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ULTRAVIOLET PHOTOELECTRON STUDIES OF METHYL SUBSTITUTED CRYSENES

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Summary: Ultraviolet photoelectron spectroscopy and CNDO/S3 molecular orbital calculations have been employed to investigate the ground-state electronic structure of all six of the monomethyl-substituted crysenes including the highly carcinogenic 5-methylcrysene. The photoelectron results yield ionization potentials for the five highest occupied π orbitals in each of these molecules. The data has been employed to test whether the radical cation theory of hydrocarbon carcinogenicity applies to methyl substituted crysenes.

Recent studies indicate that UV photoelectron spectroscopy yields a very detailed picture of π electronic structure in polycyclic aromatic hydrocarbons.[1-2] In the study reported here photoelectron measurements have been carried out on a series of crysenes which exhibit widely varying carcinogenic activity. Besides crysene, the molecules which were investigated include 1-methylchrysene, 2-methylchrysene, 3-methylchrysene, 4-methylchrysene, 5-methylchrysene and 6-methylchrysene.

In addition to providing π orbital ionization potentials of a biologically important series of hydrocarbons, a major goal of this study has been to examine previously proposed relationships between hydrocarbon ionization potentials and carcinogenic activity.

It has long been recognized that methyl substitution in key positions can radically alter the carcinogenic activity of aromatic hydrocarbons. For example crysene and most of its methyl derivatives are not strongly carcinogenic. On the other hand 5-methylcrysene is an extremely potent carcinogen.[3,4]

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Table 1. Vertical Ionization Potentials of Upper Occupied π Orbitals[a,b,c]

Chrysenes		π_1	π_2	π_3	π_4	π_5
unsubstituted	[125°C]	7.60 (7.60)	8.10 (8.10)	8.66 (8.68)	9.48 (9.46)	9.69 (9.76)
1-methyl	[121°C]	7.46	7.99	8.43	9.31	9.49
2-methyl	[118°C]	7.49	7.93	8.58	9.24	9.65
3-methyl	[111°C]	7.46	7.98	8.53	9.32	9.55
4-methyl	[104°C]	7.44	8.00	8.53	9.35	9.48
5-methyl	[112°C]	7.40	7.95	8.53	9.35	9.60
6-methyl	[113°C]	7.44	8.02	8.58	9.41	9.52

[a]All ionization potentials reported in eV. [b]For crysene, values in parentheses are those previously reported in ref. 1. [c]Temperatures at which spectra were measured are given in square brackets.

There are currently opposing theories concerning the mechanisms through which aromatic hydrocarbons induce cancer. One theory stresses enzymatic activation of the parent hydrocarbon leading to the formation of highly reactive epoxide metabolites.[5] Another theory involves a simpler mechanism which stresses the importance of radical cations.[6] These cations are thought to be formed directly from the parent hydrocarbon. Because photoelectron data provides information about the structure of radical cations and the ease with which they are formed, this technique is useful for testing some important features of the radical cation theory of hydrocarbon carcinogenesis.

EXPERIMENTAL

Spectra were measured with a Perkin Elmer PS-18 Photoelectron Spectra equipped with a HeI lamp and a heated probe. The sample temperatures at which spectra were measured are given in Table 1. Values of vertical ionization potentials reported here are averages taken from three measurements and were reproducible to within ± 0.03eV.

Chrysene was purchased from Aldrich Chemical Company (Milwaukee, Wis.). All the methyl substituted chrysenes were provided by Dr. Stephene S. Hecht (American Health Foundation, Naylor Dana Institute for Disease Prevention, Valhalla, N.Y.). These compounds were used without further purification.

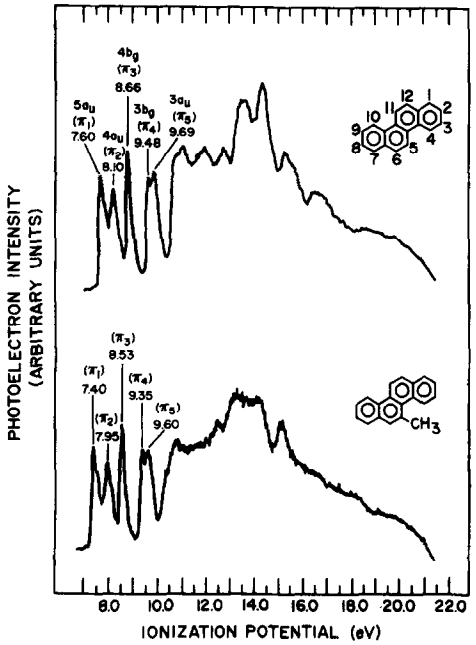

Fig. 1. He(I) photoelectron spectra of crysene and, 5-methylcrysene. Assignments are given for the five highest occupied orbitals.

RESULTS AND DISCUSSION

Figure 1 shows He(I) photoelectron spectra along with assignments and vertical ionization potentials for the five uppermost occupied orbitals in chrysene and 5-methylcrysene. The spectrum of chrysene has been previously studied[1] and the assignments given in Fig. 1 are the same as those reported earlier. The assignment of the spectrum of 5-methylcrysene as well as of the other methyl substituted crysenes is facilitated by a comparison with the spectrum of chrysene. In the low energy region, 7.0 eV to 10.0 eV, the spectra are well resolved and contain five photoelectron bands. These five bands arise from π orbitals and the symmetry assignments are based on the assignments for chrysene. The most striking feature of the results in Fig 1 is that the spectrum of 5-methylcrysene is very similar to that of crysene in the energy region below 10.0 eV.

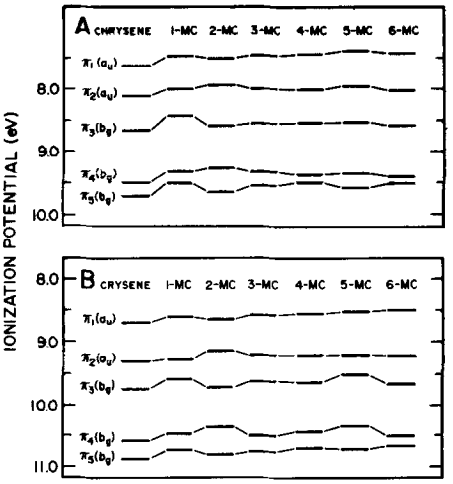

Fig. 2. Energy level diagrams showing the highest occupied orbitals in crysene and the methyl crysenes studied. Panel A shows vertical ionization potentials obtained experimentally. Panel B shows ionization potentials predicted by CNDO/S3. The abbreviation MC denotes methylcrysene.

Table 1 lists the vertical ionization potentials of the five highest occupied orbitals of all of the molecules studied. Table 1 also gives previously reported ionization potentials for crysene[1] which agree well with those reported here. An examination of the table indicates that the first ionization potentials of all of the methylcrysenes differ by less than 0.1eV.

In order to further confirm the assignments of the spectra of crysene and the methyl substituted crysenes which are given in Fig. 1 the spectroscopic results have been compared with energy levels predicted by CNDO/S3 molecular orbital calculations.[7] The geometries employed in the calculation were based upon crystallographic data.[8]

Figure 2 contains a comparison of experimental and theoretical results obtained for the molecules studied. Panel A shows vertical ionization potentials obtained from the photoelectron measurements. Panel B shows energy levels predicted by the CNDO/S3 calculations. A comparison of the theoretical and experimental results indicates that CNDO/S3

predicts ionization potentials which are approximately one electron volt too large. However the assignments of the five highest occupied orbitals as predicted by CNDO/S3 agree with those given in Fig. 1 and Table 1. Furthermore the perturbation pattern of π orbitals predicted by CNDO/S3 is in general agreement with the experimental data.

It has been speculated that if radical cation formation is an important step in hydrocarbon carcinogenesis then the energy required to form radical cations is important in determining carcinogenic activity. From this point of view, methyl substituted derivatives of crysene with the lowest ionization potentials are expected to be the most carcinogenic.

However both the photoelectron experiments and CNDO/S3 calculations indicate that there is very little difference in the ionization potentials of the carcinogenic and noncarcinogenic crysene derivatives. For example the ionization potential of the highly carcinogenic 5-methylcrysene differs by less than 0.05 eV (1.2 kcal/mole) from that of the noncarcinogenic 4- and 6-methyl crysenes. This energy is of similar magnitude as that associated with thermal motion at room temperature. Such small differences don't provide support for a theory of carcinogenesis which stresses the importance of these differences.

Furthermore the present results indicate that not only is the first ionization potential of 5-methyl crysene similar to that of the noncarcinogenic crysenes but that the ionization potentials of the lower π orbitals are also similar. For example the sum of the ionization potentials of the five highest occupied π orbitals in 5-methyl crysene differs by less than 0.35 eV from the sums of the first five ionization potentials of 4-methylcrysene and of 6-methylcrysene.

These observations indicate the unlikelihood that the 5-methyl group alters the π system of crysene in a way that strongly influences carcinogenic activity. The similarity of π orbital structure in the

carcinogenic and noncarcinogenic crysenes suggest some possible explanations for the significance of the 5-methyl group. One is that the group plays only a steric role. Another is that electronic effects of this group are only important in influencing the carcinogenic activity of 5-methylcrysene metabolites.

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