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Research Article

CHEMISTRY

A Spectroscopic and Photochemical Behavior of Some Coumarin Derivatives

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Abstract: The electronic absorption, emission spectra as well as fluorescence quantum yields of some coumarin derivatives were measured in different solvents of different polarities. pKa and pKa* were calculated using universal buffers.

The dyes undergo micellization in different micelles and may be used as a probe to determine the critical micelle concentrations (CMC) of CTAB and SDS. The effect of metal ions like [Cu^{+2}, Co^{+3}, Ni^{+2}] as quenchers and the effect of temperature on quenching are studied and thermodynamic parameters have been calculated.

Key words: *fluorescence quantum yield, coumarin derivatives, metal ion quencher*
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Introduction:

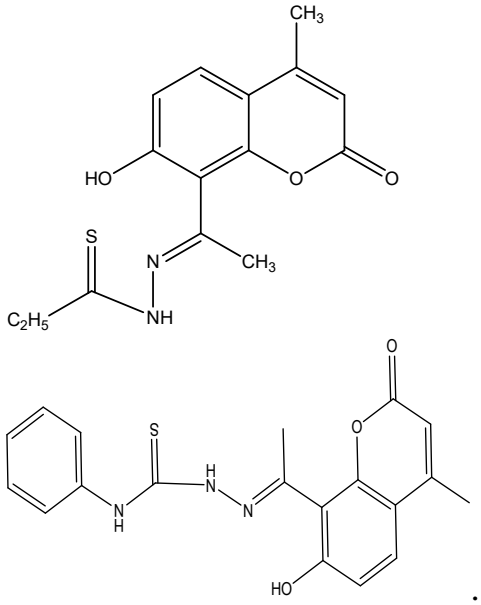
Coumarin (1, 2-benzopyrone or phenylpropanoids) and its derivatives are widely distributed throughout nature and many exhibit useful and diverse biological activities [1, 2]. Coumarins occur as secondary metabolites in the seeds, roots and leaves of many plant species, notably in high concentration in the tonka bean and thus the name comes from a French word, *coumarou*, for the tonka bean.

Their function is far from clear, although suggestions include plant growth regulations, fungistasis, bacteriostasis and, even, waste products [3]. Some naturally occurring coumarin derivatives include warfarin, umbelliferone (7-hydroxycoumarin, aesculetin (6,7-dihydroxycoumarin), herniarin (7-methoxycoumarin, psoralen and imperatorin. Now the diversity of coumarin derivatives, both natural and synthetic, has grown and are thus divided into several subclasses. Most reviews classify coumarins according to whether particular compounds are simple coumarins (e.g. coumarin, and limettin), linear furanocoumarins (e.g. imperatorin, 7 and isopimpinellin, angular furanocoumarins (e.g. angelicin), linear pyranocoumarins (e.g. xanthyletin) or angular pyranocoumarins (e.g. seselin) [4]. Murray *et al*. [5], however, used a biogenetic approach based upon the number of nuclear oxygen atoms in classifying coumarin-containing compounds.

Coumarin derivatives have been found to have numerous therapeutic applications including photo chemotherapy, antitumor and anti-HIV therapy [6, 7], and as central nervous system (CNS) stimulants [8], antibacterial [9, 10] antiinflammatory [11], anti-coagulants [12] and dyes [13]. In addition, coumarins are known to be lipid lowering agents with moderate triglyceride lowering activity [14]. Furthermore, hydroxycoumarins are powerful chain-breaking antioxidants and can prevent free radical injury by scavenging reactive oxygen species [15].

Some of the coumarin derivatives formerly used as fixative and flavoring agents, are now regulated as food adulterants by the Food and Drug

Administration (FDA) in the United States due to their adverse effects such as mild nausea, diarrhea, and hepatotoxicity when used in certain amounts [16–19]. Although currently marketed in several European countries, coumarin type drugs used for the treatment of lymphoedema, has not been approved for therapeutic purposes in the United States, due to their hepatotoxicity. However, recent discovery of coumarins having weak estrogenic activity resulted in the use of such derivatives as therapeutic agents in preventing the emergence of menopause related diseases, such as osteoporosis, increased risk for cardiovascular event / disease and cognitive deficiencies [20].



1.Experimental

In the present communication we present a study of two thiocoumarin derivatives namely (E)-1-(1-(7-hydroxy-4-methyl-2-oxo-2H-chromen-8-yl) ethylene)-4-phenylthiosemicarbazide (I) and (E)-N'-(1-(7-hydroxy-4-methyl-2-oxo-2H-chromen-8-yl) ethylene) propanethiohydrazide

(II) Synthesized and purified according to the previously reported method [21] were kindly provided by prof. Dr. Mohamed Hussein of Cairo University. Chemicals were purchased from Sigma and Aldrich and were used without further purification. All solvents used in the study were of highest o available purity from Merck.

The electronic absorption spectra were recorded on Cary-400 UV-visible spectrophotometer connected to a Cary data acquisition system using 1 cm matched silica cells, while the fluorescence spectra were recorded by using Perkin- Elmer LS50B scanning spectrofluorophotometer. The temperature controller consists of a peltier element for heating and cooling, requisite amount of substrate and other reagents were transferred into the 1 cm fluorescence cell. The cell was placed in the cell holder and allowed to equilibrate thermally.

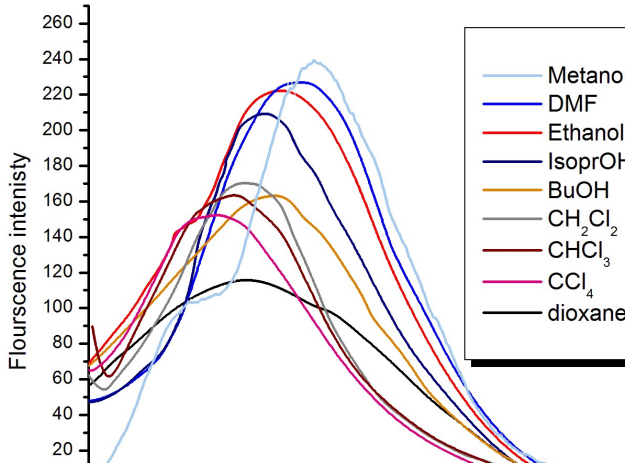
3.Results and discussion

3.1. Absorption and emission behavior of coumarin derivatives (I) and (II) in organic solvents.

The electronic absorption and emission spectra of 1 x 10^{-5} M coumarin derivatives were measured at room temperature in different solvents of different polarities (Δf) with f given by the relation [22]

$$\Delta f = \frac{(\varepsilon - 1)}{(2\varepsilon + 1)} - \frac{(n^2 - 1)}{(4n^2 + 2)}$$

Where (Ɛ) is the dielectric constant and n is the refractive index of the solvent. The absorption of coumarin is not affected by solvent polarity as shown in Table (1, 2), whereas the emission spectra are significantly influenced by the medium. With



increasing solvent polarity, the fluorescence maximum is shifted to longer wavelengths from 395 nm in CCl_4 (Δf = 0.115) to 450 nm in methanol (Δf = 0.408), as shown in Figure 1(a,b).

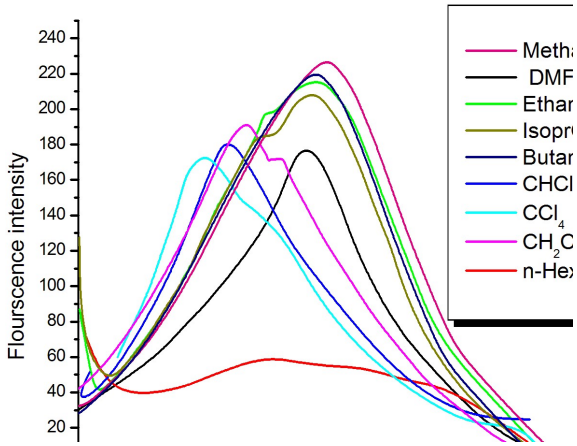


Figure (1). Fluorescence spectra of coumarine derivatives with different solvent polarities (a) coumarin I, (b) coumarin II

Table (1): Some spectral maxima and photo physical parameters of coumarin derivative (I) in different solvents.

Solvents	$E_T(30)$ Kcal/mol	Dielectric Constant	Δf	λ_f (nm)	$\lambda_{max(Abs)}$ (nm)	ε_{max} $dm^3.mol^{-1}\ cm^{-1}$	ϕ_f
CCl_4	32.4	2.24	0.115	409	308	15000	0.076
$CHCl_3$	39.1	4.81	0.251	417	309	15320	0.086
CH_2Cl_2	40.7	9.08	0.319	425	309	15600	0.088
dioxan	36	2.21	0.121	410	309	15150	0.079
DMF	43.8	38.25	0.377	451	311	16150	0.099
MeOH	55.4	32.6	0.393	455	312	16300	0.102
EtOH	51.9	24.6	0.379	449	312	16000	0.099
IsoprOH	49.2	18.3	0.367	443	312	15680	0.096
BuOH	50.2	17.8	0.36	440	311	15400	0.087

Table (2): Spectral maxima and photo physical parameters of coumarin derivative (II) in different solvents.

Solvents	$E_T(30)$ Kcal/mol	Dielectric constant	Δf	λ_f (nm)	$\lambda_{max(Abs)}$ (nm)	ε_{max} $dm^3.mol^{-1}\ cm^{-1}$	ϕ_f
CCl_4	32.4	2.24	0.115	395	307	17400	0.065
$CHCl_3$	39.1	4.81	0.251	408	306	18000	0.074
CH_2Cl_2	40.7	9.08	0.319	418	307	18300	0.078

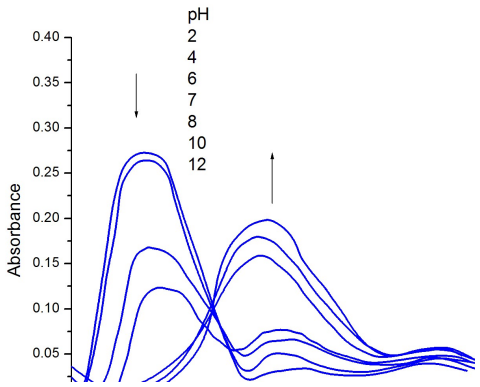
DMF	43.8	38.25	0.377	449	308	
MeOH	55.4	32.6	0.393	451	308	
EtOH	51.9	24.6	0.379	445	308	
iso-prOH	49.2	18.3	0.359	443	307	
n-BuOH	50.2	17.8	0.36	442	307	

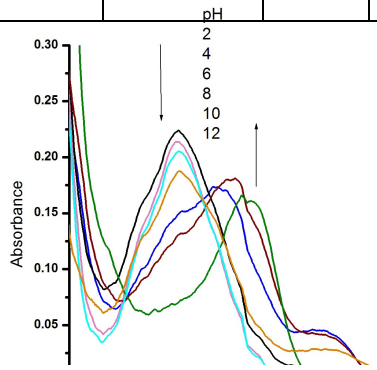
For solvents with similar viscosities, a linear correlation exists between the solvent polarity (Δf) and emission maximum (λ_f max) as shown in Figure (2)

3.2. Absorption and emission spectral behavior of coumarin derivatives in buffer solutions and estimation of pKa and pKa*

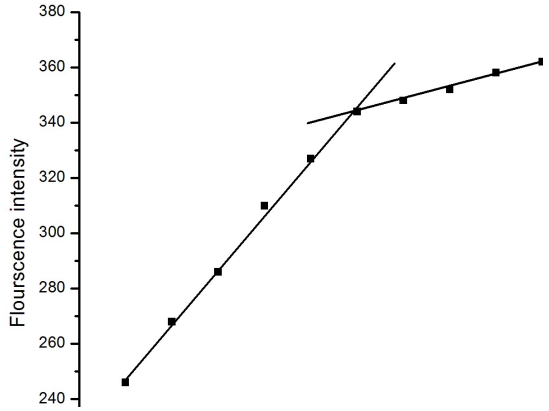
The electronic absorption spectra of coumarin derivatives were recorded in the presence of buffer solutions showing regular changes with isosbestic points as shown in Figure (4). In acid solutions, pH = 2, the drugs exhibit bands around 320 nm and 309 nm for coumarin I and coumarin II respectively which may be due to ionization of OH group. upon increasing pH values the extinction coefficient decreases with spectral red shift. Further increase in pH values leads the ionization of OH group and new band characteristics to the anionic form appears at 367 nm and 565 nm for coumarins (I and II).

The fluorescence spectral bands for coumarin (I and II) increases in basic medium as shown in Figure (5) which may due to increasing formation of hydrogen bond in basic medium as well as modification of electronic transitions. According to half-height method and the modified limiting absorbance method the values of pK_a and pK_a* were determined. The data were collected in Table 3. Plots of the absorbance vs pH values gaves sigmoidal curves as shown in Figure 6 and 7 for coumarins (I and II), while the plots of pH vs $\log\frac{A-A_{min}}{A_{max}-A}$ gave linear relation (Figures 8 and 9)





Figure(10). Fluorescence spectra of coumarin I (a) and coumarin II (b) in SDS solution. The emission intensities increase as the surfactant concentration increases.



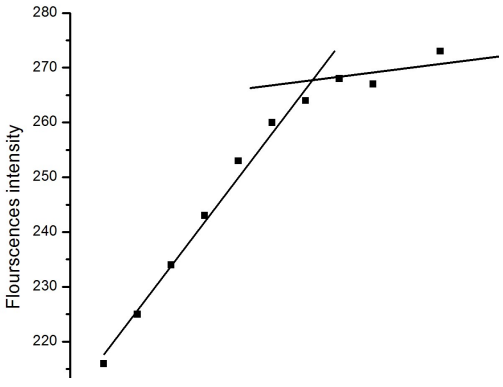


Figure (11). Plots of fluorescence intensity of coumarin derivatives vs SDS concentration,(a) Coumarin I and (b) coumarin II

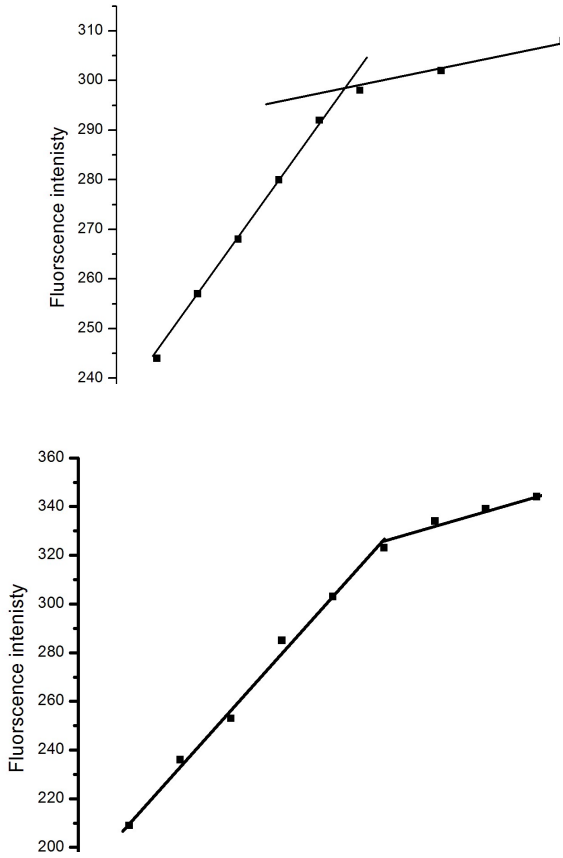
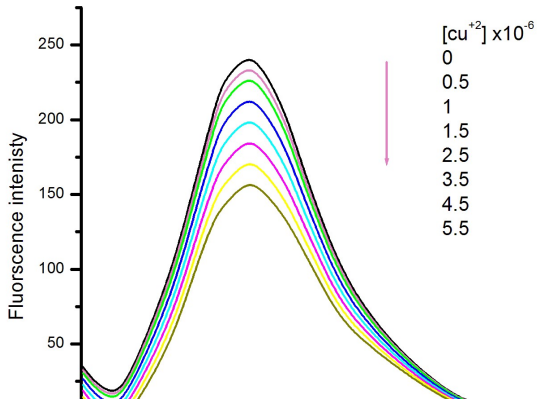


Figure (12). Plots of fluorescence intensity of coumarin derivatives vs CTAB concentration, (a) Coumarin I and (b) coumarin II.

3.4. Quenching of fluorescence spectra using metal ions

The fluorescence quenching of coumarin derivatives (I and II) were studied using Cu^{+2} and Co^{+2} metal ions as quenchers in methanol. The fluorescence emission of coumarin derivatives (I and II) exhibits maxima at 450 nm and 455 nm for coumarin I and II respectively. As the concentration of the quencher (Cu^{+2} or Co^{+2} metal ion) increases, the fluorescence intensities of derivatives I and II decrease as shown in Figures (13)

The Stern-Volmer plots of the quenching process of coumarin I and II emission using Cu^{+2} and Co^{+2} metal ions at different temperature are shown in Figures (14, 15 and 16). The plots are linear and as the temperature increase the rate of quenching increases indicating that the quenching process is diffusion-controlled i.e. dynamic quenching mechanism. The energy of activation Ea was determined form Arrhenius equation as shown in Figures ((17, 18, and 19). The thermodynamic parameters for quenching process were calculated and tabulated in Tables (4 and 5). It was found that the energy of activation, ΔS and ΔH decreased in the following order $Co^{+2} > Ni^{+2} > Cu^{+2}$ and the quenching rate increases from $Co^{+2} < Ni^{+2} < Cu^{+2}$ this confirms that the quenching process is diffusion-controlled. Also quenching process for coumarin II is greater than coumarin I. This may be due to flexibility of aliphatic chain (ethyl group) in Coumarin II.



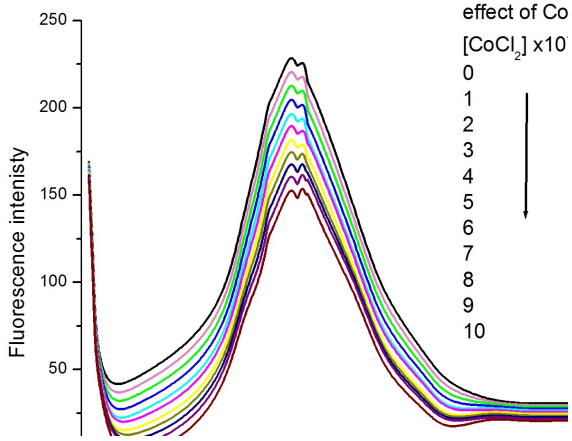


Figure (13). Fluorescence quenching of coumarin derivative (I)
as a function of metal ion concentration

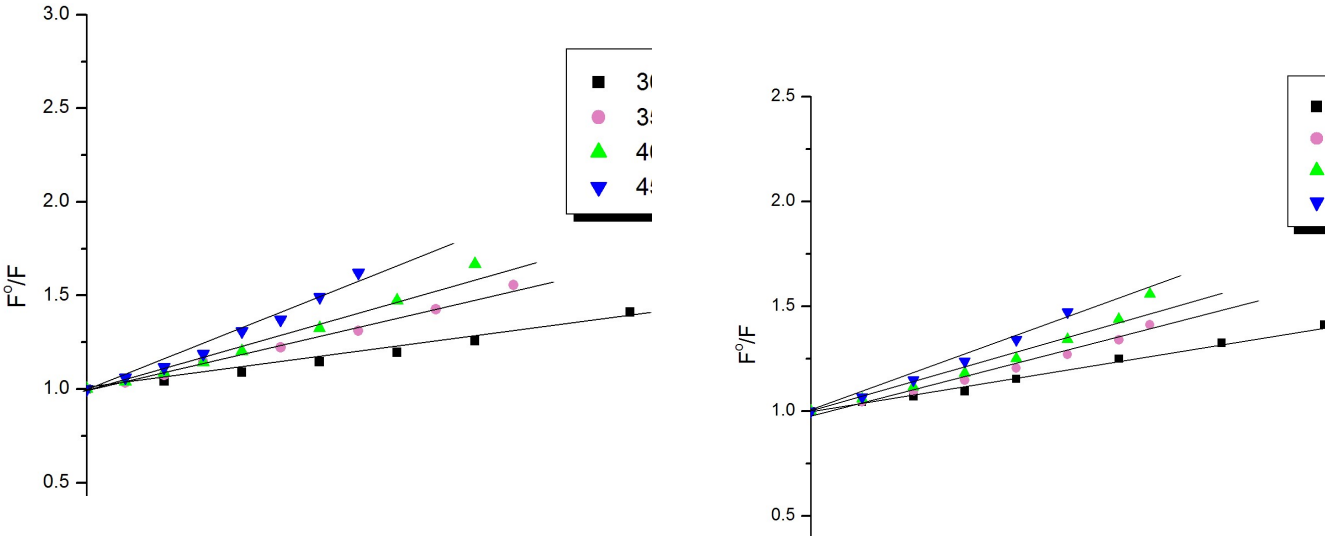


Figure (14). Stern-Volmer plots of the quenching of 1 x10^{-5} M Coumarin by Cu^{+2} metal ions in methanol at different temperatures (a) Coumarin I and (b) Coumarin II

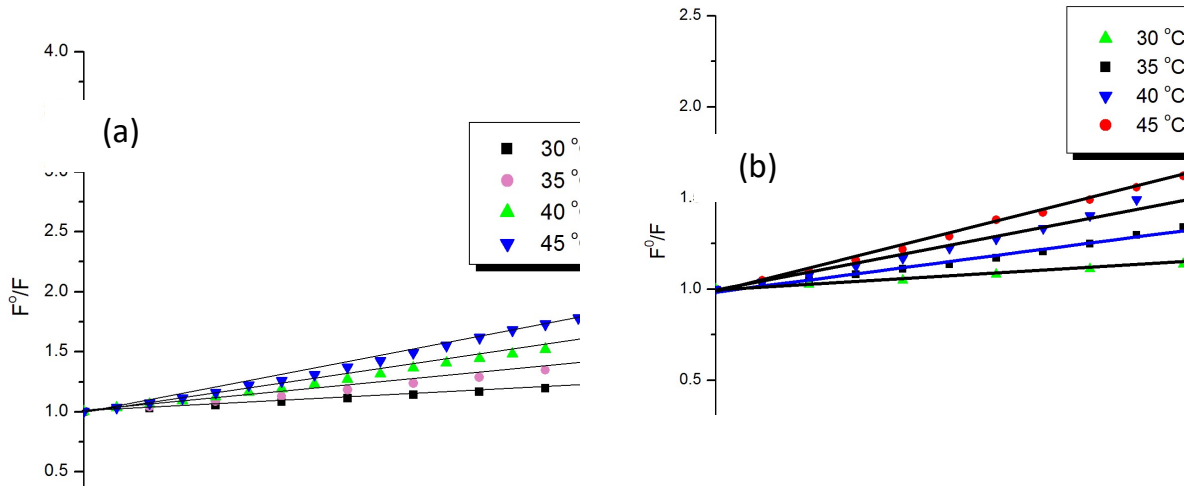


Figure (15). Stern-Volmer plots of the quenching of 1 x10^{-5} M coumarin by Ni^{+2} metal ions in methanol at different temperatures (a) Coumarin I and (b) Coumarin II

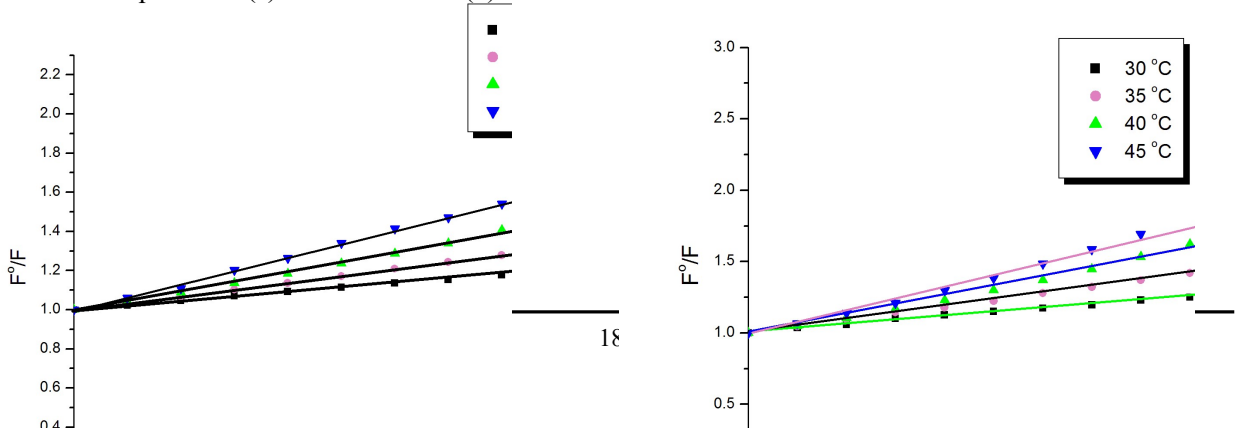


Figure (16). Stern-Volmer plots of the quenching of 1 x10^{-5} M coumarins by Co^{+2} metal ions in methanol at different temperatures (a) coumarin I and (b) Coumarin II

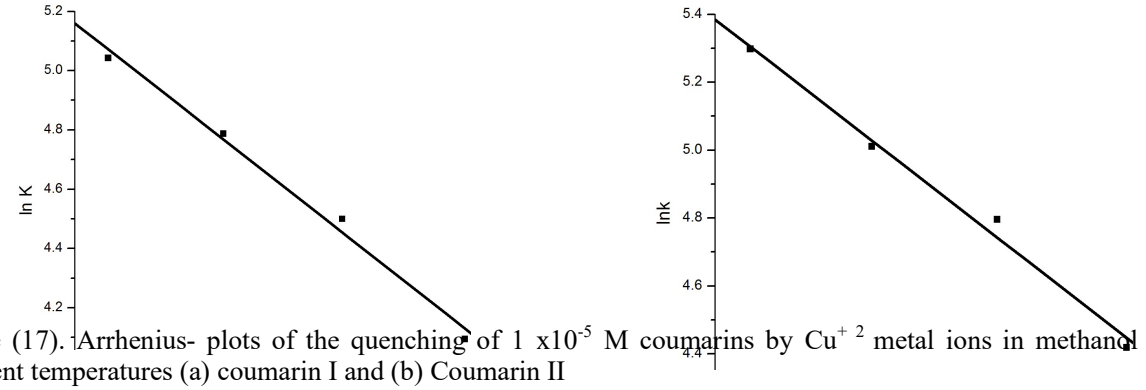


Figure (17). Arrhenius- plots of the quenching of 1 x10^{-5} M coumarins by Cu^{+2} metal ions in methanol at different temperatures (a) coumarin I and (b) Coumarin II

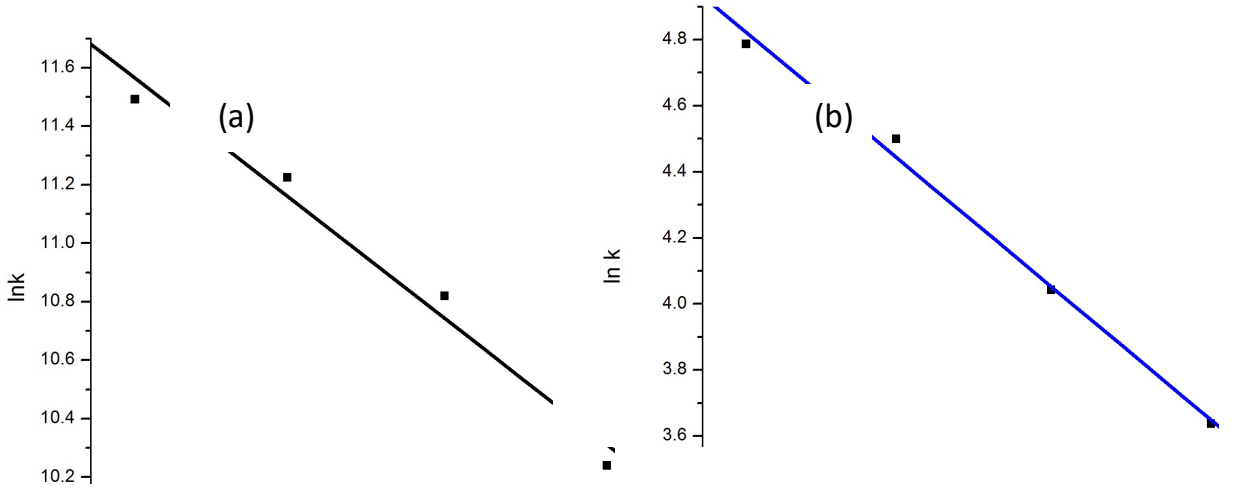


Figure (18). Arrhenius- plots of the quenching of 1 x10^{-5} M coumarins by Ni^{+2} metal ions in methanol at different temperatures (a) coumarin I and (b) Coumarin II

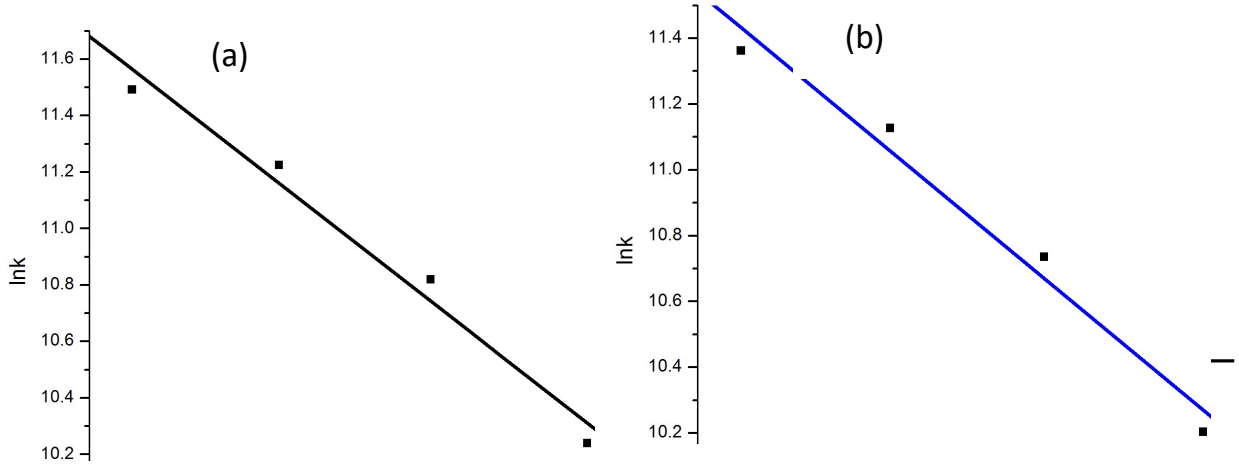


Figure (19). Arrhenius- plots of the quenching of 1 x10^{-5} M coumarins by Co^{+2} metal ions in methanol at different temperatures (a) coumarin I and (b) coumarin II

Table. 4. Thermodynamic parameters for quenching 1 x10^{-5} M coumarin I derivative using different metal ions at different temperatures

Quecher	T (K)	$K_{SV} \times 10^6$ kJ/mole	Ea kJ/mole	$\Delta H^{\#}$ kJ/mole	$\Delta G^{\#}$ kJ/mole	$\Delta S^{\#}$ J/mole K
Cu^{+2}	303	0.06	49.83	47.24	46.22	3.30
	308	0.09				
	313	0.12				
	318	0.155				
Ni^{+2}	303	0.032	59.76	57.20	47.72	30
	308	0.050				
	313	0.075				
	318	0.098				
Co^{+2}	303	0.021	63.00	60.44	48.70	38
	308	0.034				
	313	0.050				
	318	0.069				

Table. 5. Thermodynamic parameters for quenching 1 x10^{-5} M coumarin II derivatives using different metal ions at different temperatures

Quecher	T (K)	$K_{SV} \times 10^6$ kJ/mole	Ea kJ/mole	$\Delta H^{\#}$ kJ/mole	$\Delta G^{\#}$ kJ/mole	$\Delta S^{\#}$ J/mole.K
Cu^{+2}	303	0.083	45.65	43.09	45.46	- 28
	308	0.121				
	313	0.160				
	318	0.200				
Ni^{+2}	303	0.043	56.44	53.88	47.39	21
	308	0.057				
	313	0.090				
	318	0.12				

Co^{+2}	303	0.027	60.40	57.84	47.94	32
	308	0.046				
	313	0.068				
	318	0.086				

Conclusion

The absorption spectra of Coumarin aer not affected by solvent polarity, whereas the emission spectra are significantly influenced by the medium. This indicates a more polar excited state leading to more salvation of excited states compared with ground states. the fluorescence quantum yield is increased with increasing the solvent polarity and the maximum emission wavelength is shifted to longer wavelengths (red shifted) due to stabilization of excited state in polar solvent due to formation hydrogen bond. This was confirmed by the effect of buffer solution, where in basic medium the maximum emission wavelength is shifted to longer wavelength and the fluorescence quantum yield is increased in alkaline medium, pk_a and pk_a* are determined.

The emission intensity of coumarin I and II increased as the surfactant concentration increases with a break at surfactant concentrations which are very close to the critical micelle concentration of SDS and CTAB, due to frictional forces and decreasing of solvent-free volume required for free rotation which are responsible fluorescence quenching. The fluorescence quenching of coumarin derivatives (I and II) was studied using Cu^{+2} , Ni^{+2} and Co^{+2} metal ions at different temperatures. The rate of quenching K_{SV} increases in linear correlation with increasing the temperature, indicating that the quenching process is diffusion-controlled i.e. dynamic quenching mechanism and the thermodynamic parameters confirm this mechanism.

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الملخص العربى

السلوك الفوتوفيزيقي والفوتوكيميائي لبعض مشتقات الكومارين

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قسم الكيمياء- كلية العلوم- جامعة طنطا

مشتقات الكومارين من الاصباغ الهامه والتي تستخدم في مجالات علميه وتكنولوجيه عديده , فهي تستخدم علي نطاق واسع لبناء مجموعات متنوعه من المواد ذات الوميض الضوئي والحساسية الكيميائيه. ولهذه المشتقات الكثير من الاستخدامات في مجال الطب والدواء فتستخدم كمانع للتجلط والاورام وكمضادات للميكروبات والالتهابات وايضا في مكافحة فيروس الايدز .

في هذا البحث تم دراسه السلوك الفوتوفيزيقي والفوتوكيميائي لمركبين من مشتقات الكومارين حيث وجد ان طيف الامتصاص لا يتاثر بقطبية المذيب في حين يتأثر طيف الانبعاث بقطبية المذيب, وبزياده قطبية المذيب يزداد الناتج الفلورسيني الضوئي (ϕ_f) كما يزداد الطول الموجي المقابل للانبعاث مما يؤكد ان الحاله المثاره للمركبات اكثر ثباتا في المذيبات القطبيه, وتم دراسه تاثير ايون الهيدوجين علي الانبعاث ووجد ان الانبعاث يزداد في الوسط القاعدي اكثر من الحامضي وتم تعيين ثابت التأين(pk_a*& pk_a) لهذه المركبات في كلا الحالتين الارضيه والمثاره .

كما تم دراسه تاثير المواد ذات النشاط السطحي مثل الدوديسيل سلفات و سيتيل ثلاثي ميثيل الامونيوم بروميد علي الانبعاث الفلورسيني الضوئي (ϕ_f) ووجد ان زياده تركيز المواد ذات النشاط السطحي يؤدي الي زيادة الناتج الضوئي (ϕ_f) حيث يصل اقصاه في حاله تكون الميسل .

كما تم دراسه تاثير ايونات بعض المعادن علي الانبعاث الفلورسني الضوئي (ϕ_f) ووجد ان ايونات هذه المعادن تعمل علي اضعاف وتقليل الانبعاث الفلوروسيني (ϕ_f) خاصه مع زياده درجات الحراره مما يؤكد ان ميكانيكيه اضعاف الانبعاث الفلورسيني بسبب ايونات المعادن تتم عن طريق الانتشار الديناميكي الحراري كما تم تعيين ثابت (Stern Volmer) كما تم تعيين ثوابت الديناميكا الحراريه($\Delta G^{\#}$ و$\Delta S^{\#}$ و$\Delta H^{\#}$) التي تؤكد هذه المكانيكيه (الانتشار الديناميكي الحراري) .