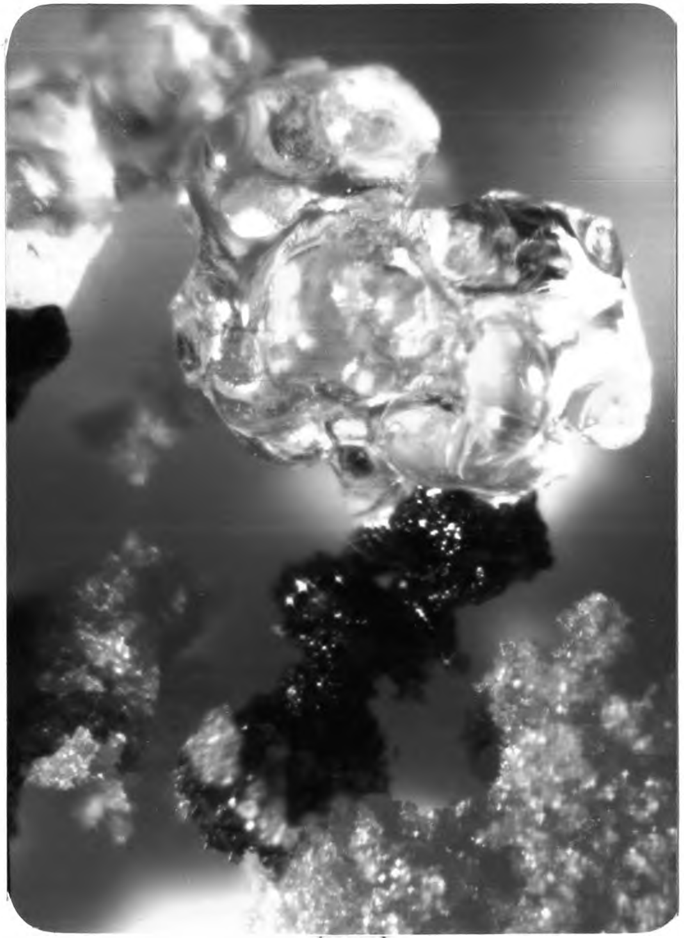


Fig 6.3.4 The progression of blue product of $CoCl_2 6H_2O$ + NaSCN by microscope observation at 100 times magnification.

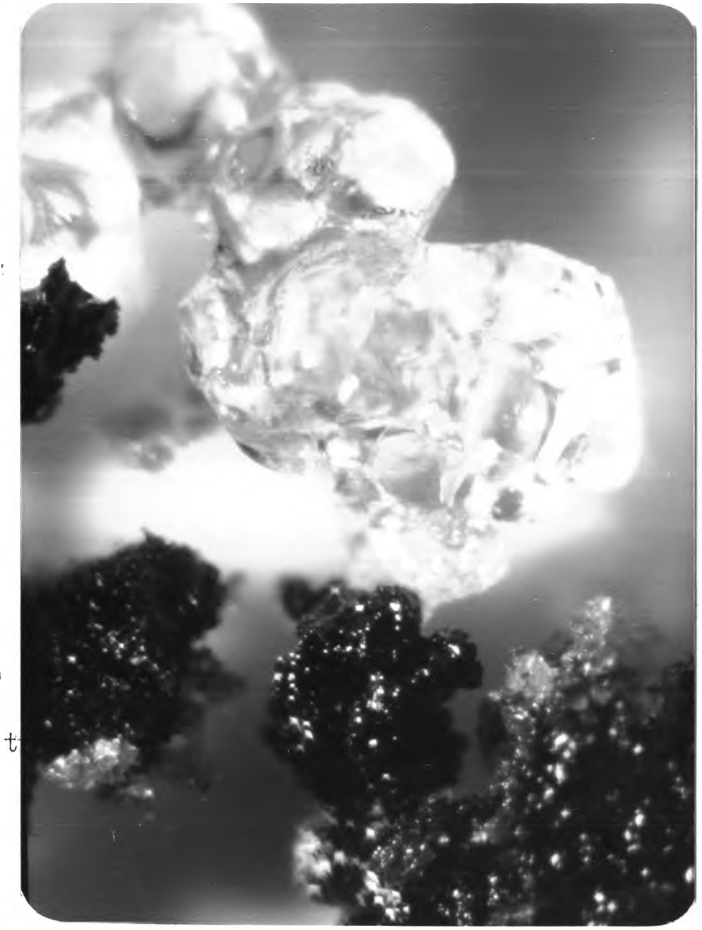


NaSCN

colourless

$CoCl_2 6H_2O$

red-violet



(III)

(IV)

Fig 6.3.4 (continued)

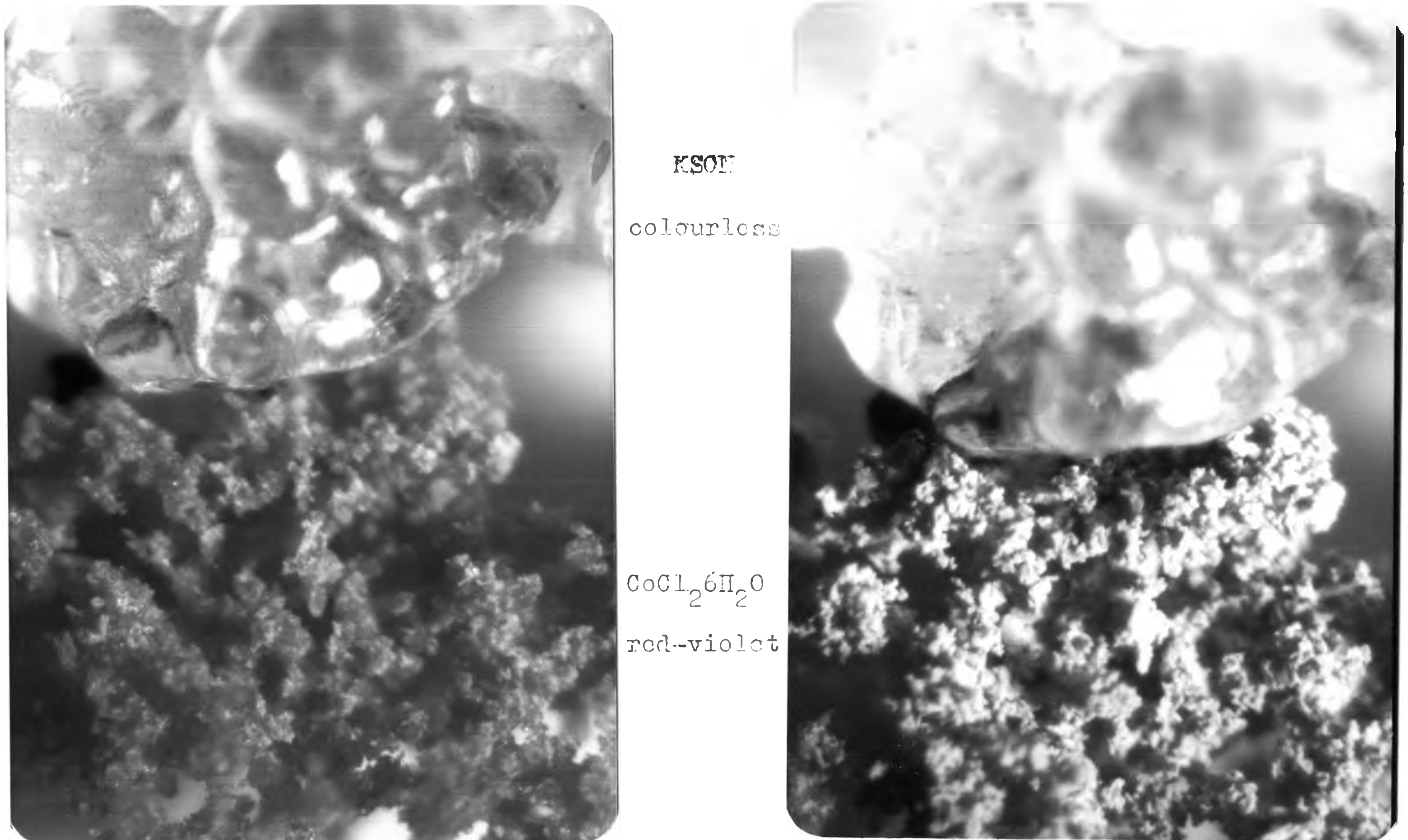


Fig 6.3.5 The progression of blue product of $CoCl_2 6H_2O$ + KSCN by microscope observation at 100 times magnification.

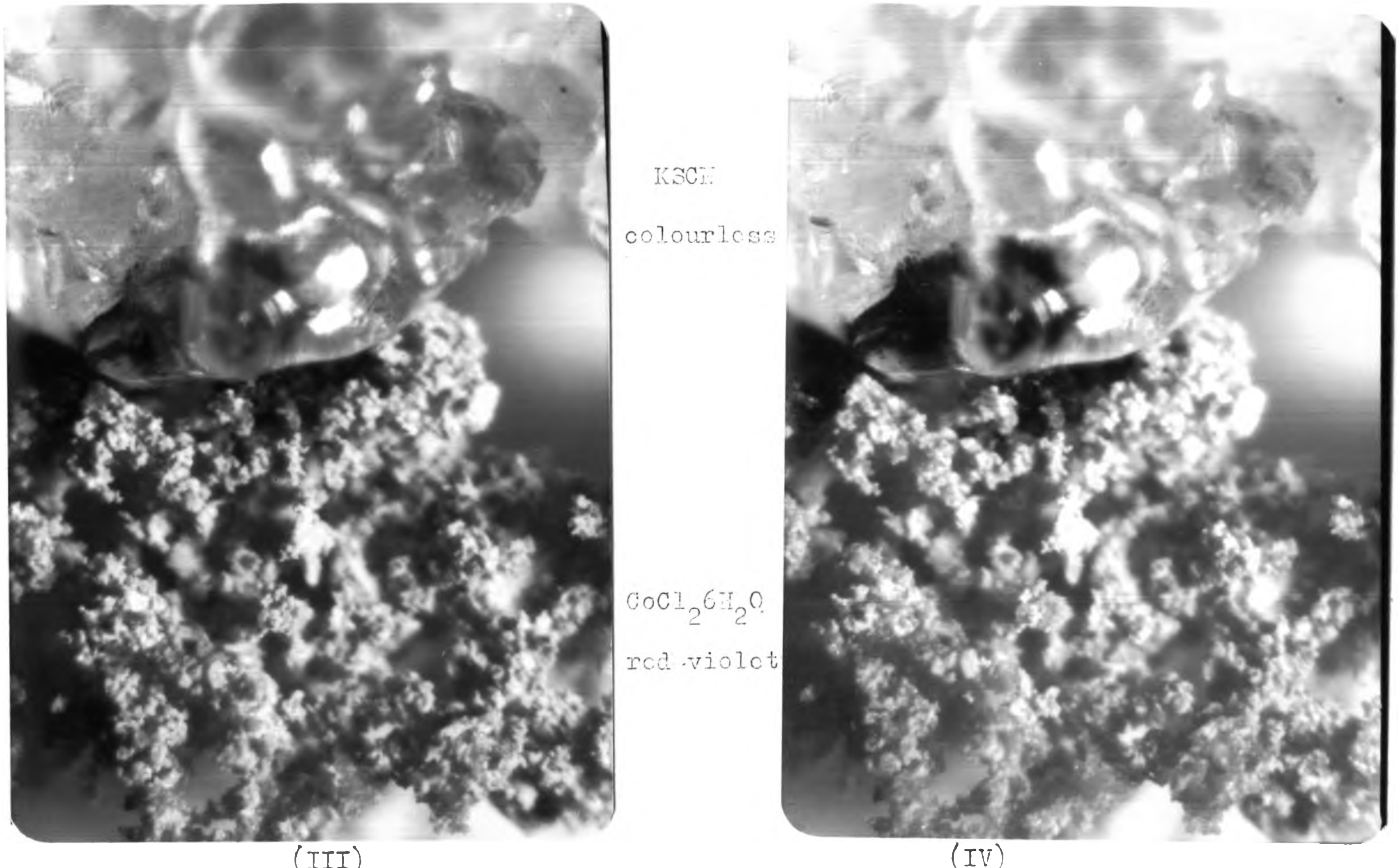
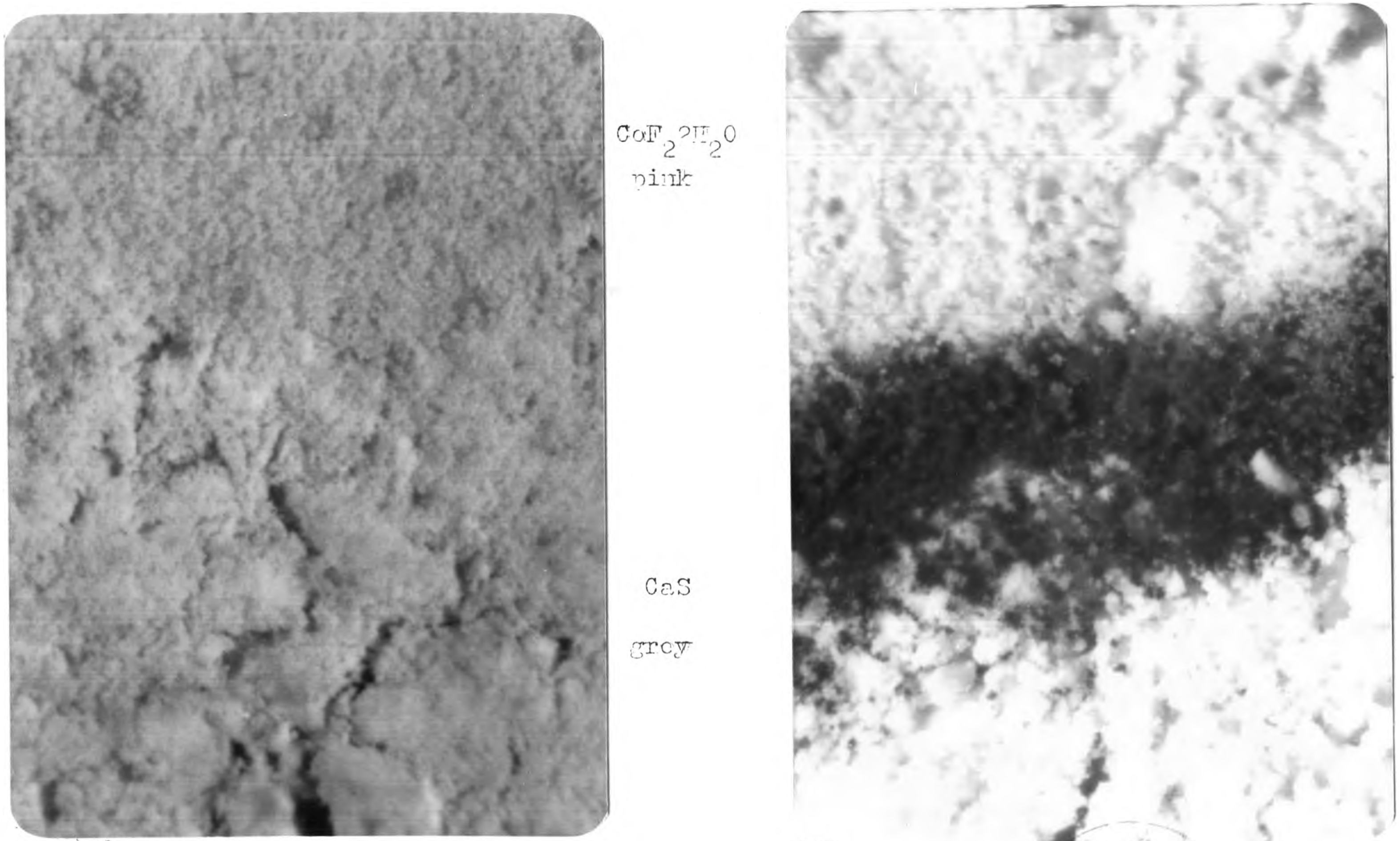
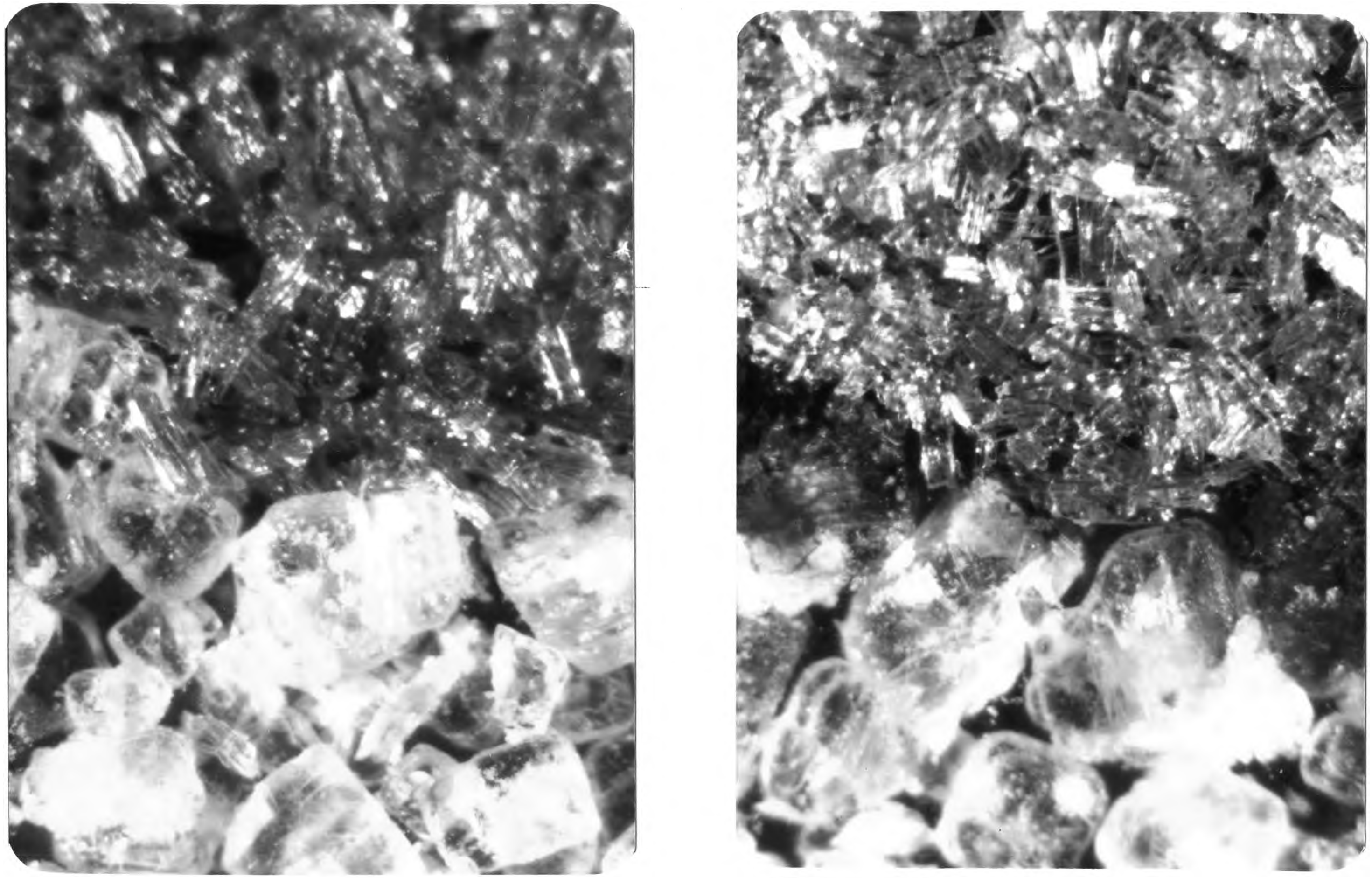


Fig 6.3.5 (continued)



$\frac{CoF_2 2H_2O \text{ (pink)}}{CaS \quad \text{(grey)}}$ 30 mins → pink / black / grey

Fig 6.3.6 The progression of black product of $CoF_2 2H_2O$ + CaS by microscope observation at 100 times magnification



$\frac{CuCl_2 2H_2O \text{ (blue green)}}{K_4Fe(CN)_6 \text{ (pale yellow)}}$ 10 hrs $\frac{\text{blue green}}{\text{black}}$ pale yellow

Fig 6.3.7 The progression of black product of $CuCl_2 2H_2O + K_4Fe(CN)_6$ by microscope observation at 100 times magnification.

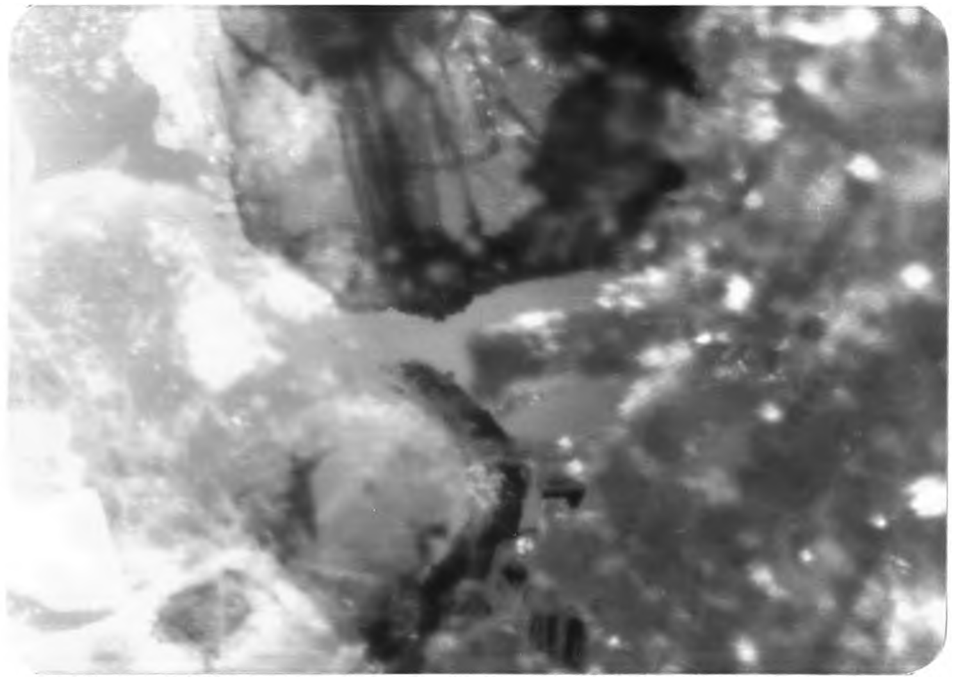
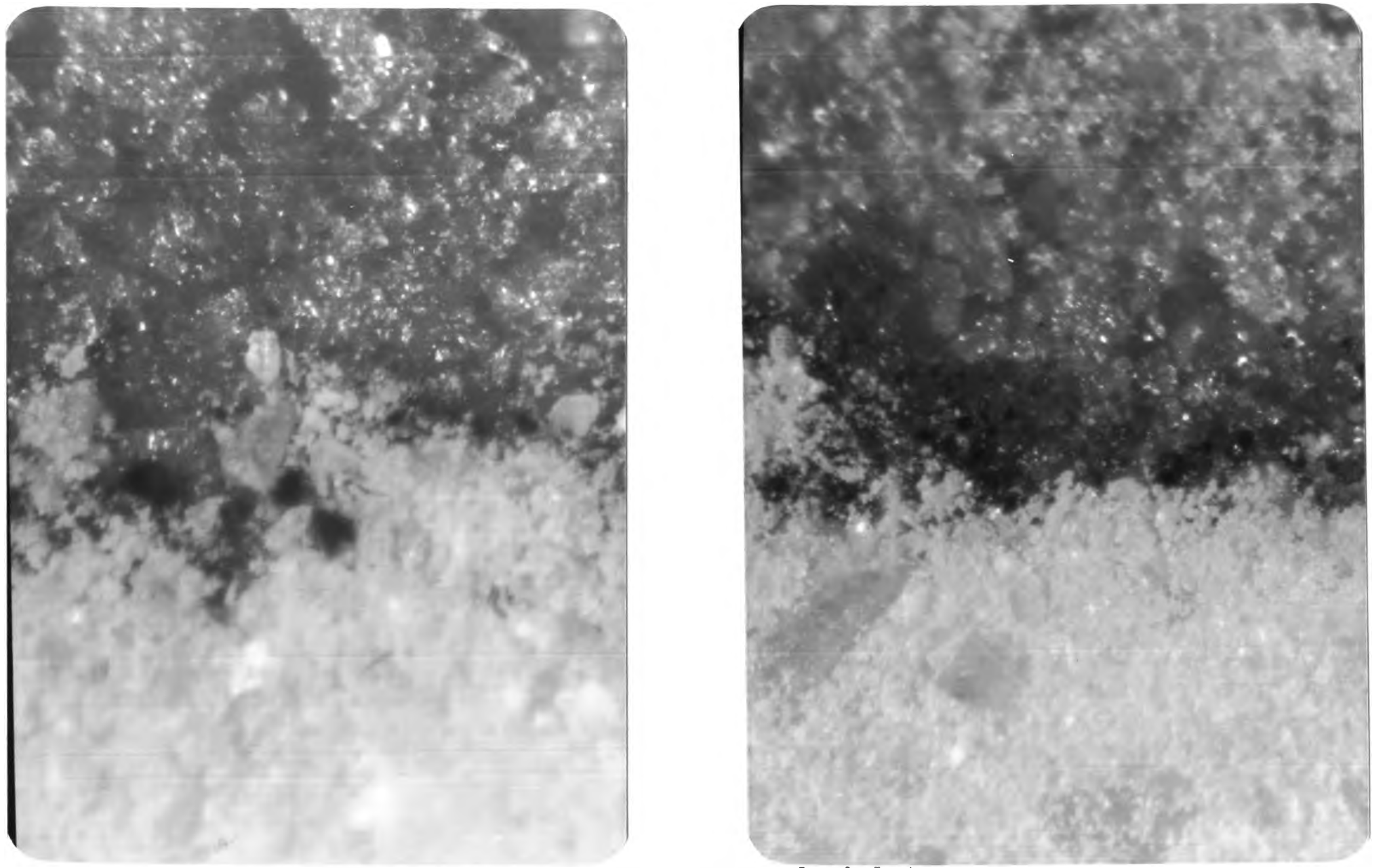
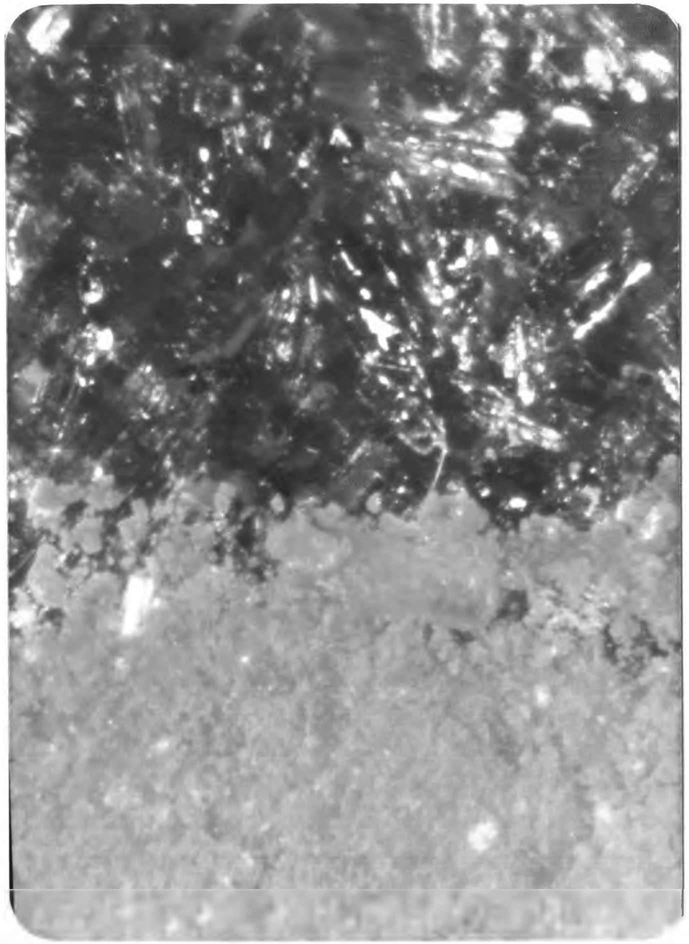


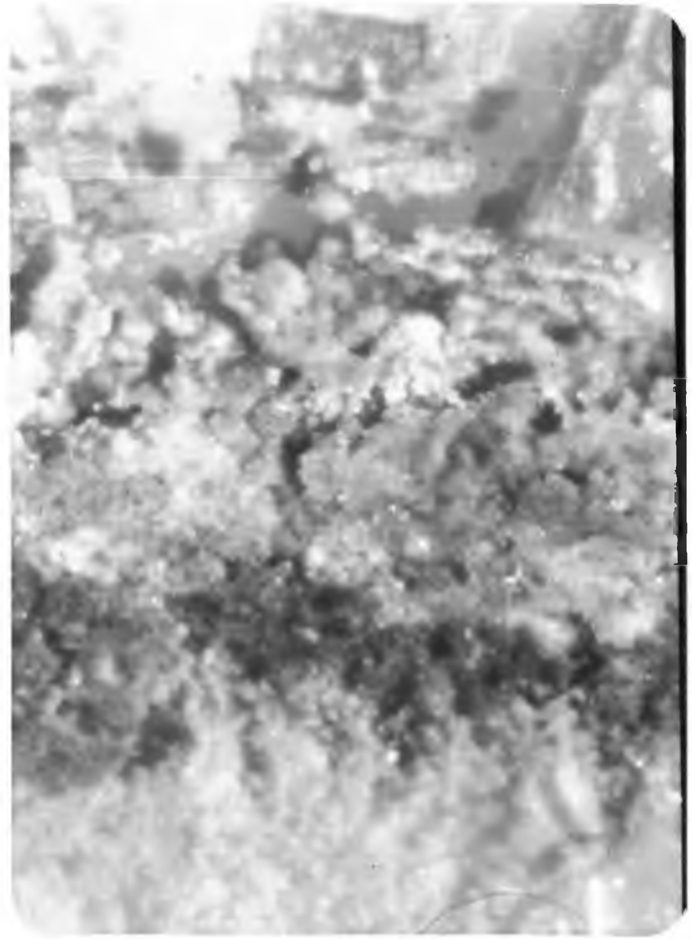
Fig 6.3.8 The black product of $CuCl_2 2H_2O + K_4Fe(CN)_6$ was magnificated.



$\frac{CoCl_2 6H_2O \text{ red violet}}{(NH_4)_2CrO_4 \text{ yellow}}$ $\xrightarrow{5 \text{ mins.}}$ red violet / black / yellow

Fig 6.3.9 The progression of black product from $CoCl_2 6H_2O$ + $(NH_4)_2CrO_4$ by microscope observation at 100 times magnification.





$\frac{CuCl_2 2H_2O \text{ blue green}}{(NH_4)_2CrO_4 \text{ yellow}} \xrightarrow{\text{10 hrs.}} \frac{\text{blue green}}{\frac{\text{brown}}{\text{yellow}}}$

Fig 6.3.10 The progression of brown, green products by microscope observation of $CuCl_2 2H_2O$ + $(NH_4)_2CrO_4$ at 100 times magnification.

From the study of mechanism or process of change in the solid-solid reaction through microscope, provided a new concept which was unconcerned with the imperfection concept, an only good evidence used to explain the mechanism of solid by migration within the system.

The translational motion of pieces of the distant reactant toward the other one which was observed by microscope, showed the distant space was not an obstacle to cobalt compound in drawing a small piece of alkali thiocyanate to move closer against its large size of crystal and then they could get into contact together. This might be a role of electrical magnetic property to produce such a driving force.

6.4 Determination of composition of interesting product

The analytical results from X-ray fluorescence, atomic absorption, gravimetric and volumetric method are listed in the following table.

6.4.1 Composition of the product by X-ray fluorescence method

Table 6.4.1.1 Data for the relationship between activities and percentage of heavy metal by X-ray fluorescence technique

Reactant			% heavy metal in standard			
A	B					
$CoSO_4 7H_2O$	$(NH_4)_2CrO_4$	% Co	0.25	0.5	0.8	1.04
		Activities	9200 ± 5	9398 ± 7	9510 ± 9	9691 ± 20
		% Cr	0.85	1.026	1.3	1.7
		Activities	5540 ± 20	5595 ± 12	5700 ± 10	5960 ± 7
*$CoCl_2 6H_2O$	$(NH_4)_2CrO_4$	% Co	0.619	0.928	1.238	1.610
		Activities	125,360	129,716	138,372	139,968
		% Cr	0.375	0.875	1.625	1.875
		Activities	229,900	242,000	250,000	255,181
$Cu(C_2H_3O_2)_2$	$Na_2S_2O_3$	% Cu	0.397	0.795	1.591	2.338
		Activities	1130	1276	1616	1820

* Another X-ray fluorescence instrument was used.

Table 6.4.1.1 (continued)

Reactants			% heavy metal in standard			
A	B					
$CoSO_4 7H_2O$	NaSCN	% Co	2.8	7.6	19	22.8
		Activities	359± 10	860± 23	2260± 10	2810±12
$CuCl_2 2H_2O$	$Fe(NH_4)_2 (SO_4)_2 6H_2O$	% Cu	0.496	0.925	1.875	2.800
		Activities	525± 3	701± 10	1135± 5	1650± 14
		% Fe	0.375	0.375	1.06	1.25
		Activities	250± 5	350± 5	510± 7	630± 10
$CuCl_2 2H_2O$	$K_4Fe(CN)_6$	% Cu	26.1	18.7	11.1	3.6
		Activities	1626± 6	1200± 8	855± 10	360± 5
		% Fe	2.6	5.4	7.9	10.5
		Activities	5100±10	12,500±10	15,460±5	20,000±5

Table 6.4.1.2 Results of percentage determination of heavy metal by X-ray fluorescence technique

System	Colour of product	Activities	Percentage of some elements	
$CoSO_4 7H_2O + (NH_4)_2CrO_4$	black	5,380± 20	% Cr	11.47
		9,056± 10	% Co	10.23
$CoCl_2 6H_2O + (NH_4)_2CrO_4$	black	12,350± 10	% Co	4.78
		255,181± 12	% Cr	30.00
$Cu(C_2H_3O_2)_2 + Na_2S_2O_3$	white	1,280± 5	% Cu	7.80
	yellow	1,500± 10	% Cu	29.85
	orange	1,150± 10	% Cu	33.33
$CoSO_4 7H_2O$ + NaSCN	blue	1,280± 10	% Co	9.80
$CuCl_2 2H_2O + Fe(NH_4)_2(SO_4)_2$ $6H_2O$	brown	516± 10	% Fe	13.42
	green	199± 10	% Fe	9.86
	brown	398± 10	% Cu	2.68
	green	478± 10	% Cu	15.78
$CuCl_2 2H_2O + K_4Fe(CN)_6$	black	1560± 5	% Cu	23.80
		1,260±10	% Fe	5.70

In the case that small amount of product was obtained, calcium carbonate or sulphur, an uneffective substance in X-ray fluorescence was added in order to make the same thickness as the standard. When the percentages of heavy elements in the mixture were determined from their calibration curves, the percentages of heavy elements in product could be computed by using the equation,

$$\% \text{ metal in product} = \frac{\% \text{ metal in mixture} \times 2}{\text{weight of product in mixture}}$$

* where 2 = weight of total mixture in gram.

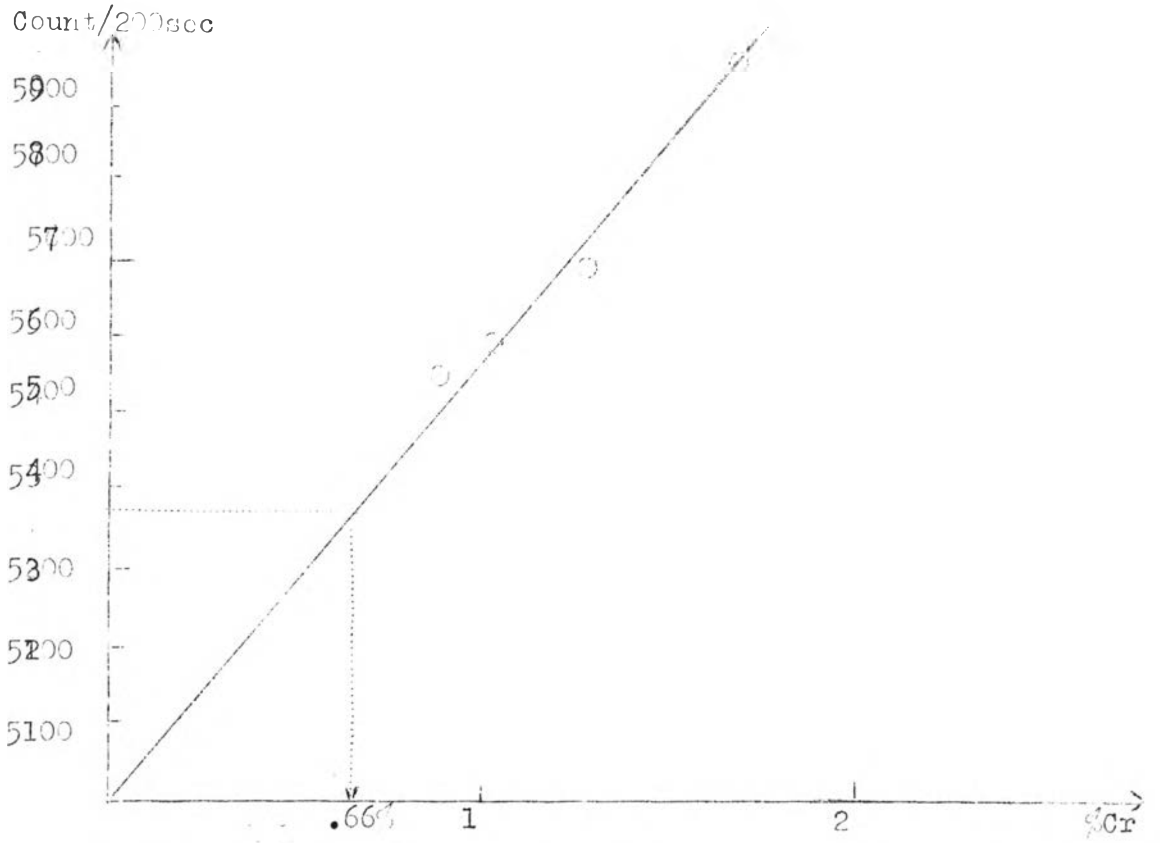


Fig 6.4.1.1. The relationship of activities and concentrations of cromium in $CoSO_4 7H_2O$ + $(NH_4)_2CrO_4$ by x-ray fluorescence technique

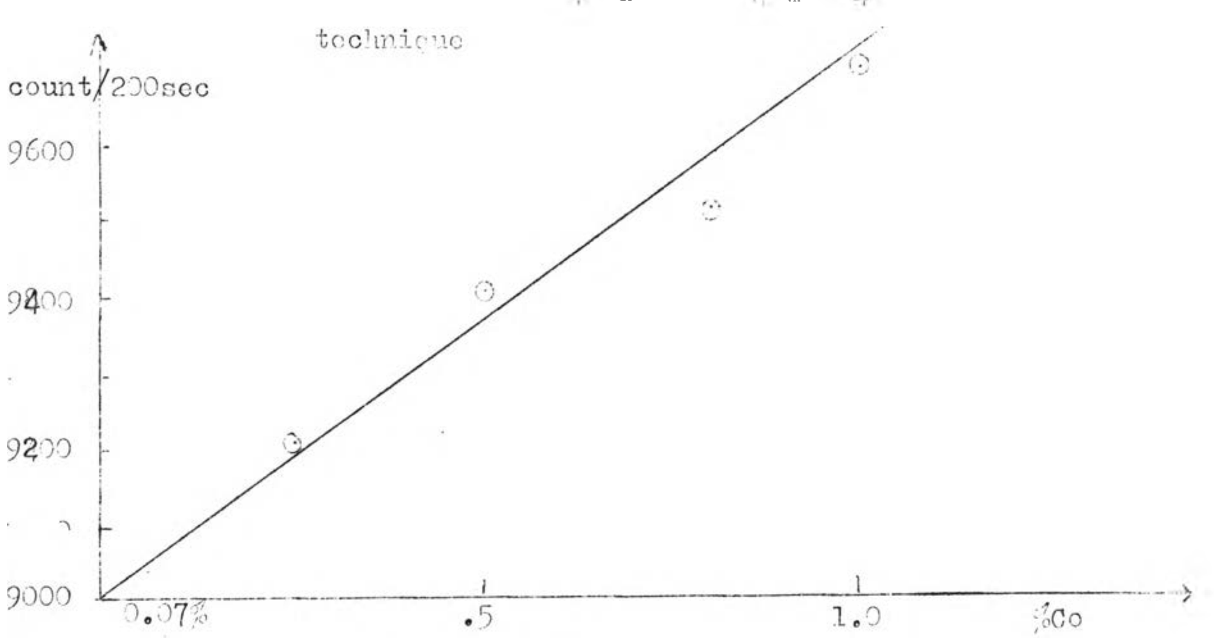


Fig 6.4.1.2. The relationship of activities and concentrations of cobolt in $CoSO_4 7H_2O$ + $(NH_4)_2CrO_4$ by x-ray fluorescence technique.

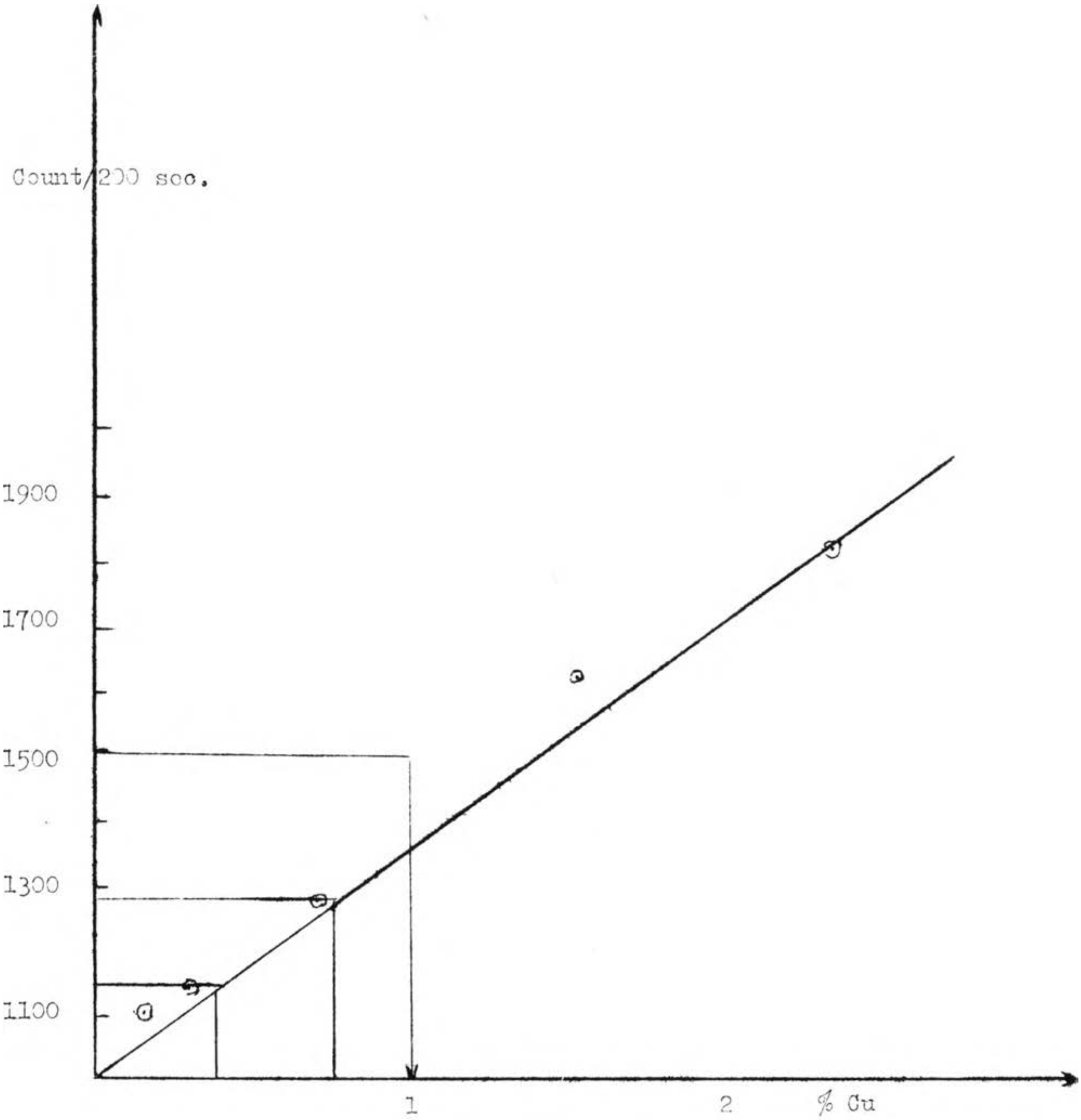


Fig 6.4.1.3 The relationship between activities and percentages of copper in $Cu(C_2H_3O_2)_2 + Na_2S_2O_3$ by X-ray fluorescence technique

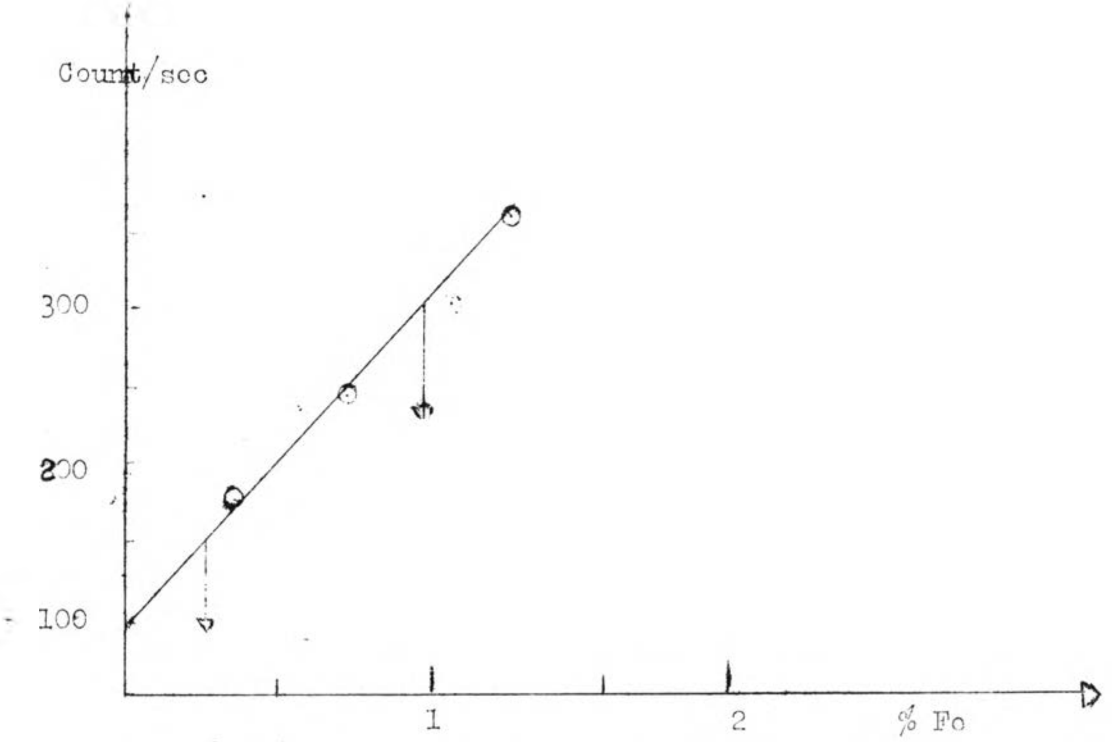


Fig 6.4.1.4 The relationship between activities and percentages of iron in $CuCl_2 2H_2O$ + $Fe(NH_4)_2(SO_4)_2 6H_2O$ by X-ray fluorescence technique

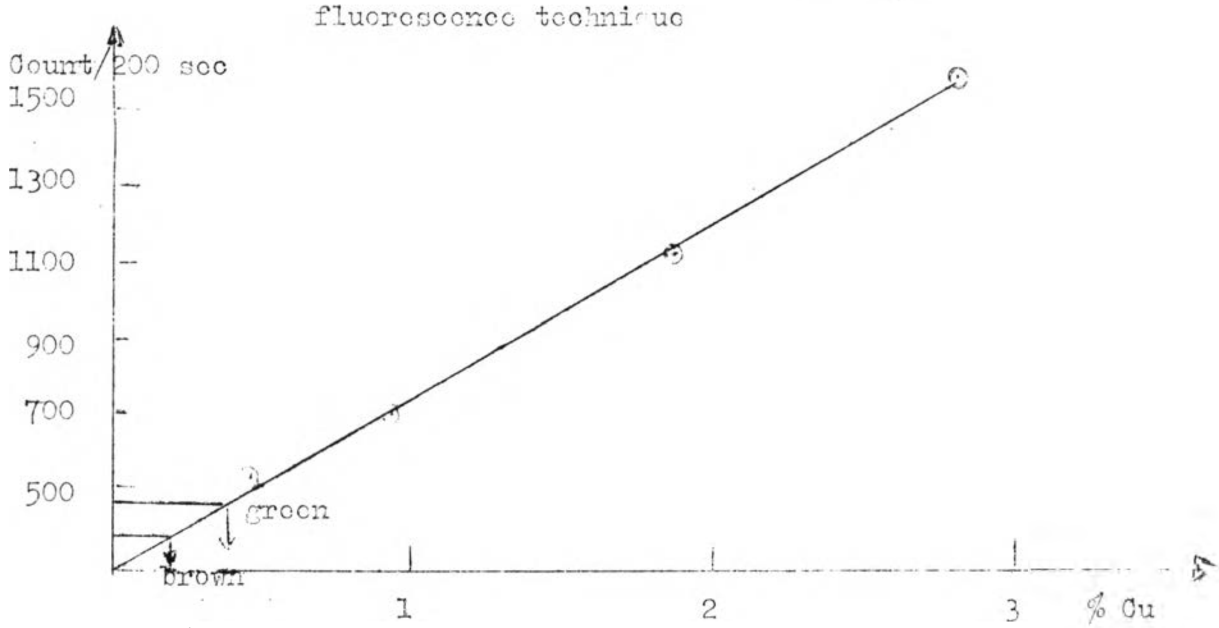


Fig 6.4.1.5 The relationship between activities and percentages of copper in $CuCl_2 2H_2O$ + $Fe(NH_4)_2(SO_4)_2 6H_2O$ by X-ray fluorescence technique

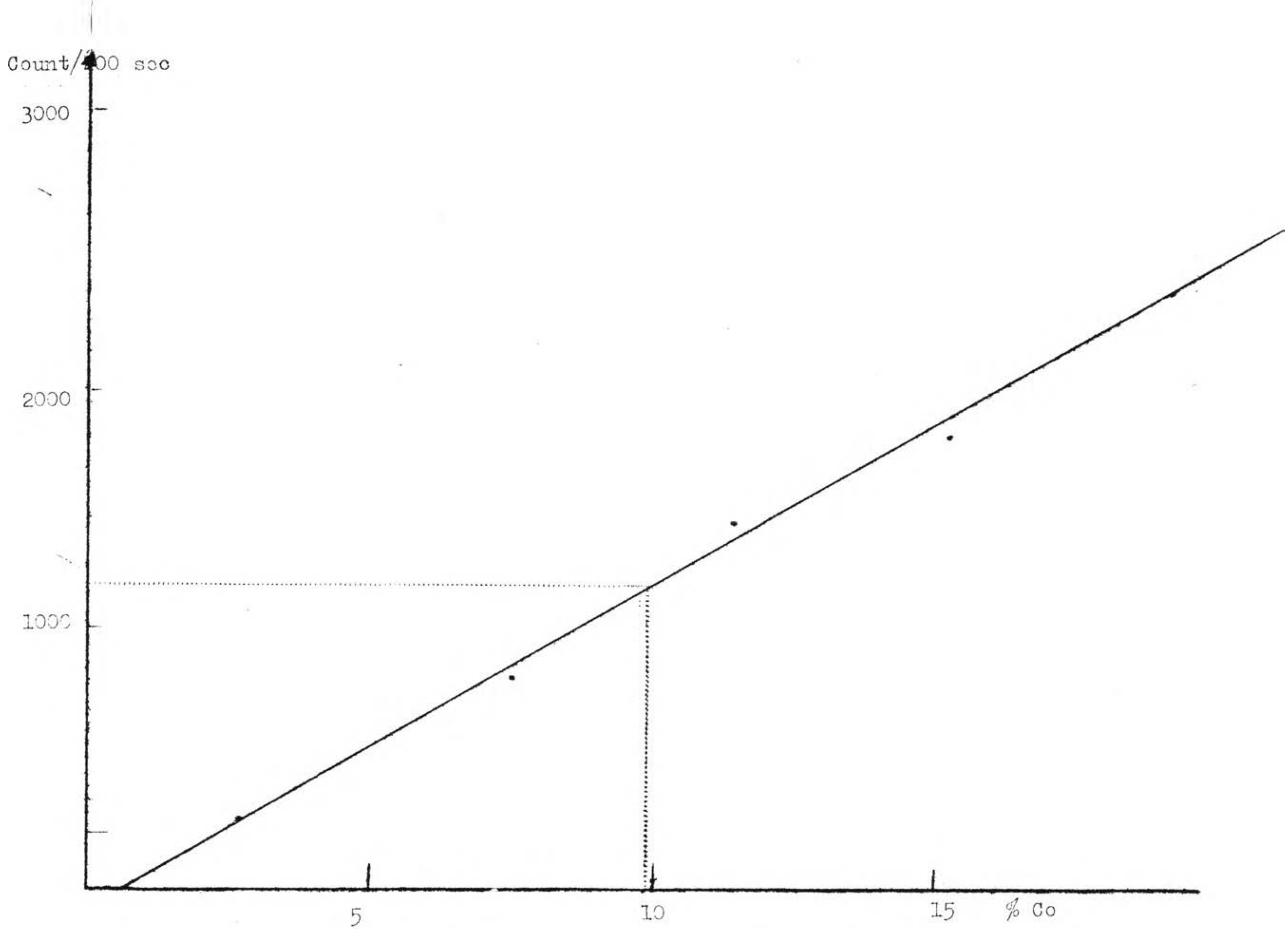


Fig 6.4.1.6 The relationship between activities and percentages of cobalt in $CoSO_4 7H_2O$ + NaSCN by X-ray fluorescence technique

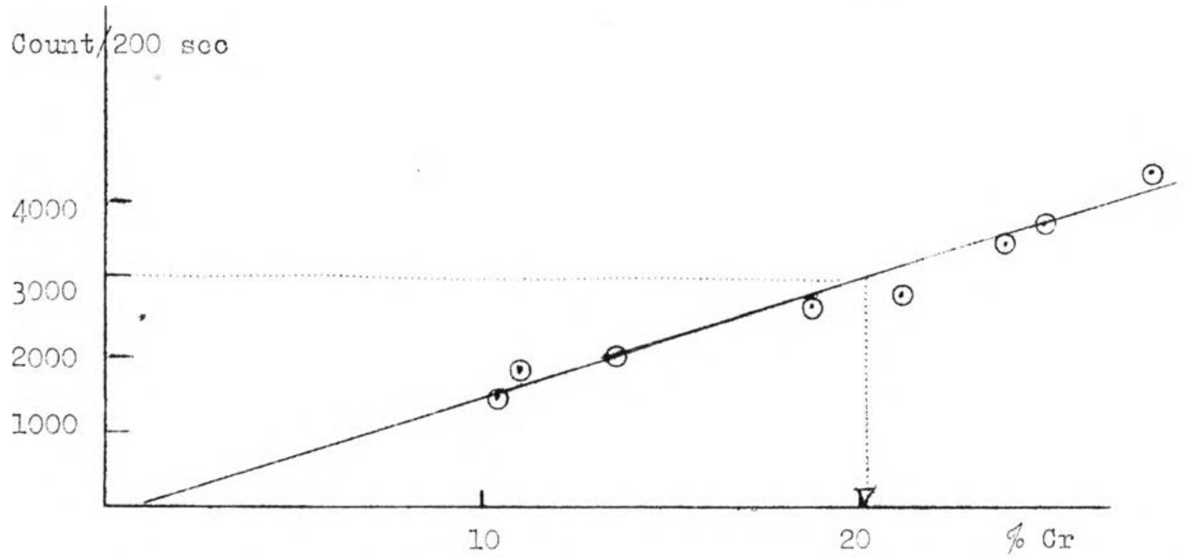


Fig 6.4.1.7 The relationship between activities and percentages of chromium in $CoCl_2 6H_2O$ + $(NH_4)_2CrO_4$ by X-ray fluorescence technique

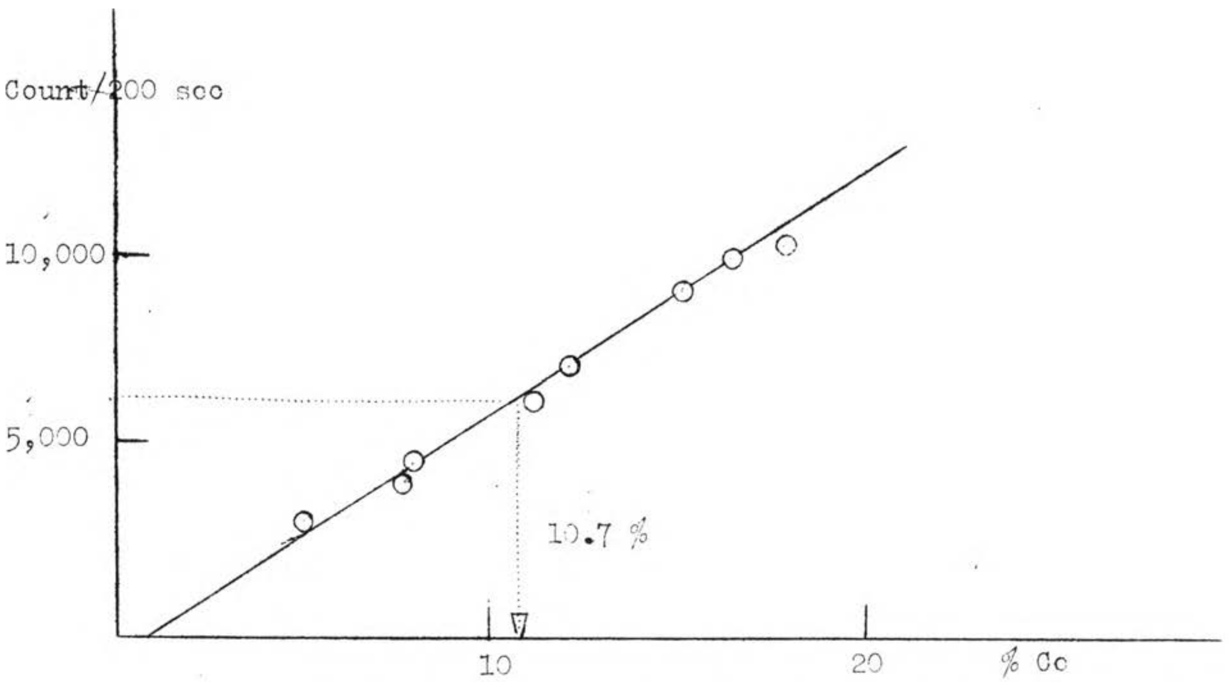


Fig 6.4.1.8 The relationship between activities and percentages of cobalt in $CoCl_2 6H_2O$ + $(NH_4)_2CrO_4$ by X-ray fluorescence technique

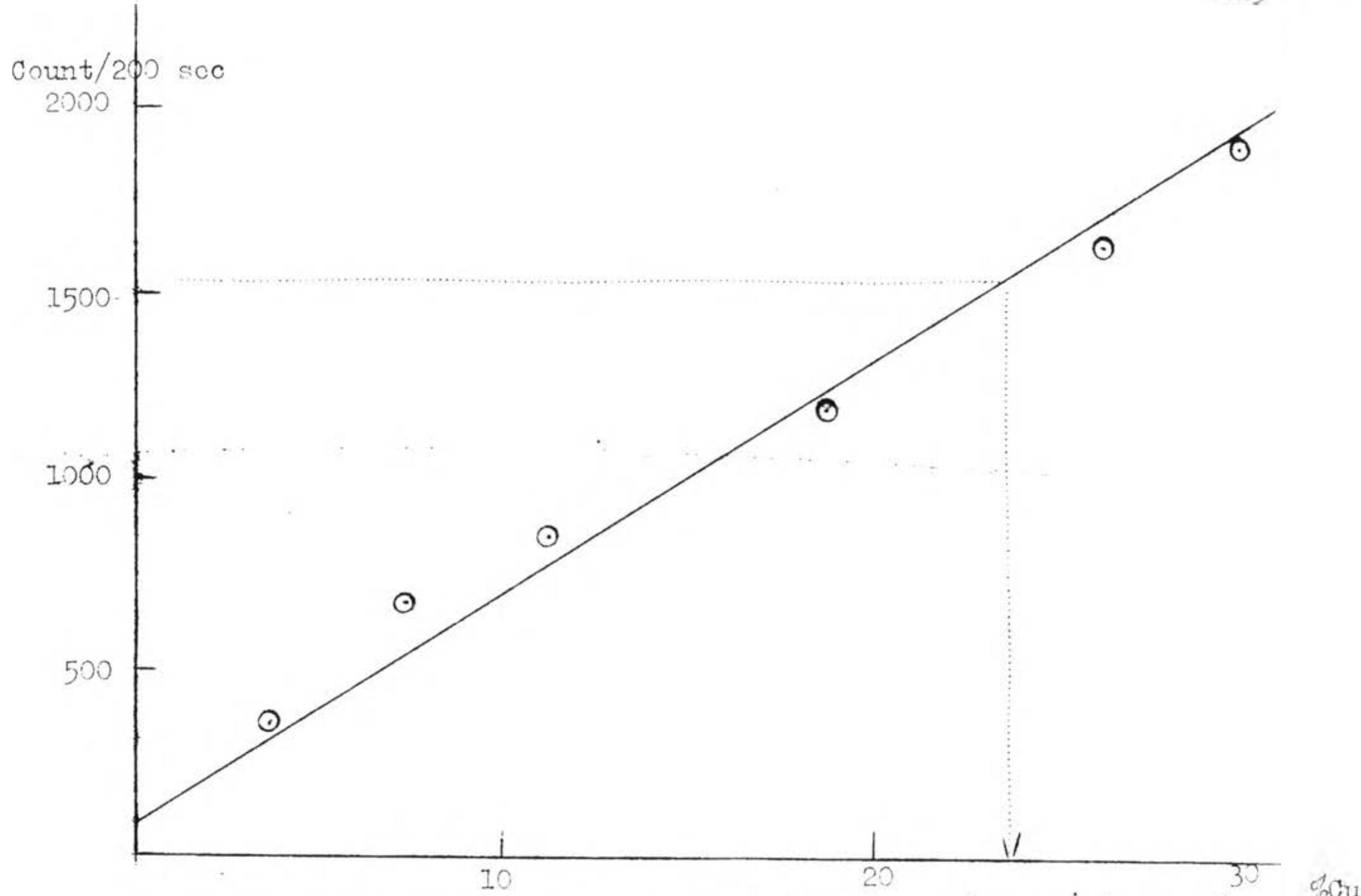


Fig 6.4.1.9 The relationship between activities and percentages of copper in $CuCl_2 2H_2O + K_4Fe(CN)_6$ by X-ray fluorescence technique

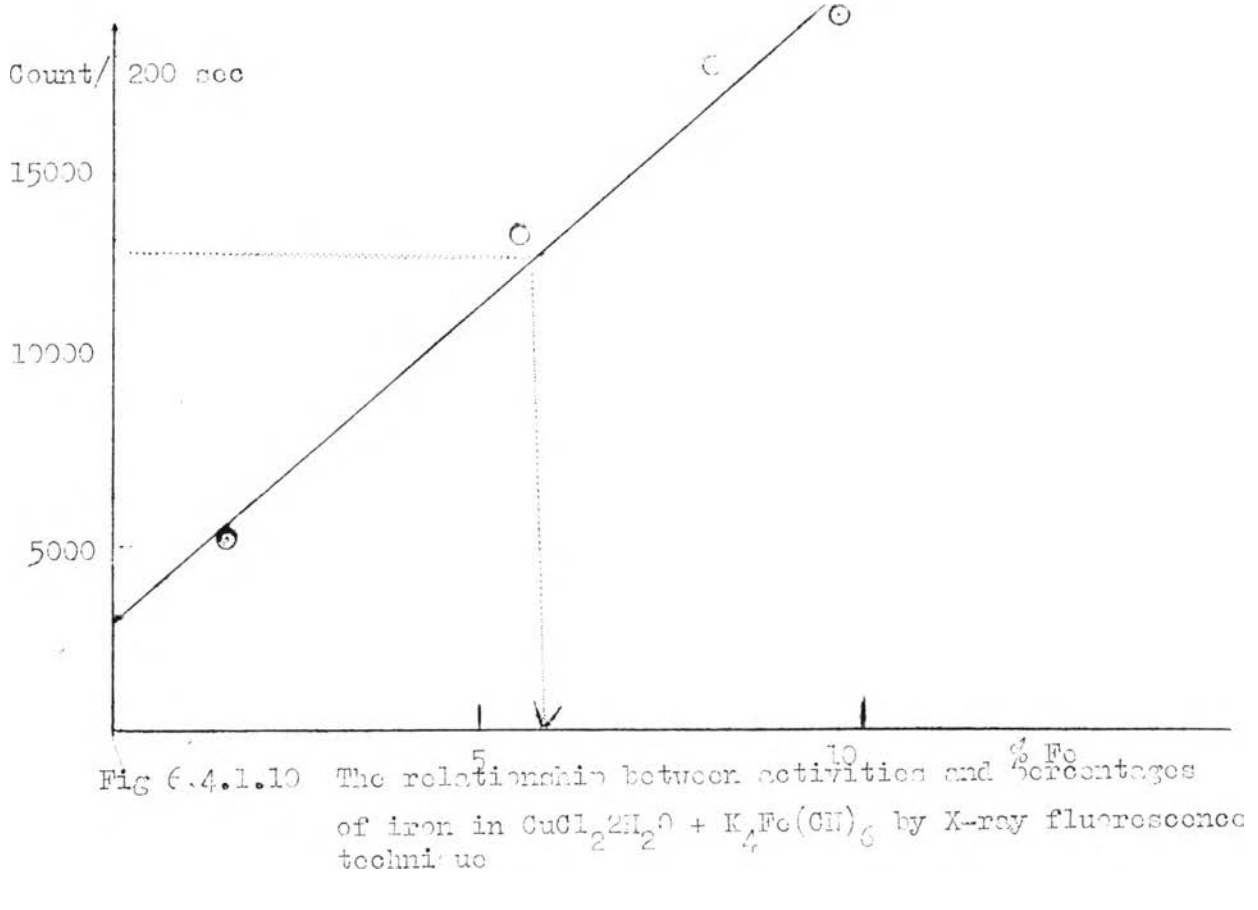


Fig 6.4.1.10 The relationship between activities and percentages of iron in $CuCl_2 2H_2O + K_4Fe(CN)_6$ by X-ray fluorescence technique

6.4.2 Determination of all metal by atomic absorption , turbidimetric, gravimetric and volumetric methods

The analytical techniques were selected reasonably for determining metals and molecular species.

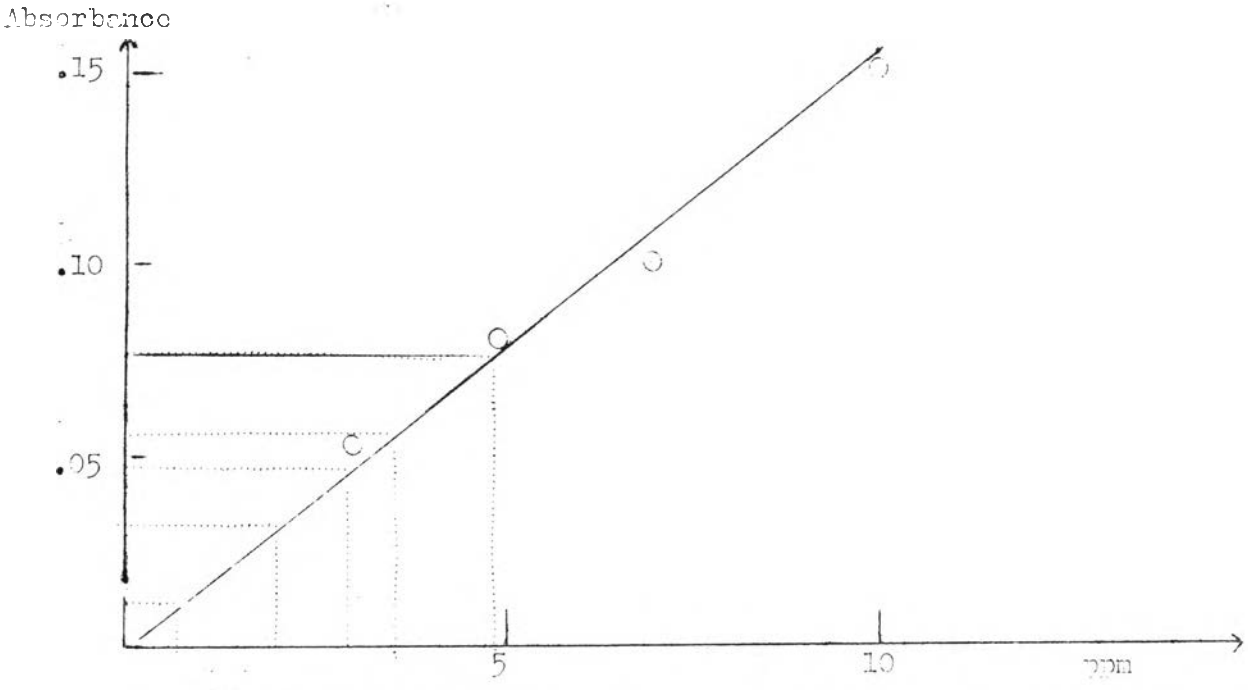


Fig 6.4.2.1 The relationship between absorbances and concentrations of chromium by atomic absorption technique

Table 6.4.2.1 The relationship between absorbances and concentrations of chromium by atomic absorption technique

Concentration of standard ppm	Absorbance
1	0.017
3	0.050
5	0.080
7	0.100
9	0.140
10	0.150

Table 6.4.2.2 Determination of chromium in various products

Product	Absorbance	% chromium
$CuCl_2 2H_2O + (NH_4)_2CrO_4$	0.075	22.84
$Cu(C_2H_3O_2)_2 + K_2CrO_4$	0.031	19.98
$CoCl_2 6H_2O + (NH_4)_2CrO_4$	0.055	26.26
$CuCl_2 2H_2O + K_2CrO_4$	0.757	27.71
$CuSO_4 5H_2O + (NH_4)_2CrO_4$	0.013	16.24
$CoCl_2 6H_2O + K_2CrO_4$	0.045	24.35
$Fe(NH_4)_2(SO_4)_2 + (NH_4)_2CrO_4$ $6H_2O$	0.055	3.02
$Fe_2(C_2O_4)_3 + (NH_4)_2CrO_4$ $5H_2O$	0.055	.44

Table 6.4.2.3 The relationship between absorbances and concentrations of cobalt by atomic absorbtion technique

Concentration of cobalt ppm	Absorbance		
	I	II	average
1	0.040	0.040	0.040
2	0.085	0.075	0.080
5	0.245	0.250	0.245
10	0.435	0.435	0.435
15	0.620	0.620	0.620
20	0.820	0.800	0.810

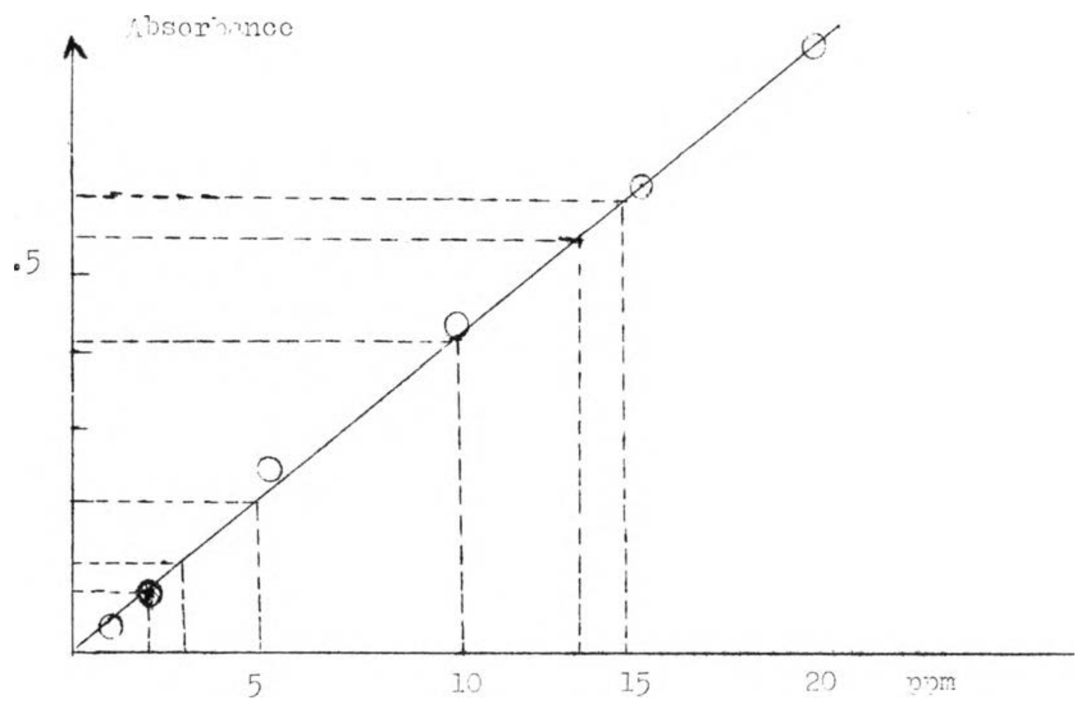


Fig 6.4.2.2 The relationship between absorbances and concentrations of cobalt by atomic absorption.

Table 6.4.2.4 Determination of cobalt in various products

Product of	absorbance	% Co by weight
$CoCl_2 6H_2O$ + $(NH_4)_2CrO_4$	0.120	21.90
$CoCl_2 6H_2O$ + K_2CrO_4	0.080	8.92
$CoCl_2 6H_2O$ + $(NH_4)_2CO_3$	0.530	12.89
$CoCl_2 6H_2O$ + NaSCN	0.230	4.03
$CoCl_2 6H_2O$ + KSCN	0.690	6.80
$CoF_2 2H_2O$ + CaS	0.560	22.47
$CoF_2 2H_2O$ + NaSCN	0.410	7.87
$CoSO_4 7H_2O$ +KSCN	0.340	8.41
$CoSO_4 7H_2O$ + NaSCN	0.150	4.29

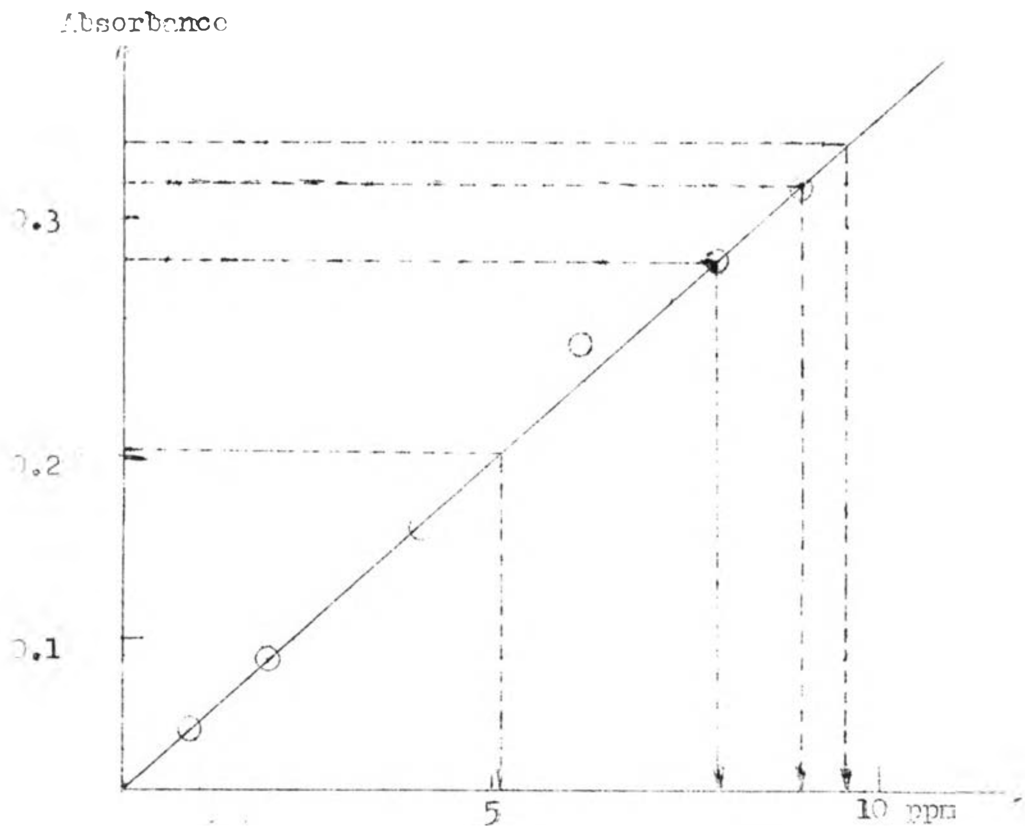


Fig 6.4.2.3 The relationship between absorbances and concentrations of iron by atomic absorption technique

Table 6.4.2.5 The relationship between absorbance and concentrations of iron by atomic absorption technique

Concentration of Fe (ppm)	Absorbance (average)
1	0.035
2	0.070
4	0.140
6	0.230
8	0.280
9	0.320

Table [illegible].4.2.6 Determination of Fe in various products

Product of	colour	Absorbance	% Fe
$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O + (NH_4)_2CrO_4$	brown	0.340	43.96
$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O + CuCl_2 2H_2O$	brown	0.285	30.18
$Fe_2(C_2O_4)_3 5H_2O + (NH_4)_2CO_3$	brown	0.185	47.50
$Fe_2(C_2O_4)_3 5H_2O + (NH_4)_2CrO_4$	brown	0.320	29.98

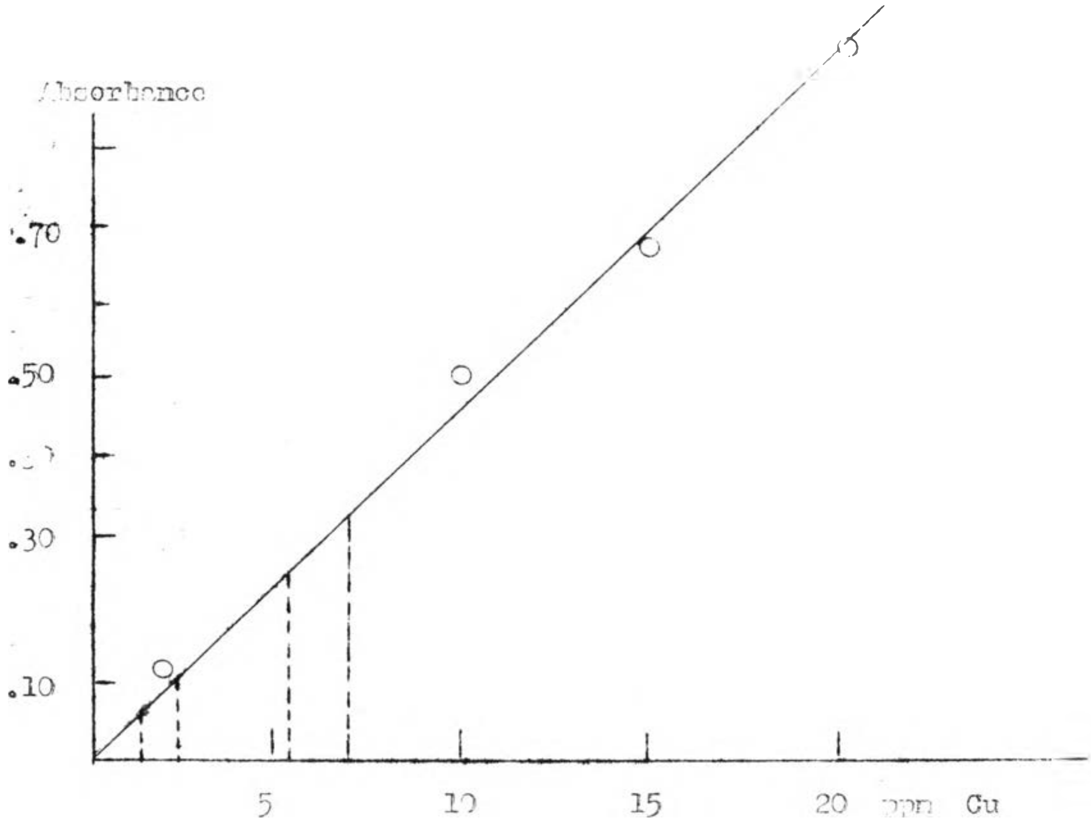


Fig 6.4.2.6 The relationship between absorbances and concentrations of copper by atomic absorption techniqure

Fig 6.4.2.7 The relationship between absorbances and concentrations of copper by atomic absorption techniqure

Concentration of (ppm)	Absorbance
1	0.070
2	0.120
5	0.220
10	0.500
15	0.670
20	0.930

Table 6.4.2.8 Determination of percentage of Cu in various products

Product of	colour	Absorbance	% Cu
$CuCl_2 2H_2O$ + $(NH_4)_2CrO_4$	brown	0.330	32.63
$Cu(C_2H_3O_2)_2$ + K_2CrO_4	black	0.130	23.98
$CuCl_2 2H_2O$ + K_2CrO_4	brown	0.260	30.54
$CuSO_4 5H_2O$ + $(NH_4)_2CrO_4$	brown	0.065	15.31
$CuSO_4 5H_2O$ + $(NH_4)_2CrO_4$	green	0.250	35.31
$Fe(NH_4)_2(SO_4)_2$ + $CuCl_2 2H_2O$ $6H_2O$	brown	0.320	.88
$Cu(C_2H_3O_2)_2$ + $Na_2S_2O_3$	white	0.260	16.42
$Cu(C_2H_3O_2)_2$ + $Na_2S_2O_3$	orange	0.440	14.025
$Cu(C_2H_3O_2)_2$ + $Na_2S_2O_3$	yellow	0.440	25.25

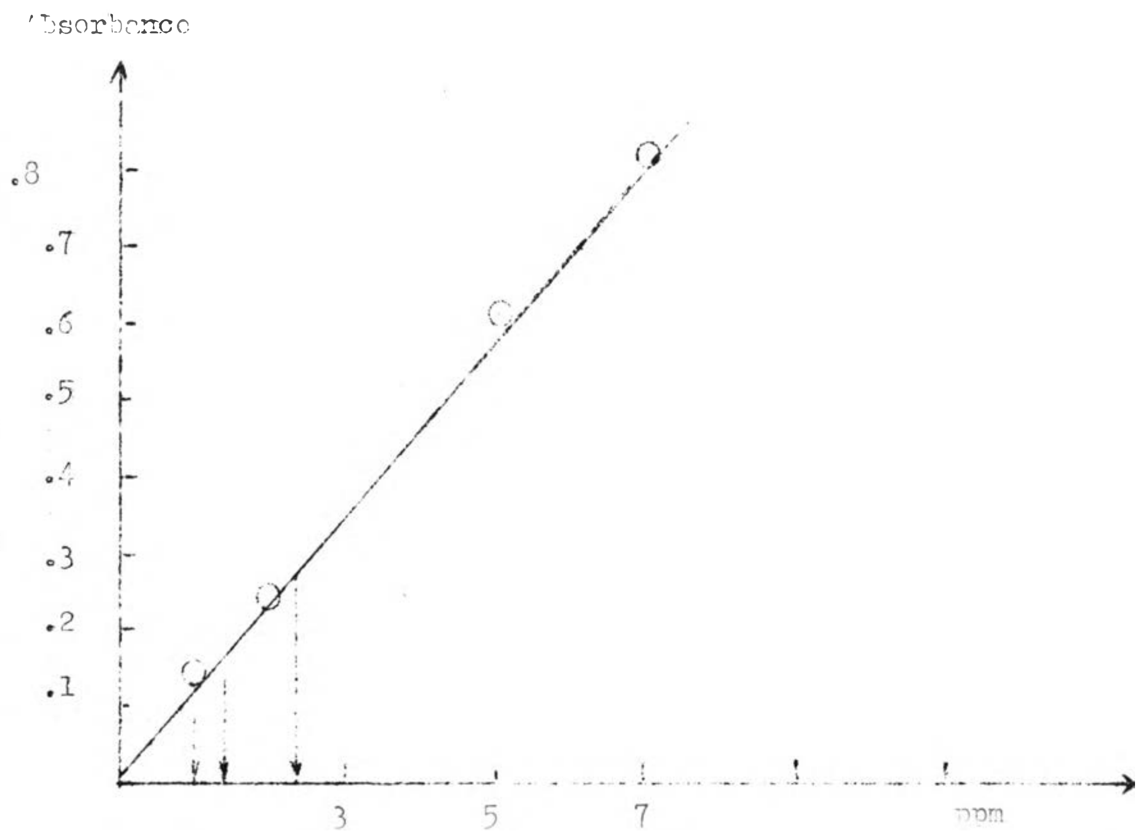


Fig 6.4.2.5 The relationship between absorbances and concentrations of potassium by atomic absorption technique

Table 6.4.2.9 The relationship between absorbances and concentrations of potassium by atomic absorption technique

Concentration of K	Absorbance
1	0 .150
2	0 .260
5	0 .610
7	0 .830

Table 6.4.2.10 Determination of potassium in various products

Products of	colour	Absorbance	% K
$Cu(C_2H_3O_2)_2$ + K_2CrO_4	black	0.16	13.98
$CuCl_2 2H_2O$ + K_2CrO_4	black	0.22	10.74
$CoCl_2 2H_2O$ + K_2CrO_4	black	0.13	4.46
$CuCl_2 2H_2O$ + $K_4Fe(CN)_6$	black	0.28	15.90
$CoSO_4.7H_2O$ + KSCN	blue	0.44	36.62

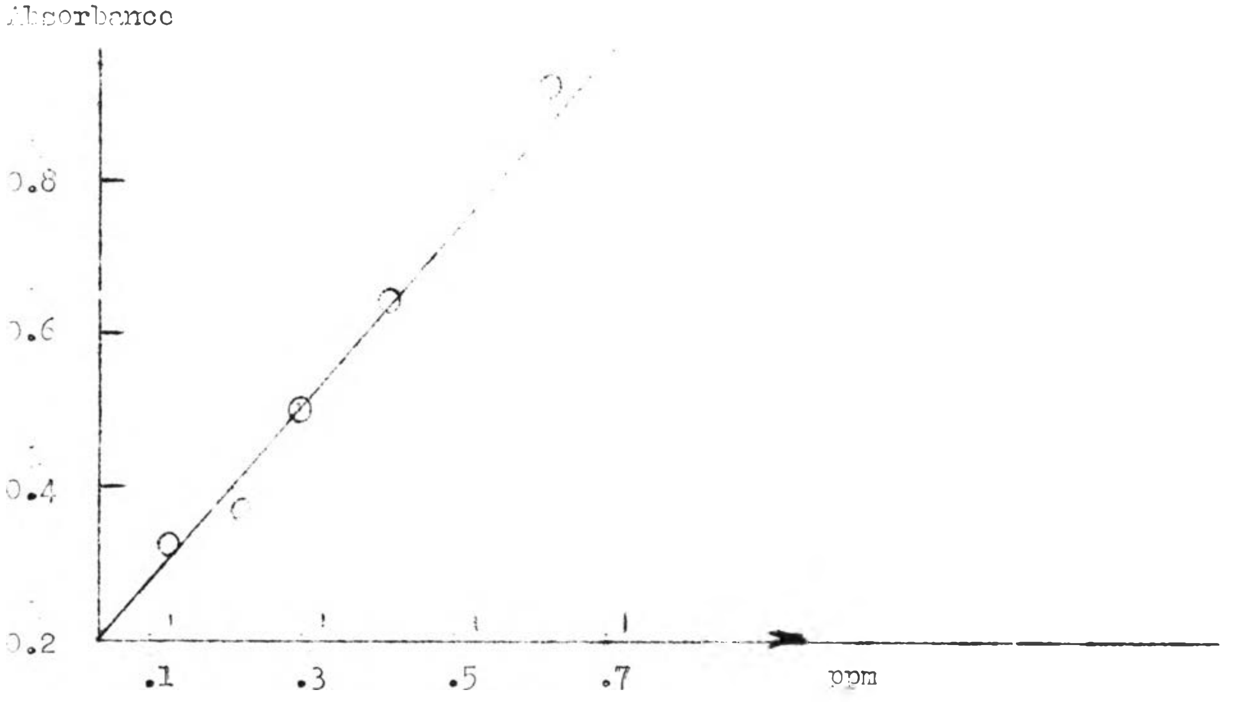


Fig 6.4.2.6 The relationship between absorbances and concentrations of sodium by atomic absorption technique

Table 6.4.2.11 The relationship between absorbances and concentrations of sodium by atomic absorption technique

Concentration of Na	Absorbance (average)
0.12	0.130
0.2	0.175
0.28	0.300
0.4	0.440
0.6	0.720

Table 6.4.2.12 Determination of Na in various products

Products of	colour	Absorbance	% Na
$CoCl_2 6H_2O$ + NaSCN	blue	0.720	22.39
$CoF_2 2H_2O$ + NaSCN	blue	0.445	8.62
$Cu(C_2H_3O_2)_2$ + $Na_2S_2O_3$	white	0.320	13.09
$Cu(C_2H_3O_2)_2$ + $Na_2S_2O_3$	orange	0.170	33.96
$Cu(C_2H_3O_2)_2$ + $Na_2S_2O_3$	yellow	0.350	25.67

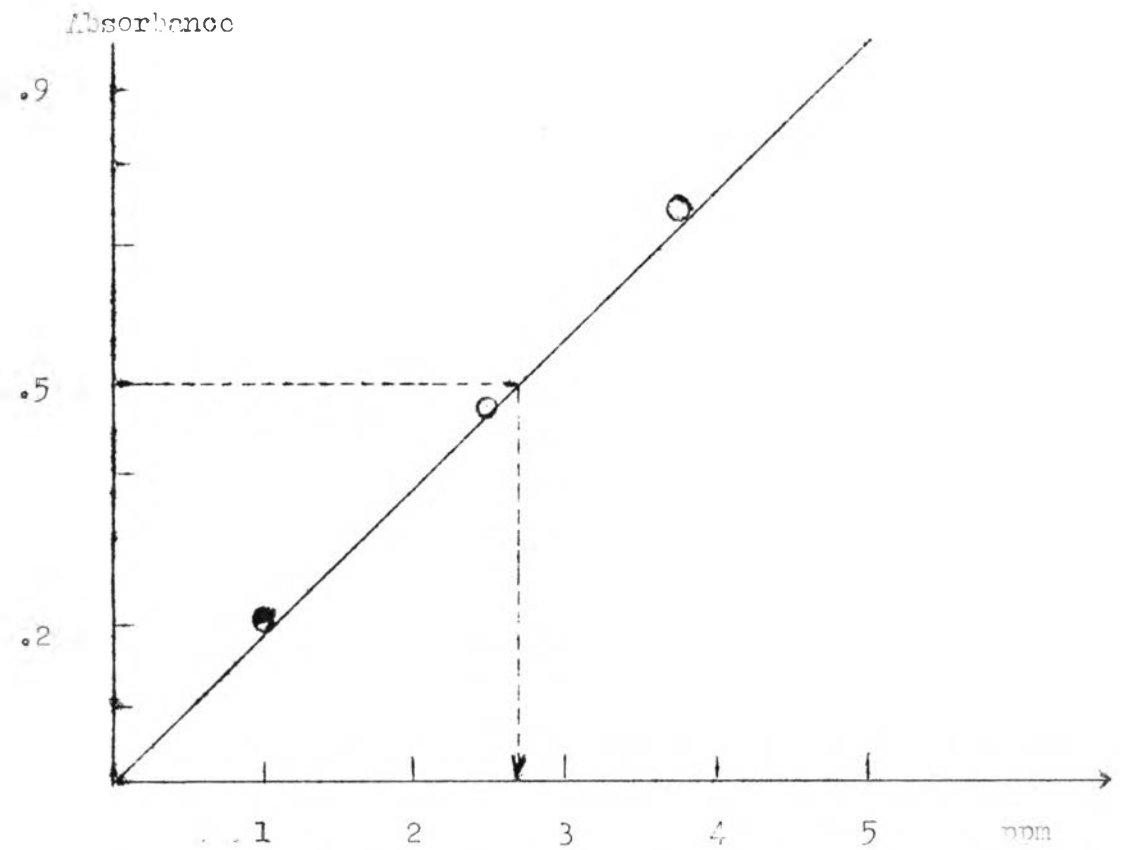


Fig 6.4.2.7 The relationship between absorbances and concentrations of calcium by atomic absorption technique

Table 6.4.2.13 The relationship between absorbances and concentrations of calcium by atomic absorption technique

Concentration of Ca (ppm)	Absorbance
1	0.210
2.5	0.490
3.75	0.750
5	0.970
product of $CoF_2 2H_2O$ + CaS	0.530

Table 6.4.2.14. The relationship between absorbances and concentrations of cobalt ($CoSO_4 7H_2O$ + $(NH_4)_2CrO_4$) by atomic absorption

(ppm) Concentration	Absorbance
1	0.022
2	0.060
5	0.119
10	0.260
15	0.347
20	0.450
black product	0.229
blue product	0.301

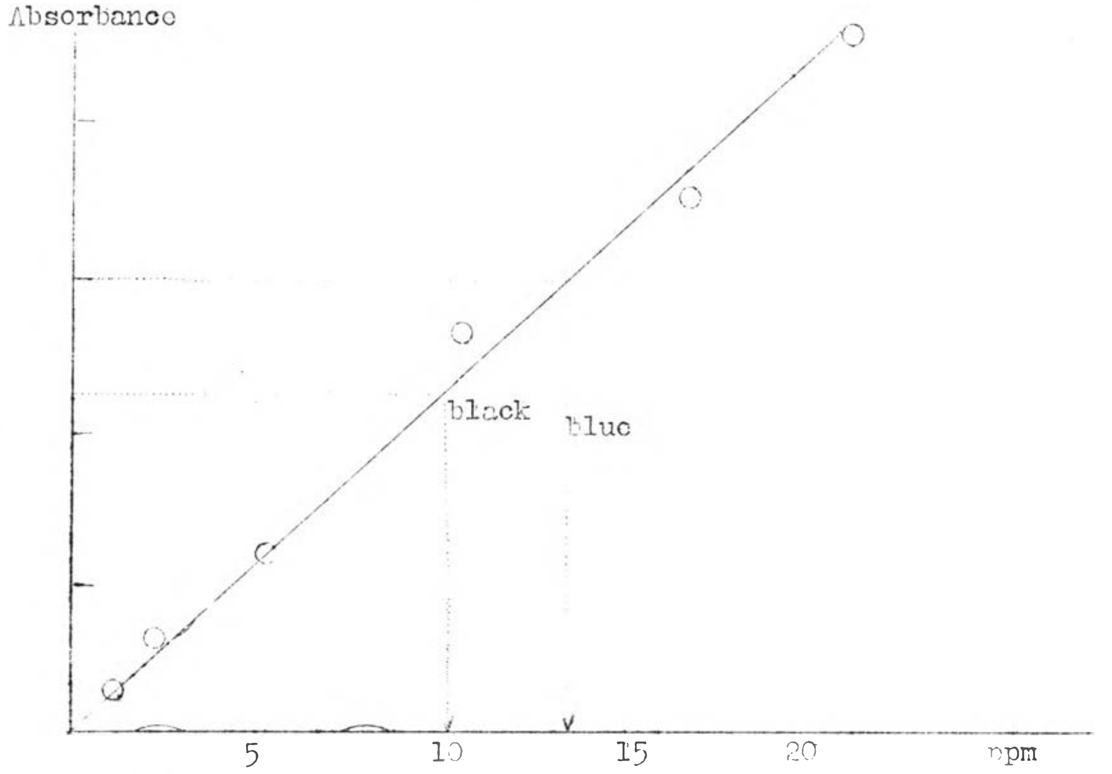


Fig 6.4.2.8 The relationship between absorbances and concentrations of cobalt ($CoSO_4 7H_2O$ + $(NH_4)_2CrO_4$) by atomic absorption

Table 6.4.2.15 The relationship between absorbances and concentrations of chromium ($CoSO_4 7H_2O$ + $(NH_4)_2CrO_4$) by atomic absorption

Concentration	Absorbance
100	0.086
200	0.167
400	0.244
1000	0.568
black product	0.201
orange product	0.346

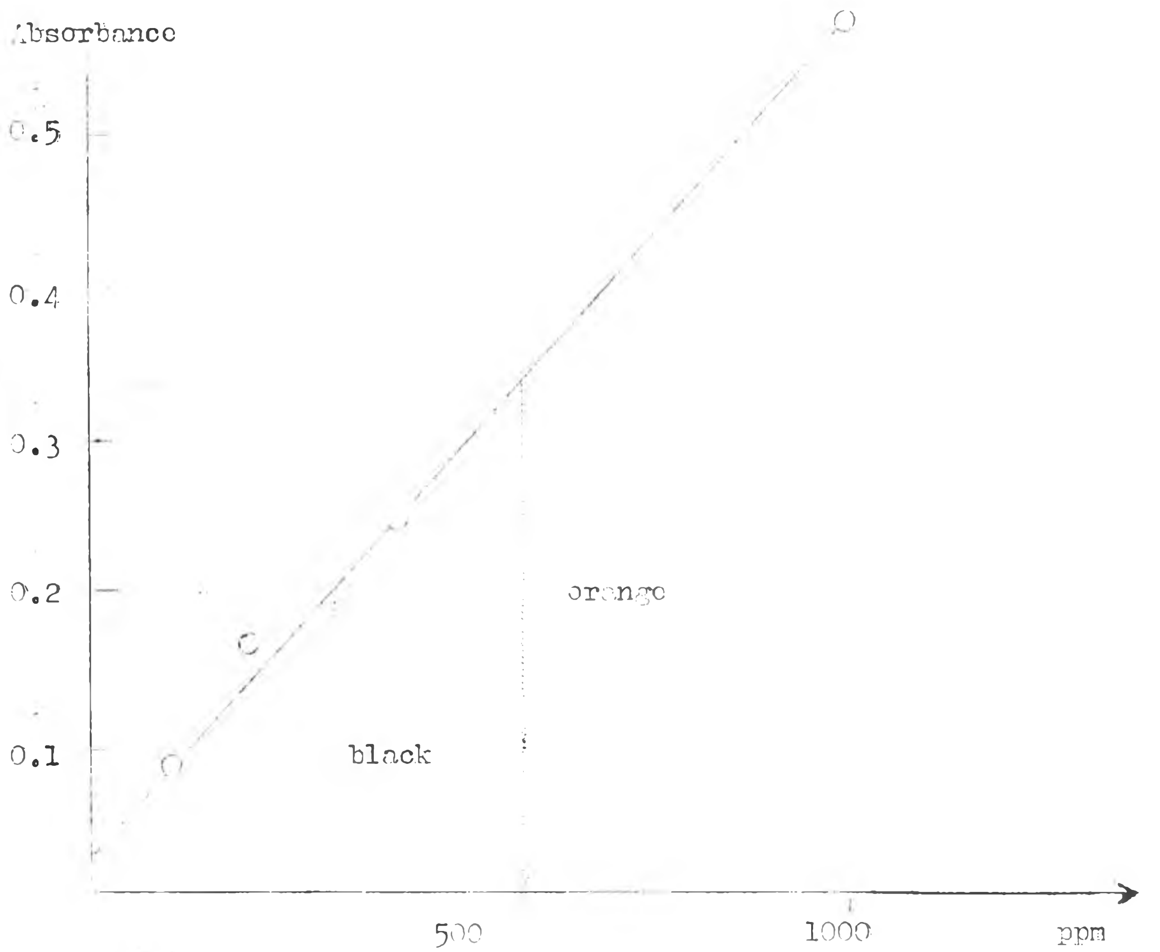


Fig 6.4.2.9 The relationship between absorbances and concentrations of chromium ($CoSO_4 7H_2O$ + $(NH_4)_2CrO_4$) by atomic absorption

Table 6.4.2.16 The relationship between absorbances and concentrations of SO_4^{2-} by turbidimetry method

Concentration (ppm)	Absorbance
1	0.071
2	0.180
3	0.251
4	0.305
5	0.401
6	0.500
black product	0.490
blue product	0.194

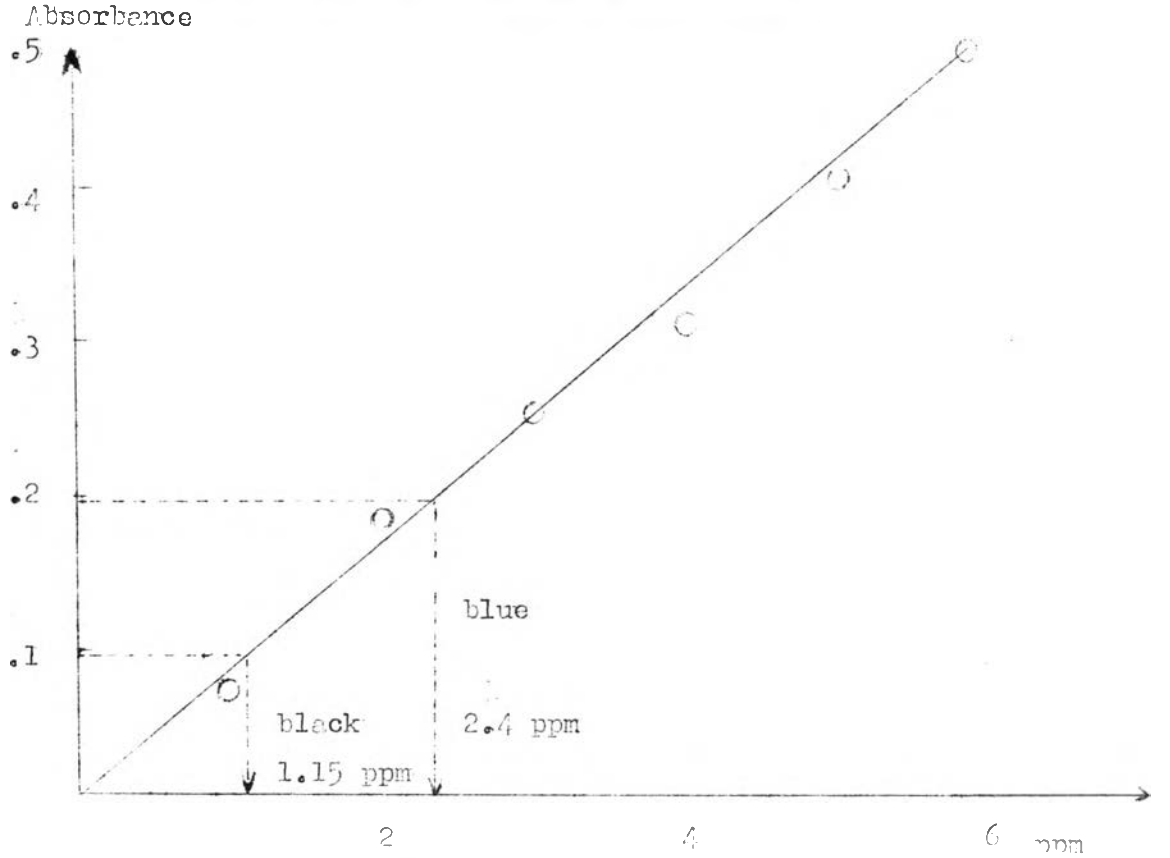


Fig 6.4.2.10 The relationship between absorbances and concentrations of SO_4^{2-} by turbidimetry method

The duplicate results showed the very strange dispersion of reacting species. Most of solid-solid reaction products were formed in a different mechanism from aqueous system. The rearrangement of new species was very difficult to predict the structure without confirmation of X-ray crystallography technique.

Three products from $CoSO_4 7H_2O$ and $(NH_4)_2CrO_4$ system, were chosen to display the complexity of atoms rearrangement, which derived from analytical results. The percentages by weight of them were listed in Table 6.4.2.1.5.

According to the infrared spectra of the black product showed the characteristic peak of chromate ion. Then the percentage of chromate ion was calculated from chromium which was determined by the atomic absorption technique, since the calculating chromate ion from gravimetric analysis was lower than the determinable chromium.

Table 6.4.1.17 Analytical compositions of products between $CoSO_4.7H_2O$ and $(NH_4)_2CrO_4$

Product	% Co	% CrO_4^{2-}	% NH_4^+	% H_2O	% SO_4^{2-}
black	17.4	45.88	15	-	11.5
blue	18.0	-	-	21	21.3
orange	-	73.99	28.45	7.5	-

The molar ratios of compositions of these three products are listed,

black product,

Co	:	CrO_4^{2-}	:	NH_4^+(or NH_3)	:	SO_4^{2-}
2.45		3.29		6.91		1

blue product,

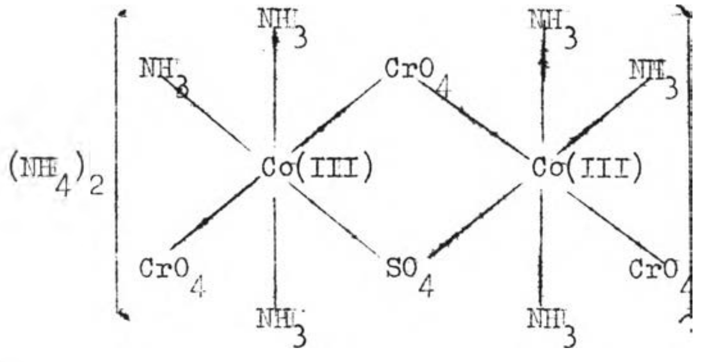
Co	:	SO_4^{2-}	:	H_2O
1.4		1		5.27

orange product,

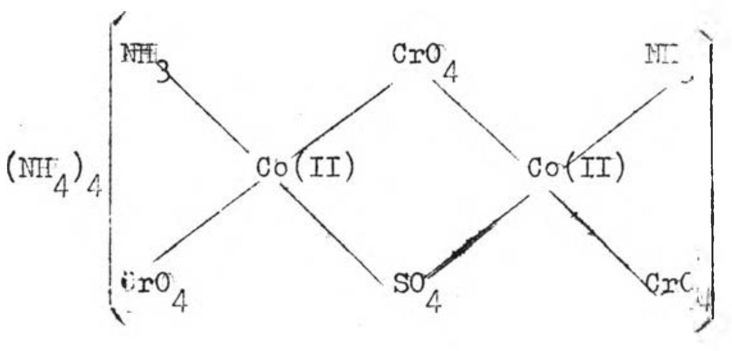
NH_4^+	:	CrO_4^{2-}	:	H_2O
3.7		1.5		1

The imperfection in solid crystal was hold a good criterion in dealing with material which could not exist with the ideal composition.

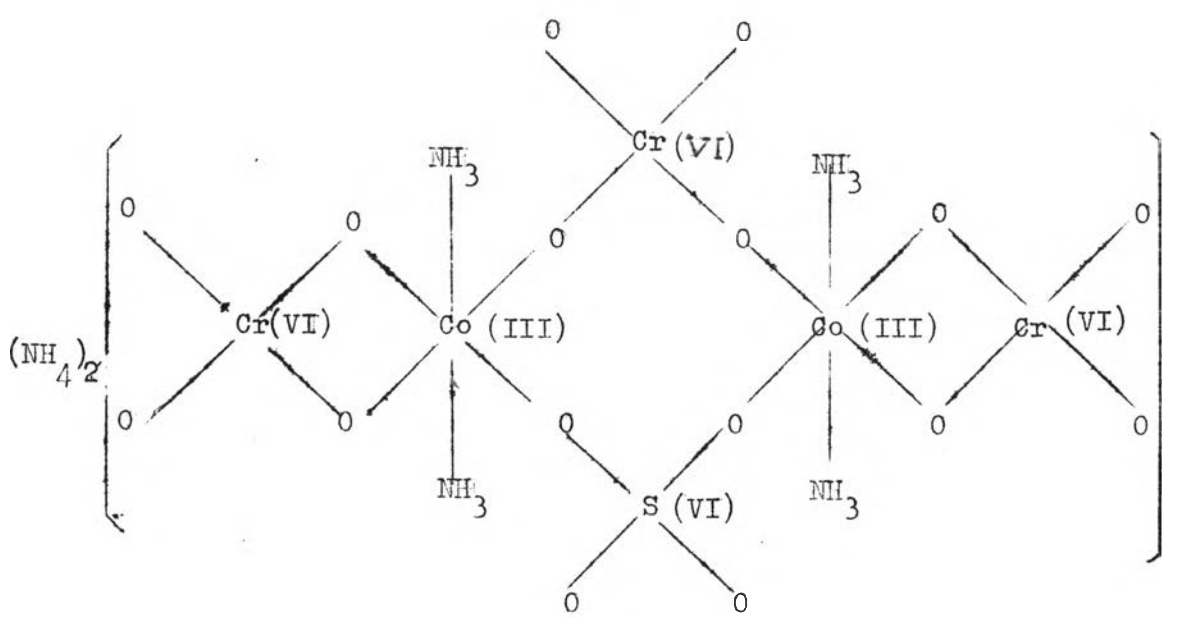
The analytical compositions of reaction products are not simple to derive their formula. It is the first attempt to construct their structures for illustrate the complexity as shown in the following, The black product,



(I)

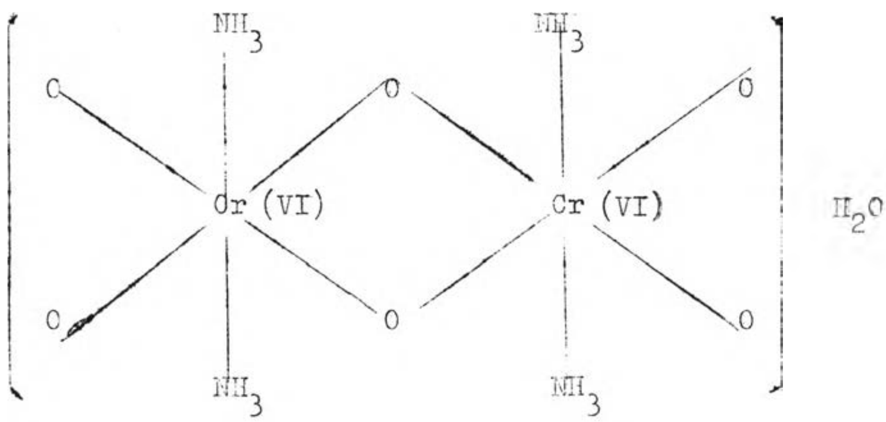


(II)

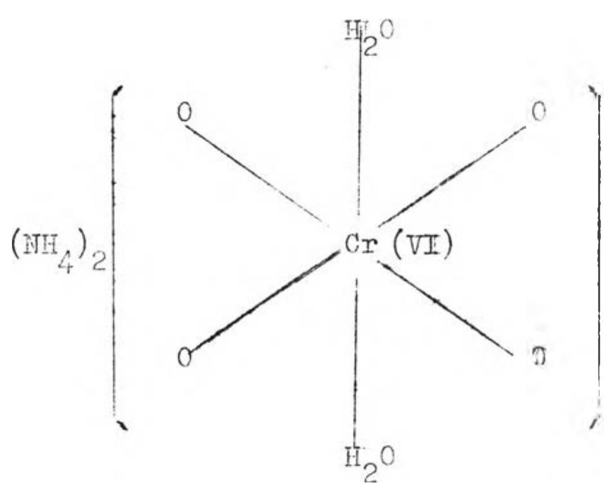


(III)

orange product.

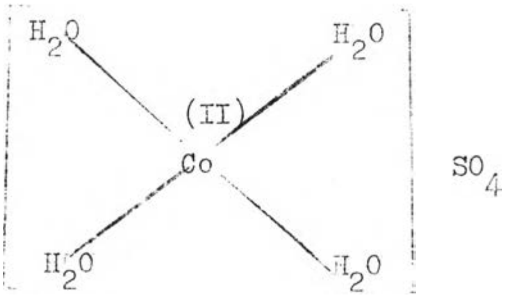


(I)

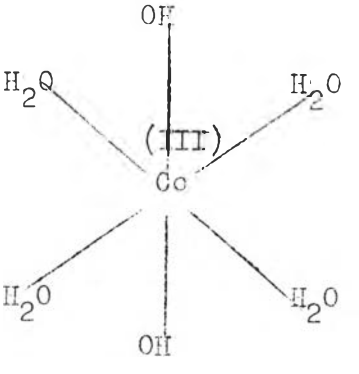


(II)

blue product,



(I)



(II)

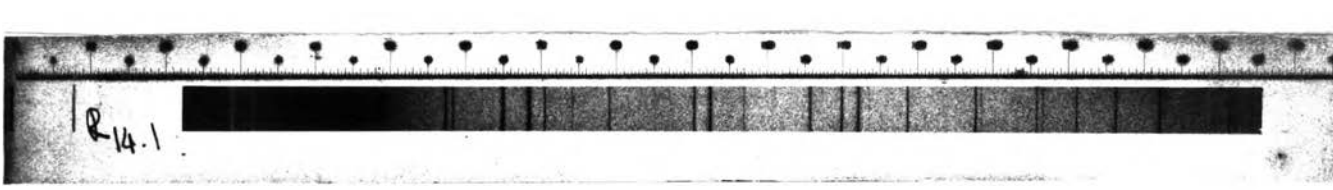
6.5 Tho comparison study by instrumental methods

6.5.1 X-ray powder diffraction pattern of product and reactants

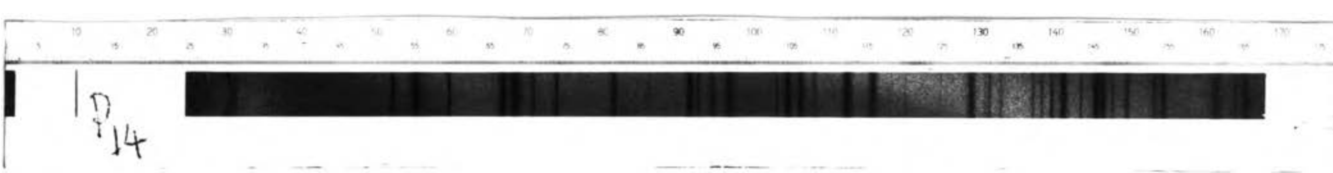
In this section, the X-ray powder diffraction pattern of product and reactants were compared as shown in Fig 6.5.1.1-6.5.1.5

6.5.1.1 $CoF_2 2H_2O$ + CaS

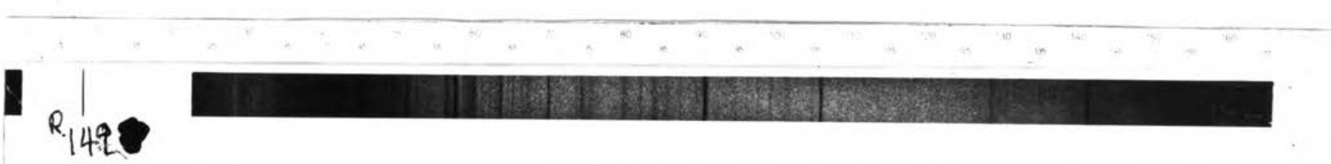
$CoF_2 2H_2O$ pink



black product



CaS - grey

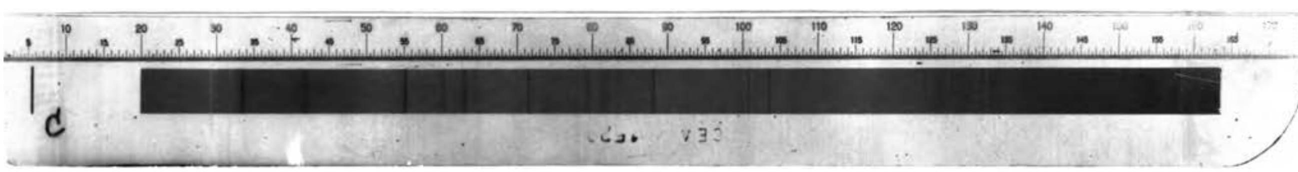


$CoF_2 2H_2O$ pink	immediatly →	pink
CaS grey		black grey

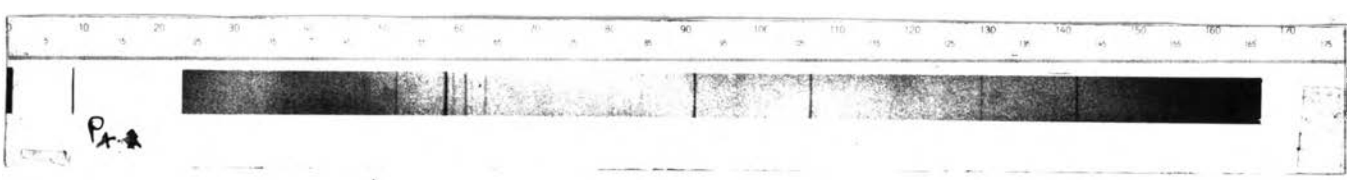
Fig 6.5.1 X-ray powder diffraction pattern of reactant and product of solid-solid reaction.(mixed with Si)

6.5.1.2 $\underline{CoCl_2 6H_2O + K_2CrO_4}$

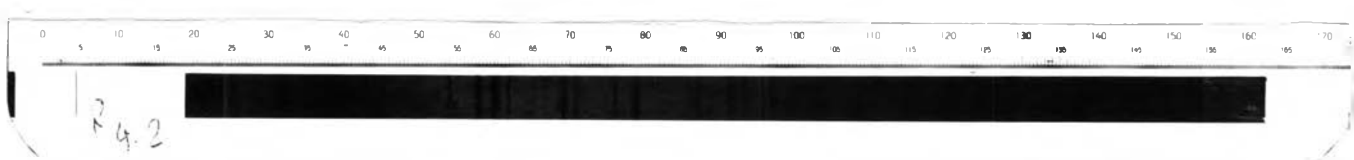
$CoCl_2 6H_2O$ red violet



dark brown product



K_2CrO_4 yellow



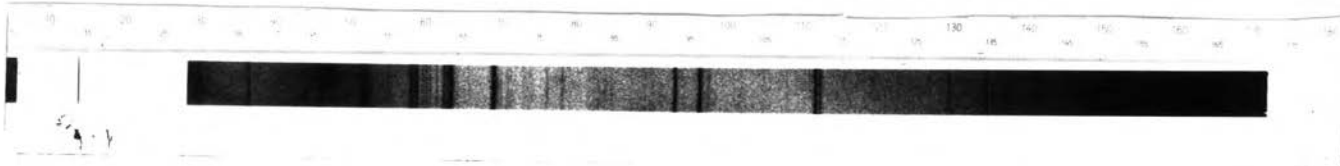
$CoCl_2 6H_2O$ red-violet		red-violet
	10hrs →	brown
K_2CrO_4 yellow		yellow

Fig 6.5.1 X-ray powder diffraction pattern of reactant and product of solid-solid reaction. (mixed with Si)

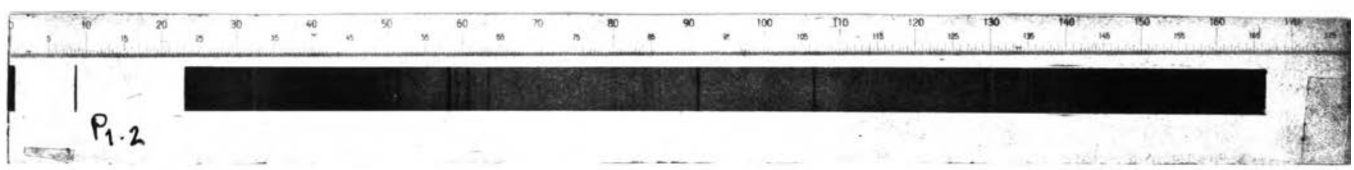
6.5.1.3 $CoSO_4 7H_2O + (NH_4)_2CrO_4$

$CoSO_4 7H_2O$ red-orange

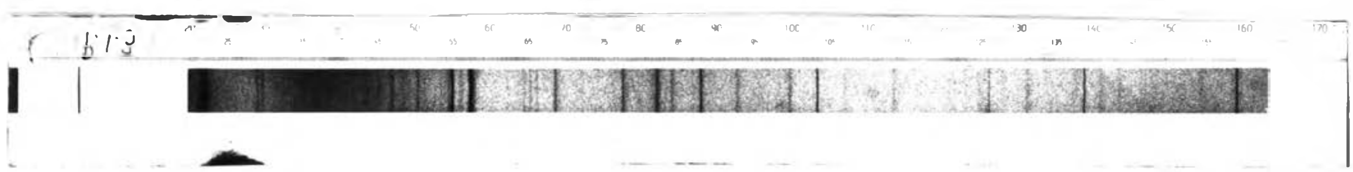
black product



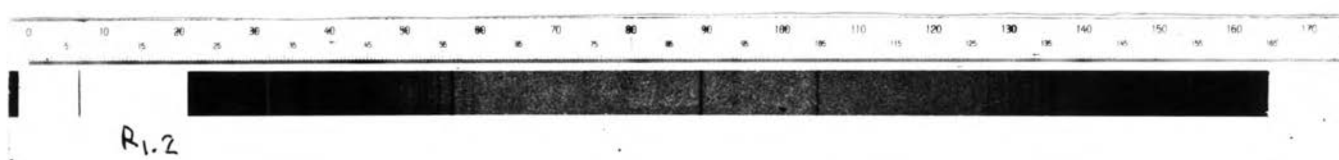
blue product



yellow-orange product



$(NH_4)_2CrO_4$ yellow



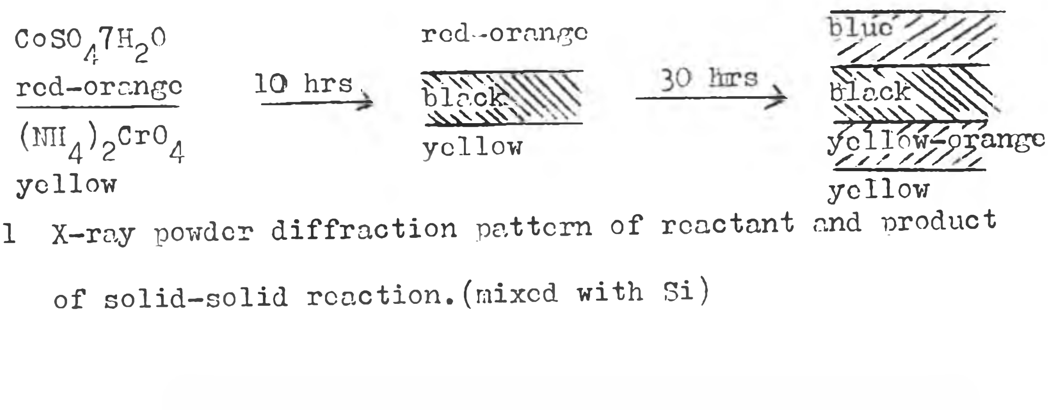


Fig 6.5.1 X-ray powder diffraction pattern of reactant and product of solid-solid reaction. (mixed with Si)

6.5.1.4 $Cu(C_2H_3O_2)_2 + Na_2S_2O_3$

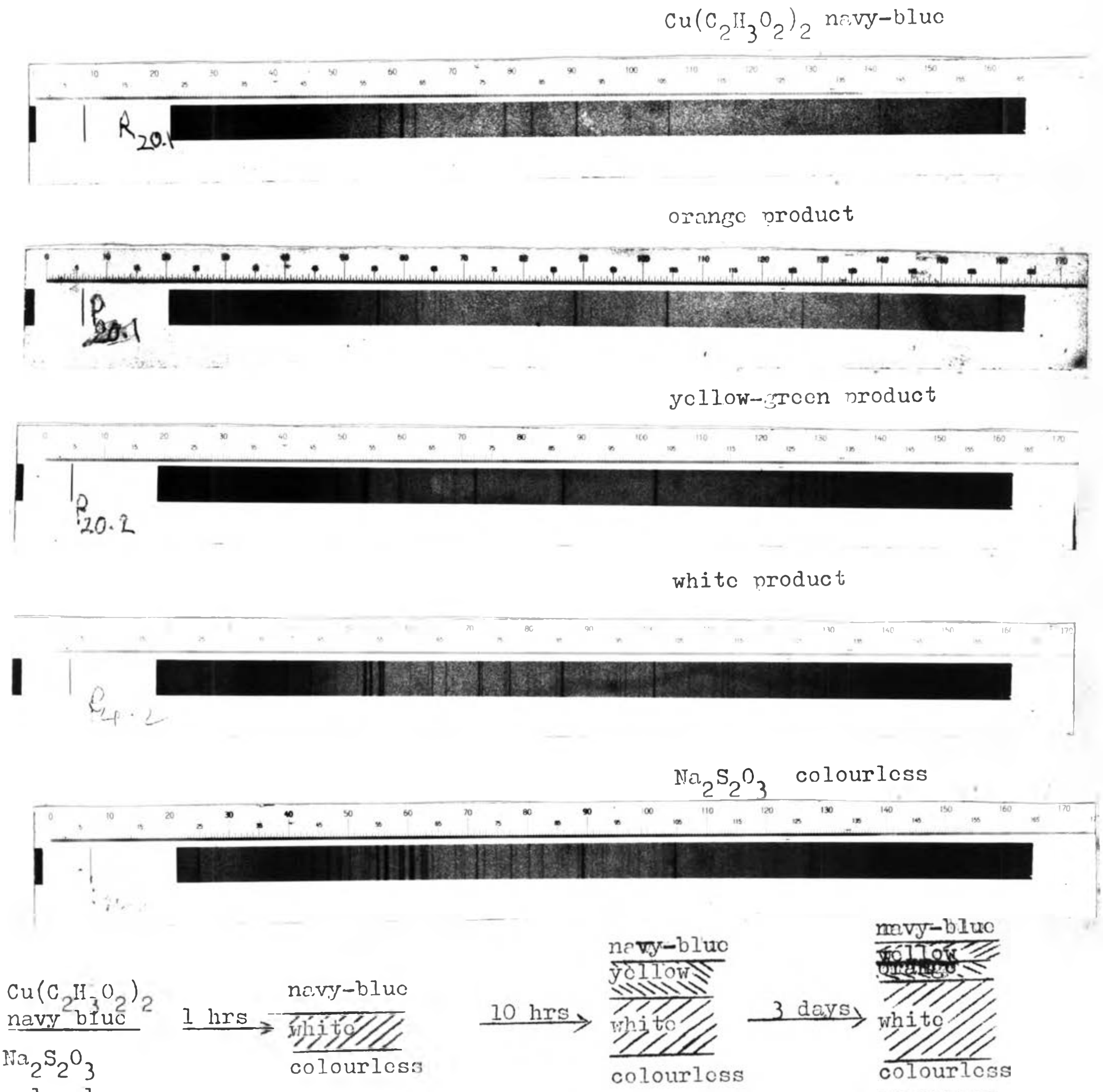
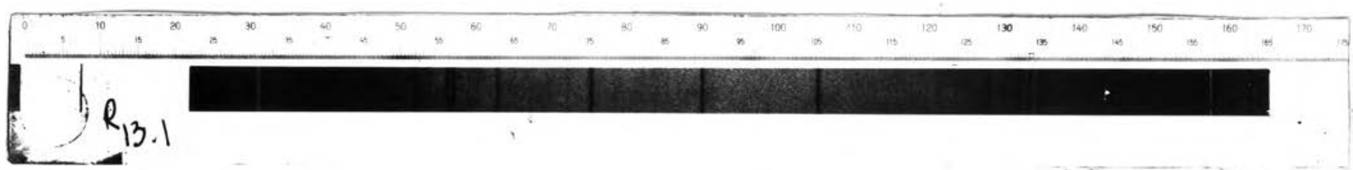


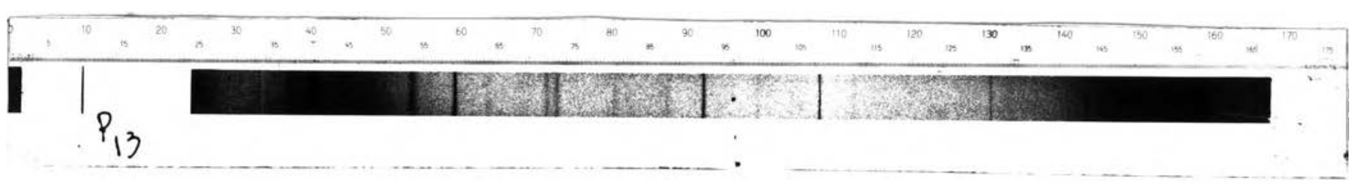
Fig 6.5.1 X-ray powder diffraction pattern of reactant and product of solid-solid reaction. (mixed with Si)

6.5.1.5 $CuCl_2 2H_2O + K_4Fe(CN)_6$

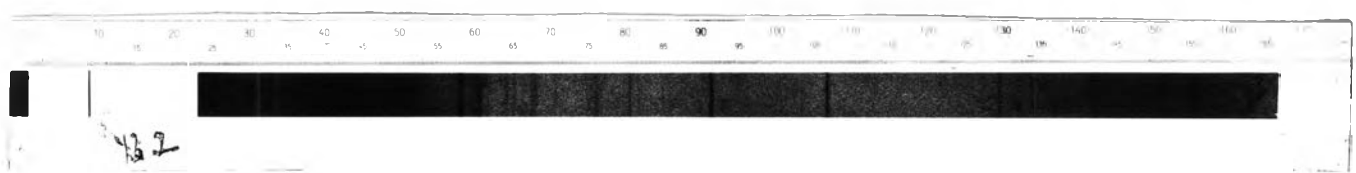
$CuCl_2 2H_2O$ blue-green



black product



$K_4Fe(CN)_6$ pale-yellow



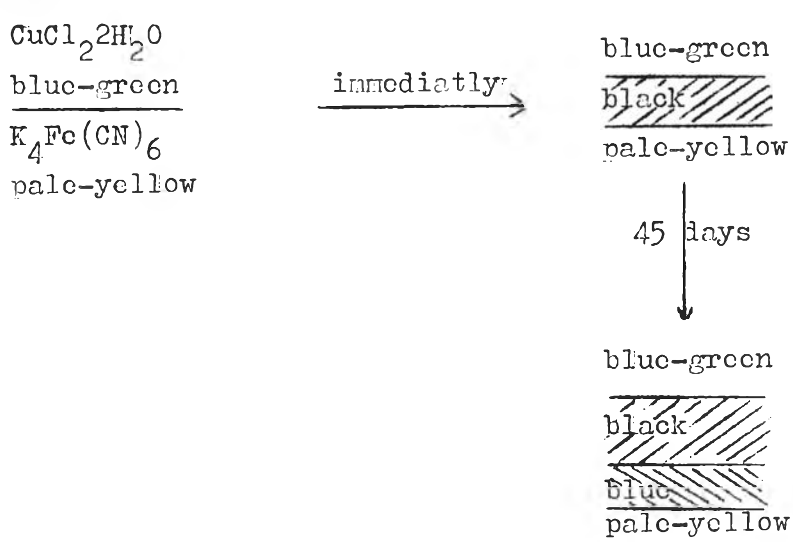


Fig 6.5.1 X-ray powder diffraction pattern of reactant and product of solid-solid reaction. (mixed with Si)

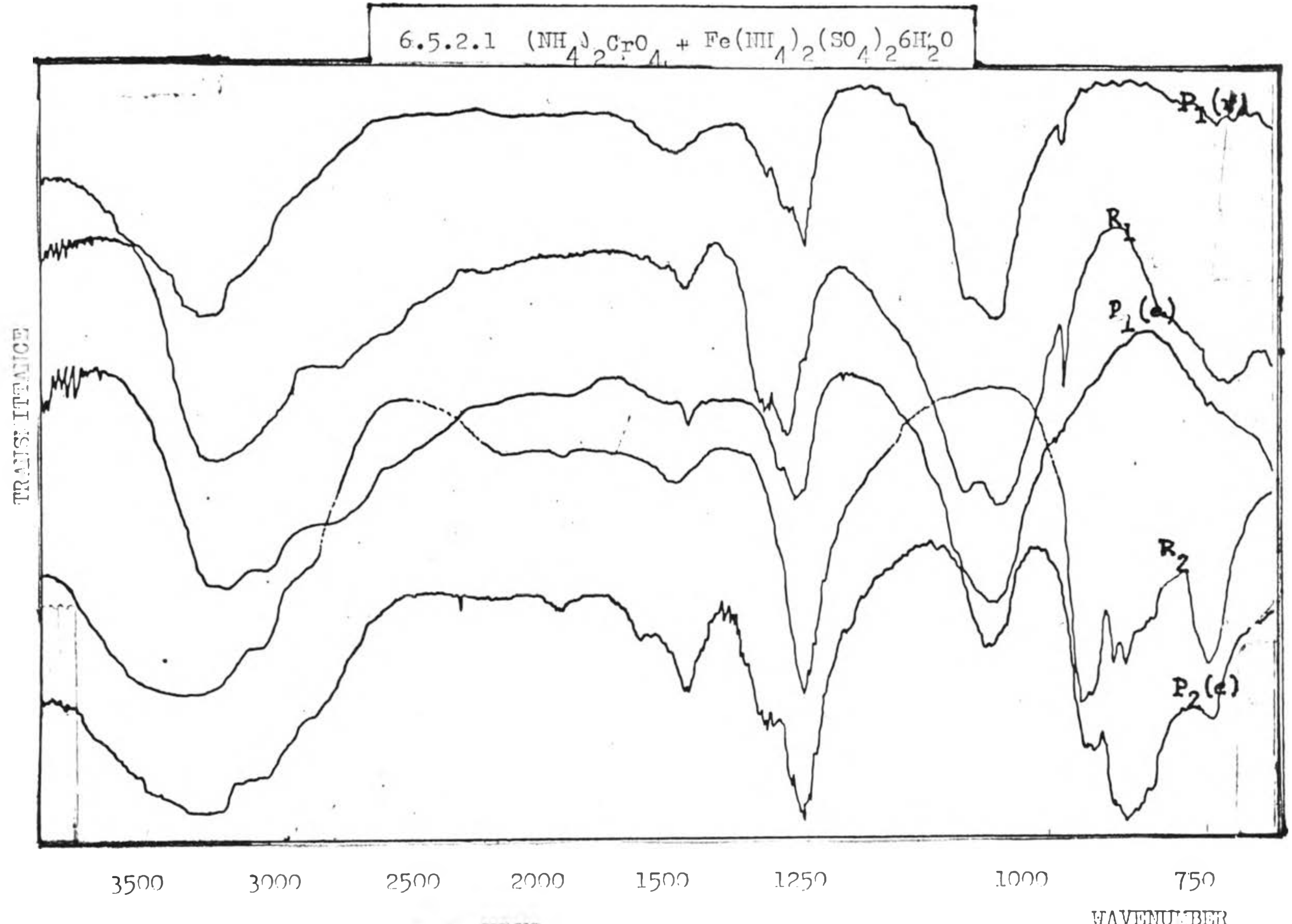
It was found that the position and intensity of reflection lines of X-ray powder diffraction of reactants and their products were different. Some reflection lines, which were similar to those of reactants, were observed in their product part. These distributions showed that a new compound was formed by solid-solid reaction.

In the reaction between $CoSO_4 7H_2O$ + $(NH_4)_2CrO_4$, the position and intensity of reflection lines of three products were distinctly different from their reactants ($CoSO_4 7H_2O$ and $(NH_4)_2CrO_4$) as shown in Fig. 6.5.1.3.

6.5.2 The comparison of infrared spectra of product and reactants

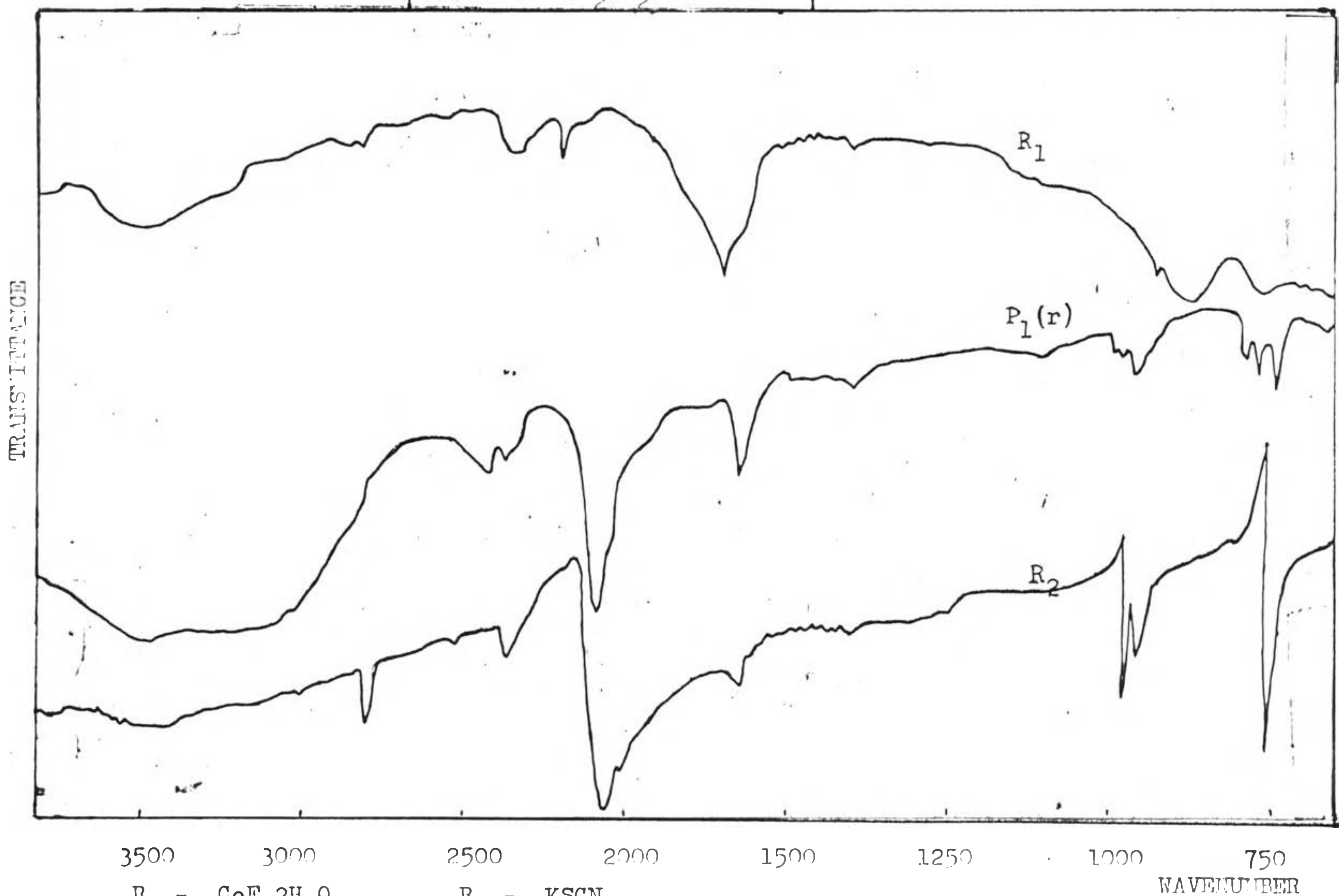
The infrared spectra of product and reactants were compared as shown in Fig 6.5.2.1-6.5.2.20.

R_1	=	first reactant
R_2	=	second reactant
$P_1(r)$	=	first product
$P_n(r)$	=	n^{th} product
$P_1(c)$	=	first product at higher temperature
$P_2(e)$	=	n^{th} product at higher temperature

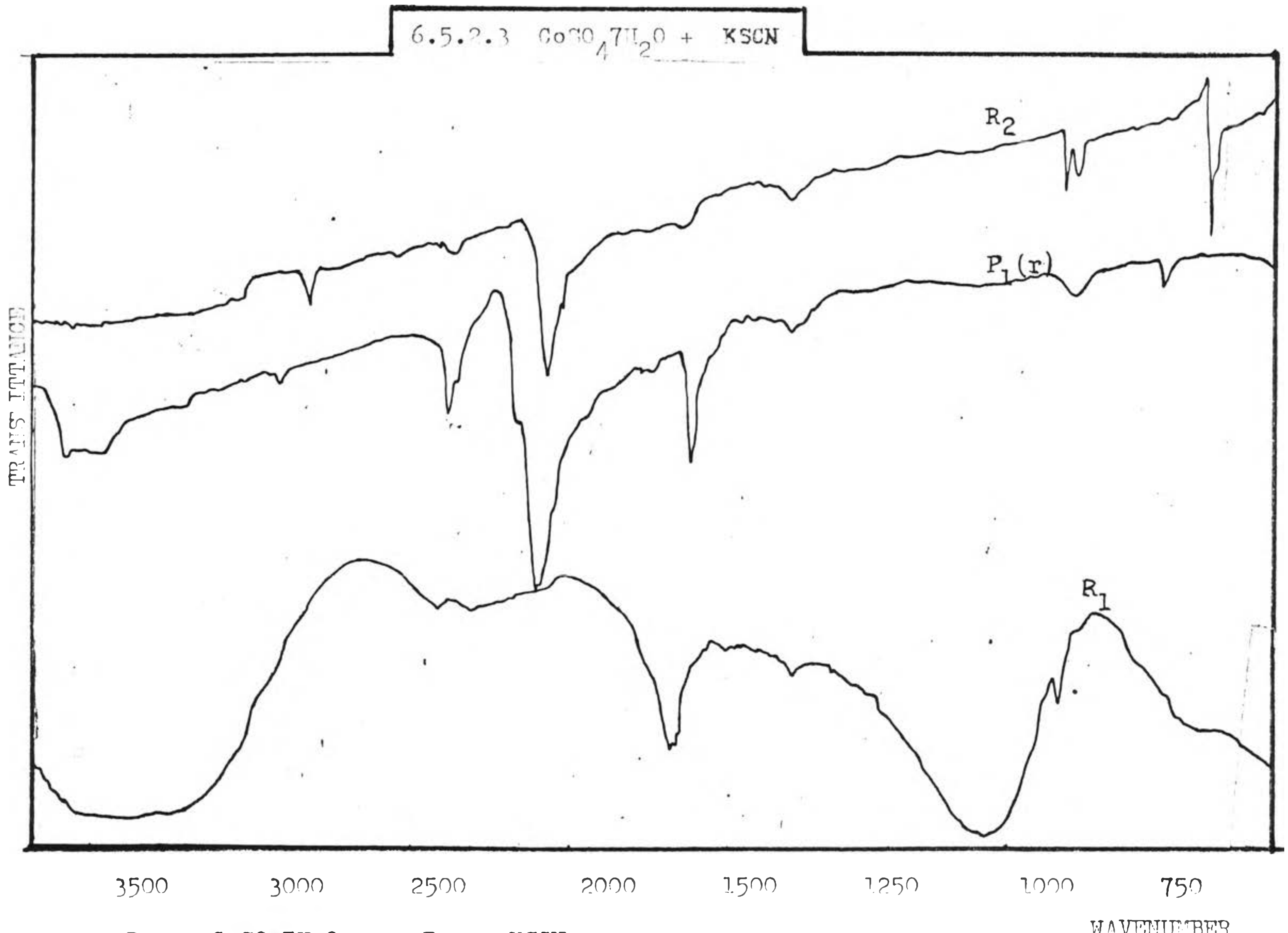


$R_1 = CoF_2 2H_2O$ $R_2 = KSCN$

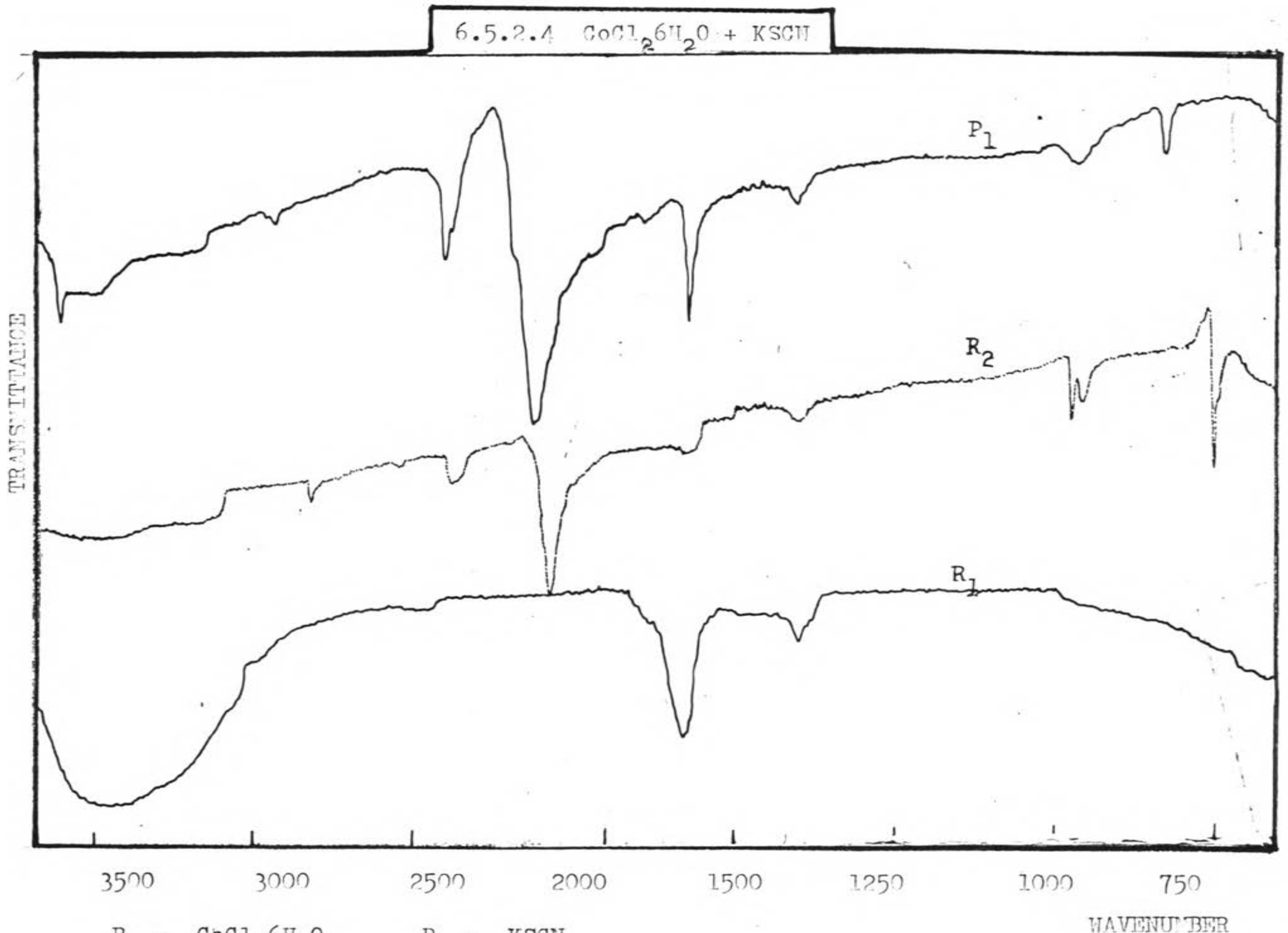
6.5.2.2 $CoF_2 2H_2O$+ KSCN



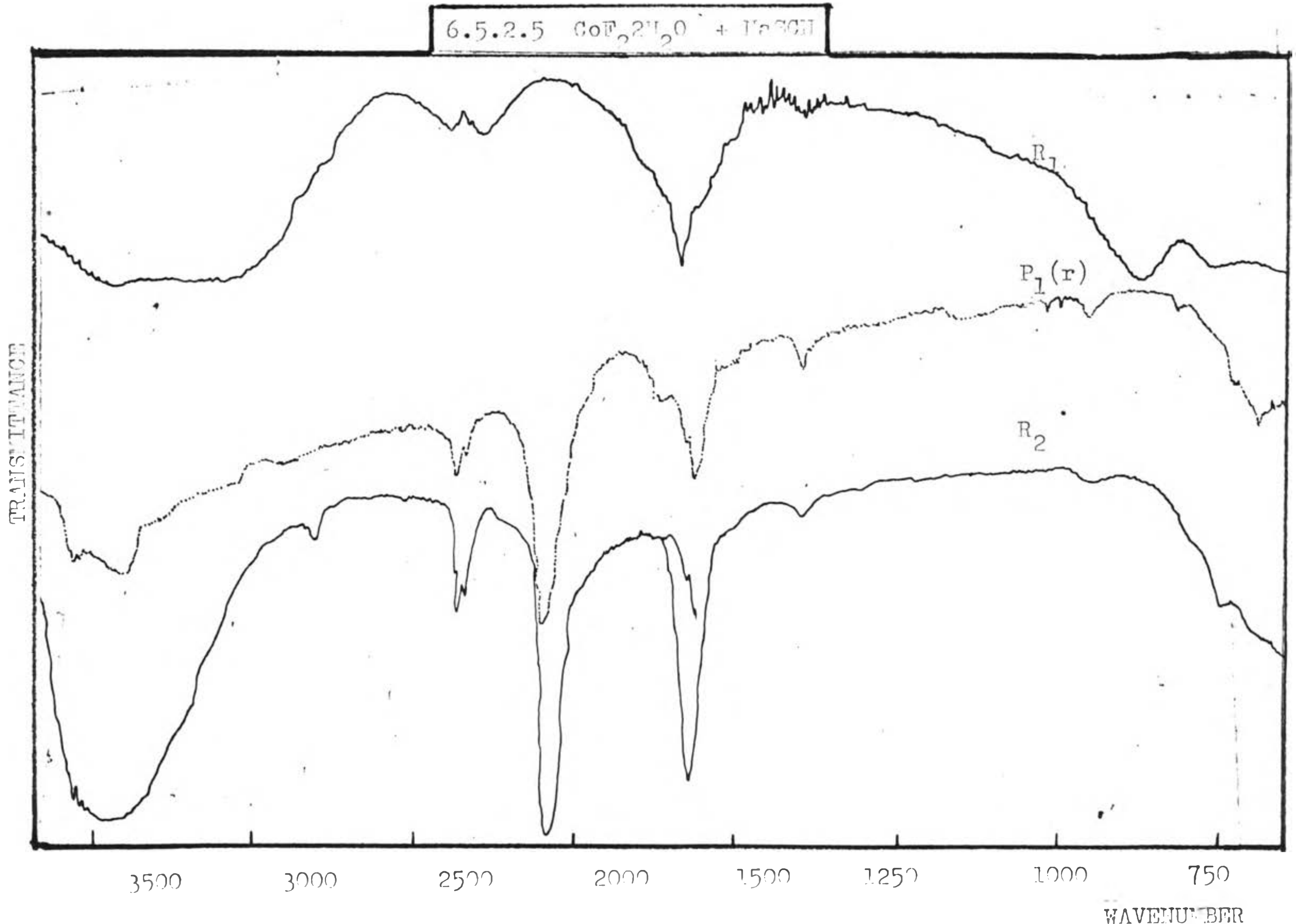
R_1 = $CoF_2 2H_2O$ R_2 = KSCN



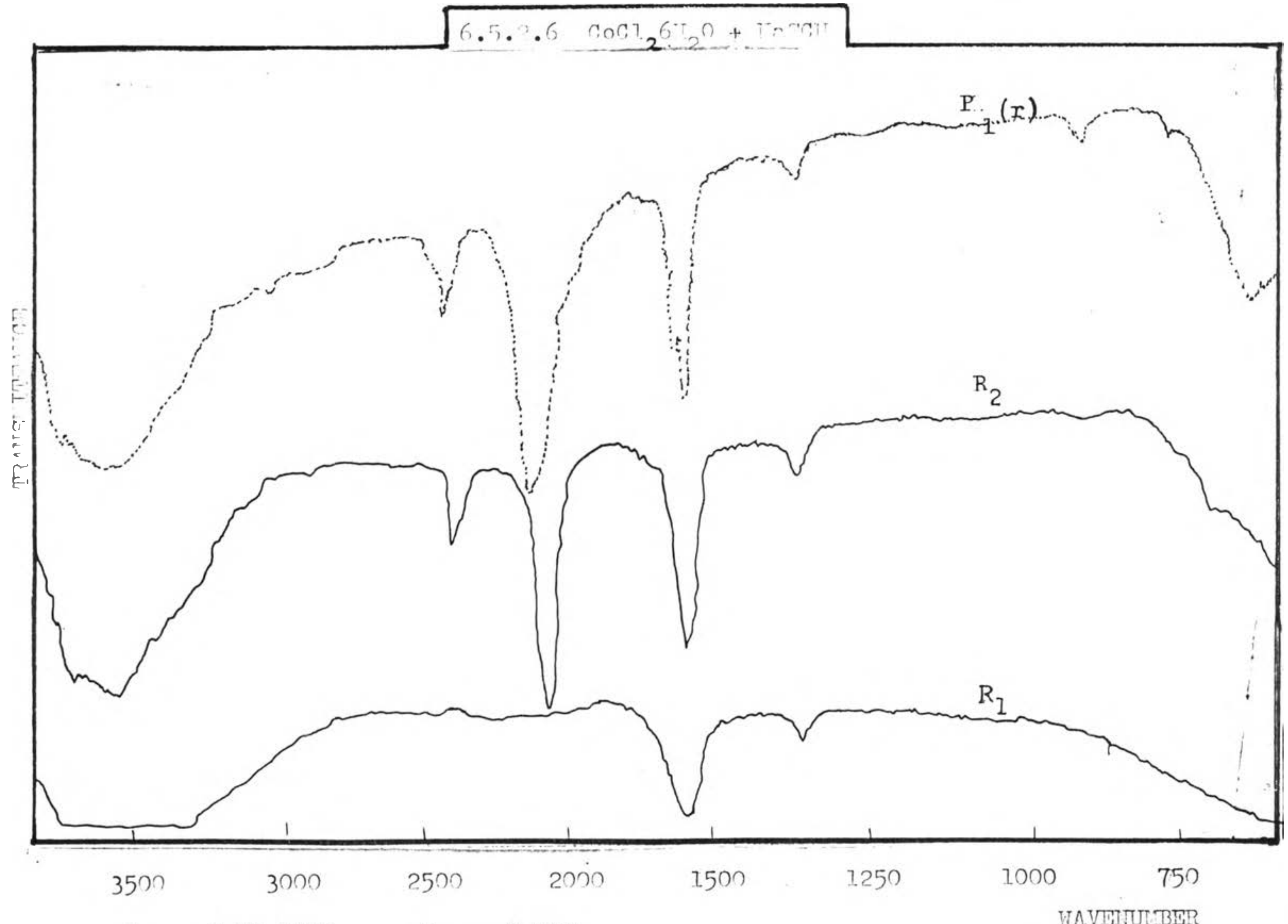
R_1 = $CoSO_4 7H_2O$ R_2 = KSCN



R_1 = $CoCl_2 6H_2O$ R_2 = KSCN

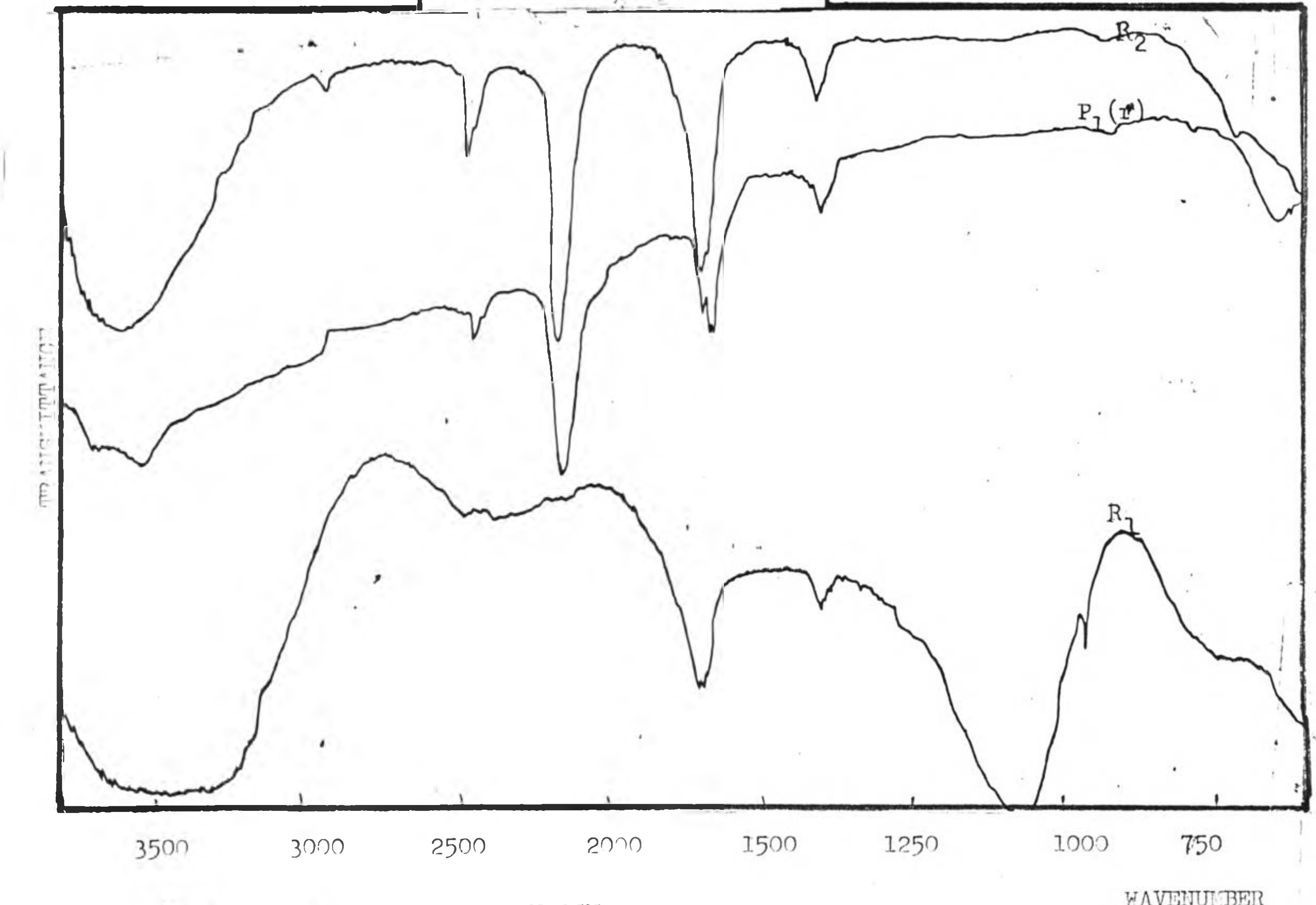


R_1 = $CoF_2 2H_2O$ R_2 = NaSCN



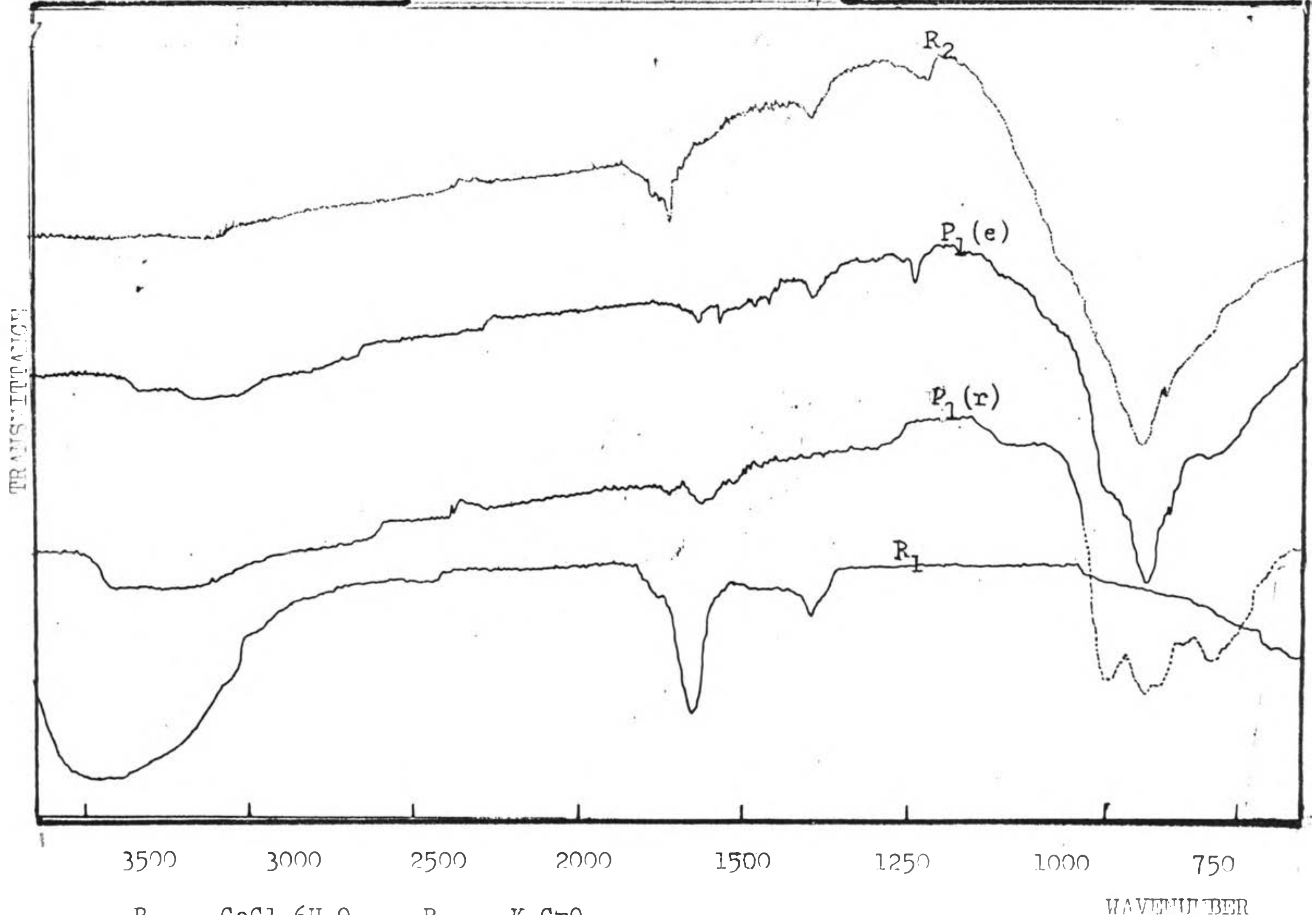
R = $CoCl_2 6H_2O$ R = NaSCN

6.5.2.7 $CoSO_4 7H_2O$ + NaSCN

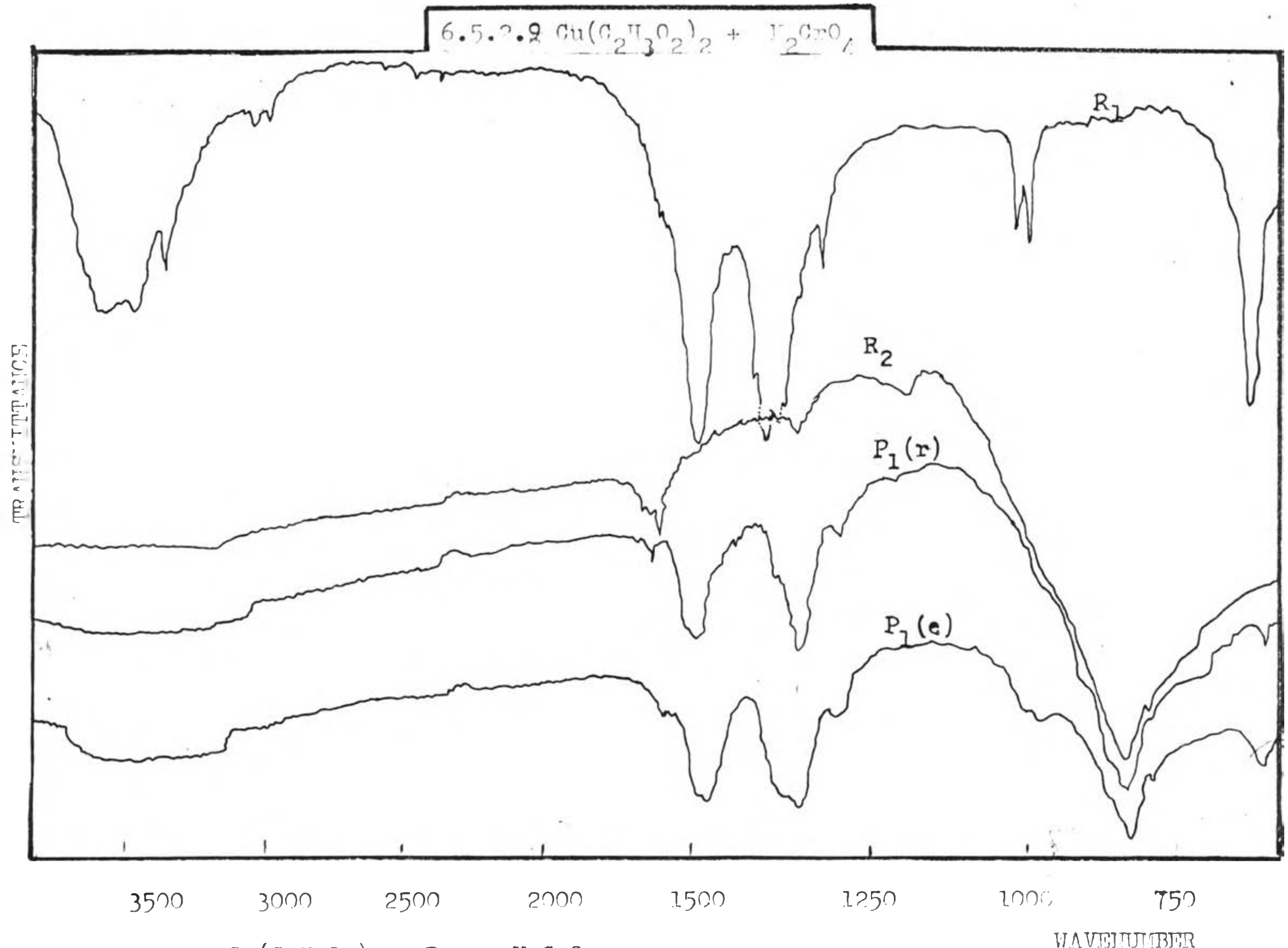


R_1 = $CoSO_4 7H_2O$ R_2 = NaSCN

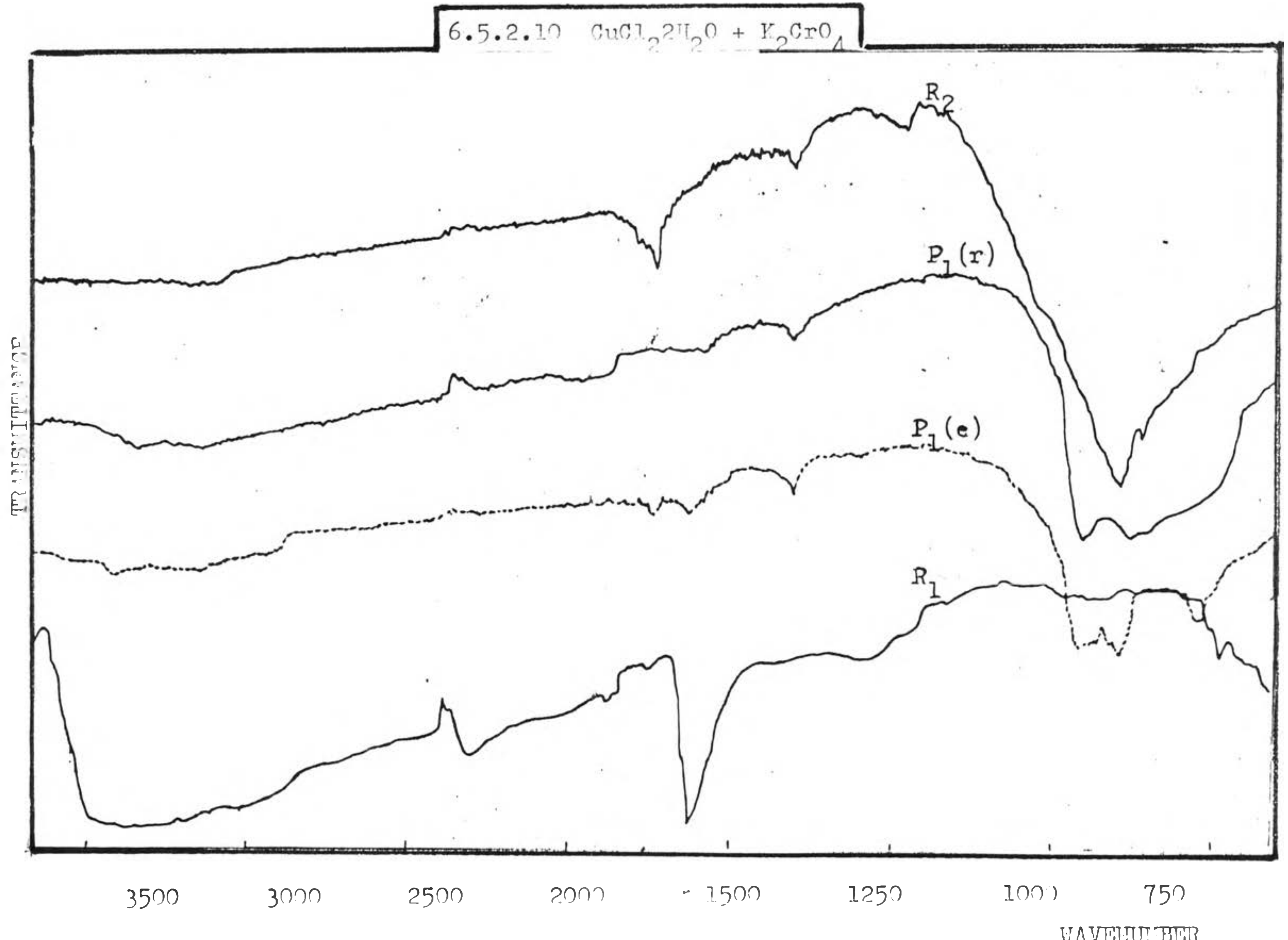
6.5.2.8 $CoCl_2 6H_2O + K_2CrO_4$



R_1 = $CoCl_2 6H_2O$ R_2 = K_2CrO_4

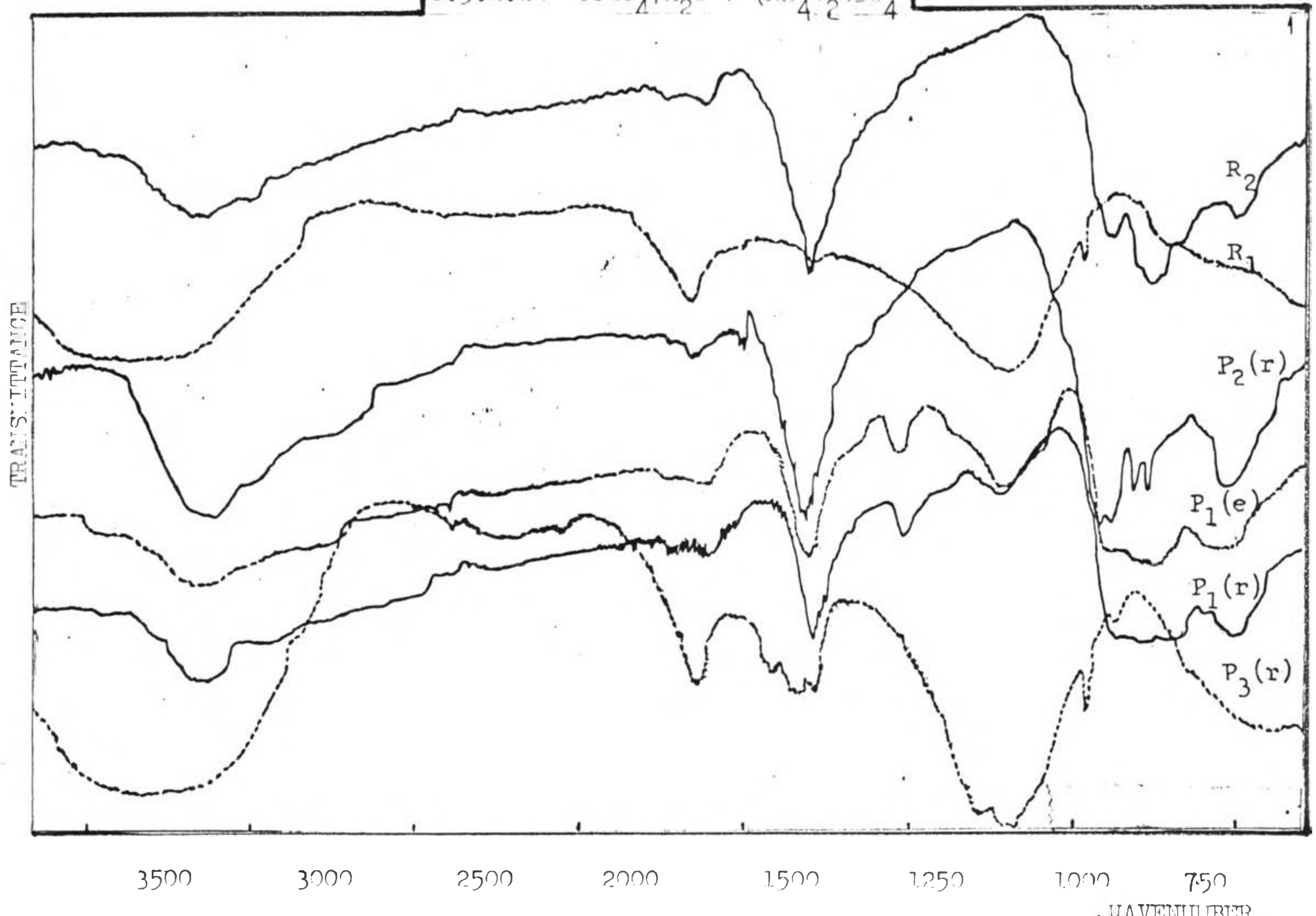


R_1 = $Cu(C_2H_3O_2)_2$ R_2 = K_2CrO_4



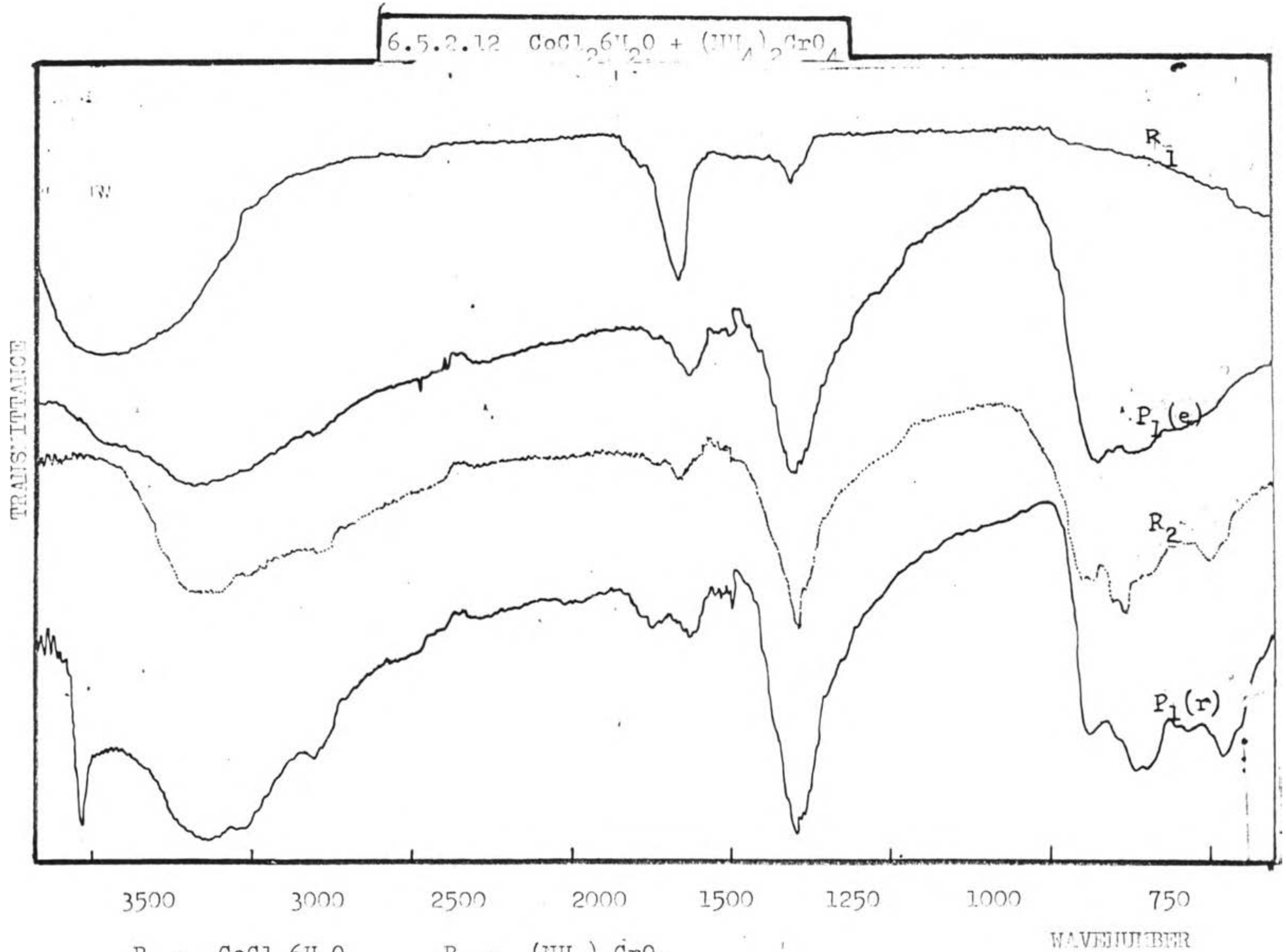
R_1 = $CuCl_2 2H_2O$ R_2 = K_2CrO_4

6.5.2.11 $CoSO_4 7H_2O + (NH_4)_2CrO_4$



R_1 = $CoSO_4 7H_2O$ $P_1(r)$ = black product $P_2(r)$ = orange product

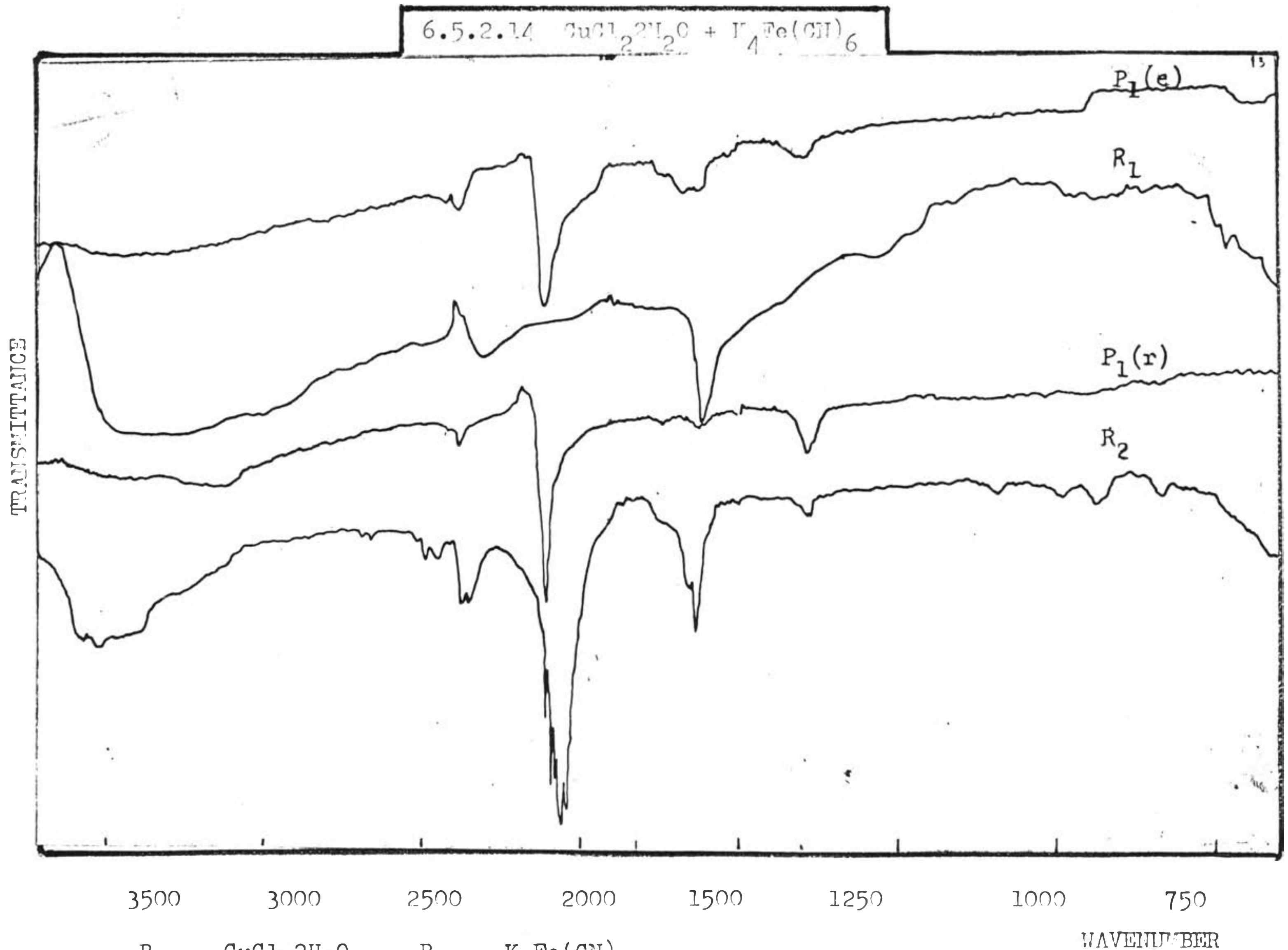
R_2 = $(NH_4)_2CrO_4$ $P_3(r)$ = blue product



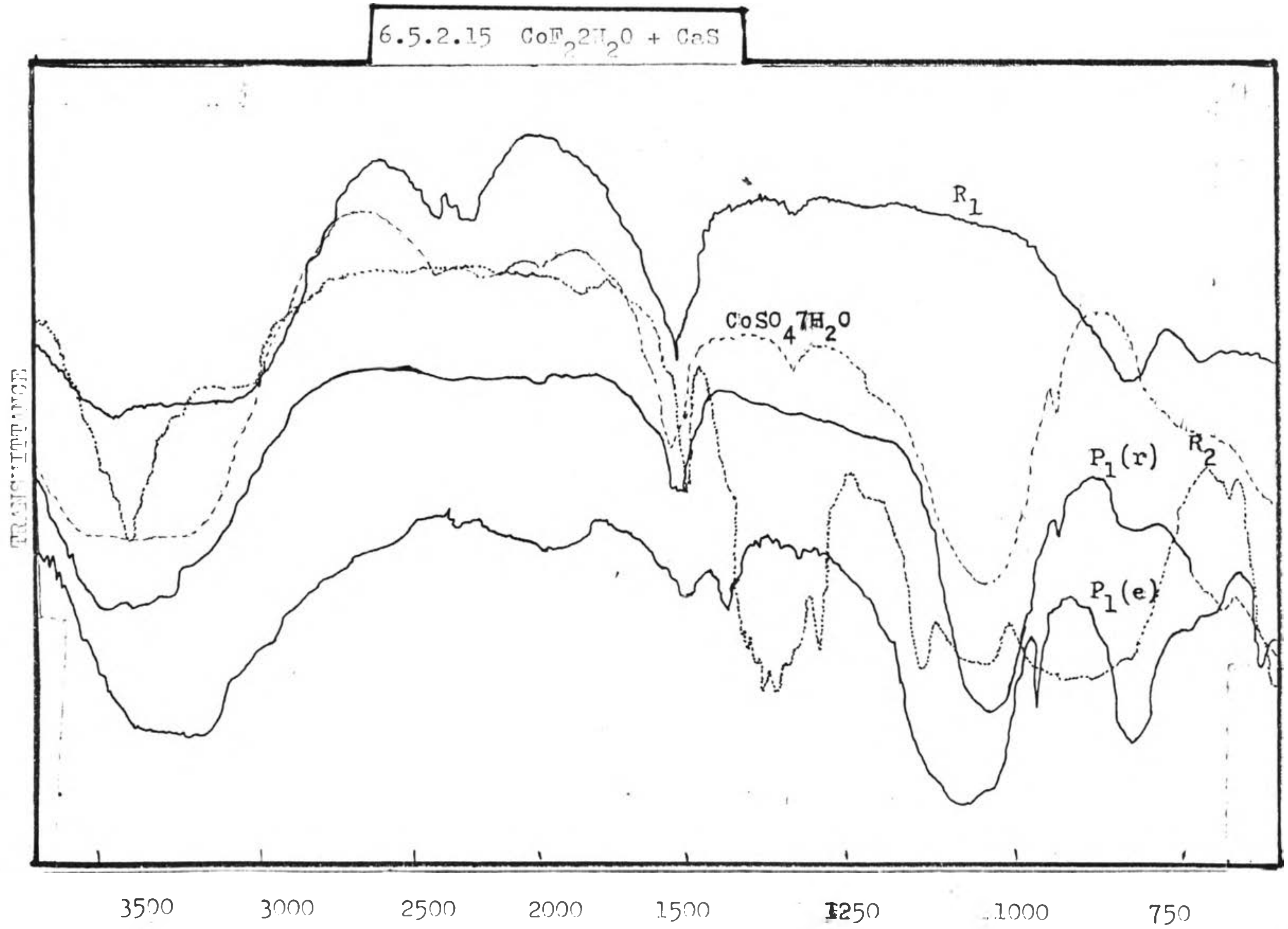
R_1 = $CoCl_2 6H_2O$ R_2 = $(NH_4)_2CrO_4$

6.5.2.13 $CuCl_2 2H_2O$ + $(NH_4)_2CrO_4$

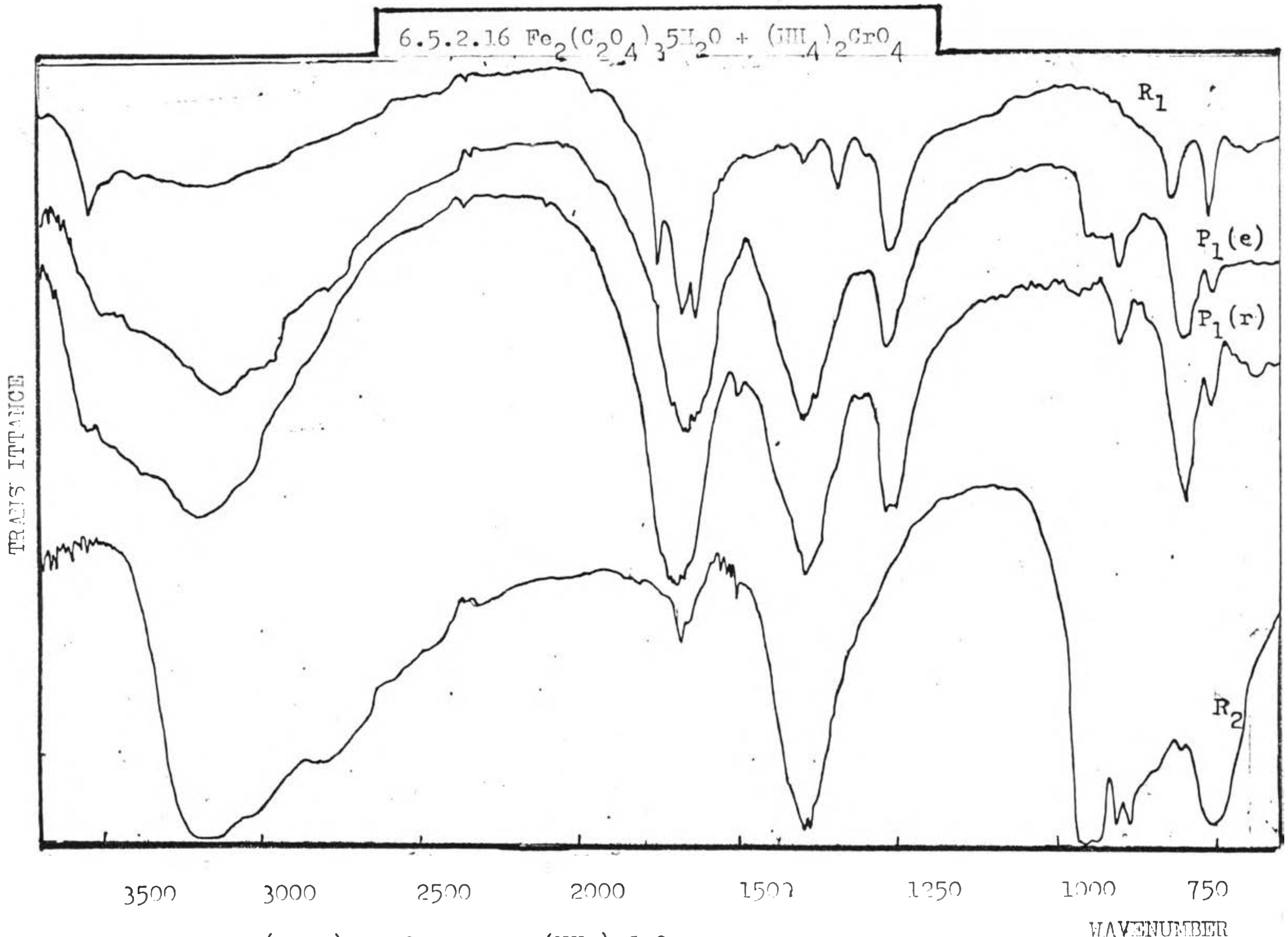
R_1 = $CuCl_2 2H_2O$ R_2 = $(NH_4)_2CrO_4$



R_1 = $CuCl_2 2H_2O$ R_2 = $K_4Fe(CN)_6$

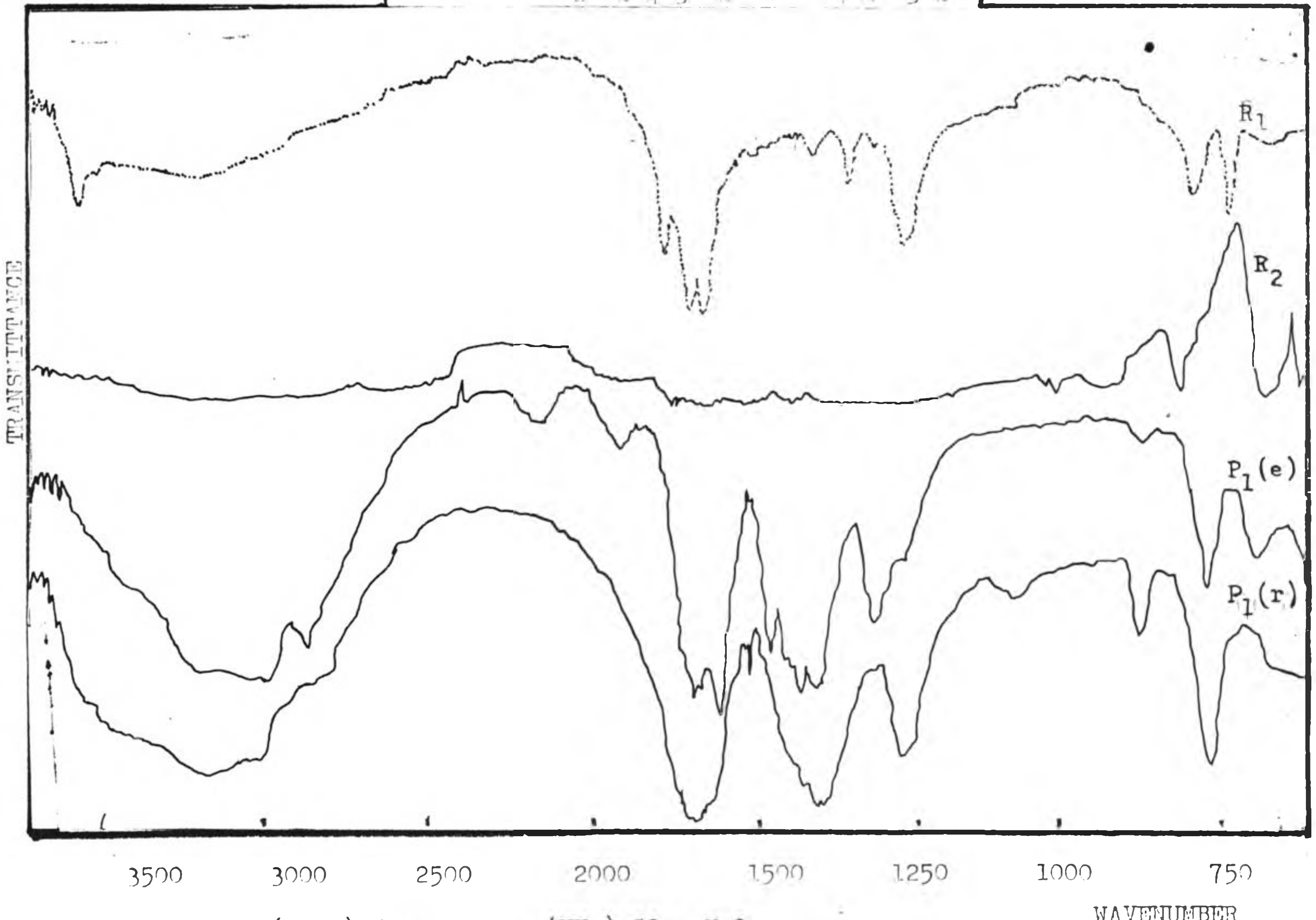


R_1 = $CoF_2 2H_2O$ R_2 = CaS



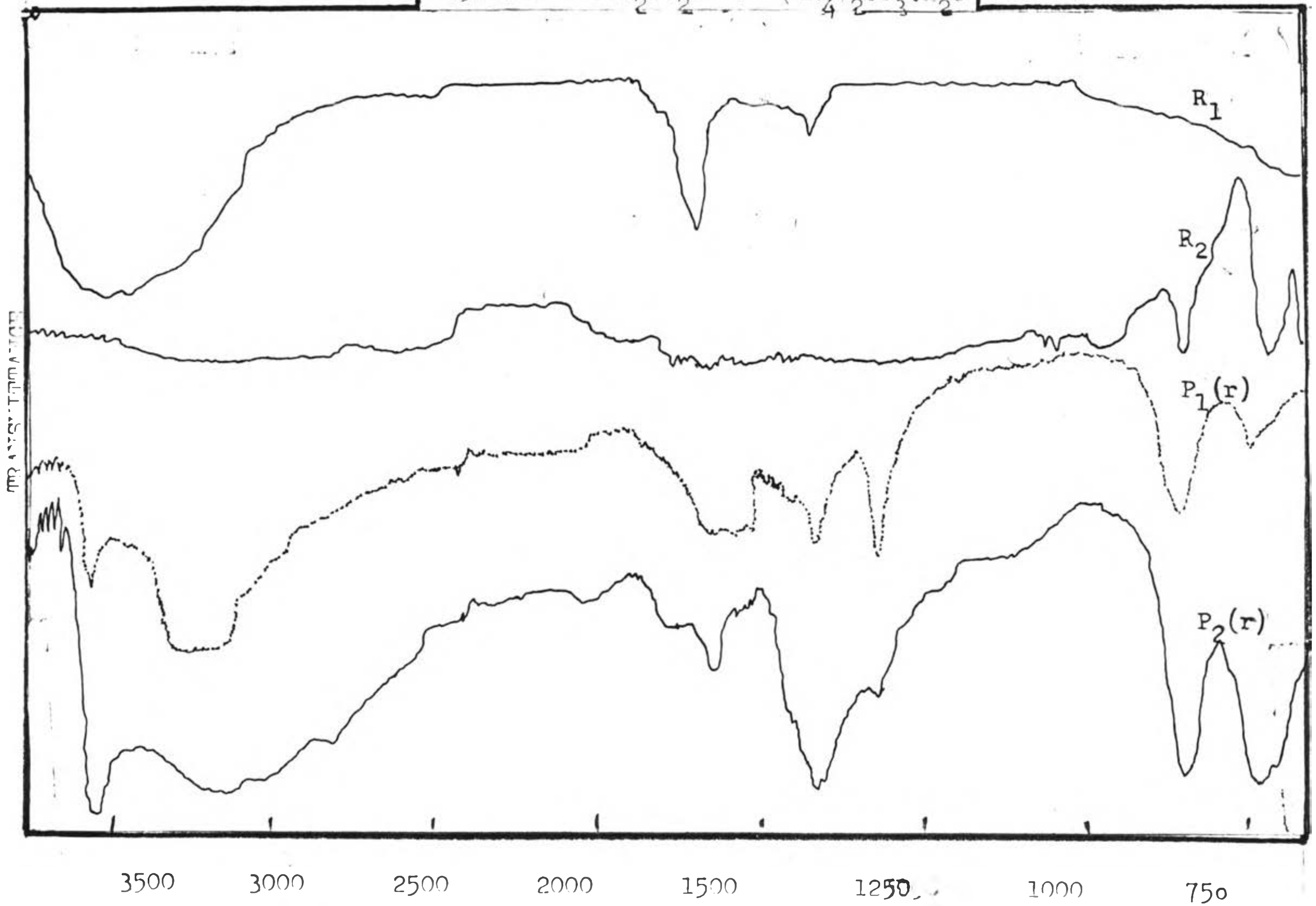
R_1 = $Fe_2(C_2O_4)_3 5H_2O$ R_2 = $(NH_4)_2CrO_4$

6.5.2.17 $Fe_2(C_2O_4)_3 5H_2O$ + $(NH_4)_2CO_3 H_2O$



R_1 = $Fe_2(C_2O_4)_3 5H_2O$ R_2 = $(NH_4)_2CO_3 \cdot H_2O$

6.5.2.18 $CoCl_2 6H_2O$ + $(NH_4)_2CO_3 . H_2O$

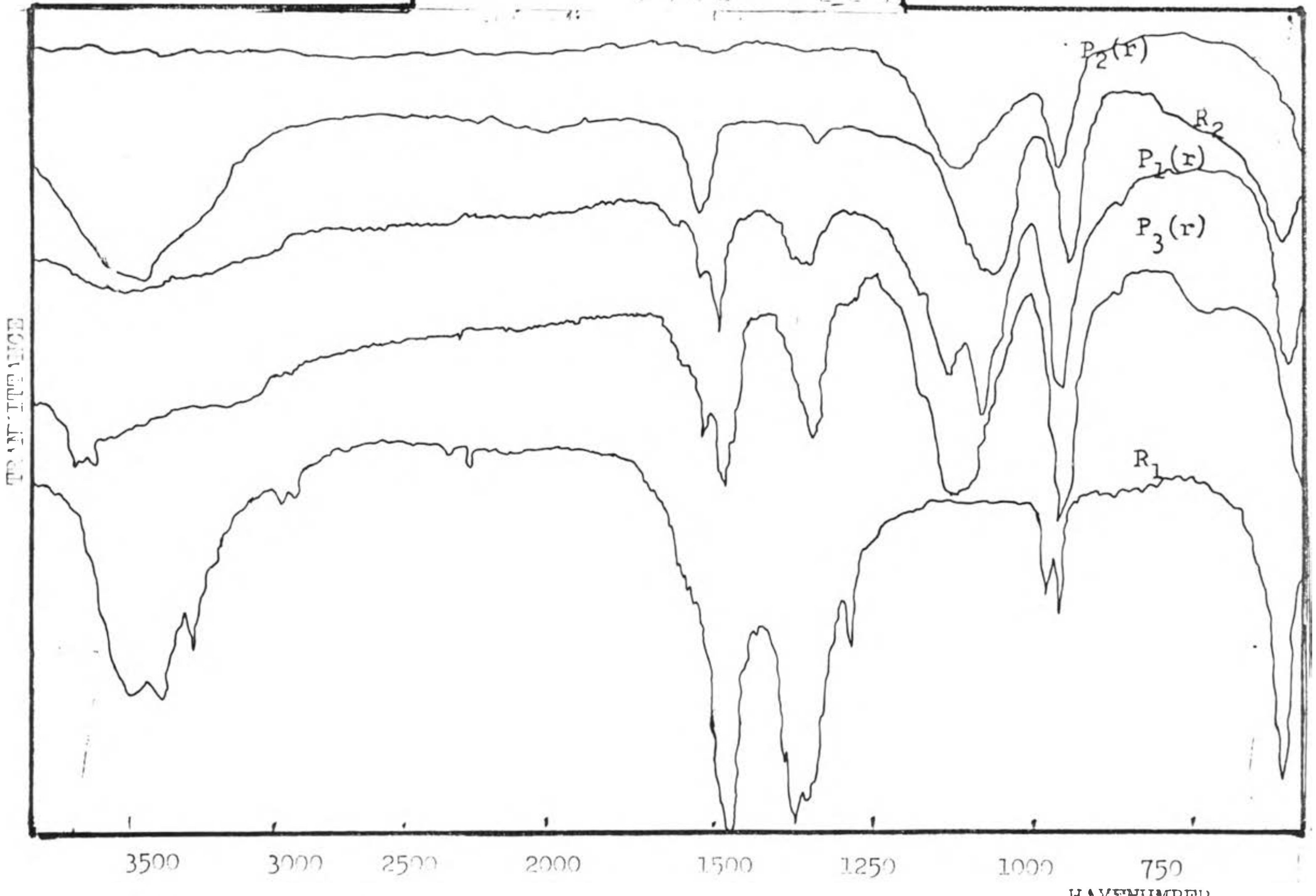


WAVENUMBER

R_1 = $CoCl_2 6H_2O$ $P_1(r)$ = red product

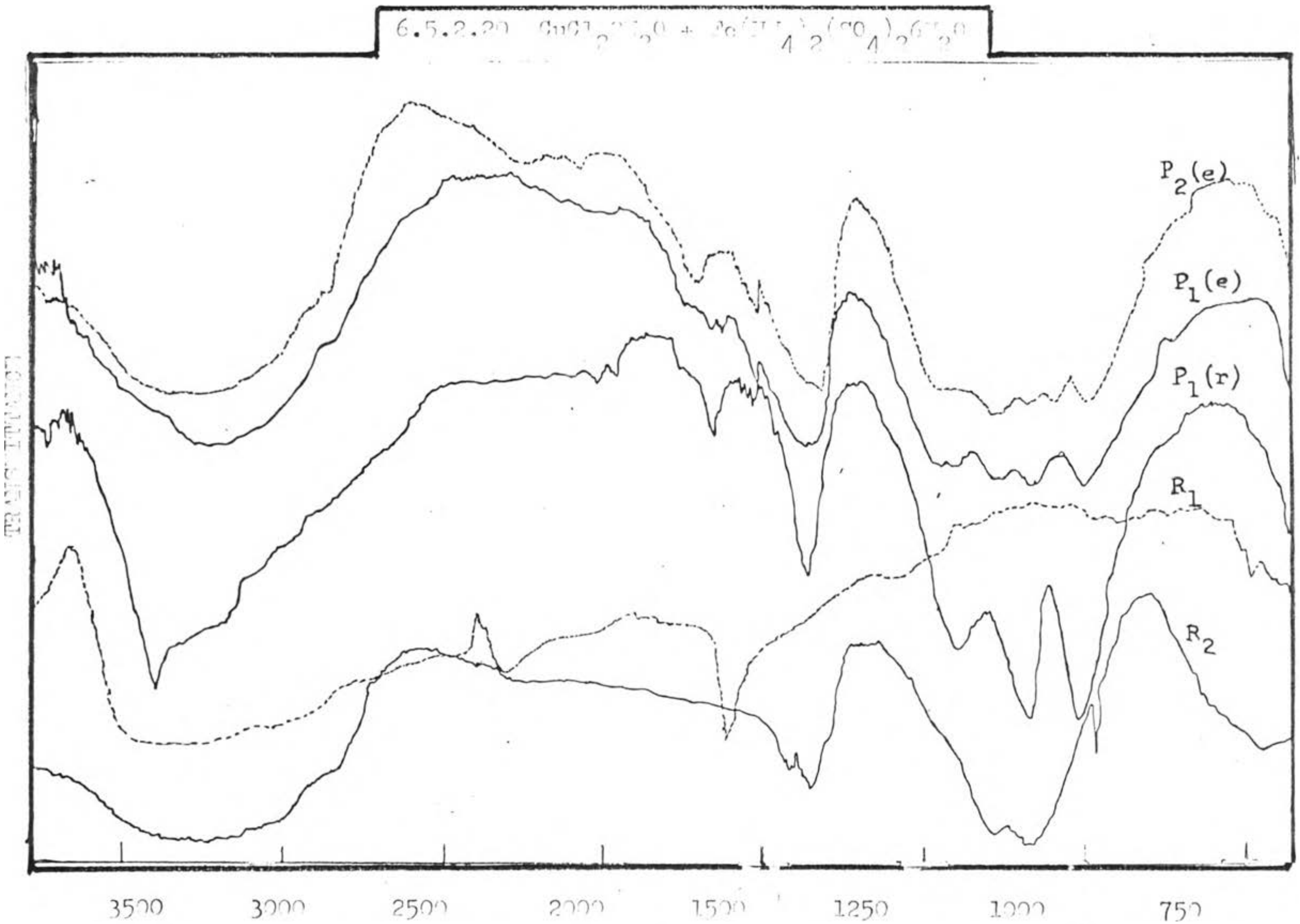
R_2 = $(NH_4)_2CO_3 . H_2O$ $P_2(r)$ = pink product

6.5.2.19 $Cu(C_2H_3O_2)_2$ + $Na_2S_2O_3$



R_1 = $Cu(C_2H_3O_2)_2$, $P_1(r)$ = white product , $P_2(r)$ = yellow product

R_2 = $Na_2S_2O_3$ $P_3(r)$ = orange product



WAVENUMBER

R_1 = $CuCl_2 2H_2O$ $P_1(e)$ = brown product

R_2 = $Fe(NH_4)_2(SO_4)_2 6H_2O$ $P_2(e)$ = green product

There was a limit of wavenumbers in the use of infrared spectra (650-4000 cm^{-1}). The characteristic peak of the functional groups, which could be observed, were SO_4^{2-} (1105 cm^{-1}), NH_4^+ (1400 and 3300 cm^{-1}), CrO_4^{2-} (950 cm^{-1}), SCN^- (2100 cm^{-1}), $C_2H_3O_2^{2-}$ (1250 and 1750 cm^{-1}), $Fe(CN)_6^{4-}$ (2020-2130 cm^{-1}), $C_2O_4^{2-}$ (1450 and 1600 cm^{-1}), CO_3^{2-} (875 and 1400 cm^{-1}), $S_2O_3^{2-}$ (1100 and 1250 cm^{-1}).

In the reaction between $CoCl_2 6H_2O$ and $(NH_4)_2CrO_4$ (Fig. 6.5.2.12), and extra spectrum peak of product at 3540 cm^{-1} showed that the new structure was constructed by the rearrangement of involved species. The metal-NH_4^+ bond might provide a new peak at 3540 cm^{-1}. The products between $CoCl_2 6H_2O$ and $(NH_4)_2CO_3$ displayed similar peak at 3540 cm^{-1}. The infrared spectra of $(NH_4)_2CO_3$ did not show the characteristic peak of N-H bending at 1400 cm^{-1}, while the two products of this reaction (red and pink) showed a peak at 1400 cm^{-1}.

The distribution of reagent species in every reaction found by infrared spectra of their products showed that the migration process was the diffusion mechanism in solid-solid reaction. It was also found that some species could be changed into a new form such as reaction of $CoF_2 2H_2O$ + CaS, its product showed only the infrared spectra of $CoSO_4 7H_2O$ which was different from the spectra of $CoF_2 2H_2O$ and CaS as compared in Fig. 6.5.2.15.

The several lines which were observed in the pattern of X-ray powder diffraction could be used to confirm in that strange event of forming this product when compared with those of reactant patterns.

6.6 Conductivity measurements

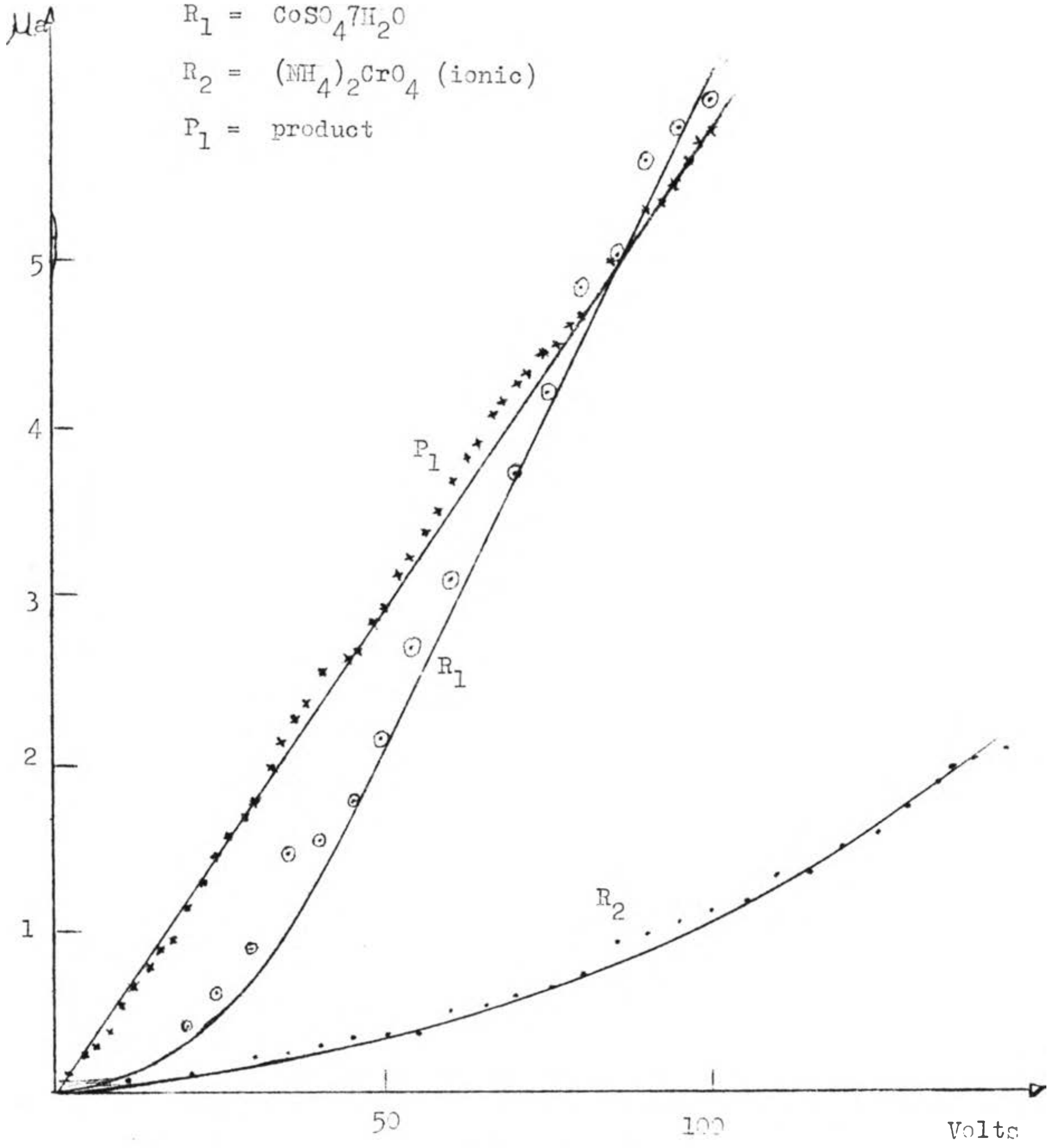


Fig 6.6.1 The comparison of conductance between product and reactant in the solid-solid reaction of $CoSO_4 7H_2O$ + $(NH_4)_2CrO_4$

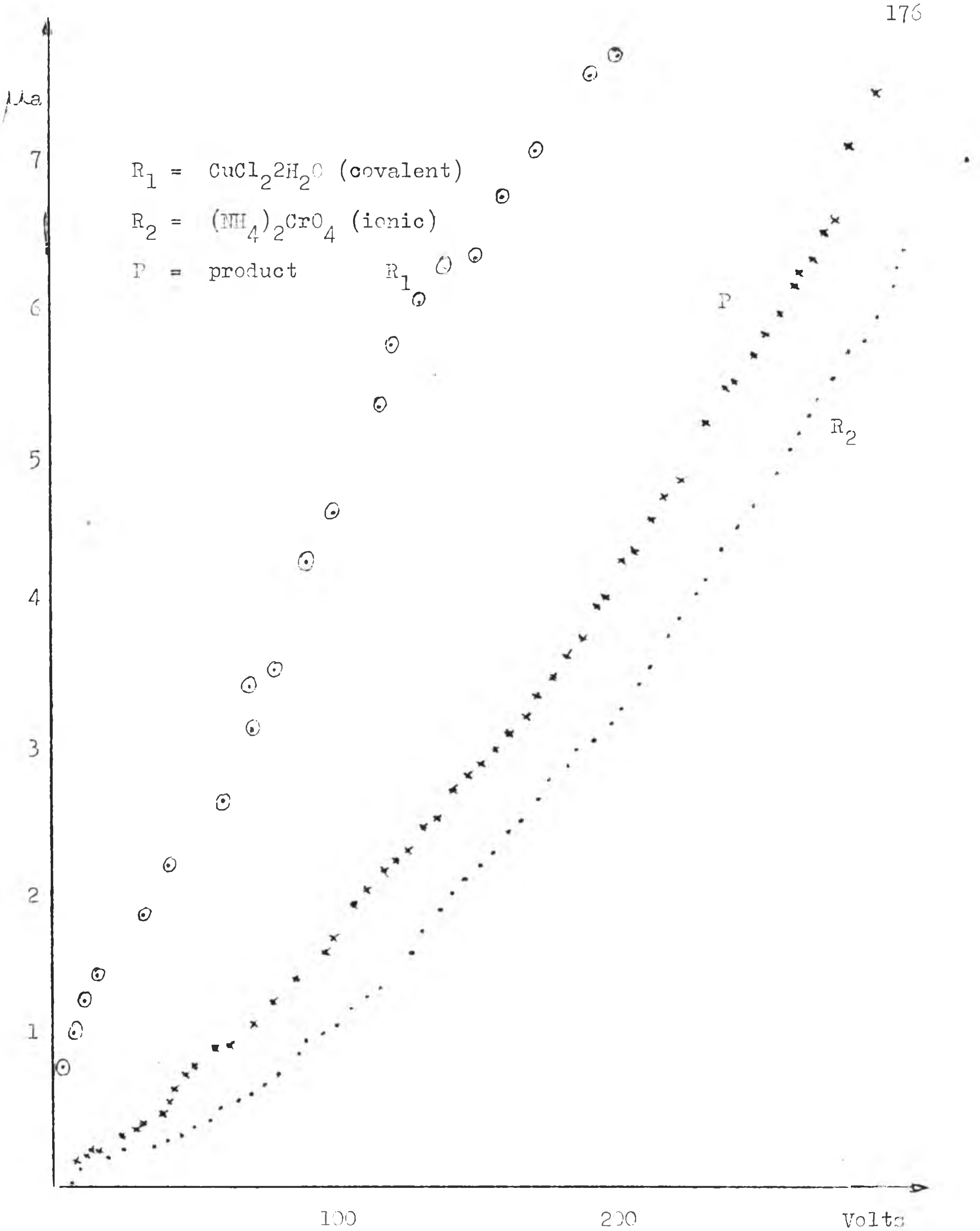


Fig 6.6.2 The comparison of conductance of product and reactant in the solid-solid reaction of $CuCl_2 2H_2O$ + $(NH_4)_2CrO_4$

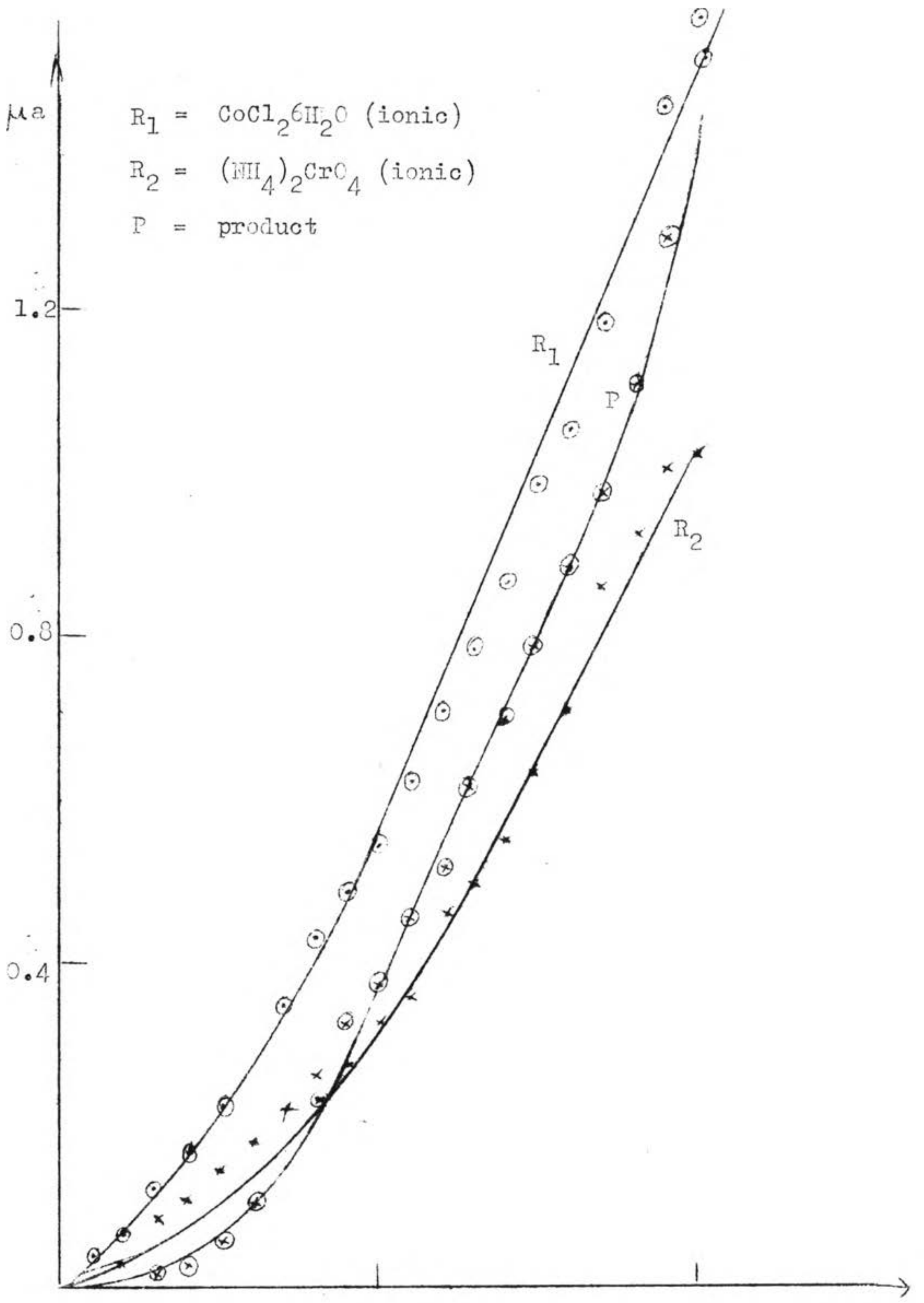


Fig. 6.6.3 The comparison of conductance between product and reactant in the solid-solid reaction of $CoCl_2 6H_2O + (NH_4)_2CrO_4$

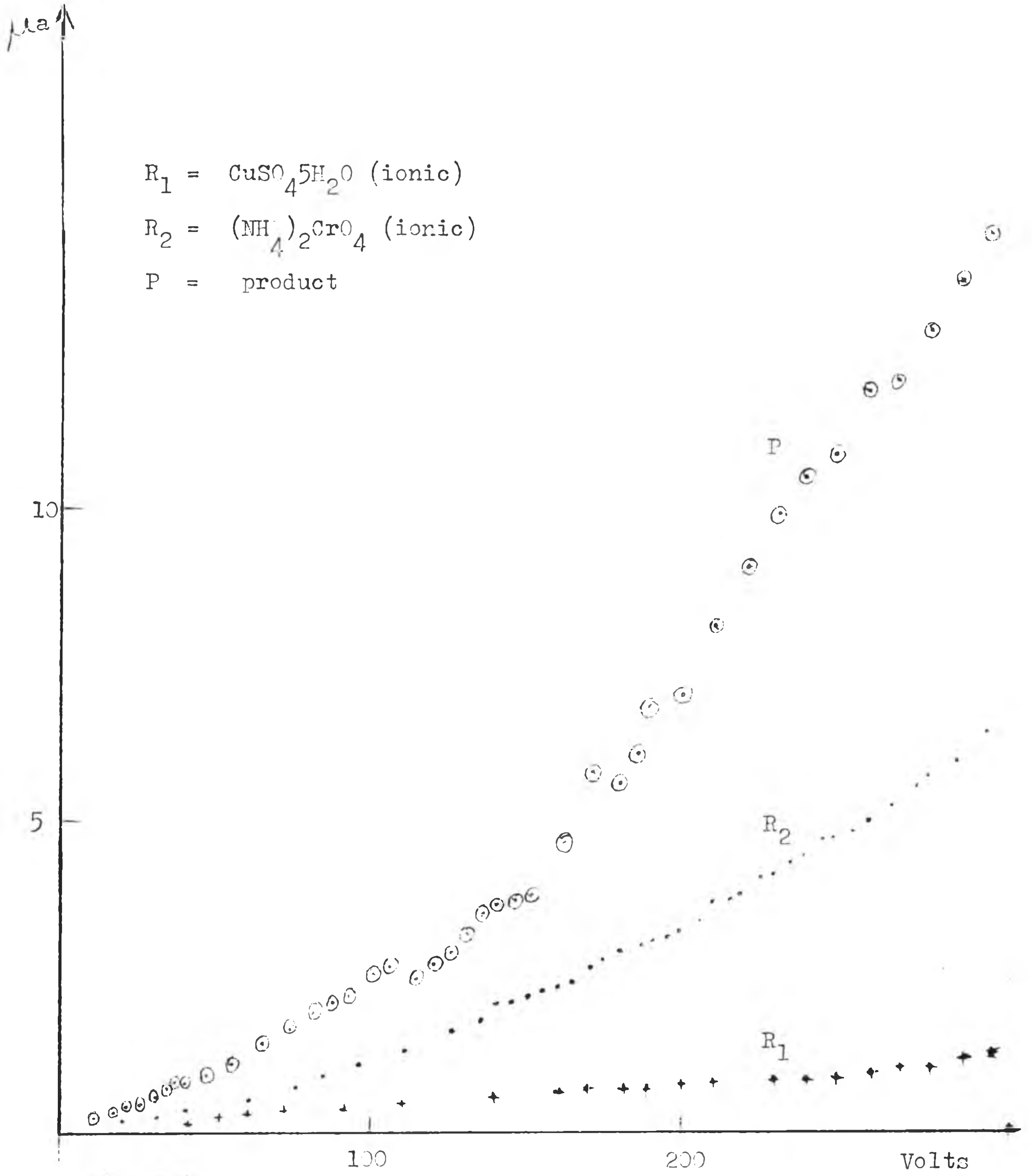


Fig.6.6.4 The comparison of conductance between product and reactant in the solid-solid reaction of $CuSO_4 5H_2O$ + $(NH_4)_2CrO_4$

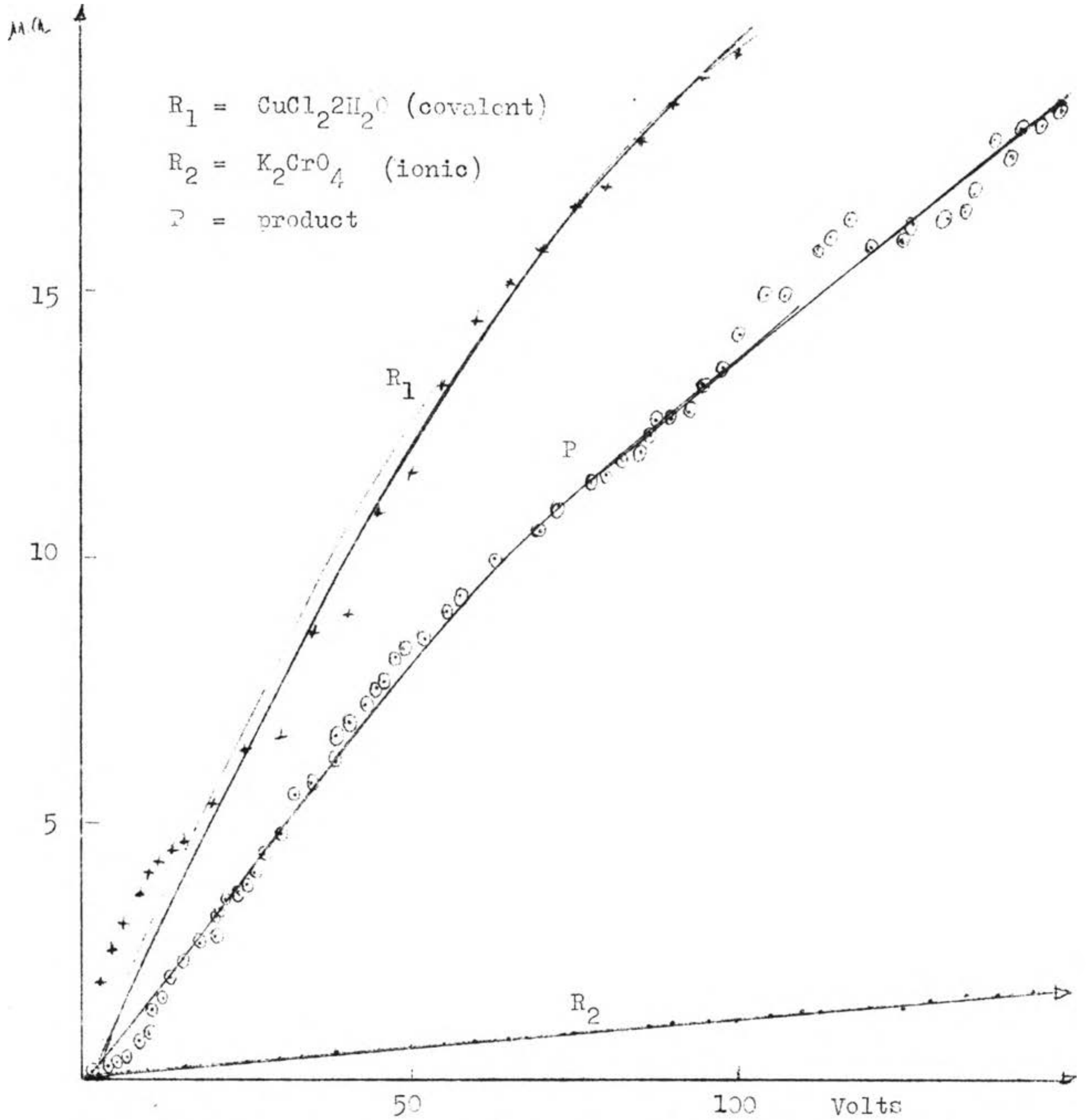


Fig 6.6.5 The comparison between conductance of product and reactant in the solid-solid reaction of $CuCl_2 + K_2CrO_4$.

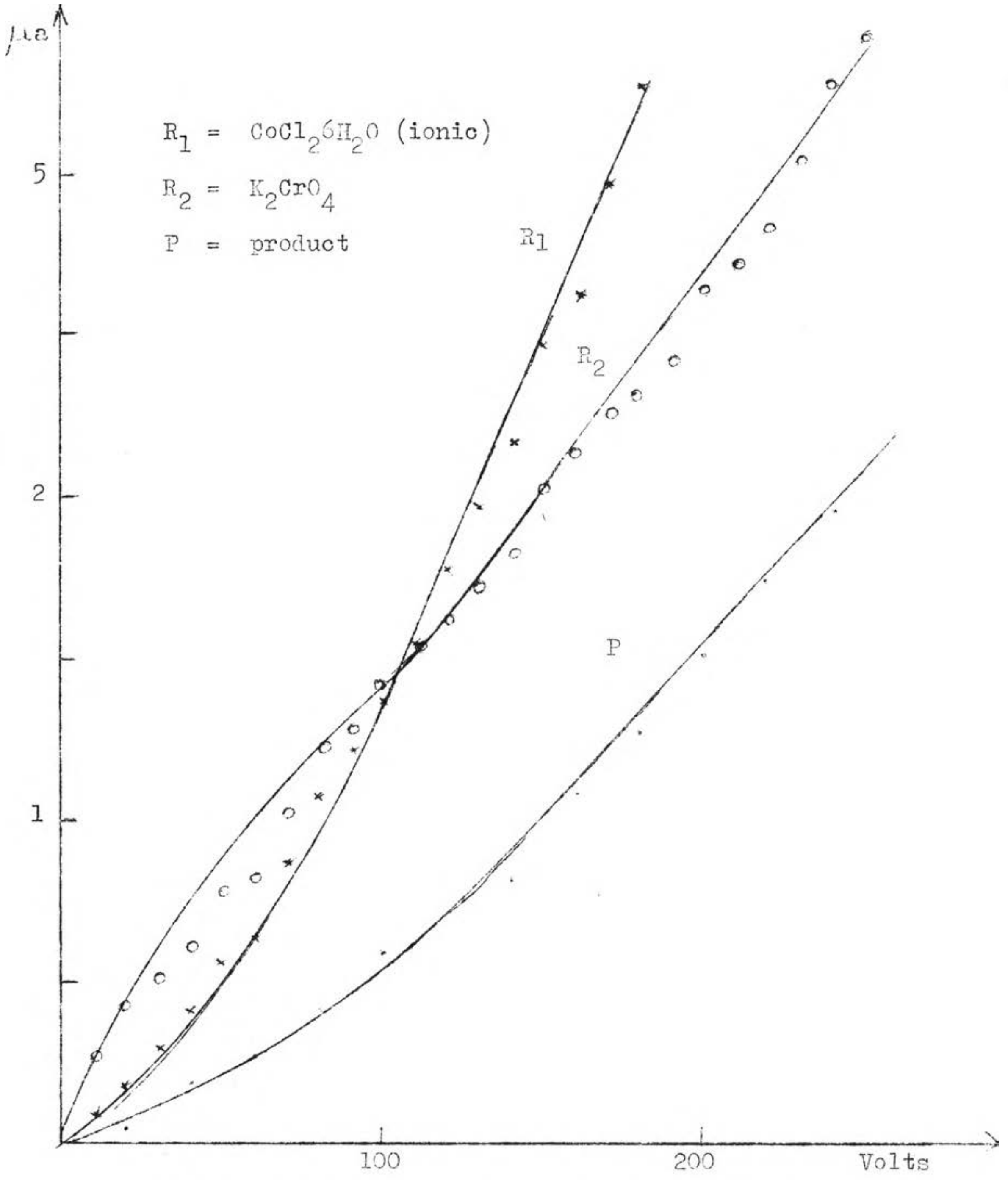


Fig 6.6.6 The comparison between conductance of product and reactant in the solid-solid reaction of $CoCl_2 6H_2O$ + K_2CrO_4.

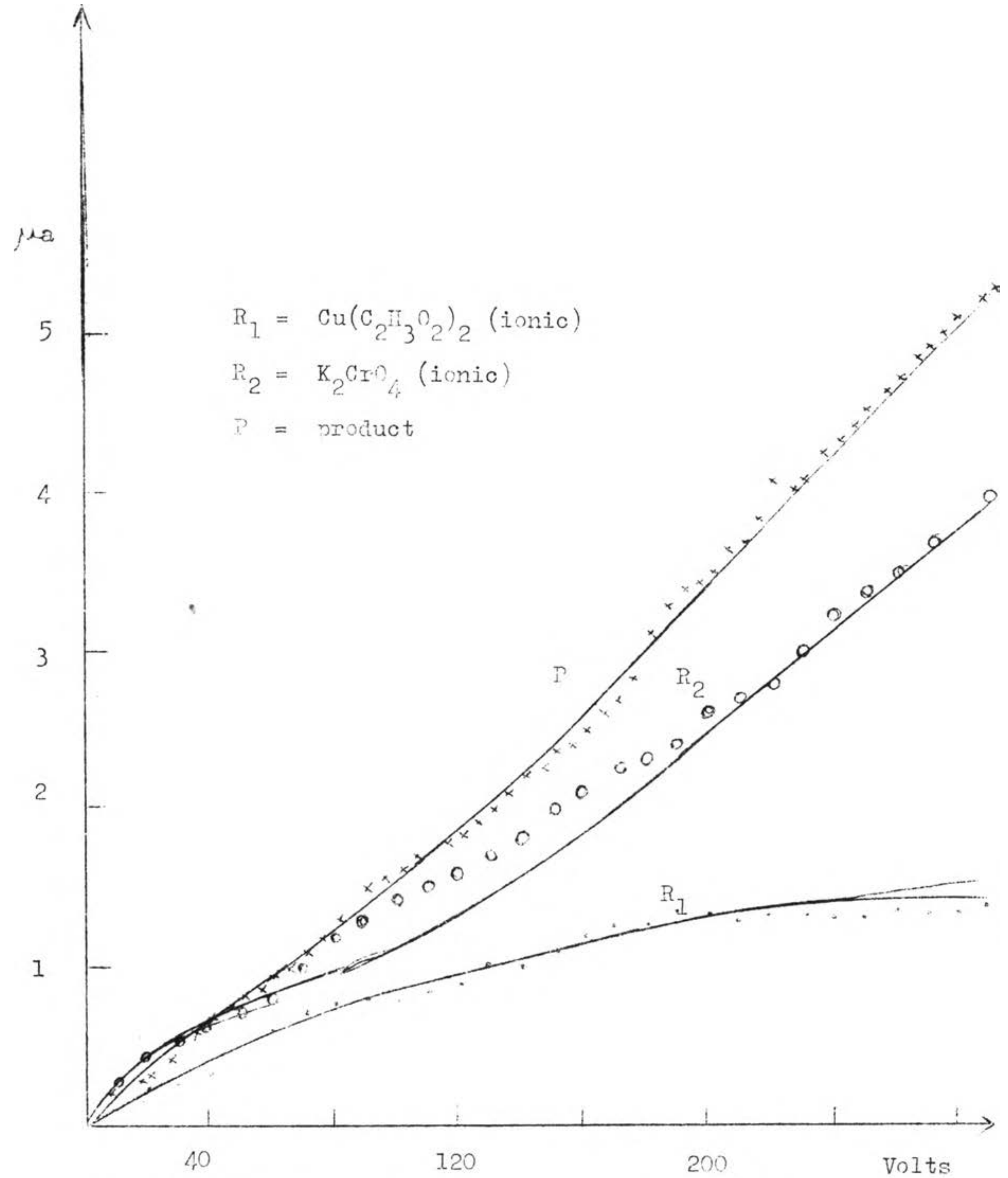


Fig 6.6.7 The comparison between conductances of product and reactant in the solid-solid reaction of $Cu(C_2H_3O_2)_2$ + K_2CrO_4.

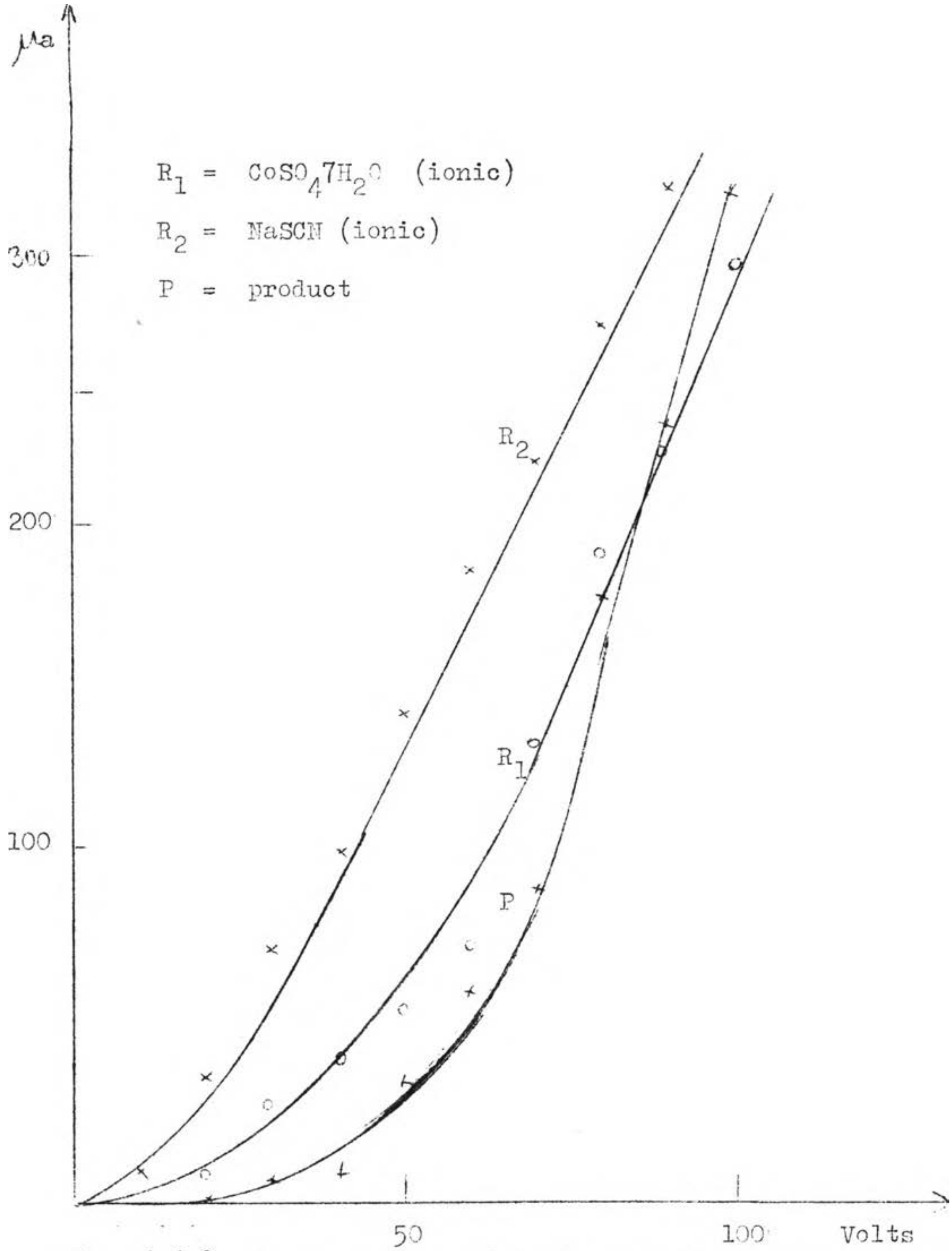


Fig. 6.6.8 The comparison of conductance between product and reactant in the solid-solid reaction of $CoSO_4 7H_2O$ + NaSCN

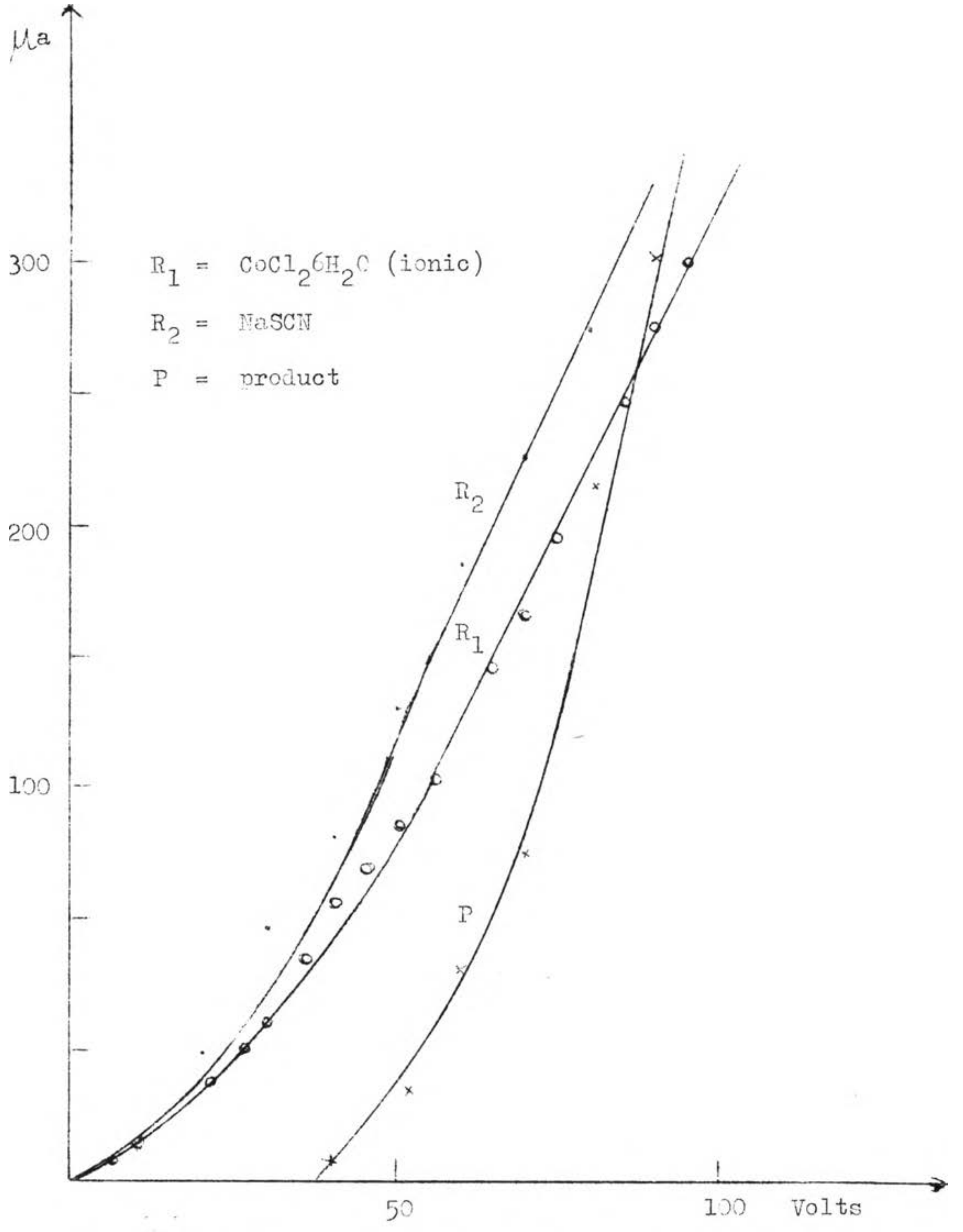


Fig.6.6.9 The comparison of conductance between product and reactant in the solid-solid reaction of $CoCl_26H_2O$ + NaSCN

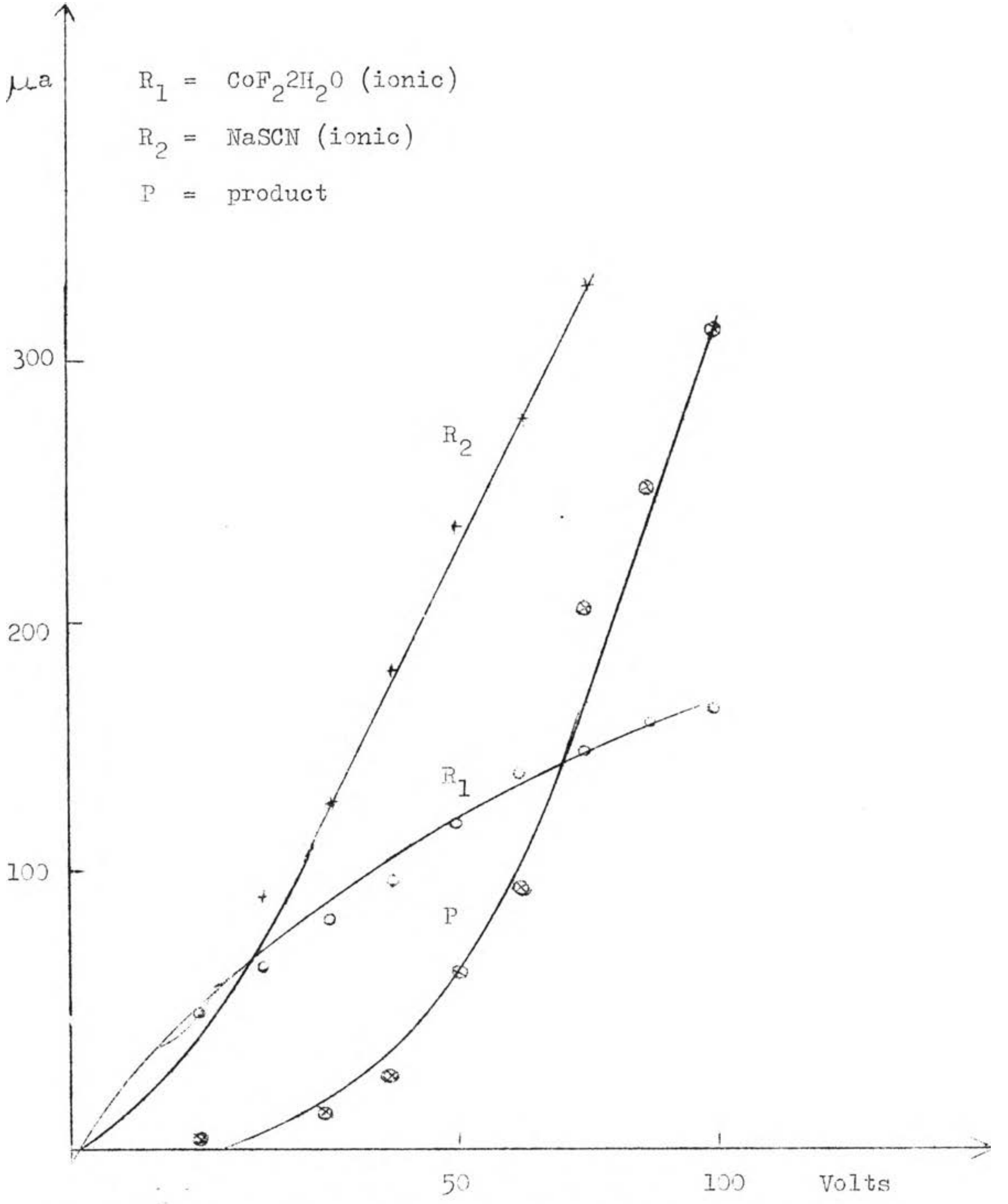


Fig. 6.6.10 The comparison of conductance between product and reactant in the solid-solid reaction of $CoF_2 2H_2O$ + NaSCN

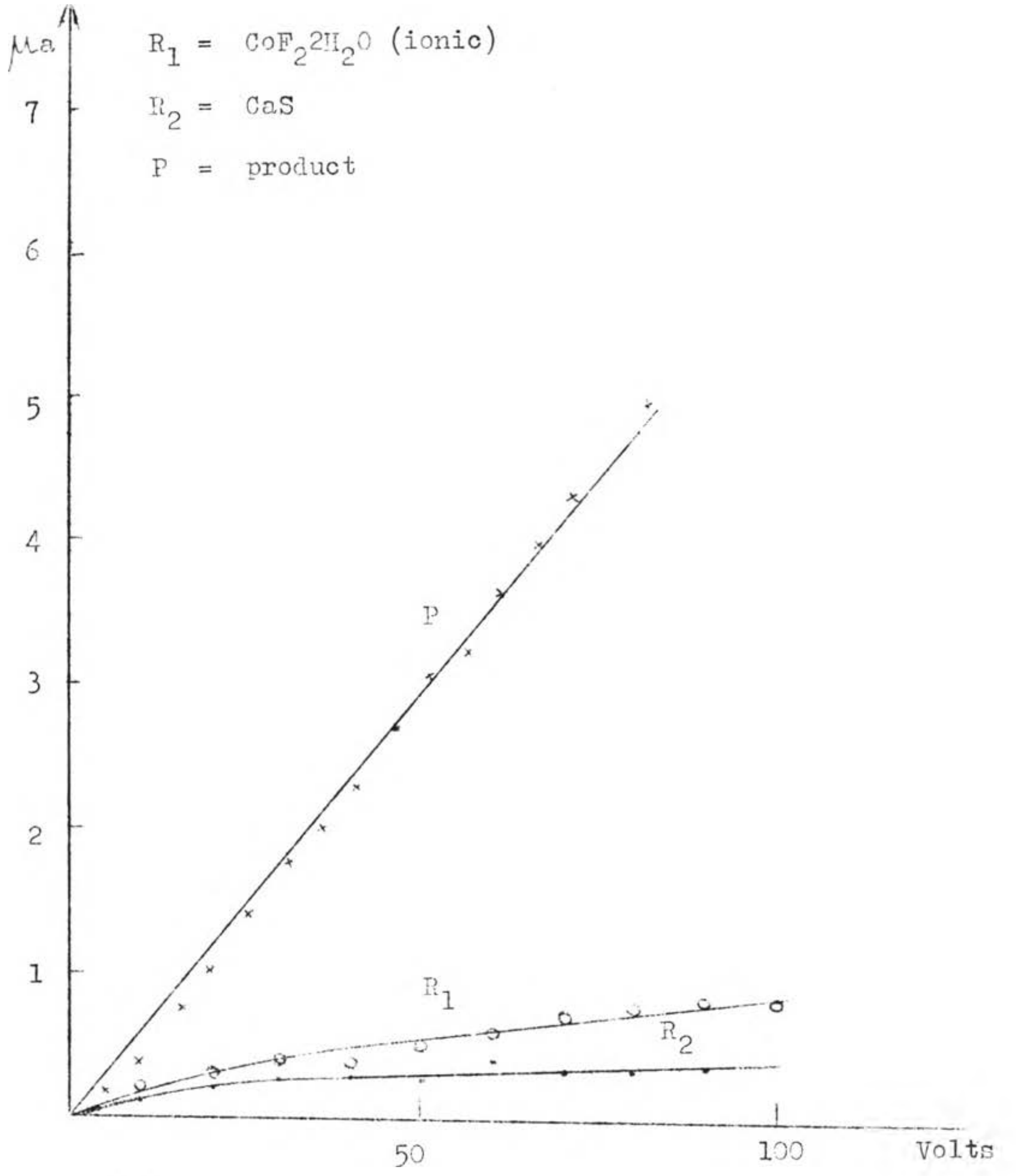


Fig.6.6.11 The comparison of conductance between product and reactant in the solid-solid reaction of $CoF_2 2H_2O$ + CaS

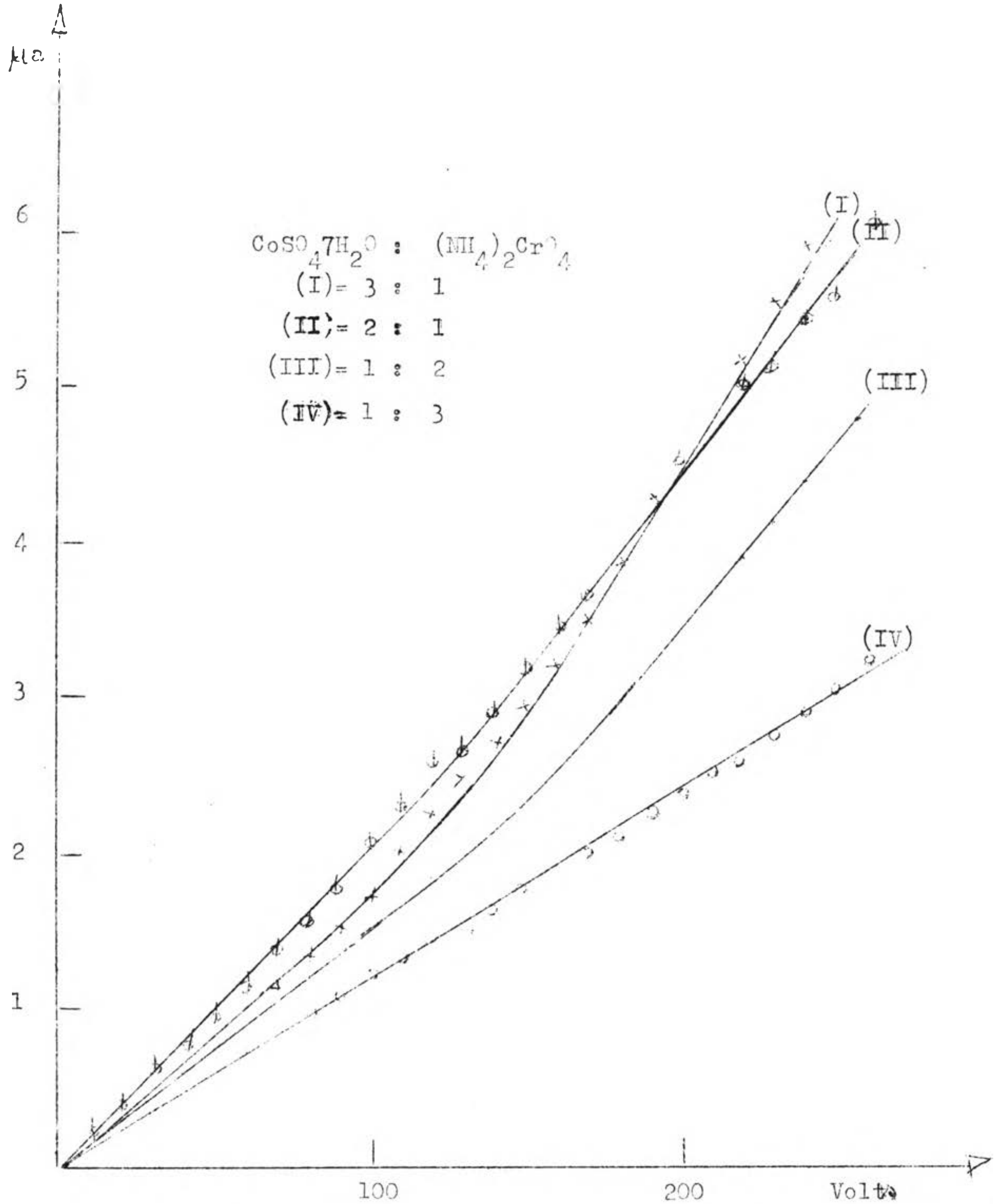


Fig 6.6.12 The conductivities of various ratios of reactants in the reaction of $CoSO_4 7H_2O$ + $(NH_4)_2CrO_4$

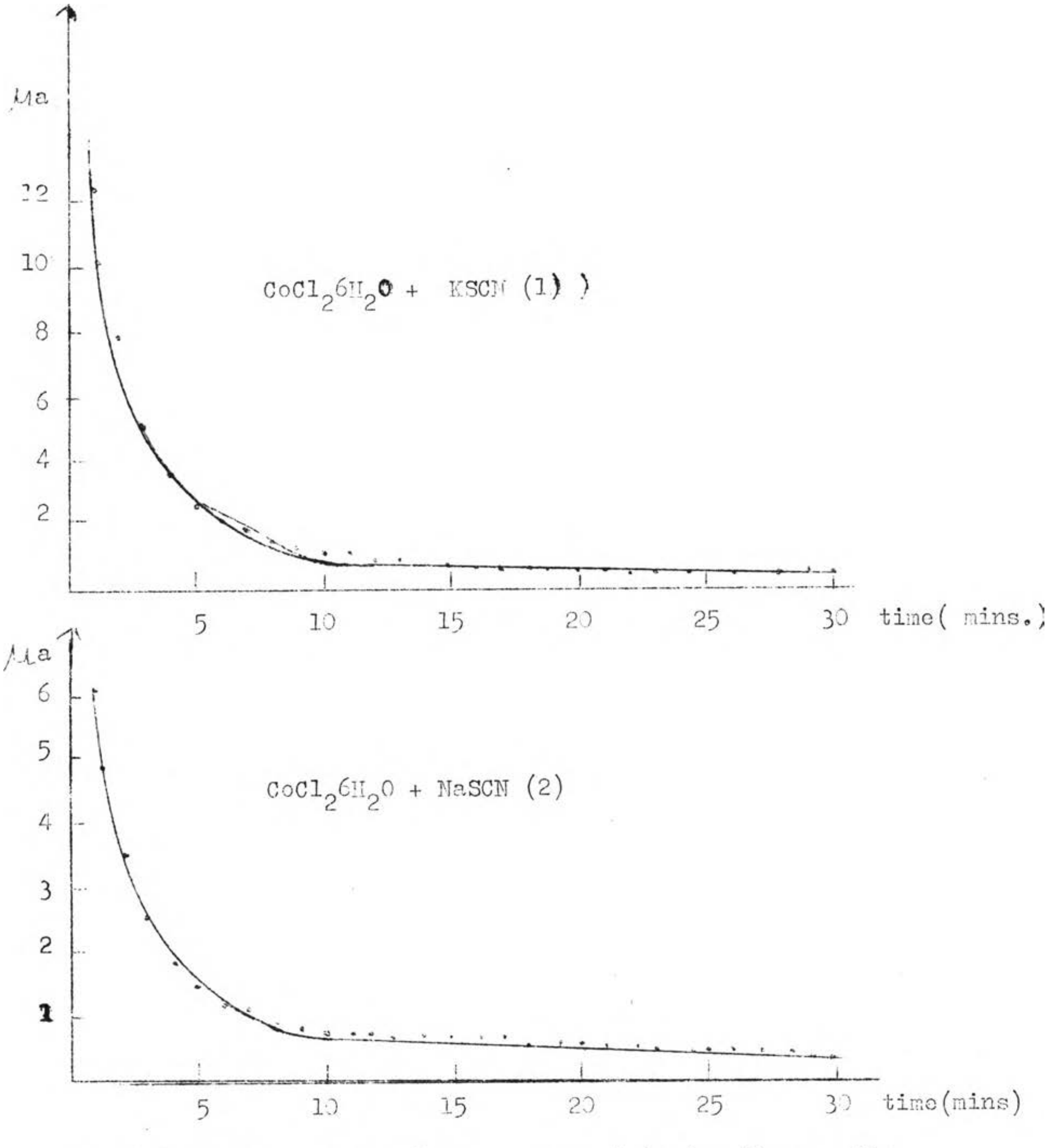


Fig.6.6.13 The conductivity measurement during the reaction of $CoCl_2 6H_2O$ + KSCN (1) and $CoCl_2 6H_2O$ + NaSCN (2)

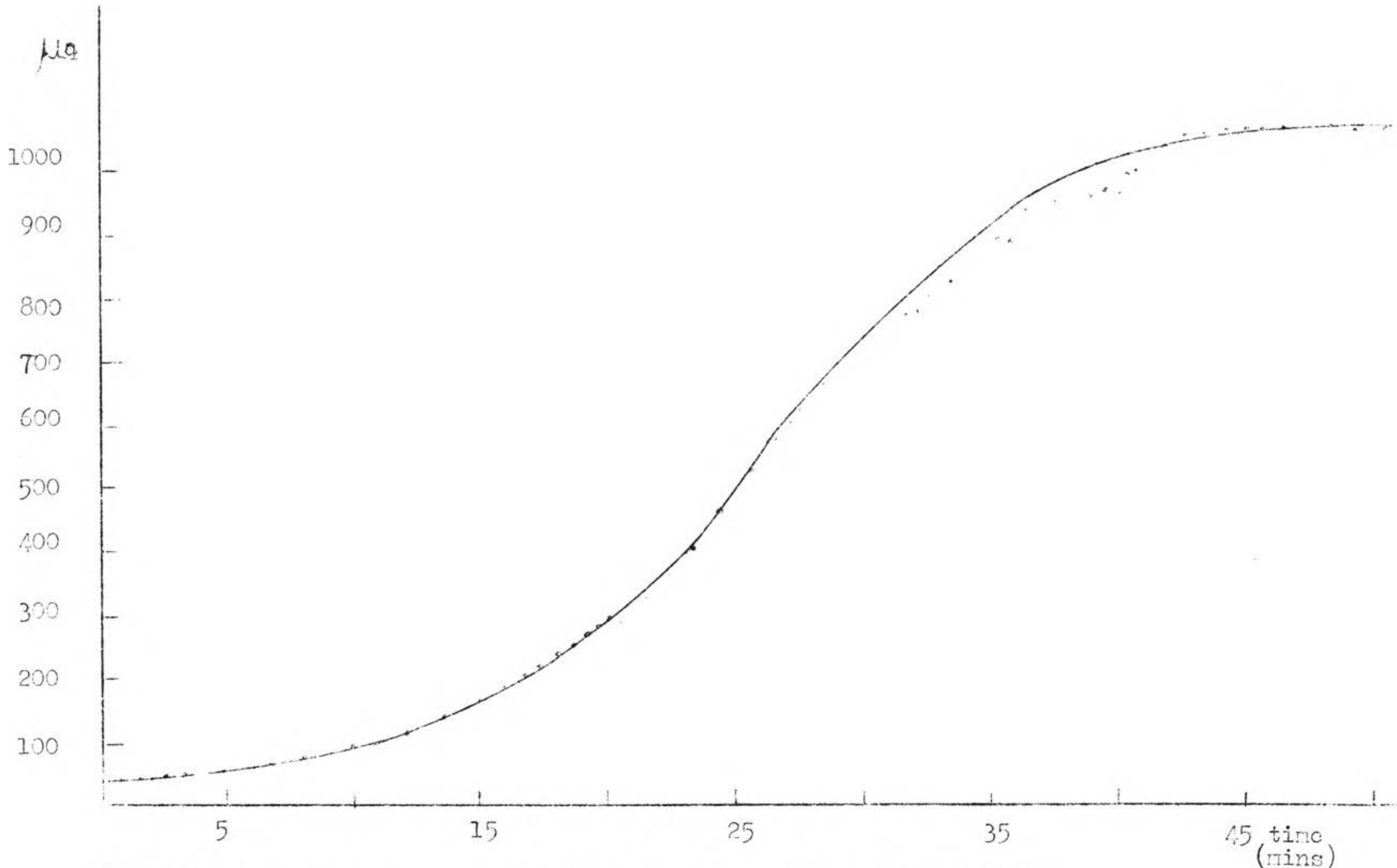


Fig 6.6.14 The conductivities of the reaction of $CoSO_4 7H_2O$ + NaSCN

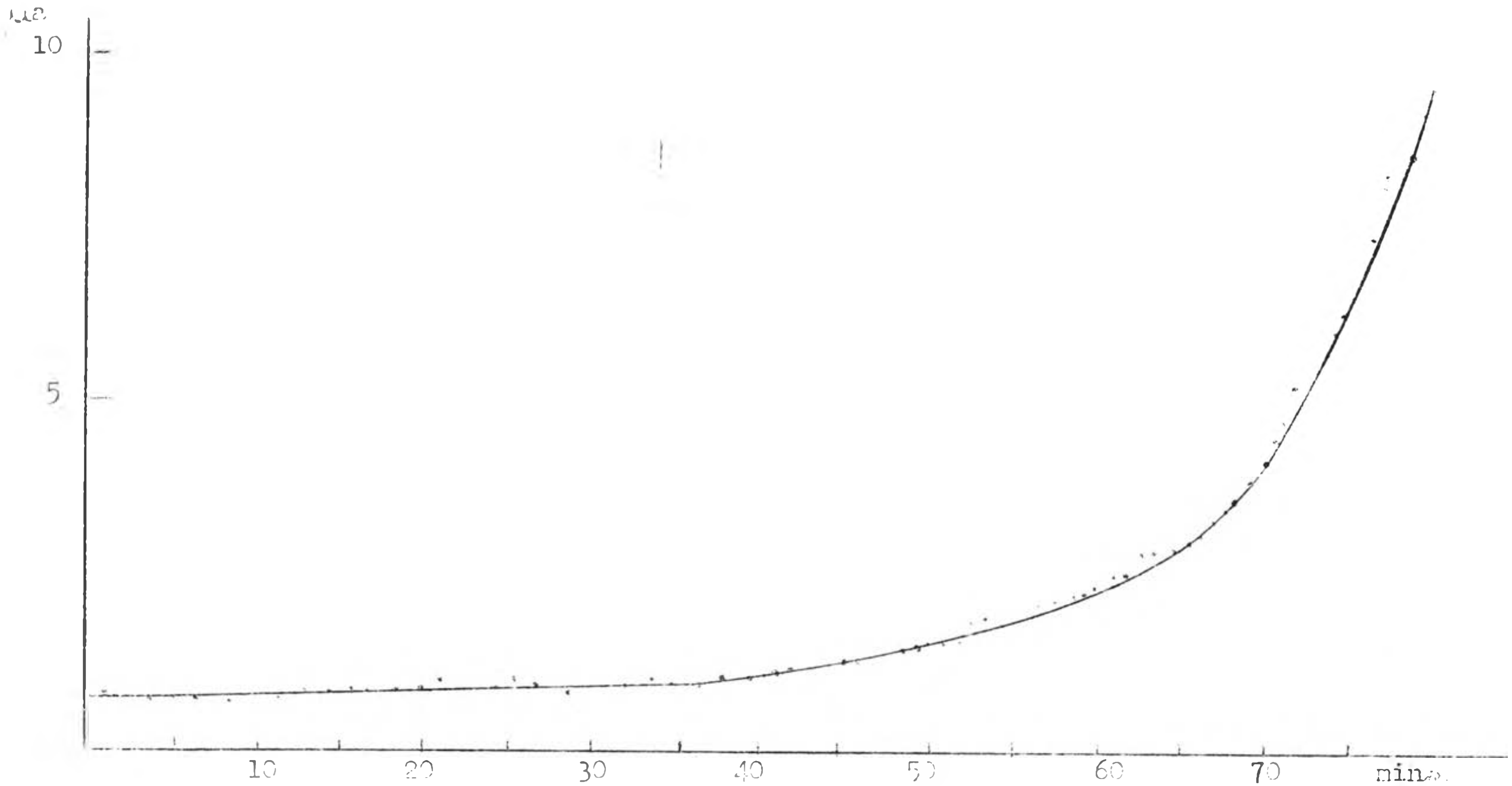


Fig 6.6.15 The conductivities of the reaction of $CuCl_2 2H_2O$ + $(NH_4)_2CrO_4$

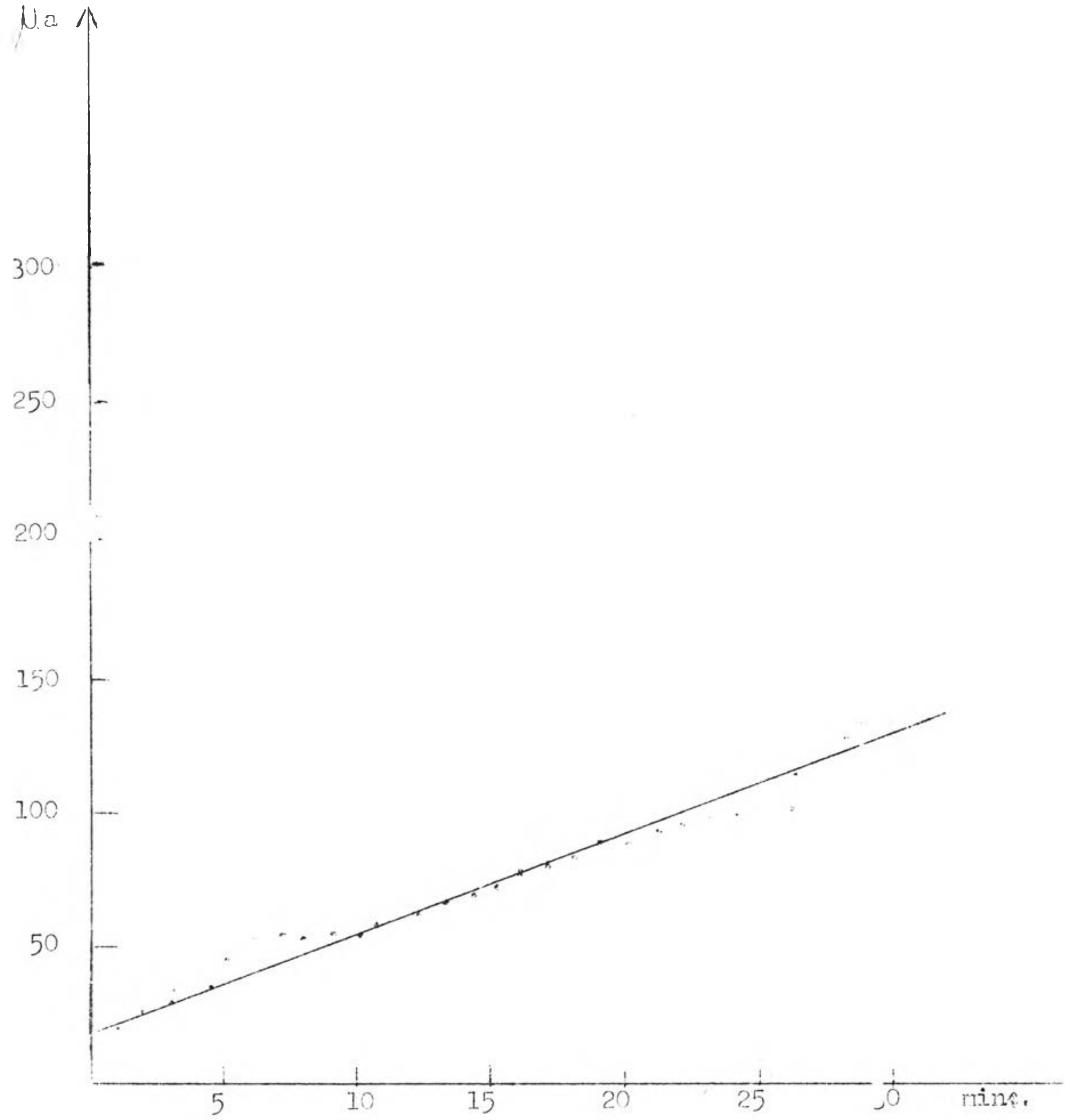


Fig 6.6.16 The conductivities of the reaction of $CoSO_4 7H_2O$ + KSCN

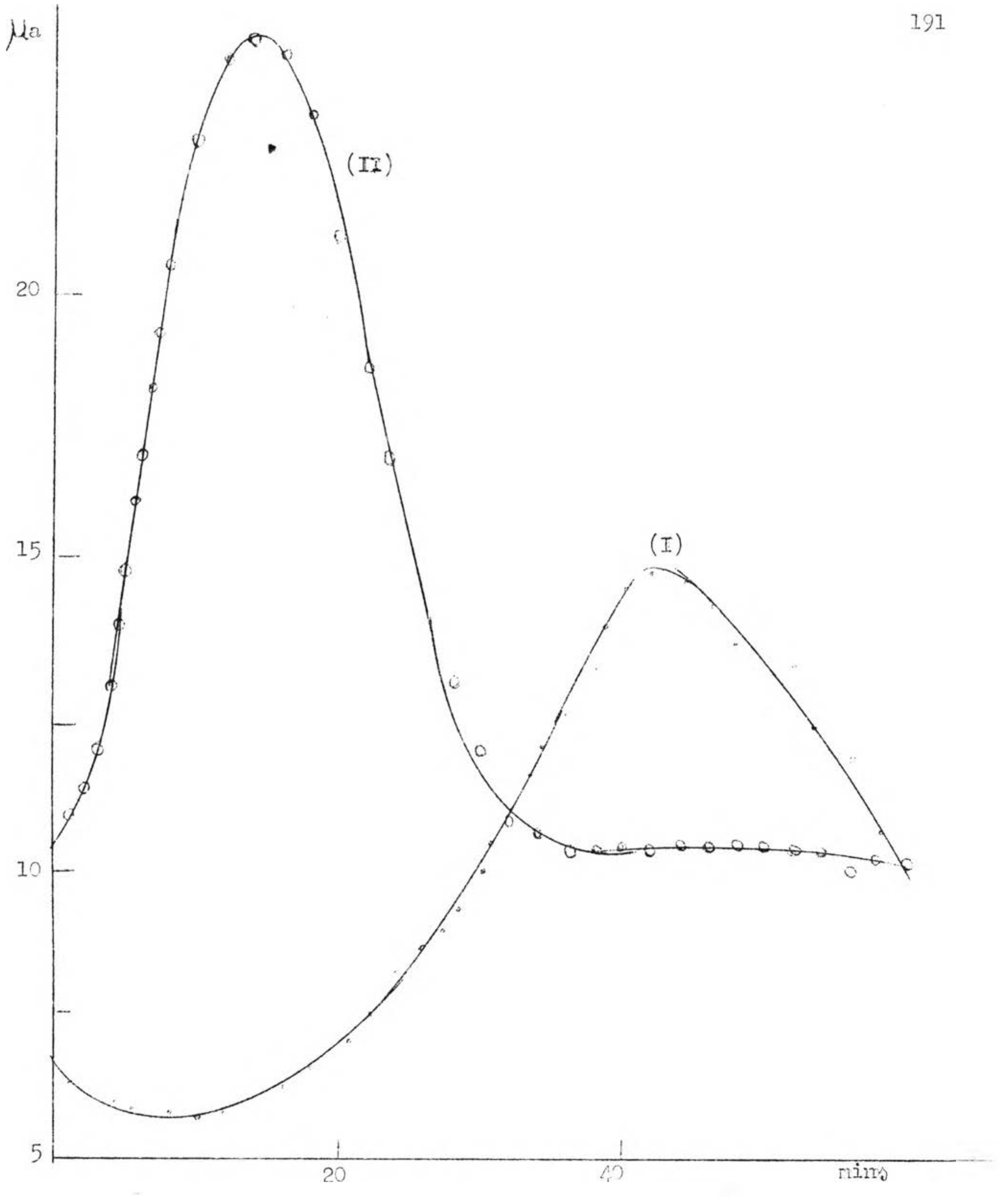


Fig 6.6.17 The conductivities of the reaction of $CoCl_2 6H_2O$ + K_2CrO_4 at 200 volts(I) and 300 volts(II)

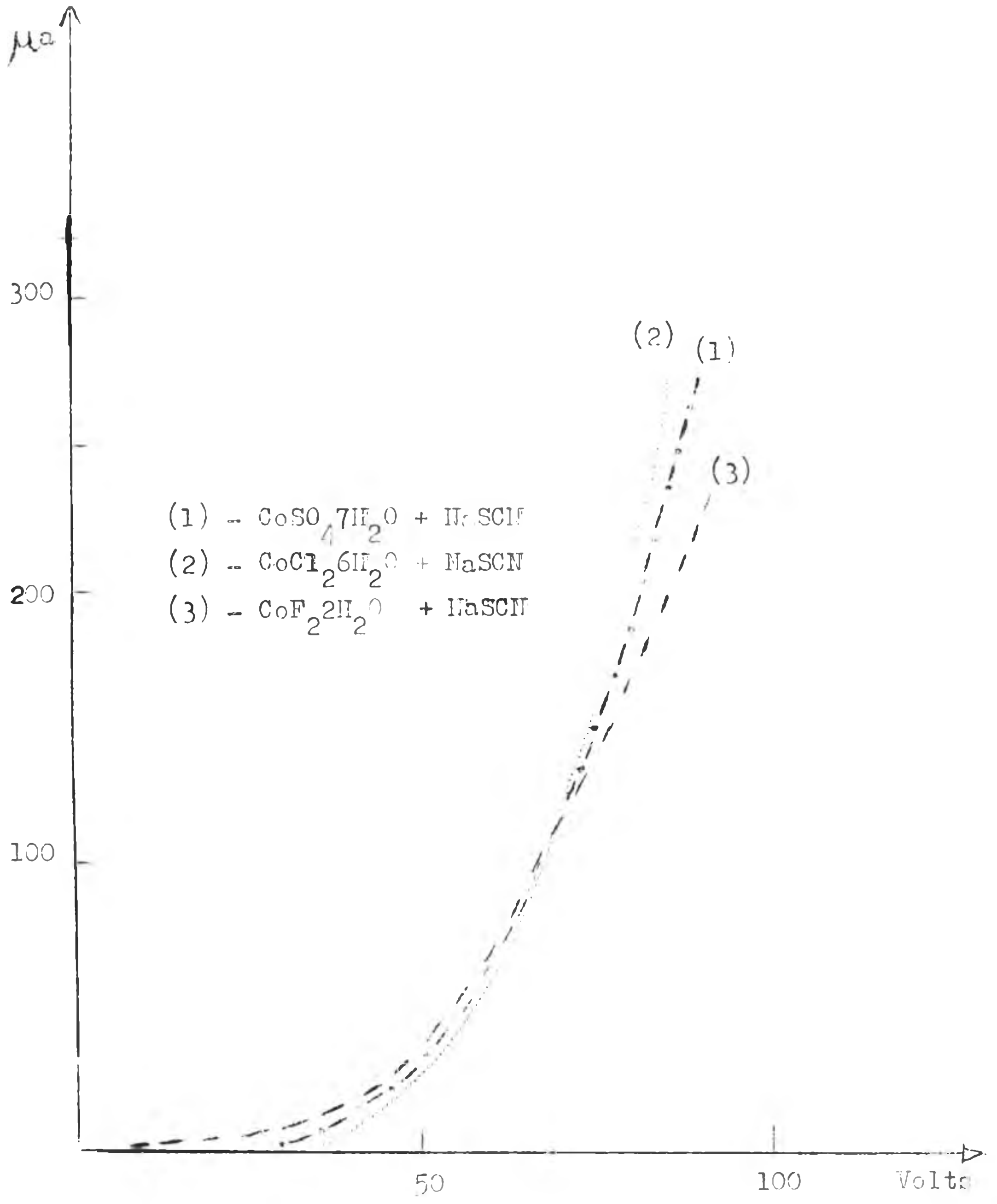


Fig 6.6.18 The comparison of conductances between products of cobalt compound and alkali thiocyanate

The characteristic of conductivity of the progressive reaction of the transition element compound, was found to depend on the amount of ionic or covalent property of the involved reactant. The more covalent species involved the higher the conductivity was observed.

The conductivity during the progressive period of the solid-solid reactions (Fig. 6.6.13-6.6.17) could be classified into three types:-

1. increasing or decreasing with exponential style
2. increasing or decreasing by a stright line equation
3. increasing and decreasing in a bell shape.

It was surprised at the system of cobalt compounds and alkali thiocyanate in showing the similar conductivity property (Fig. 6.6.18).

The variation of voltage supplied strongly affected the characteristic in the solid-solid reactions. The comparison between two voltages, 200 and 300 volts, as in the reaction of $CoCl_2 6H_2O + K_2CrO_4$ (Fig. 6.6.17), showed the difference in conductivity processes with respect to reacting time. In this case the higher voltages might increase the rate of reaction.

All of chemical changes in this present work were firstly observed by the change of colour. These relationships were not good enough in using to justify whether the reaction took place. The evidences of X-ray powder diffraction, infrared spectroscopy, conductivity methods and composition analysis provided the very important informations to support the chemical phenomena of the solid-solid reaction.

6.7 Conclusion, remarks and the suggestion for future work

Study of solid-solid reaction has come to the conclusion that temperature, particle size, nature and interface of the reactants are still the common factors for the rate of reaction. Apart from these, the imperfection and atom orientation must take into account of the important factors influenced the kinetic study.

The distribution of reactant species in various products of the solid-solid reactions, which results the bond breaking and reformation, and has known as the diffusion mechanism, is also confirmed by this present work. It takes great delight in reporting a new concept of mechanism or process of chemical change. The capability of small crystal pieces in migrating in the space toward the bigger one shows a high tendency to extend the chemical change in the solid-state reactions.

Solid-solid reactions of inorganic compounds were investigated in order to provide chemical information as much as possible. The present work was the second part of this source of study.

There were enough evidences to encourage the chemist to pay more attention about solid-state chemistry which in fact had involved several branches of science study which concerned with chemical phenomena.

The opportunity for chemical change in solid phase should be greater than in solution because solubility is not the effect.

Some other factors, which cause the different behaviour from liquid phase are very interesting to study further. They are

1. nature and structure of the reactant
2. nature and structure of each composition in the reactant
3. temperature and time
4. nature and structure of the occurring product.

There are plenty of new compounds which are easy to prepare by solid-solid reaction. Then it is a very good chance for the crystallographer to study their structures with X-ray powder or single crystal diffraction techniques. The process of chemical change will be understood clearly if their mechanism can be interpreted. The conductivity property will be very useful to technology techniques.