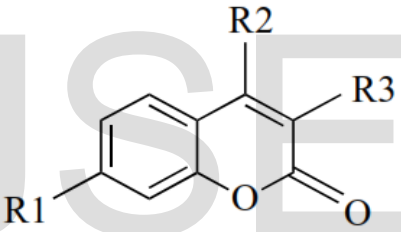
X-Ray Crystal and Molecular Structure Determination of Coumarin Derivatives – A Comparative Study

M. Kayalvizhi[a] & G. Vasuki[a*]
Lecturer in Physics, Mobile No: 8903106073, kayalvizhi.mani@gmail.com
Associate Professor of Physics, Mobile No:9791402323, vasuki.arasi@yahoo.com
[a]Kunthavai Naachiyaar Govt. Arts College (w), (Autonomous), Thanjavur- 613 007.

Introduction:

Coumarin is the simplest member of the group of oxygen heterocyclic compounds called benzo-2-pyrones. Coumarins are an important class of compound due to their presence in natural products as well as their medicinal applications, e.g. as anti-inflammatory, anti-viral, antioxidant, antibacterial, antifungal, anti-HIV and as anti-carcinogenic agents. Coumarin and its derivatives also have applications as fluorescent dyes for synthetic fibres and daylight fluorescent pigments and as cosmetics, optical brightening agents and laser dyes. Coumarin and several of its derivatives were investigated for their photosensitizing properties. In a search for new coumarin compounds with better biological activity, four compounds, were synthesized and using X-ray diffraction studies the molecular structure of these compounds were determined and they are compared.



COMPOUND	R1	R2	R3
MOCHPQ	CH_3	$C_{12}H_{14}N$	-----
MCHPQ	CH_3	$C_{12}H_{14}N$	-----
MBDC	CH_3	Fused benzochromene	
CPCPTC	-----	-----	C_3NS-N-$C_{12}H_8Cl_2$

Results and Discussion:

In MOCHPQ compound, (Fig.1), the dihedral angle between the phenyl rings (C16-C21) of the coumarin molecule and the pyranoquinoline moiety is 84.97 (8)°. The C15 atom of the carbonyl group has a distorted trigonal geometry with O2—C15—O1 [117.36 (14)°] and O2—C15—C14 [125.26 (16)°], deviating significantly from the ideal sp^2 value of 120°, which is consistent with the values observed in a related structure (Pereira Silva *et al.*, 2010). In the crystal, weak intermolecular C20—H···O2^{ii} hydrogen bonds together with C12—H···O1^{i} hydrogen bonds between inversion-related molecules (Fig.5) are observed.

Crystal packing is also stabilized by C5—H···π ring interactions [minimum C···*Cg* separation, 3.910 (3) Å]. The substituent ring (N1, C1, C6–C9) adopts a slightly distorted half-chair conformation with Q = 0.4852 (18) Å, θ = 48.0 (2)° and φ = 259.3 (3)° while the ring (O3, C7–C12) adopts a slightly distorted chair conformation with Q = 0.548 (2) Å, θ = 2.8 (2)° and φ = 300 (5)° (Cremer & Pople, 1975).

In MCHPQ compound, (Fig.2), the dihedral angle between the phenyl rings (C4A, C5-C8, C8A) of the coumarin molecule and the pyranoquinoline moiety is 48.07(9)˚. The C2 atom of the carbonyl group has a distorted trigonal geometry with O2—C2—O1 [116.90 (18)°] and O2— C2—C3 [125.67(21)˚], deviating significantly from the ideal sp^2 value of 120°. In the crystal, weak intermolecular C5—H5···O11 hydrogen bonds together with C17—H17···O2 hydrogen bonds between inversion-related molecules (Fig.6) are observed. The substituent ring (N16, C15, C14A, C20B, C20A, C16A) adopts a slightly distorted half-chair conformation with Q = 0.5226 (18) Å, θ = 48.1(2)° and φ = 93.7 (3)°while the ring (O11, C12–C14, C14A, C20B) adopts a slightly distorted chair conformation with Q = 0.5495 (19) Å, θ = 4.3 (2)° and φ = 48 (2)°.

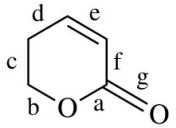
The MBDC compoud, (Fig.3), crystallizes with eight independent molecules (A-H) in the asymmetric, which have been labelled in an identical manner and are distinguished by suffixes A, B, C, D, E, F, G and H, respectively. The asymmetric unit is composed of four groups of two molecules each (AB, CD, EF & GH). In each group the molecules differ in their orientation. In each molecule fused benzene and pyranoid rings form the benzopyran system, which is planar, with the dihedral angle between the best planes of the rings are 1.1 (4)° [Molecule A], 1.6 (4)° [Molecule B], 1.4 (4)° [Molecule C], 1.2 (4)° [Molecule E], 1.5 (4)° [Molecule F], 1.3 (4)° [Molecule G] and 0.5 (4)° [Molecule H]. In each molecule, the pyran-2-one ring is planar (r.m.s. deviations vary from 0.001 to 0.017 Å), while the pyran ring has a screw-boat conformation. The crystalline solid is stabilized by C - H…O (Fig.7), C - H…π interactions and π-π interactions connecting the adjacent molecular channels.

In CPCPTC compound, Fig.4, 2H-chromene (O1/C1–C9/O2) ring system is approximately planar, with the maximum deviation of -0.025 (2) Å at atom O1. The thiazole ring (S1/N1/C10–C12) is almost planar with a r.m.s. deviation of 0.0022 Å and makes a dihedral angle of 58.52 (7)° with the chromene ring (O1/C1–C9/O2). The chromene ring system is inclined at angles of 58.3 (1)° and 55.39 (9)° with respect to the two chlorophenyl rings (C13–C18/Cl1) and (C19–C24/Cl2), respectively. The two chlorophenyl rings show significant deviation from coplanarity, with a dihedral angle between the two planes of 47.69 (8)°. The sum of bond angles around N1 [359.79 (5)°] indicates that atom N exhibits sp^2 hybridization. Torsion angles C1—C2—C10—N1 = -58.5 (4)° and C10—N1—C22—C23 = -51.8 (4)° indicate that the chromene ring and the chlorophenyl ring are substituted synclinally to the thiazole ring at atoms C2 and C22, respectively. The torsion angle C22—N1—C12—N2 [6.4 (4)°] indicates that the two chlorophenyl rings have a Z-configuration across the N1—C12 bond. In the crystal, a short intermolecular

C3—H···Cl^{i} contact is observed [3.282 (3) Å] [symmetry code: (i) x, y - 1, z] together with second longer C23—H···Cl1^{ii} contact is observed between C23 and Cl1^{ii} [3.547 (3) Å] [symmetry code: x + 1, y, z + 1] (Fig. 2). Inter-ring π—π stacking interactions between the symmetry related C4–C9 ring (centroid Cg3) and the C13–C18^{iii} ring (centroid Cg4), with Cg3···Cg4 = 3.867 (2) Å (symmetry code: (iii) x + 1, y, z + 1) stabilize the crystal structure.

CRYSTAL DATA				
Compound	**MOCHPQ**	**MCHPQ**	**MBDC**	**CPCPTC**
Chemical Formula	$C_{22}H_{21}NO_3$	$C_{22}H_{21}NO_3$	$C_{21}H_{14}O_3$	$C_{24}H_{14}Cl_2N_2O_2S$
Molecular Weight (g/mol)	347.40	347.40	314.2	465.33
Temperature (K)	296	296	296	296
Radiation (λ in Å)	Mo Kα (0.71073)	Mo Kα (0.71073)	Mo Kα (0.71073)	Mo Kα (0.71073)
Crystal system	Triclinic	Monoclinic	Monoclinic	Monoclinic
Space group	Pī	P21/c	Cc	$P2_1$
UNIT CELL DIMENSIONS				
a(Å)	7.7529 (4)	9.3400 (3)	20.7595 (16)	9.1491 (7)
b(Å)	11.2790 (7)	22.1653 (8)	20.7800 (16)	10.3099 (8)
c(Å)	11.7563 (11)	8.7044 (3)	28.427 (2)	11.9347 (10)
α(°)	117.232 (3)	90	90	90
β(°)	98.475 (3)	105.549 (1)	100.489 (2)	111.587 (2)
γ(°)	101.301 (2)	90	90	90
Volume ($Å^3$)	862.60 (11)	1736.07 (10)	12058.1 (16)	1046.80 (14)
Density(Mgm^{-3})	1.338	1.3291	1.385	1.476
Crystal description	Block, colourless	Block, colourless	Block, colourless	Block, colourless
No. of molecules in unit cell (Z)	2	4	32	2
Absorption Coefficient (μ mm^{-1})	0.09	0.088	0.09	0.44
Molecules per asymmetric unit (Z')	1	1	8	1
F(000)	368	736	5248	476
Crystal size (mm)	0.20x0.15x0.15	0.25x0.20x0.15	0.40x0.35x0.30	0.35x0.30x0.25

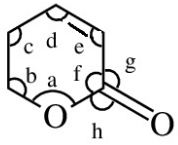
Table 1. Comparison of the bond lengths of the present work (MOCHPQ, MCHPQ, MBDC and CPCPTC) with other closely related structures taken from the literature.



Pyrone ring of Coumarin

Com.	a (Å)	b (Å)	c (Å)	d (Å)	e (Å)	f (Å)	g (Å)	Reference
1	1.362(2)	1.3720(19)	1.3948(19)	1.451(2)	1.342(2)	1.442(2)	1.207(2)	Present work MOCHPQ Kayalvizhi et al., (2013)
2	1.371(2)	1.379(2)	1.391(2)	1.453(2)	1.344(2)	1.439(3)	1.205(2)	Present work MCHPQ Kayalvizhi et al., (2014a)
3	1.358(12)	1.398(11)	1.402(12)	1.451(11)	1.384(11)	1.477(12)	1.205(11)	Present work MBDC Kayalvizhi et al.,(2014b) Molecule A
	1.367(12)	1.368(11)	1.379(12)	1.455(12)	1.375(12)	1.460(13)	1.211(11)	Molecule B
	1.357(12)	1.375(11)	1.398(12)	1.454(11)	1.397(12)	1.458(13)	1.199(11)	Molecule C
	1.351(12)	1.372(11)	1.399(11)	1.455(11)	1.386(11)	1.461(12)	1.223(11)	Molecule D
	1.352(12)	1.391(11)	1.382(12)	1.458(11)	1.391(12)	1.455(13)	1.211(11)	Molecule E
	1.364(12)	1.380(11)	1.393(12)	1.447(12)	1.387(12)	1.477(12)	1.196(11)	Molecule F
	1.359(11)	1.369(11)	1.395(12)	1.456(12)	1.388(12)	1.446(12)	1.212(11)	Molecule G
	1.358(11)	1.382(11)	1.403(12)	1.449(11)	1.393(11)	1.458(12)	1.205(10)	Molecule H
4	1.371(3)	1.382(4)	1.378(4)	1.435(3)	1.339(4)	1.457(4)	1.203(3)	Present work CPCPTC Kayalvizhi et al.,(2014c)
5	1.369(2)	1.377(2)	1.400(3)	1.432(3)	1.360(3)	1.476(3)	1.206(2)	Caracelli et al., (2015)
6	1.374(6)	1.368(6)	1.379(7)	1.438(7)	1.375(8)	1.454(8)	1.206(7)	Brahmia et al., (2015)
7	1.370(2)	1.3805(19)	1.3997(18)	1.4538(18)	1.344(2)	1.452(2)	1.204(2)	Pujar et al., (2014)
8	1.3709(19)	1.3776(18)	1.392(2)	1.434(2)	1.350(2)	1.468(2)	1.2102(19)	Matos et al., (2012)
9	1.379(2)	1.384(2)	1.396(3)	1.428(3)	1.356(3)	1.469(3)	1.209(2)	Yusufzai et al., (2012)
10	1.3805(13)	1.3834(13)	1.3944(16)	1.4453(14)	1.3502(15)	1.4687(15)	1.2128(13)	Li et al., (2012)
11	1.379(4)	1.375(4)	1.401(4)	1.443(5)	1.342(5)	1.455(5)	1.200(4)	Zhang et al., (2012)
12	1.375(3)	1.375(3)	1.389(3)	1.424(3)	1.359(3)	1.461(3)	1.209(3)	Arshad et al., (2011)
13	1.3904(15)	1.3743(15)	1.4044(17)	1.4681(16)	1.4133(16)	1.4378(17)	1.2180(16)	Rambabu et al., (2010)
14	1.375(6)	1.384(5)	1.396(6)	1.445(6)	1.410(6)	1.466(6)	1.210(5)	Mechi et al., (2009)
15	1.3804(15)	1.3784(14)	1.3969(17)	1.4500(17)	1.3488(18)	1.4413(18)	1.2119(15)	Aazam et al., (2006)

Table 2.5 Comparison of the bond angles of the present work (MOCHPQ, MCHPQ, MBDC and CPCPTC) with other closely related structures taken from the literature.



Pyrone ring of Coumarin

S.No:	a(Å)	b(Å)	c(Å)	d(Å)	e(Å)	f(Å)	g(Å)	h(Å)	Reference
1	121.40(12)	121.83(13)	117.98(13)	118.25(13)	123.12(14)	117.37(14)	125.26(16)	117.36(14)	Present work MOCHPQ Kayalvizhi et al., (2013)
2	121.51(14)	121.25(17)	118.44(16)	118.45(16)	122.80(18)	117.40(17)	125.7(2)	116.90(18)	Present work MCHPQ Kayalvizhi et al., (2014a)
3	122.1(7)	121.3(8)	119.0(8)	118.4(7)	121.6(8)	117.6(8)	124.9(10)	117.5(9)	Present work MBDC Kayalvizhi et al.,(2014b) Molecule A
	121.7(7)	122.2(9)	118.9(8)	118.0(8)	121.5(9)	117.6(8)	125.4(10)	117.0(9)	Molecule B
	121.1(7)	122.5(8)	118.3(8)	117.9(8)	121.3(8)	118.5(8)	125.1(10)	116.5(9)	Molecule C
	122.4(7)	121.4(8)	118.6(8)	118.4(7)	120.7(8)	118.4(8)	123.7(9)	117.8(8)	Molecule D
	121.3(7)	121.6(8)	119.5(8)	117.4(8)	121.2(8)	118.9(8)	124.6(10)	116.4(9)	Molecule E
	122.5(7)	121.6(8)	119.0(8)	118.5(8)	121.3(9)	117.1(8)	125.2(10)	117.7(9)	Molecule F
	121.0(7)	122.1(8)	119.0(8)	117.4(8)	121.3(8)	119.2(8)	124.8(9)	116.0(9)	Molecule G
	122.0(7)	121.5(8)	118.8(8)	118.2(8)	121.3(8)	118.2(8)	124.2(9)	117.5(9)	Molecule H
4	122.3(2)	121.1(2)	117.6(2)	121.5(3)	120.3(2)	117.1(2)	125.8(3)	117.1(3)	Present work CPCPTC Kayalvizhi et al.,(2014c)
5	122.76(15)	120.80(17)	118.32(18)	120.69(18)	120.25(17)	117.09(16)	125.43(18)	117.48(17)	Caracelli et al., (2015)
6	121.8(5)	122.1(5)	117.5(6)	121.1(5)	119.1(5)	118.2(6)	127.1(6)	114.7(5)	Brahmia et al., (2015)
7	121.88(12)	121.58(13)	117.62(13)	119.22(12)	122.65(14)	116.95(14)	125.51(17)	117.52(15)	Pujar et al., (2014)
8	122.53(12)	120.55(14)	117.93(14)	122.02(15)	118.97	117.99(14)	125.59(15)	116.41(14)	Matos et al., (2012)
9	123.02(15)	120.21(17)	117.57(18)	122.84(19)	118.84(19)	117.12(17)	126.87(18)	116.01(17)	Yusufzai et al., (2012)
10	122.30(9)	120.66(9)	117.98(10)	121.59(10)	119.56(9)	117.80(9)	125.76(10)	116.43(10)	Li et al., (2012)
11	122.3(3)	121.0(3)	119.0(3)	117.8(3)	124.2(3)	115.7(3)	127.6(3)	116.8(3)	Zhang et al., (2012)
12	122.48(18)	120.9(2)	117.5(2)	122.5(2)	118.7(2)	117.8(2)	126.9(2)	115.2(2)	Arshad et al., (2011)
13	121.68(10)	122.75(11)	117.57(11)	118.30(11)	121.68(11)	117.90(10)	127.14(11)	114.96(11)	Rambabu et al., (2010)
14	122.3(4)	122.1(4)	117.4(4)	120.9(4)	118.8(4)	118.2(4)	126.4(5)	115.4(4)	Mechi et al., (2009)
15	121.47(10)	121.24(10)	118.73(11)	118.29(11)	123.08(11)	117.19(11)	126.41(12)	116.39(11)	Aazam et al., (2006)

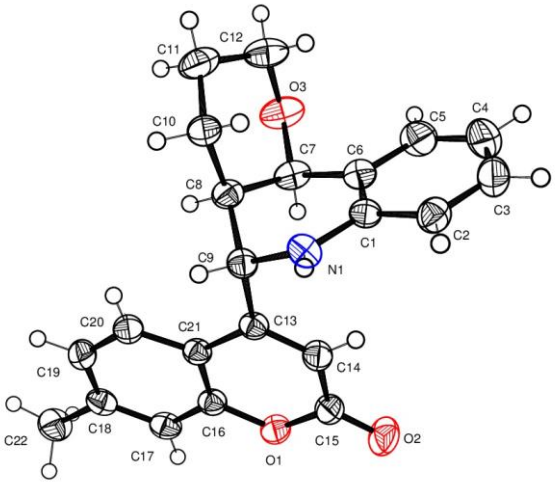


Fig.1. MOCHPQ, with displacement ellipsoids drawn at the 40% probability level.

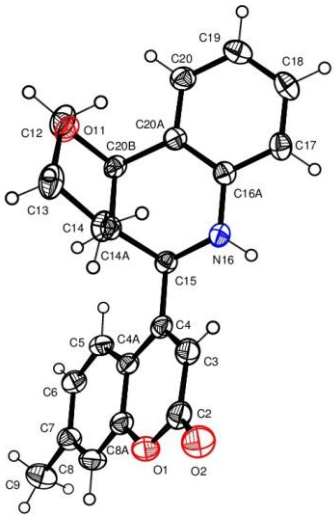


Fig.2. MCHPQ, with displacement ellipsoids drawn at the 30% probability level.

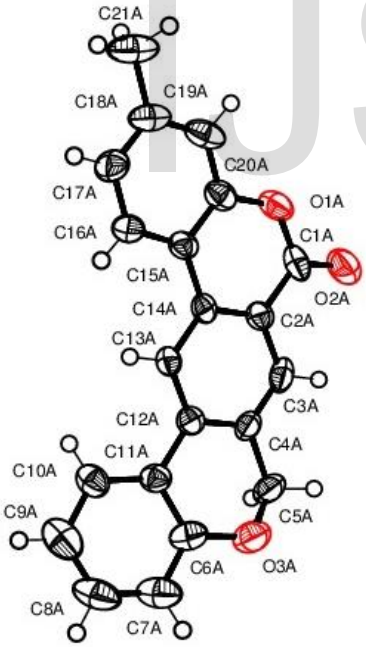


Fig.3. MBDC [Molecule A], with displacement ellipsoids drawn at the 50% probability level.

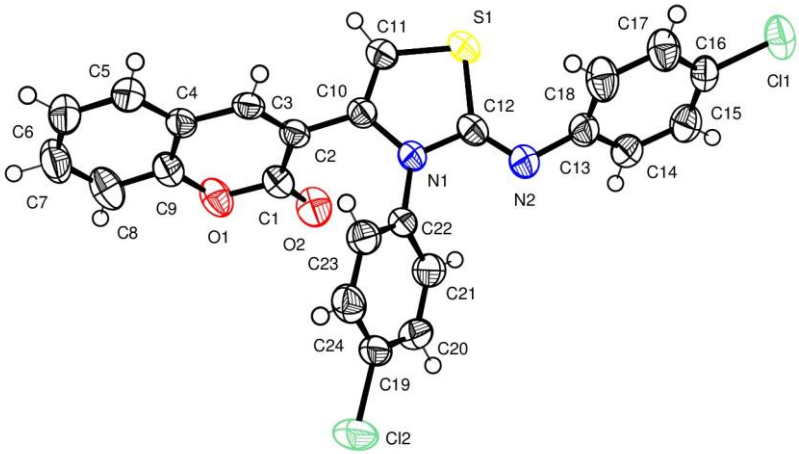


Fig.4 CPCPTC, with displacement ellipsoids drawn at the 50% probability level.

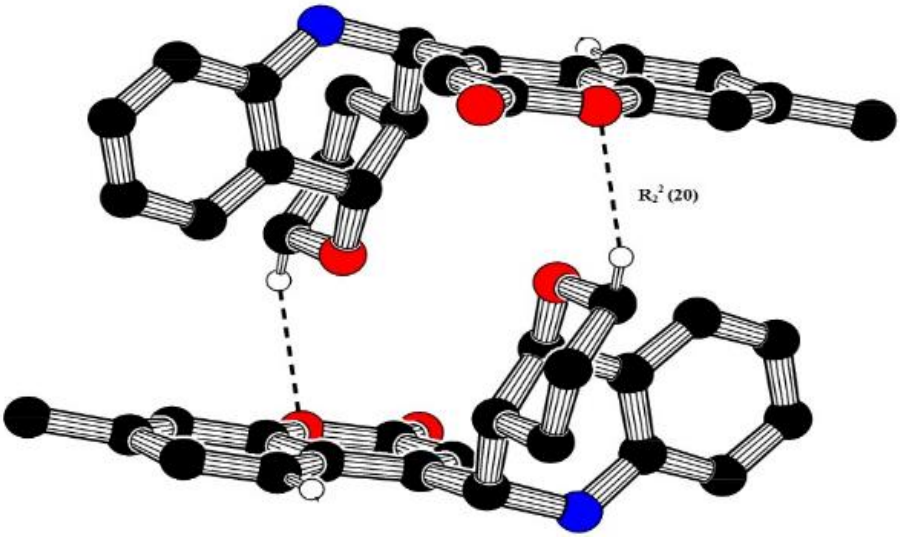


Fig.5. The formation of C - H…O interactions showing R_2^2 (20) motif in MOCHPQ

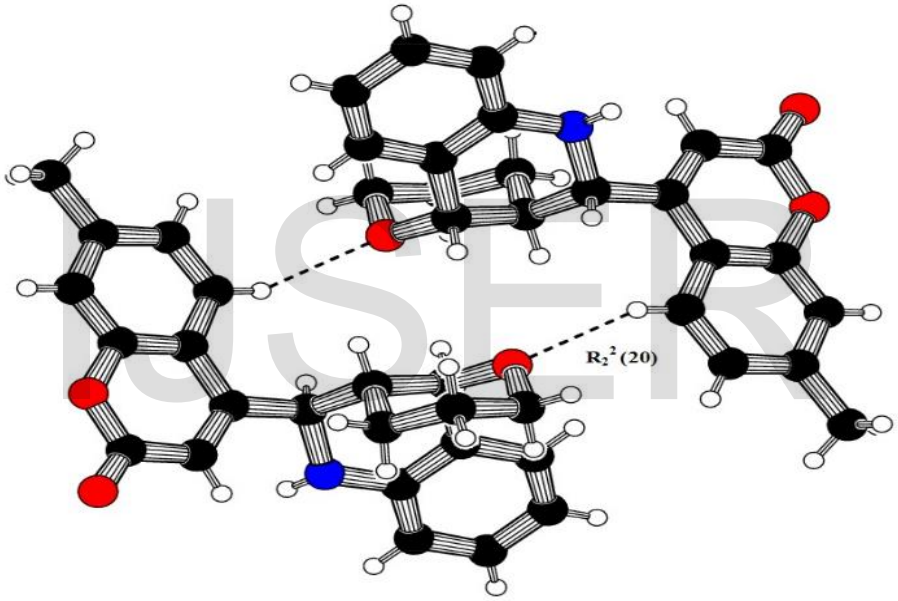


Fig.6. The formation of C - H…O interactions showing R_2^2 (20) motif in MCHPQ

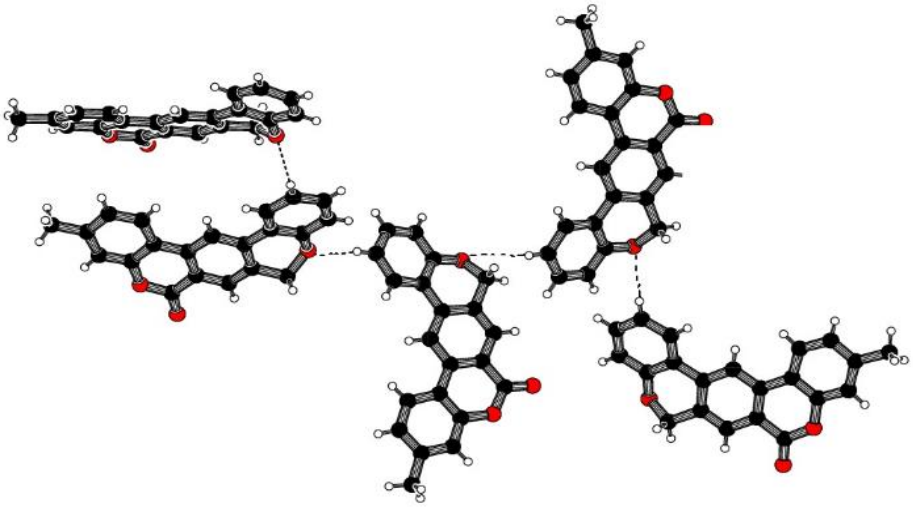


Fig.7. The formation of C - H…O interactions in MBDC

CONCLUSION

The bond lengths and bond angles of coumarin derivatives in the four related compounds taken for study are in good agreement with the expected values and are largely comparable with the corresponding values reported in the related structures (Table.1 & 2). The compound is cyclic, planar and aromatic in nature due to the continuous delocalization of electrons over the coumarin rings system. The detailed conformational analyses of the four related coumarin derivatives show that the coumarin moiety is planar and it is in close agreement with other closely related compounds taken from the literature. C - H…π interaction is observed in two compounds (MOCHPQ and MBDC). The π - π interactions are observed in all the four compounds. C - H…O interaction is present in three compounds (MOCHPQ, MCHPQ, MBDC). C - H…Cl interaction is present in one compound (CPCPTC). All the compounds have different conformation in their substituents. In compounds MOCHPQ and MCHPQ the quinoline ring have distorted half Chair conformation and the pyran ring have distorted chair conformation. In compound MBDC, pyran ring have screw-boat conformation. The substituents in the CPCPTC compound ie., the two chlorophenyl rings and thiazole ring are in planar conformation.

REFERENCES:

1. rac-4a,10b-cis,10b,5c-trans-5-(7-Methyl-2-oxo-2H-chromen-4-yl)-3,4,4a,5,6,10b-hexahydro-2H-pyrano[3,2-c]quinoline. Acta Cryst. (2013). E69, o280. **Kayalvizhi, M.,** Vasuki, G., Samant, S.D & Sanap, K. K. CCDC NO: 925937, REFCODE: LERZAL.
2. [1]HNMR and X-Ray Crystallographic Structure Determination of 4aR*,5R*,10bR*-5-(7- Methylcoumarin-4yl)-3,4,4a,5,6,10b-Hexahydro-2H-Pyrano[3,2-c] Quinoline. Physical Review & Research International. (2014). 4(1),1-8.
3. **Kayalvizhi, M.,**Vasuki, G., Samant, S.D & Sanap, K. K. CCDC NO: 901323, REFCODE: QORRIA.
4. 3-Methylbenzo [1,2-c:5,4-c']dichromen-6(8H)one. Acta Cryst. (2014). E70, o838. **Kayalvizhi, M.,** Vasuki, G.,Khatri, A. I & Samant, S.D.CCDC NO: 1010326, REFCODE: KOJDOE.
   Crystal structure of (Z)-3-{3-(4-Chlorophenyl)-2-[(4-chlorophenyl)imino]-2,3-dihydrothiazol-4-yl}-2H-chromen-2-one. Acta Cryst. (2014). E70, o1268-o1269. **Kayalvizhi, M.,** Vasuki, G., Kumar, R. R. & Rao, V. R.
   CCDC NO: 1027667, REFCODE: ZOWVOY.
5. Aazam, E. S., Fawazy, A. & Hitchcock, P. B. (2006). Acta Cryst. E62, o4285-o4287.
6. Arshad, A., Osman, H., Lam, C. K., Hemamalini, M. & Fun, H.-K. (2011).Acta Cryst. E67, o1825.
7. Brahmia, A., Ghouili, A. & Hassen, R. B. (2015). Acta Cryst. E71, 121-123.
8. Caracelli, I., Maganhi, S. H., Stefani, H. A., Gueogjian, K. & Tiekink, E. R. T. (2015). Acta Cryst. E71, o154-o155.
9. Cremer, D. & Pople, J. A. (1975). J. Am. Chem. Soc. 97, 1354–1358.
10. Li, G. -Q., Li, Y. -L., Jiang, T., Jiang, R. -W. & Wang, G. -C. (2012). Acta Cryst. E68, o1504.
11. Matos, M. J., Santana, L. & Uriarte, E. (2012). Acta Cryst. E68, o2645.
12. Mechi, L., Chtiba, S., Hamdi, N. & Hassen, R. B. (2009). Acta Cryst. E65, o1652-o1653.
13. Pereira Silva, P. S., Parveen, M., Khanam, Z., Ali, A. & Ramos Silva, M. (2010). Acta Cryst. E66, o988.
14. Pujar, K. K., Kulkarni, M. V. & Kumar, G. N. A. (2014). Acta Cryst. E70, 319-321.
15. Rambabu, D., Krishna, G. R., Reddy, C. M. & Pal, M. (2010). Acta Cryst. E66, o2870.
16. Yusufzai, S. K., Osman, H., Sulaiman, O., Wahab, H. A., Rosli, M. M. & Razak, I. A. (2012). Acta Cryst. E68, o2005.
17. Zhang, T., Xing, H., Miao, C., Sun, X. & Xi. H. (2012). Acta Cryst. E68, o1108.