

## Electrochemical Study on the Coumarin Derivatives

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**Abstract :** The electrochemical reduction of coumarin derivatives in 0.1M TEAP acetonitrile solution was investigated by the direct current, differential pulse polarography, cyclic voltammetry and controlled potential coulometry. The electrochemical reduction of 7-acetoxy-4-bromomethyl-coumarin(ABMC) was proceeded as an irreversible three steps(-0.58, -1.63 and -2.25 volts) of electrochemical transfer before chemical reaction. The solution color turned to yellow after the carboxyl group was reduced at 2nd step(-1.63 volts vs. Ag-AgCl) and the change in color was independant to the bromo group. Upon the basis of the results on the products analysis and the interpretaton of polarograms, a possible electrochemical reaction mechanism was suggested.

**Keywords :** 7-Acetoxy-4-bromomethyl-coumarin(ABMC), Differential pulse polarography, Cyclic voltammetry, Electrochemical reduction.

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### 1. Introduction

Coumarin derivatives antagonize vitamin K in liver and prohibit the production of prothrombin as an inhibitor of blood condensation[1-4]. It was also reported that coumarin derivatives are used as photosensitizer of laser dye.[5~7]

Researches on coumarin derivatives available for a blood anticoagulant as well as a laser dye

have been proceeded by spectrophotometry[8,9], fluorescence[10], luminescence[11], HPLC[12,13], NMR[14], and photodimerization of coumarin derivatives[15]. As an electrochemical study, Rogers[16] has studied the study on the reduction of coumarin and Shkumat[17] has suggested the polarographic determination method on 4-hydroxy-3-formylcoumarin. But there is no report on the electrochemical

mechanism of coumarin derivatives.

In this study, the current type and reversibility of the reduction reaction to coumarin derivatives was investigated by the direct polarography, the differential pulse polarography and the cyclic voltammetry. The reduction products by controlled potential electrolysis were analyzed by GC-mass in order to suggest a possible reaction mechanism.

## 2. Experimental

### 2.1 Reagents

Coumarin derivatives (Aldrich Co.), tetra ethyl ammonium perchlorate(Fluka Co.) and tetra ethyl ammonium hydroxide(TEAOH) was used as purchased.

A solvent, acetonitrile(AN), was purified by Walter and Ramalay method[18]. And nitrogen gas was passed through calcium chloride solution and basic pyrogallol solution before use.

### 2.2 Instruments

By connecting PARC model 303A Static Mercury Drop Electrode System(3 electrode system for ohmic drop compensation) and PARC model RE0074 X-Y Recorder with EG & PARC model 174A Polarographic Analyzer. Cyclic voltammogram was obtained by PARC model 175 Universal Programmer and PARC model 173 Potentiostat was used to perform controlled potential electrolysis.

Measurement of pH was performed with Model 520A Digital PH-meter from Orion Research Co., and A-Line Lab. Thermo Cool

was used for temperature control.

### 2.3 Experimental Method

The electrochemical cell was constructed with Ag/AgCl reference electrode, platinum wire auxillary electrode and static mercury drop working electrode. Polarograms were obtained under nitrogen gas passed 0.1M TEAP solution for 8 min. and also produced with changing pH and temperature. Potentiostat was controlled at constant potential through electrometer probe to proceed stepwise reduction.

## 3. Results & Discussion

### 3.1 Diffusion current of coumarin derivatives

In acetonitrile(AN) of 0.1M TEAP the polarograms of coumarin, 7-acetoxy-4-methyl coumarin(AMC) and 7-acetoxy-4-bromomethyl coumarin(ABMC) were obtained and the typical direct current and the differential pulse polarograms were shown in *Fig. 1*, and the cyclic voltammograms in *Fig. 2*. In order to know whether each reduction wave is caused by a diffusion wave or by a reaction or not, it is firstly investigated the changes in the limiting current according to increases in concentration. All of the reduction waves were well proportionated to concentration and this means that the currents was caused by diffusion.

### 3.2 Irreversibility of electrochemical reduction of coumarin derivatives.

Upon the reduction wave of ABMC that

Table 1. Polarographic data on the reduction of ABMC in Acetonitrile

Reduction step	$-E_{1/2}$ (volts vs. Ag/AgCl)	- Slope (mV)	$E_{3/4} - E_{1/4}$ (mV)	$\alpha n$ (polarographic electron transfer)	$\alpha n$ (coulometric electron transfer)
1st	0.48	84	82	0.70	1.70
2nd	1.55	73	72	0.81	2.20
3rd	2.25	poor to define		-	0.78

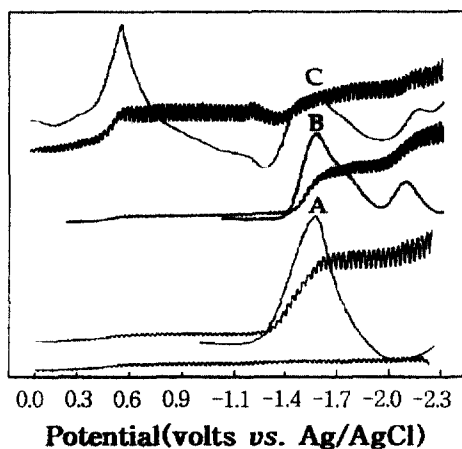


Fig. 1. Typical DC and DP polarogram of coumarin derivatives in 0.1M TEAP acetonitrile solution. Scan rate : 50mV/sec. Current range : 0.02mA. A:  $1 \times 10^{-3}$ M coumarin, B:  $1 \times 10^{-3}$ M AMC, C:  $5 \times 10^{-4}$ M ABMC.

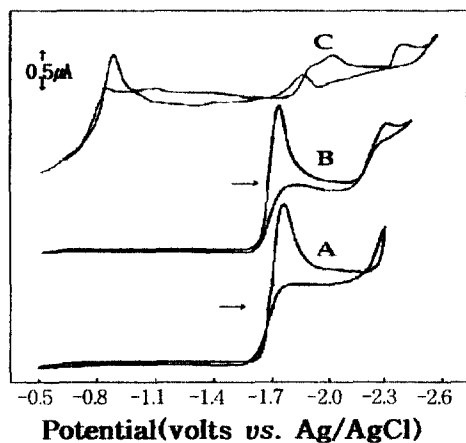


Fig. 2. Typical cyclic voltammograms of coumarin derivatives in 0.1M TEAP acetonitrile solution. Scan rate : 50mV/sec. A:  $1 \times 10^{-3}$ M coumarin, B:  $1 \times 10^{-3}$ M AMC, C:  $5 \times 10^{-4}$ M ABMC.

showed the 3rd reduction was investigated. In reduction wave of ABMC, the results of plotting  $\log[i/(i_d-i)]$  values for the changes in potentials were shown in Fig. 3, and the slope and electron transfer number noted in Fig. 3 were shown in Table 1, with electron number

obtained by coulometry. The changes of  $i_{pc}/\nu^{1/2}$  value for scan rate obtained from cyclic voltammogram (Fig. 2) were shown in Table 2.

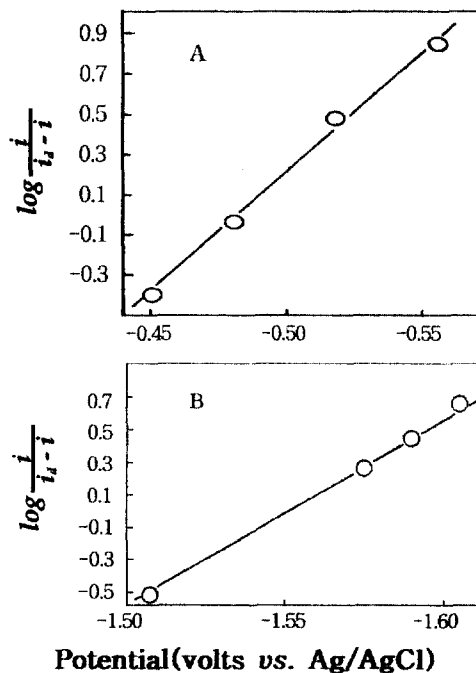


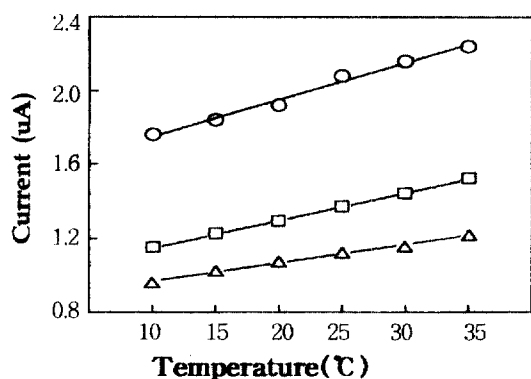
Fig. 3. A plot of  $\log i/(i_d-i)$  vs. potential from  $1 \times 10^{-3}$ M ABMC polarograms. A : 1st wave : slope 84mV, B : 2nd wave : slope 73mV, \* : 3rd wave : poor DC polarogram to plot

Table 2. Cyclovoltammetric data for the reduction of  $1 \times 10^{-3}$ M ABMC in 0.1M TEAP acetonitrile solution.

Reduction step	Scan rate (mV/sec)	Peak potential (Volts)		Current ( $\mu$ A)		$i_{pc}/\nu^{1/2}$
		$-E_{pc}$	$-E_{pa}$	$i_{pc}$	$i_{pa}$	
1st wave	200	-0.94	-	1.75	-	0.53
	100	-0.85	-	1.68	-	0.57
	50	-0.85	-	1.20	-	0.57
2nd wave	200	-2.03	-	1.15	-	0.08
	100	-1.99	-	0.97	-	0.09
	50	-1.99	-	0.60	-	0.08
3rd wave	200	-2.47	-	1.15	-	0.06
	100	-2.41	-	0.97	-	0.06
	50	-2.41	-	0.60	-	0.06

In the plot of polarogram of  $\log[i/(i_d-i)]$  vs. volts, the slope value is  $59.1/n$  mV or the potential difference value of  $E_{3/4}-E_{1/4}$  comes to have one near to  $59.1/n$  mV. An electrode

reaction is near to reversibility. An irreversible process can be defined as the potential difference value between  $E_{pc}$  and  $E_{pa}$  becomes larger. In *Table 1*, when the slope of the 1st reduction wave is 84 mV and  $E_{3/4}-E_{1/4}$  value is 82 mV, and the slope of the 2nd reduction wave is 73 mV and  $E_{3/4}-E_{1/4}$  value is 72 mV, it can be seen that the 1st and 2nd reduction waves were proceeded to the irreversible process. From the result of cyclic voltammogram as seen in *Table 2*,  $i_{pc}/v_{1/2}$  values were nearly constant as the scan rate decreased, it can be seen that they are the diffusion current. For the all of the three reduction waves, each anodic peak current for cathodic peak currents did not appear in CV. It means that all the three reduction steps were an irreversible process.



*Fig. 4.* Effect of temperature change in peak current of  $1 \times 10^{-3} \text{M}$  ABMC in 0.1M TEAP acetonitrile solution.  $\circ$ — $\circ$  : 1st wave  $\square$ — $\square$  : 2nd wave  $\triangle$ — $\triangle$  : 3rd wave  
The temperature coefficient of reduction currents have shown as 1.2%, 2%, 1% respectively, which have been identified as diffusion current.

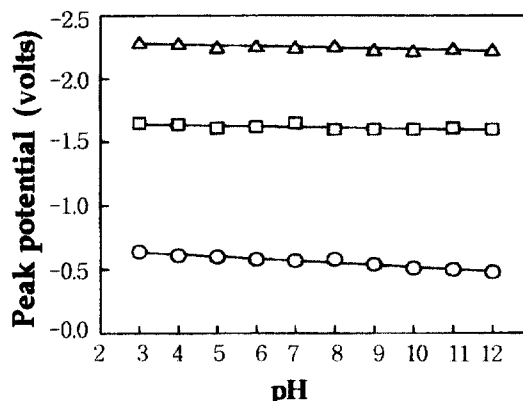
### 3.3 Effect of Temperature

CV was performed under the condition that temperature was changed at intervals of about 5°C from 10 to 35°C, the result of which was summarized in *Fig. 4*. The reduction current

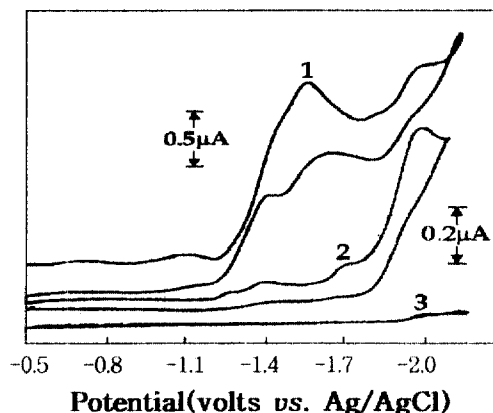
has increased in proportion to temperature, and the temperature coefficients of reduction currents have shown as 1.2%, 2%, and 1% respectively, from which it implies that the 1st and 2nd reduction waves were under diffusion control and the 2nd one was that containing a little reaction current by interpretation of Meites.[20]

### 3.4 Effect of pH

By observing of diffusion current and half-wave potentials of polarogram to the changes of pH, a reaction process can be easily defined. pH of sample solution changed with tetraethyl ammonium hydroxide and  $\text{HClO}_4$  from pH 2 to pH 11. The changes of wave peak potential according to pH were appeared in *Fig. 5*. pH increased to 11, the peaks shifted to slightly anodic potential and could be account as independent on pH. This means that it is not nearly affected on the electron transfer by adding TEAOH or  $\text{HClO}_4$ , and the whole electrode reaction can be seen as proceeding with electron transfer before chemical reaction (EC).



*Fig. 5.* Effect of pH change in peak potentials of  $1 \times 10^{-3} \text{M}$  ABMC in 0.1M TEAP acetonitrile solution.  $\circ$ — $\circ$  : 1st wave  $\square$ — $\square$  : 2nd wave  $\triangle$ — $\triangle$  : 3rd wave



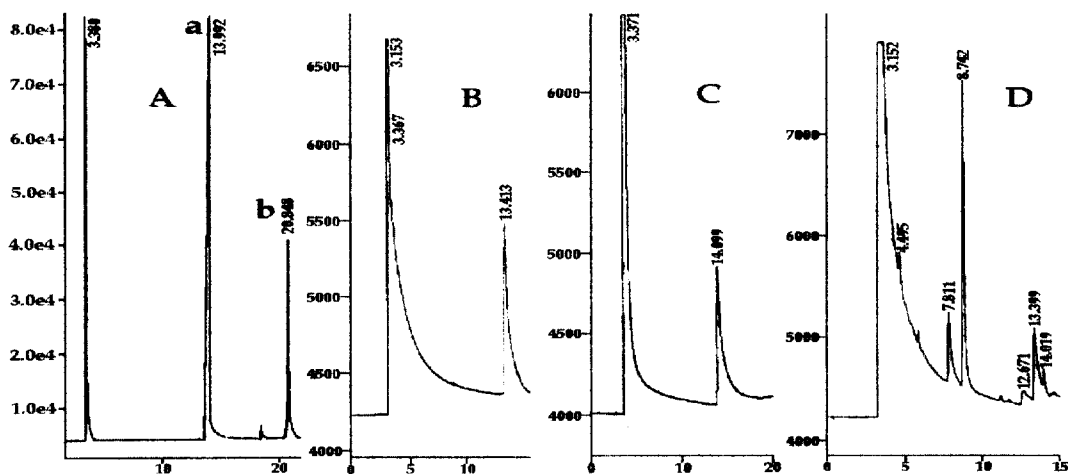
**Fig. 6.** Cyclic voltammograms on the electrolysis of ABMC in 0.1M TEAP acetonitrile solution (pH 5.6, Scan rate : 100mV/sce). 1 : 1st electrolysis (-1.2 volts): eliminated the peak of bromo at -0.58 volts. 2 : 2nd electrolysis (-1.8 volts): eliminated the peak of carboxyl at -1.63 volts changed to yellow from this step. 3 : 3rd electrolysis (-2.3 volts): eliminated the peak of acetoxy bond at -2.25 volts

### 3.5 Controlled Potential Electrolysis

As the method to know the number of electrons participated in electrochemical reaction, it can be easily obtained by the slope plotted the current values against potentials from DC polarogram (Table 1). But, it is more rational

that use control potential electrolysis for the electrode reaction of complex compounds and multiple electron transfer. From cyclic voltammetry of ABMC shown in Fig. 2, it was selected -1.2 volts for the 1st, -1.8 volts for the 2nd and -2.3 volts for the 3rd electrolysis and electrolyzed on mercury pool working electrode with stirring (Fig. 6).

The number of electrode reaction electrons calculated from the current amount this time was shown in Table 1. After the 1st electrolysis (-1.2 volts), a white precipitate of AgBr was formed by adding AgNO<sub>3</sub> solution after the reduction wave was entirely disappeared. It is identified that the bromo group was reduced and removed from coumarin. After the 2nd electrolysis (-1.7 volts), the reduction wave was nearly disappeared and the solution was turned to yellow color. After the 3rd electrolysis, -2.2 volts reduction wave was identified as disappearing entirely. And also, AMC was electrolyzed by -1.9 volts in order to identify whether which was reduced between acetoxy group and C=O of the ring by the 2nd electrolysis.



**Fig. 7.** GC spectra of coumarin derivatives, and the electrolyzed ABMC.

- A : Standard coumarin derivatives (a : AMC, b : ABMC)
- B : 1st electrolysis at -1.2 volts : cleaved bromo group
- C : 2nd electrolysis at -1.8 volts : reduced carbonyl group
- D : 3rd electrolysis at -2.3 volts : cleaved acetoxy group

### 3.6 Identification of Products & Reaction Instrument

For ABMC, the half-wave potentials and the reduction current values were nearly constant in the 1st step electrode reaction. It can be seen that this was an irreversible EC process accompanying proton transfer after electron transfer, in which the bromo group was reduced and removed. Also in the 2nd step, this was an irreversible EC process similar to the 1st one, in which the hydroxy coumarin was produced after a competitive reduction between C=O of the acetoxy group and C=O of coumarin itself, and then the solution became a yellow. In the 3rd step, it can be known that 2-hydroxy-4-methyl-coumarin(I) or 2,7-dihydroxy-4-methyl-coumarin(II) were produced after transferring one electron and cleaving the acetoxy group. The products of these controlled potential electrolysis were analyzed by GC-mass(Fig. 7). Looking into Fig. 8, it can be identified that the acetoxy group was removed in the electrolysis of the last step(-2.3 volts), and then there was a possibility that dimer could be formed, but it was not identified by GC-mass.

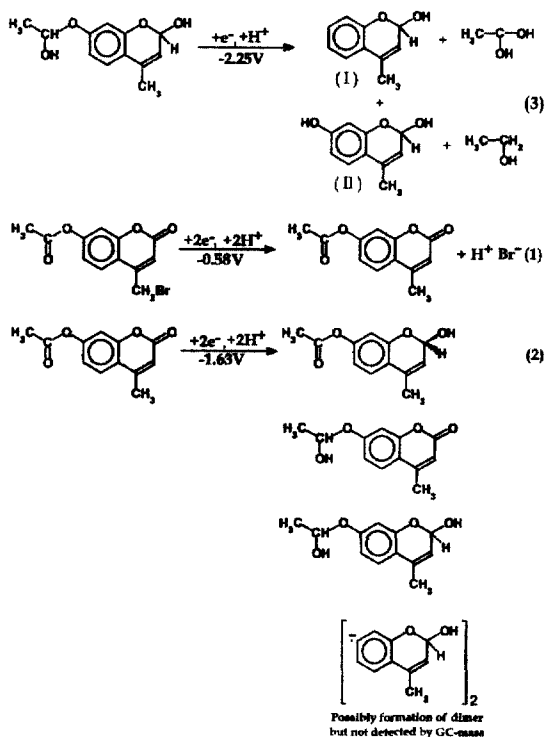
From the basis of this result, it can be summarized that the electrode reaction is an irreversible EC process, in which the subsequent processes such that the bromo group is removed at 1st step, C=O is reduced at 2nd step, and the acetoxy group is removed at 3rd step are proceeded, which can be suggested as the following *scheme 1*.

### Conclusion

The electrochemical reductions of ABMC were proceeded as the three steps(-0.6, -1.7, -2.0 volts). All the 1st, 2nd and 3rd steps were the irreversible processes, which was the EC mechanism accompanying a chemical reaction after electron transfer, in which the

bromo group was removed at the 1st step, the C=O group was reduced into CH-OH at the 2nd step, and the acetoxy group was removed at the 3rd step, the processes of which were identified by GC-mass.

From that the solution became to yellow after the moment that the C=O was reduced by the 2nd controlled potential electrolysis, the change in color was irrelevant to the bromo group. It can be stated that a comparatively stable radical was formed in coumarin ring in the case that electron was transferred to coumarin, and the change in color was caused by the excitation of this radical.



*Scheme 1.* Electrochemical reduction mechanism of ABMC.

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