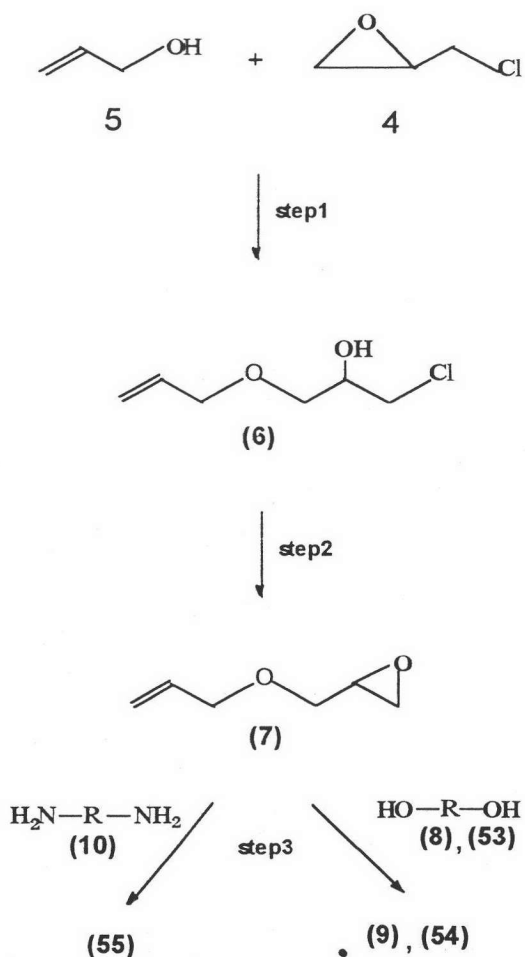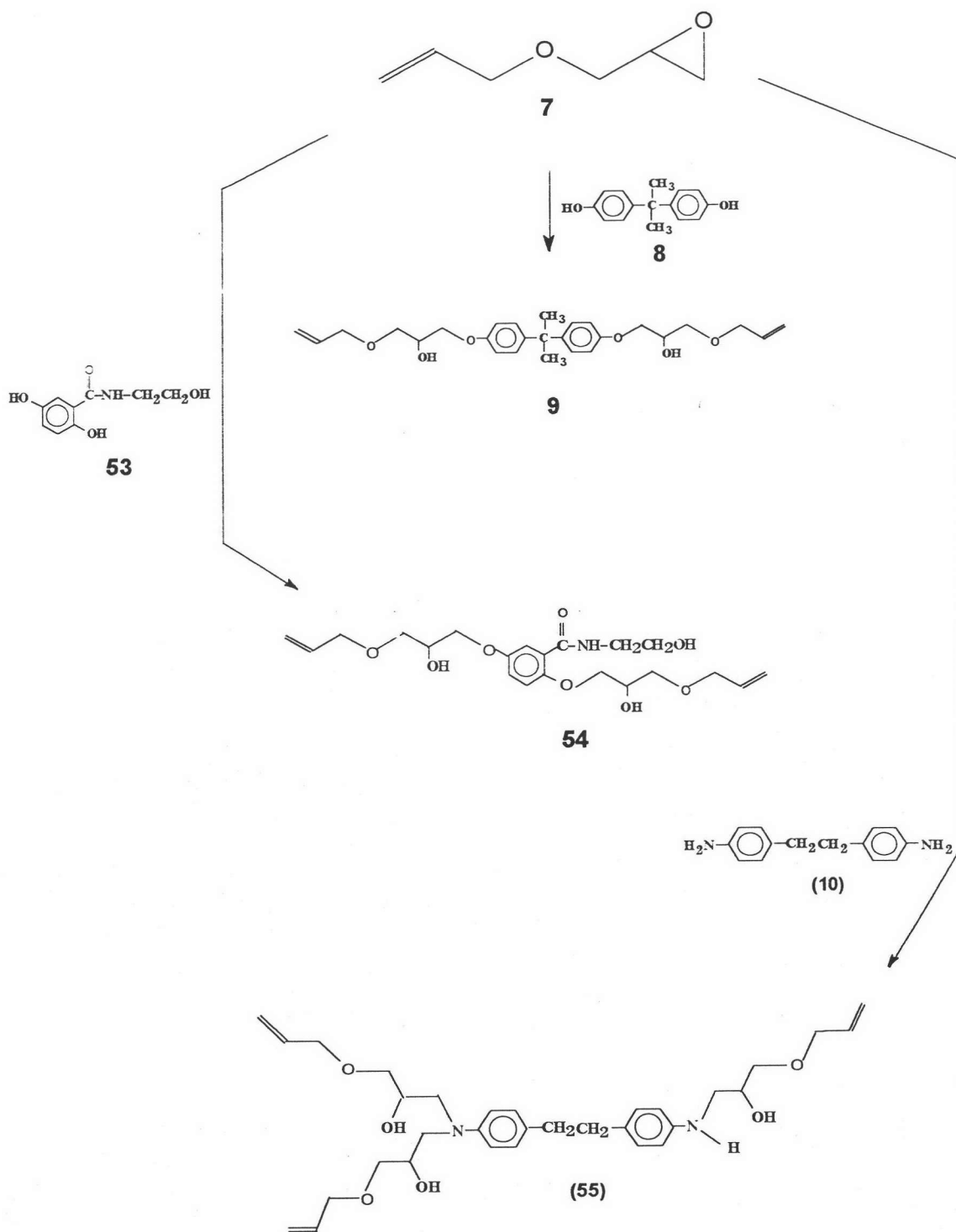# CHAPTER IV
RESULTS AND DISCUSSION

In this research, a series of unsaturated 2°-alcohols (**9**, **55**, and **54**) were synthesized from the reaction of an epoxide **7** with nucleophiles (**8**, **10**, and **53**) as shown in Scheme 4.1 and Scheme 4.2.
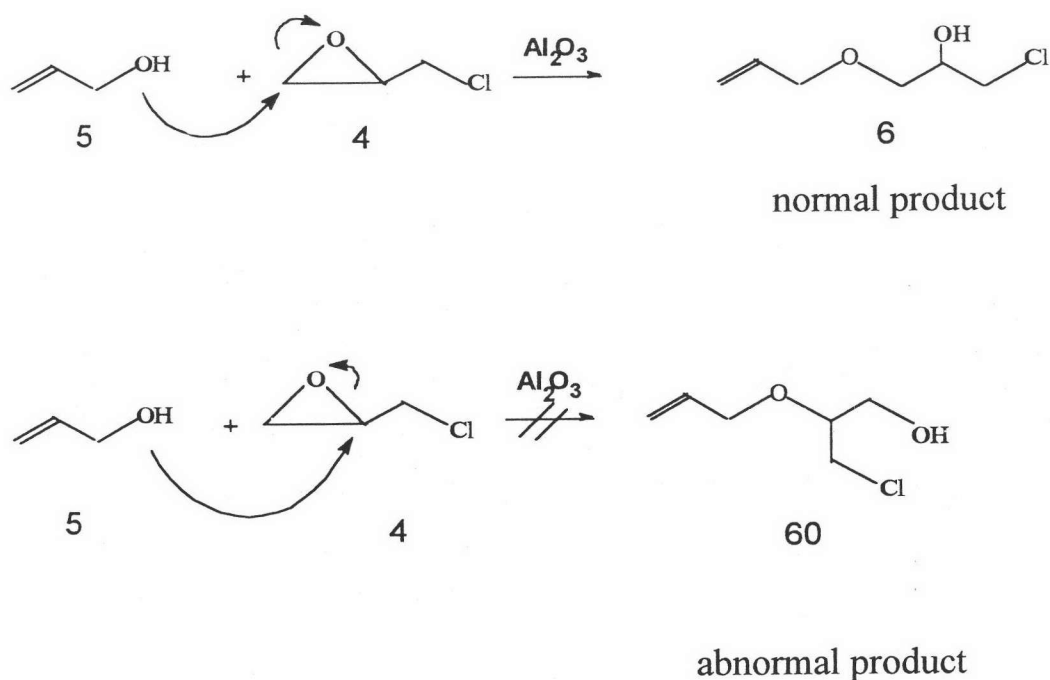

Scheme 4.1

Scheme 4.2

There are three steps in the synthetic route. Each synthetic step will be described in details as follows:

4.1 Preparation of Chlorohydrin (6)

In the first step, a chlorohydrin (**6**) was prepared by the reaction of epichlorohydrin (**4**) and allyl alcohol (**5**) using aluminium oxide to accelerate the reaction. The ring-opening reaction of **4** involved the attack hydroxy group in **5** on the epoxide carbon of **4,** and the displacement of the epoxide oxygen atom at the normal position to yield **6** as a normal product (Scheme 4.3).


normal product

abnormal product

Scheme 4.3

The normal isomer of chlorohydrin product (**6**) was isolated as the major product when the reaction temperature was 70-80°C. The progress of this reaction was monitored using TLC. Because **4** and **5**

don't have many chromophores, the spots of **4** and **5** could not be well observed. It was quite difficult to observe the progress of the reaction. The reaction time for 3 days was used since there was no sinificant change on TLC after 3 days. The mole ratio of the substance **4:5** used in the reaction was 1:2 in order to use most of epichlorohydrin. After the reaction was completed, allyl alcohol could be easily removed by water extraction.

The crude reaction mixture was purified in 2 steps, the first step was extraction with water to remove allyl alcohol. Then the organic layer was then distillated under the reduced pressure to remove epichlorohydrin, giving the crude products of **6**.

In order to prove the chemical structure of **6**, a portion of crude product **6** was purify by column chromatography. The spectroscopic data of **6** was shown in section 3.2.1 where the broad IR absorption in the region at 3413 cm^{-1} shows the O-H stretching and a sharp peak at 1646 cm^{-1} shows the C=C stretching.
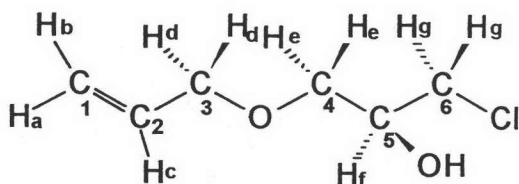
^{1}H-NMR (d$_6$-acetone + CDCl$_3$) spectrum of the purified product indicated the structure of **6** [δ 3.58 (dd, J = 12.2 and 5.5 Hz, 2H, H$_e$), δ 3.65 (dd, J = 12.2 and 5.3 Hz, 2H, H$_g$), δ 3.93-4.09 (m, 3H,

$H_d + H_f$), δ 5.17-5.32 (m, 2H, $H_a + H_b$), δ 5.82-5.96 (m, 1H, H_c)].
and ^{13}C-NMR (d_6-acetone + CDCl$_3$) showed at [δ 45.9 (C_6), δ 70.1
(C_5), 70.7 (C_3), 72.2(C_4), 117.1(C_1), 134.2(C_2)].

The normal product **6** was the only product isolated and the
present abnormal product was not observed. It was important to
remove **60** if there was any before using **6** in the next step because the
normal product can be cyclized to give the epoxide **7** (Scheme 4.2) but
the abnormal one (**60**) cannot undergo the cyclization reaction.

These reactions are well known to be sensitive to steric
hindrance, the epichlorchydrin contains the -CH$_2$Cl group that has no
polar or conjugative effect. It is expected that the normal product will
be formed for steric reasons.

Aluminium oxide accelerates the reaction as described before by
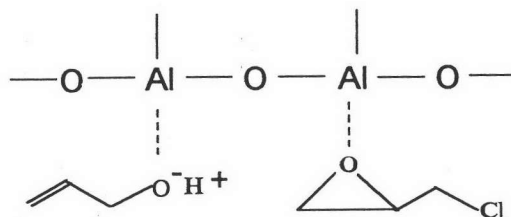Posner [32-36]; Its mechanism is shown in Fig.4.3.

Figure 4.1

From Fig. 4.3, Al_2O_3 forms complex with both allyl alcohol and epichlorohydrin. Therefore both substantes are brought into proximity. From the experimental results, the yield of chlorohydrin (**6**) increased with the increase of aluminium oxide added into the reaction (Table 4.1).

Table 4.1 Yield of 7-chloro-6-hydroxy-4-oxa-1-heptene(**6**).

| Al_2O_3 (wt.%)	yield of **6**[#] (%)
18.08	43.60
29.65	52.32
55.04	73.32

[#] crude product after removal of the starting materials

The chlorohydrin (**6**) was prepared by Otera *et al.*with the reaction under organotin phosphate catalyst [41]. The chlorohydrin (**6**) was prepared from the reaction of epichlorohydrin (**4**) and allyl alcohol (**5**) (mole ratio of **4** : **5** = 2 : 15) to give chlorohydrin (**6**) in 74% yield.

Compare to the procedure from our experiment, although Otera's condition gave high yield, the reaction was prepared using a large excess amout of **5** and the reaction scale was small (0.18 g of **4** and 0.87g of **5**). The method for preparation of the catalyst was complicated, and the reaction must be done under the dry condition. Thus the method is not satisfactory for the synthesis in large scale. On

the other hand, our reaction used a commercially available alumina. The reaction could be carried out easily. Alumina can be removed from the reaction and might be able to reused again [36]. Furthermore, this reaction can be done in a larger scale (73g of **4** and 94g of **5**).

Other reaction conditions was also attemped in this research. Aluminium chloride and hydrochloric acid were used instead of aluminium oxide. When the reactions were carried out under these conditions, a small amout of chlorohydrin (**6**) and the other side reaction products were observed by TLC. The side reaction may be the reaction to form abnormal product (**60**) as described in Scheme 4.4.

60
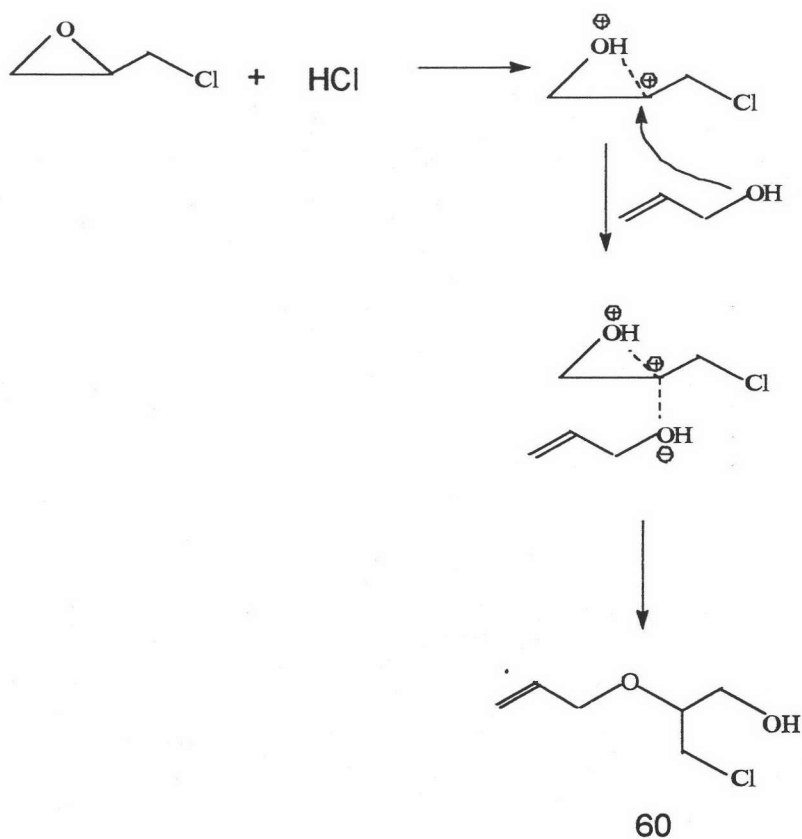
Scheme 4.4

4.2 Formation of Epoxide (7)

It has already been mentioned in Chapter 2 that the cyclization of halohydrin was a well known method for the preparation of an epoxide. In this part the chlorohydrin from the first step reacts with the sodium hydroxide in mixture of water and methanol. The mechanism was suggested by Lucas as shown in Scheme 4.5

(7)
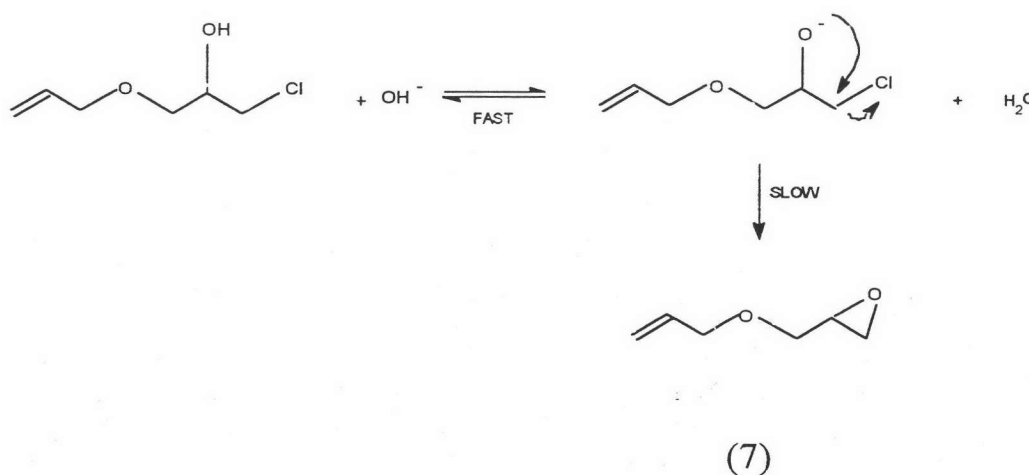
**Scheme 4.5**

The reaction was carried out at 0°C for 6 hours in the mixtures of water and methanol at different ratio (Table 4.3). The epoxide **7** was not form if the reaction was carried out at higher temperature. Most of starting material disappeared (by TLC) after 3 hours, but the reaction was left stirring until 6 hours to complete the reaction.

The reaction was monitored by TLC and using I_2 chamber, product **7** was less polar than **6**. A portion of **7** was purified using silica gel column chlomatography to proof the structure but significant amount of product **7** was lost during purification. Thus the crude product **7** was use in the next step without purification.

The structure of **7** was shown by the spectroscopic data in the section 3.2.2 where the broad IR absorption in the region board band at 3413 cm^{-1} (O-H stretching) of **6** disappear.
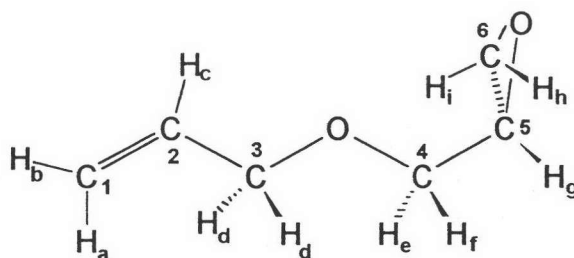
^{1}H-NMR (CDCl$_3$) spectrum of the purified product indicated the structure of **7** [δ 2.61 (dd, J = 2.7 and 5.0 Hz, 1H, H$_h$), δ 2.79 (dd, J = 4.2 and 5.0 Hz, 1H, H$_i$), δ 3.15-3.18 (m, 1H, H$_g$), δ 3.14 (dd, J = 5.8 and 11.6 Hz, 1H, H$_f$), δ 3.72 (dd, J = 3.1 and 11.6 Hz, 1H, H$_e$), δ 4.01-4.06 (m, 2H, H$_d$), δ 5.16-5.32 (m, 2H, H$_a$ + H$_b$), δ 5.84 (ddt, J = 4.9, 10.4 and 15.5 Hz, 1H, H$_c$)]. and ^{13}C-NMR (CDCl$_3$) showed at [δ 44.1 (C$_6$), δ 50.6 (C$_5$), 70.6 (C$_3$), 72.1(C$_4$), 117.1(C$_1$), 134.3(C$_2$)].

In the experiments the ratio of solvent (water : methanol) was varied, and the result was shown in Table 4.3 and Fig 4.4.

Table 4.2 Yield of **7** (crude product) in different solvent ratio.

Experi -ments	Volumn of MeOH (ml.)	Volumn of water (ml.)	Ratio of water: MeOH	Yield of (**7**)* (%)
1	35	21	0.6	58
2	10	16	1.6	74
3	60	114	1.9	79
4	60	122	2.0	80
5	50	120	2.4	76
6	50	122	2.4	74
7	70	175	2.5	85
8	40	121	3.0	86
9	200	676	3.4	86
10	100	700	7.0	72
11	100	700	7.0	68
12	70	500	7.1	82
13	100	800	8.0	81
14	80	800	10.0	53
15	80	800	10.0	46
16	80	800	10.0	78

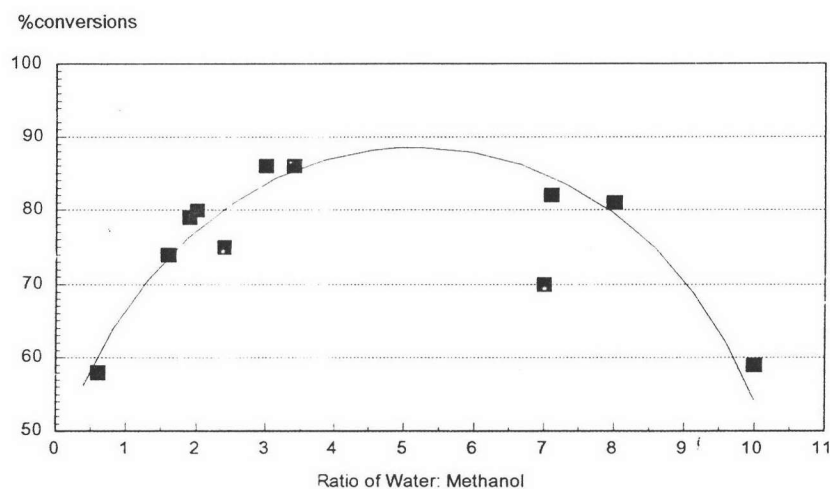*   crude product without purification.

%conversions

Figure 4.2 The relationship between the ratio of solvent and
yield of product **7**.

From the Fig 4.4, the percent yields increased with the increase
the ratio of water to methanol, because the intermediate will be more
stable in the solvent which has high dielectric constant. If the solvent
systems have high amount of water, the dielectric constant will be
higher resulting in better reaction. The optimum yield (86%) was
obtained when the ratio of water : MeOH = 1 : 3.

For the ratio around 1:7 and 1:8 (Table 4.3, Experiment 12, 13),
it was found that if amount of water increased the product yield would
decrease. However, the reaction was cleaner and this solvent ratio was
used for preparation of the epoxide.

4.3 The Reaction of Epoxide with Nucleophiles

4.3.1 Reaction with Bisphenol A

The reaction of 4,4'-isopropylidenediphenol or bisphenol A (**8**) and epoxide (**7**), with sodium hydroxide as a base in the mixure of methanol and water, gave the unsaturated 2°-alcohol (**9**). An excess amount of **7** (8 equivalents) was needed. When 4 equivalents of **7** was used, the reaction time was longer and the product was obtained in lower yield. TLC spot at R_f 0.53 (monoaddition product **56**) and at R_f 0.40 (diadditon product **9**) were observed.

The reaction was monitored by TLC; the spot of starting material **8** (R_f = 0.66) disappeared after 12 hours. The reaction was reflux until at R_f = 0.53 (monoaddition product **56**) disappeared, and the diaddition **9** (R_f = 0.40) was the major product on TLC.

The crude product **9** and **56** was purify using column chromatography. The ^{1}H-NMR of **56** was different from **9** at the integration ratio of δ 6.82:5.90 (four proton of aromatic : one proton of double bond). This integration ratio of **56** is 4:1 and the ratio of **9** is 2:1.

The structure of **9** was confirmed by spectroscopic data (Section 3.2.3) where three characteristic IR absorption in the region 3413 cm^{-1} (board, O-H stretching), 1646 cm^{-1} (sharp, C=C stretching)

and the group of 1609 cm^{-1},1582 cm^{-1} and 1462 cm^{-1} (C=C aromatic stretching).

The MS spectrum of 9 showed the molecular ion (M$^+$) at 456, m/e(% relative intensity), 456(51)[M$^+$], 441(100), 327(29), 213(46), 135(35), 41(34).

Product **9** may be a mixture of stereoisomers. However, this stereochemistry effect will not affect on the crosslinking reaction when using in polyurethane and the polyurethane properties.

The mechanism of this reaction is that the hydroxide ion will abstract the proton from bisphenol A to generate the phenoxide ions, and enhance the nucleophilicity of nucleophile leading to the attack of the least substituted epoxide carbon. Because of the steric effects of substituent groups, the normal product **9** was the only product isolated (Scheme 4.6).
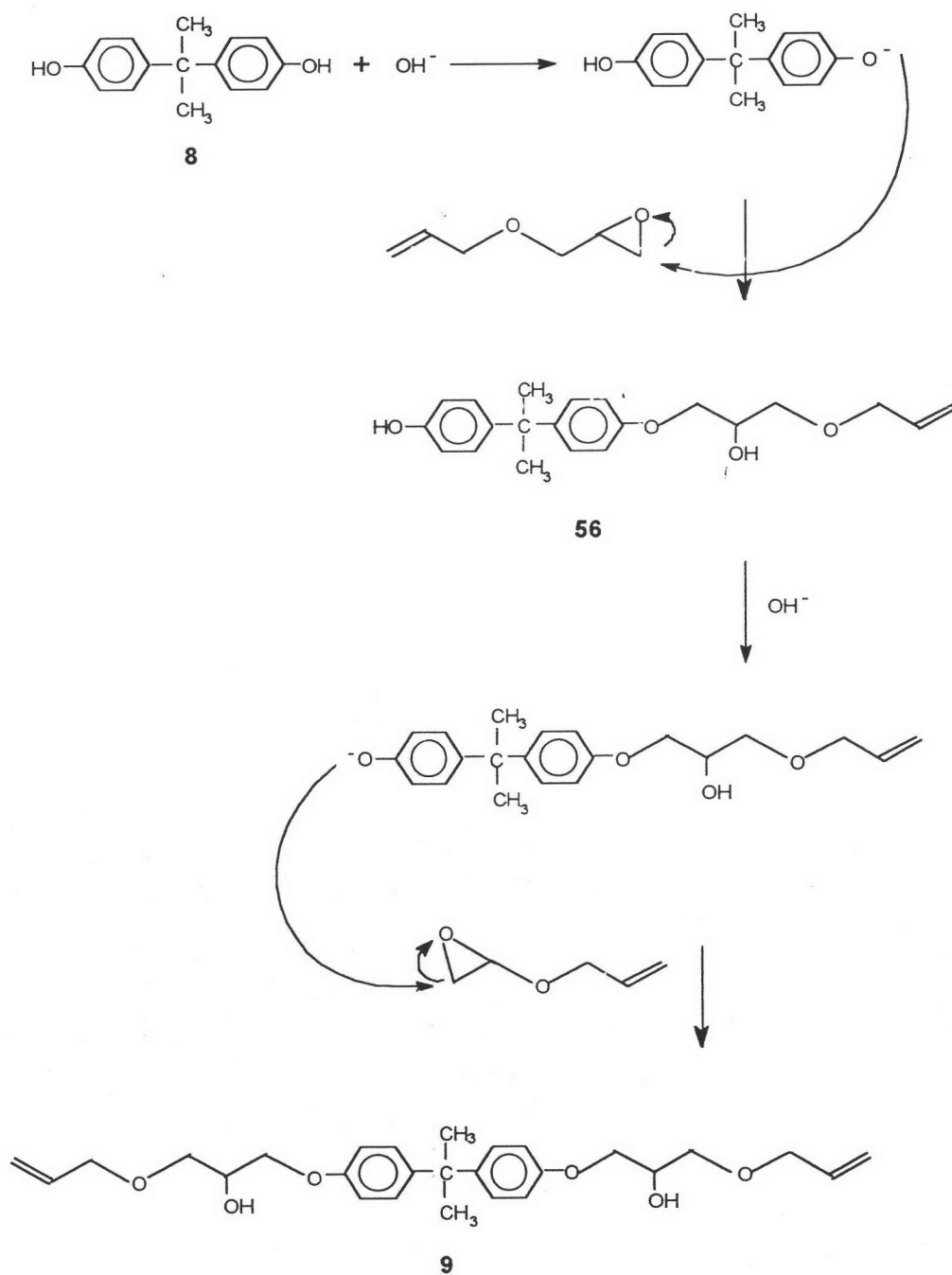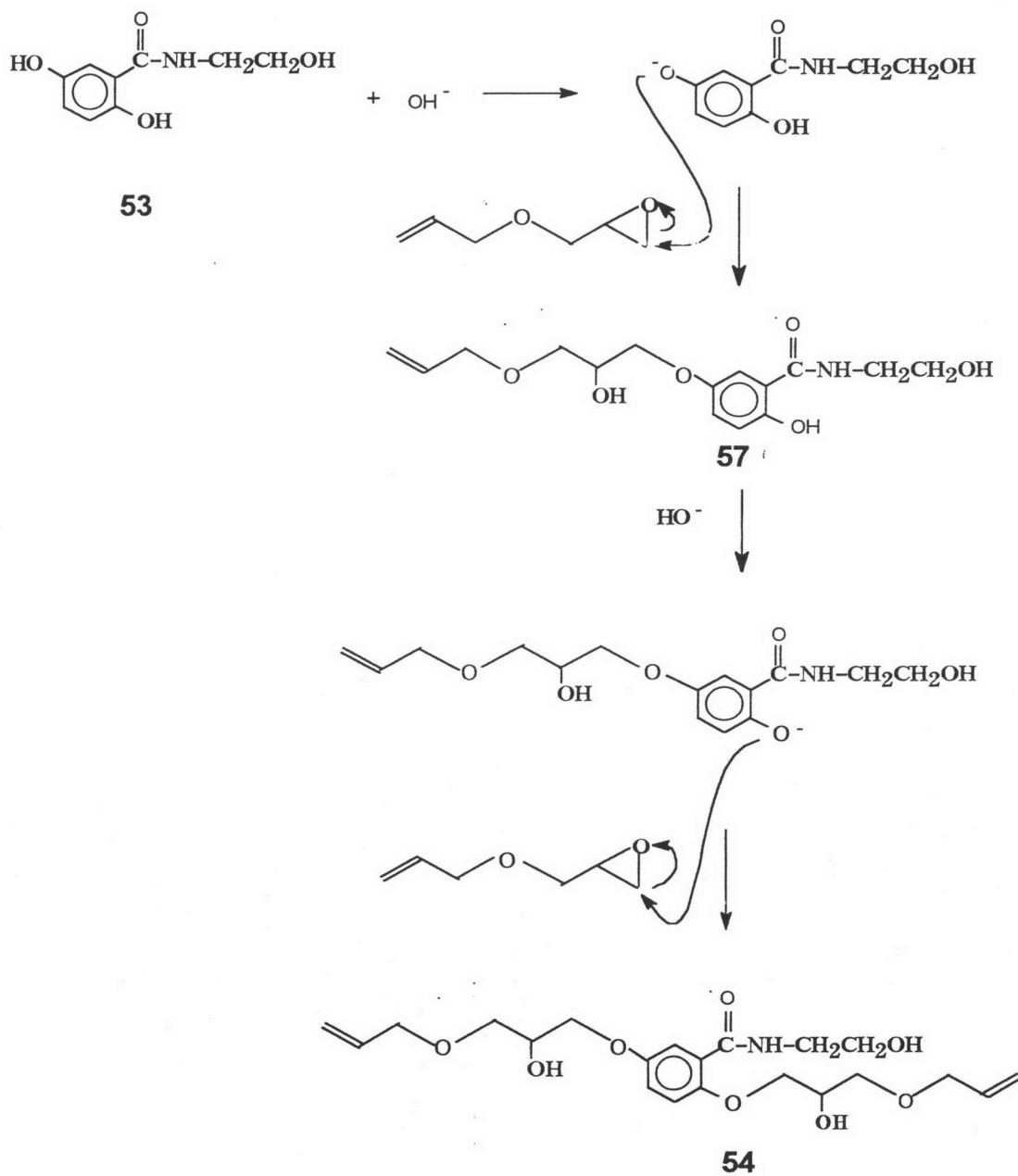
Scheme 4.6

4.3.2 Reaction with 2,5-dihydroxy-N-(2-hydroxyethyl)benzamide 53

The same reaction condition of the bisphenol A and epoxide (**7**), was employed except 2,5-dihydroxy-N-(2-hydroxyethyl) benzamide (**53**) was used as nucleophile inplace of bisphenol A.

The reaction was monitored by TLC; the spot of starting material **53** (R_f = 0.27) disappeared after 3 hours, then the reaction was heated to reflux until spot at R_f = 0.30 (monoaddition, **57**) disappeared (around 10 hours). The diaddition **54** (R_f = 0.33) was the major and isolated. The crude products was purified using column chlomatography to proved the structure of **54**. The main difference between **54** and **57** in ^{1}H-NMR is the ratio of δ (5.82-5.90) : 7.68. The ratio is 1:1 for monoaddition (**57**), and 2:1 for diaddition (**54**).

This addition product (**54**) was obtained in less yield than the reaction using bisphenol A as nucleophile because the benzamide compound has the amide group on the aromatic ring. This group is very good in withdrawing electron from the ring making oxygen atom of the hydroxyl groups has poor neucleophilicity to opening the epoxide ring. The reaction mechanism is shown in Scheme 4.7.

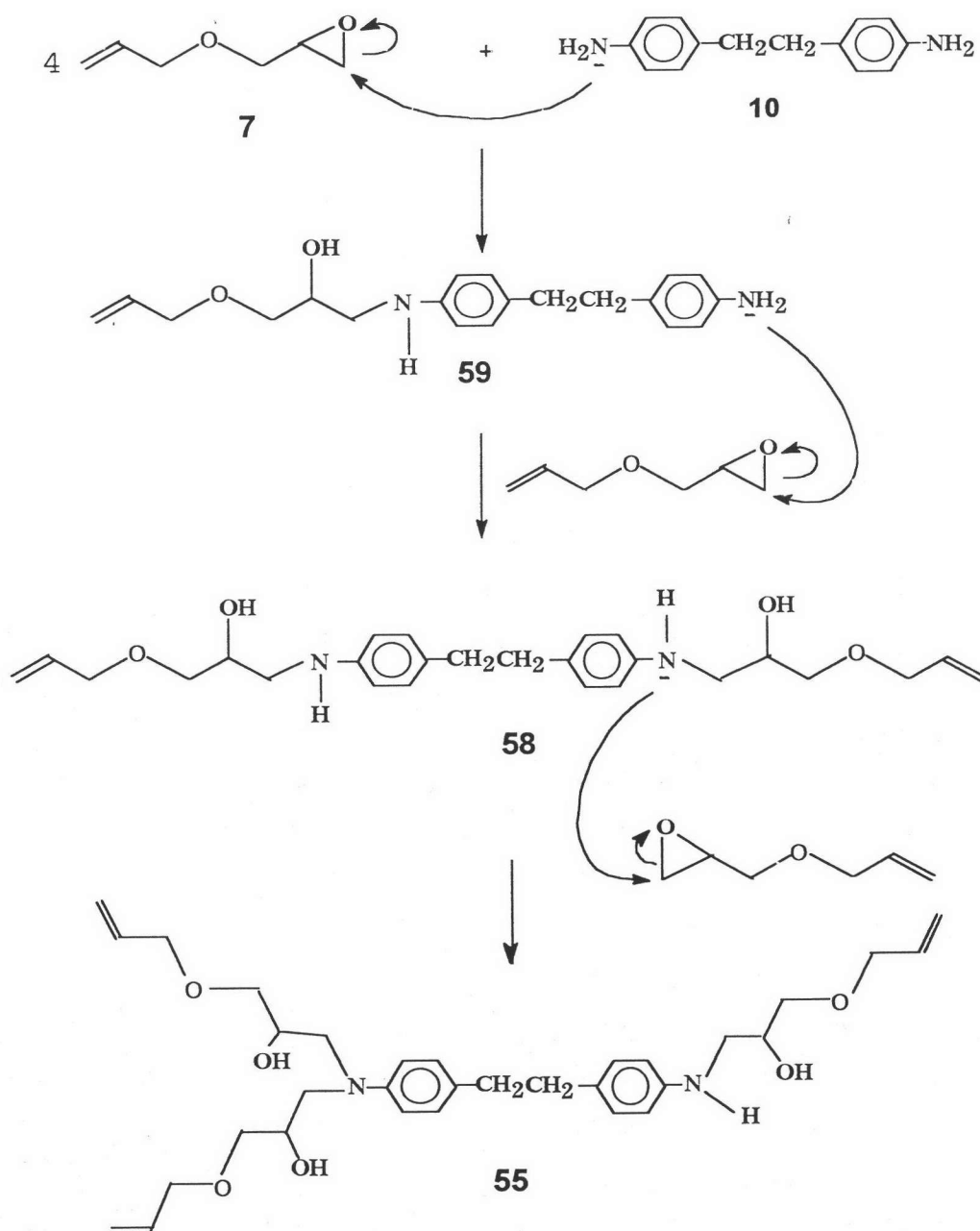**Scheme 4.7**

4.3.3 Reaction with Ethylene Dianiline

In general, the order of reactivity of hydrogen compounds in uncatalyzed systems is as follows [1]:

Aliphatic amines > aromatic amines > primary alcohols > water > secondary alcohols > tertialy alcohols > phenols > carboxylic acids

Because amines have higher reactivity than alcohols, the reaction between epoxide (**7**) with diamines was faster and yielded many products.

The reaction between aromatic diamine (ethylene dianiline, **10**) and **7** in the mixure of toluene and ethanol was carried out and **7** was used in axcess amount (13 equivalent). The reaction was monitored by TLC. After the mixture was refluxed for 12 hours, the starting material **10** disappeared and the 3 new spots appeared on TLC at the R_f values 0.10 (**55**), 0.31 (**59**), and 0.38 (**58**), (0.49 for **10**). When the reaction time was 24 hours, **59** and **58** disappear and the other new spots were obtained. The reaction mixture observed from TLC was more complicated so that the reaction must be stopped. The reaction mechanism can be proposed as shown in Scheme 4.8, The reaction should proceed step by step, the primary amine was reacted first according to the more reactive than the secondary amine. The reaction of the less reactive secondary amine and epoxide **7** is difficult,

therefore the 4-substituted product (**11**) was not formed. The 3-sutstituted product (**55**) was isolated and characterized.

Scheme 4.8

The reaction had to be carried out in toluene or mixture of toluene and ethanol to obtain product **55**. None of **55** was observed when the solvent was changed to methylene chloride, methanol, ethanol, ethyl acetate or when no of solvent was used.

The side reaction occured may be because 3°-amine could catalyzed the polymerization reaction of the epoxide group to give polyethers which was difficult to isolate into pure products.
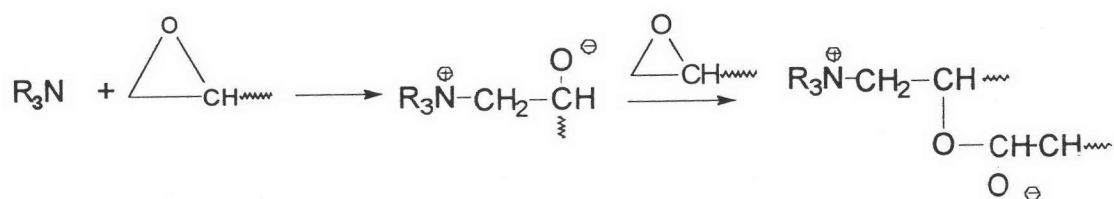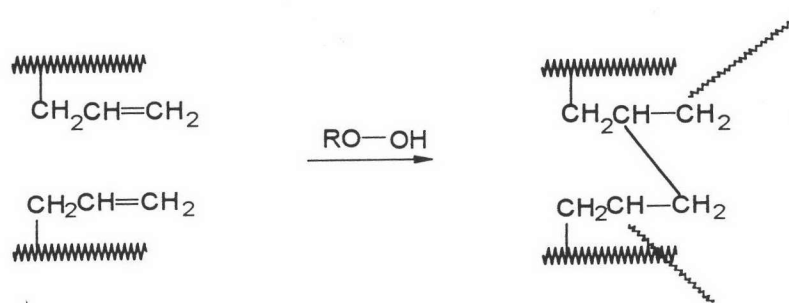

Scheme 4.9

The reaction of **7** with hexamethylene diamine was attemped, Due to the higher reactivity and polarity of starting material and products, hexamethylene diamine reacted with epoxide **7** and gave more complicated products than the aromatic diamine. The one, two three and four substituted products might occur but they could not be isolated due to their high polarity.

The reaction of epoxide **7** with ethylene diamine gave the same result as the reaction with hexamethylene diamine. The reaction was very complicated and the products could not isolated.

The application of the crosslinking agents **9**, **54** and **55** is that they can be used in making polyurethane. The expected crosslinking reaction of isocyanated prepolymer and the obtained crosslinking agent such as **9** is shown below:

1) The reaction of hydroxy curatives and isocyanate-terminated prepolymers to give urethane linkage

(9)

2) The polymerization of terminal double bonds can be achieved by using free radical initiators such as benzoyl peroxide.

$$CH_2CH{=}CH_2$$

$$CH_2CH{=}CH_2$$

RO—OH →

$$CH_2CH{-}CH_2$$

$$CH_2CH{-}CH_2$$

R =CO-Ph

The synthetic crosslinking agents above which have four functionality or more, can improve the physical property of the polyurethane. From the crosslinking reactions described above, the final polyurethane may have the interpenetrating network (IPN) structure.