697. *A Theoretical Treatment of the Chemistry of Quinoline.*

By R. D. Brown and R. D. Harcourt.

Extensive calculations by the simple Hückel molecular-orbital method are reported for quinoline and some related systems. They lead to an interpretation of many of the chemical properties of quinoline and especially of the variety of orientations displayed under different conditions of electrophilic substitution. Some mechanisms are tentatively suggested for several reactions of quinoline.

The values of the Hückel parameters found necessary for interpreting the chemistry of quinoline agree with values found in studies on other related heterocyclic systems.

The simple Hückel molecular-orbital method has been able to account for some of the main features of heterocyclic chemistry,[1-3] especially when, more recently, a possible plurality of mechanism of electrophilic substitution arising from protonation or deprotonation of heteroatoms was considered.[4,5] In the present paper a detailed correlation of the chemistry of quinoline with Hückel molecular-orbital calculations is presented. Previous molecular-orbital treatments of quinoline [2,6,7] have been successful in explaining some of the chemistry, but the present study offers an interpretation of a wider range of reactions and especially of some of the finer details of electrophilic substitution which have recently been revealed.[5,8-10] In the case of almost every reaction discussed in the ensuing analysis there is no detailed mechanistic evidence available; we have had to assume plausible mechanisms, and one outcome of the present study has been the proposing of mechanisms for several reactions, based mainly on theoretical data.

Another purpose of the present study was to provide more information on the molecular-orbital parameters. It was of interest to see if the values of the parameters which are needed to account for the chemistry of quinoline are in accord with recent estimates of parameters by the V.E.S.C.F. method [11,12] and with some Hückel molecular-orbital studies of other heterocycles.[13]

Details of Calculations

The appropriate values of the coulomb parameter h for nitrogen ($\alpha^0_N = \alpha^0 + h\beta^0$) * in the Hückel molecular-orbital treatment of quinoline and the quinolinium cation (the nitrogen core in these conjugated systems presenting charges of +1 and +2 respectively to the π-electron cloud) may be roughly established from the results of more elaborate theoretical studies of pyridine [12,14,15] and of pyrrole.[16] For a core charge of +1, values of h in the range 0·2—0·5 have been found; we have therefore selected $h = 0{\cdot}5$ to represent nitrogen of core charge +1 when studying the variation of other parameters for constant h. In the quinolinium cation

---

* The superscript zero's are used with the symbols designating coulomb and resonance integrals to indicate that Hückel molecular-orbital quantities are being considered. The symbols α and β are used, with somewhat different meanings, in more elaborate calculations on π-electron systems.

[1] Wheland and Pauling, *J. Amer. Chem. Soc.*, 1935, **57**, 2086.
[2] Longuet-Higgins and Coulson, *Trans. Faraday Soc.*, 1947, **43**, 87.
[3] Longuet-Higgins and Coulson, *J.*, 1949, 971; Brown and Heffernan, *Austral. J. Chem.*, 1956, **9**, 83.
[4] Bassett and Brown, *J.*, 1954, 2701; Brown and Heffernan, *J.*, 1956, 4288.
[5] Brown, " Current Trends in Heterocyclic Chemistry," Butterworths, London, 1958, p. 13.
[6] Sandorfy and Yvan, *Bull. Soc. chim. France*, 1950, **17**, 131.
[7] Dewar and Maitlis, *J.*, 1957, 2521.
[8] Dewar and Maitlis, *J.*, 1957, 944.
[9] Brown, unpublished experiments (preliminary report of some results in ref. 5).
[10] de la Mare, Kiamud-Din, and Ridd, *Chem. and Ind.*, 1958, 361.
[11] Brown and Heffernan, *Trans. Faraday Soc.*, 1958, **54**, 757.
[12] Brown and Heffernan, V.E.S.C.F. results for pyridine in course of publication.
[13] Brown and Coller, *Austral. J. Chem.*, 1959, **12**, 152.
[14] Brown and Heffernan, *Austral. J. Chem.*, 1957, **10**, 211.
[15] McWeeny and Peacock, *Proc. Phys. Soc.*, 1957, **70**, *A*, 41; Nishimoto and Mataga, *Z. phys. Chem.*, 1957, **12**, 335.
[16] Brown and Heffernan, *Austral. J. Chem.*, 1959, **12**, 319.

values of h around 2·0 should be appropriate as judged from the study of pyrrole and related compounds.[13,16]

It is also possible to decide in advance the approximate magnitude of the auxiliary inductive coulomb parameter h' for the carbon atoms adjacent to nitrogen. For the quinolinium cation a value near 0·25 should be appropriate since both direct theoretical studies of pyrrole [16] and an analysis of the chemistry of pyrrole, indole, and carbazole [13] indicate this value when the nitrogen has a core charge of $+2$. To account for the chemistry of quinoline it seems necessary to select a slightly smaller value, about 0·2. The value of the auxiliary parameter for the free base should be less than this because there is now good evidence [12,16] that the auxiliary inductive effect arises largely from core attraction effects, and nitrogen of core charge $+1$ will clearly have less effect on adjacent carbon atoms than will nitrogen of core charge $+2$. Theoretical studies of pyridine [12,14] indicate a value rather less than 0·1. The present analysis of the chemistry, with $h = 0{\cdot}5$, requires h' to lie in the range 0·07—0·09, and the value $0{\cdot}08_5$ seems to be most appropriate.

The CN resonance integral β^0_{CN} has for simplicity been taken to have the standard value β^0. To test the sensitivity of the results to the value of this integral the charge densities for quinoline were also calculated * for $\beta^0_{\text{CN}} = 1{\cdot}1\beta^0$. The results, shown in Table 1, reveal that the π-electron densities are insensitive to the value assumed for β^0_{CN}. This is not surprising because quinoline may be regarded as a slightly perturbed alternant hydrocarbon, and for the latter the atom-bond polarizabilities are identically zero.[17] The value adopted in this work for β^0_{CN} is also supported by the V.E.S.C.F. calculations on pyridine.[12,14]

TABLE 1. *Variation of π-electron densities of quinoline with β^0_{CN}.* ($k = \beta^0_{\text{CN}}/\beta^0$ with values for $h = 0{\cdot}5$, $h' = 0$).

Position	$k = 1{\cdot}0$	$k = 1{\cdot}1$	Position	$k = 1{\cdot}0$	$k = 1{\cdot}1$
1	1·2159	1·1940	6	1·0029	1·0028
2	0·8961	0·9049	7	0·9840	0·9861
3	1·0084	1·0079	8	1·0125	1·0122
4	0·9318	0·9404	9	0·9566	0·9588
5	0·9884	0·9901	10	1·0016	1·0016

Localization energies, especially for the 2-position, are more sensitive to the value adopted for β^0_{CN} than are the π-electron densities (compare Figs. 6—7, 9—10, 14—15). However, an acceptable correlation of theory and experiment is found in the present analysis over a range of physically reasonable values of this resonance integral.

The values of electrophilic and radical localization energies for the 2-position are more uncertain than those for other positions when the auxiliary inductive parameter is used because it is not clear what energy should be assigned to the electrons localized at the position of attack.[18] We have used the value $\alpha^0 + h'\beta^0$ for such electrons whereas Wheland,[18] who included the overlap integral, used $\alpha^0 + 0{\cdot}75h'\beta^0$. It is possible that our electrophilic and radical localization energies unduly favour the 2-position. Fortunately the 2-position plays an important part in our analysis only for attack by nucleophiles, and this uncertainty does not enter for nucleophilic localization energies.

The plan of the calculations was to cover all reasonable values of h and h' to rule out the possibility of attributing any discrepancy between theory and experiment to an inappropriate choice of these coulomb parameters. To make it easy to assess how each theoretical quantity (π-electron density or localization energy) will alter when different values of h and h' are selected, the theoretical results are presented in graphical form as follows: First, the quantity is plotted as a function of h for a constant value of h' (the value of zero for h' is convenient; a corresponding graph for any other constant value of h' up to, say, 0·5 can be estimated by linear interpolation if necessary by using data from the graph with h' as abscissa). Then the quantity is plotted as a function of h' for constant h, values being chosen which are thought to be near the optimum values for the conjugated systems under discussion (usually quinoline and quinolinium). These graphs make it possible to estimate readily the values of the theoretical quantities for any other reasonable value of h and h' by linear interpolation.

---

* Our results were mostly obtained on the Melbourne University computer C.S.I.R.A.C. and it was more convenient to calculate two separate sets of π-electron densities than to re-programme the computer for calculating atom-bond polarizabilities directly.

[17] Coulson and Longuet-Higgins, *Proc. Roy. Soc.*, 1947, *A*, **192**, 16.

[18] Wheland, *J. Amer. Chem. Soc.*, 1942, **64**, 900.

RESULTS AND DISCUSSION

Attack by Nucleophiles.—It is convenient to start by considering some reactions of quinoline and its derivatives which involve attack by nucleophiles because our analysis of these reactions has bearing on other reactions considered below.

FIG. 1. *π-Electron densities of quinoline as a function of h for h′ = 0.*

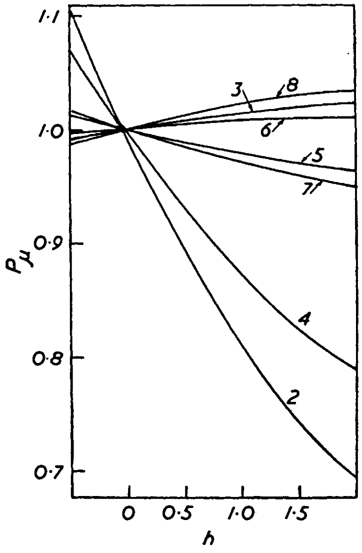


FIG. 3. *Nucleophilic localization energies of quinoline as a function of h for h′ = 0.*

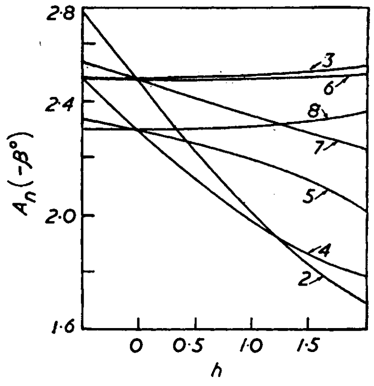


FIG. 2. *π-Electron densities of quinoline (h = 0·5) as a function of the auxiliary inductive parameter.*

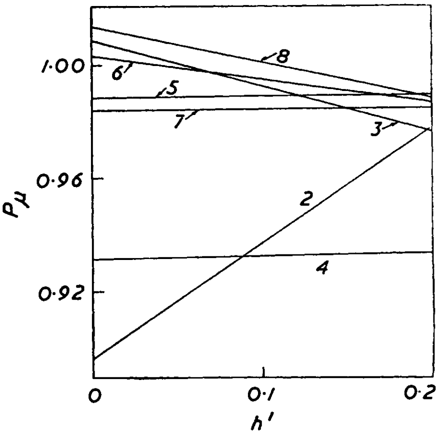
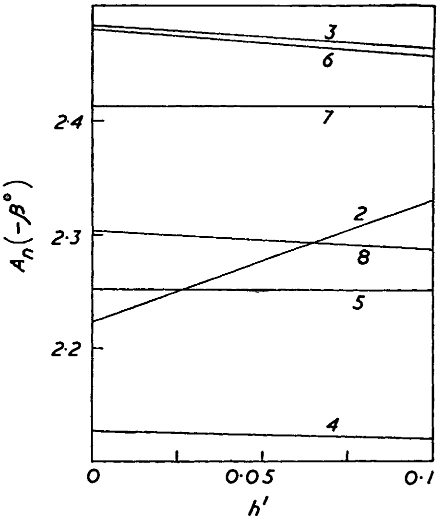


FIG. 4. *Nucleophilic localization energies of quinoline (h = 0·5) as a function of the auxiliary inductive parameter.*



In the amination of quinoline in liquid ammonia it is possible that the reaction takes place between a quinoline molecule and an amide anion. The order of reactivity of quinoline positions towards the nucleophile is unambiguously 2 > 4 > others.[19] Since the reaction occurs readily it would be expected [5,20,21] that the orientation of attack would tend to be correlated with the π-electron distribution (Figs. 1 and 2) rather than with

---

[19] Bergstrom, *J. Amer. Chem. Soc.*, 1934, **56**, 1748.

[20] Hammond, *ibid.*, 1955, **77**, 334.

[21] Bassett, Brown, and Penfold, *Chem. and Ind.*, 1956, 892.

nucleophilic localization energies (Figs. 3 and 4). It is evident from Fig. 2 that the experimental observations can be correlated with the π-electron densities of the quinoline

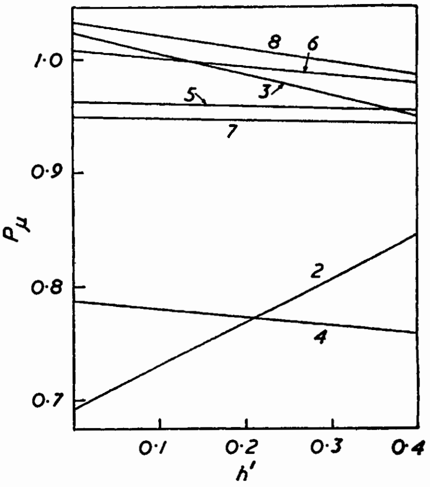


FIG. 5. *π-Electron densities of quinolinium ($h = 2$) as a function of the auxiliary inductive parameter.*

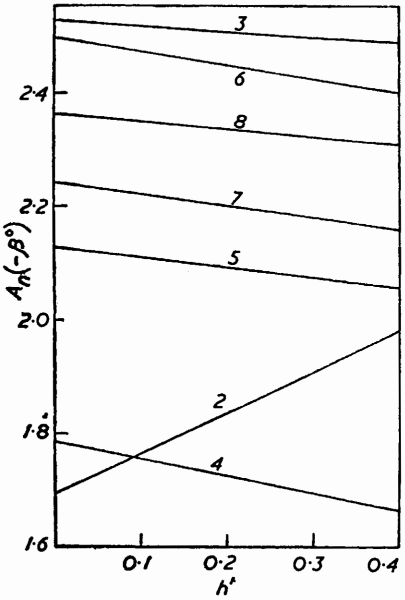


FIG. 6. *Nucleophilic localization energies of quinolinium ($h = 2$, $\beta^0_{CN} = \beta^0$) as a function of the auxiliary inductive parameter.*

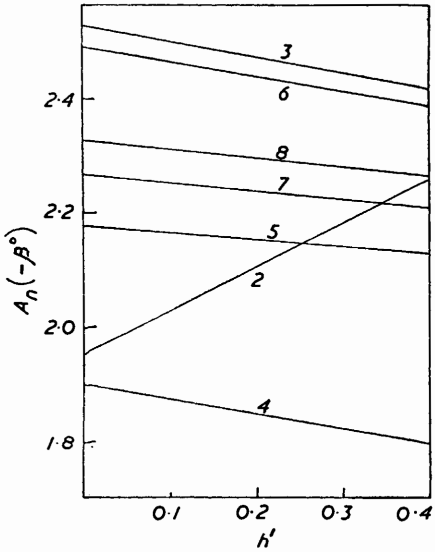


FIG. 7. *Nucleophilic localization energies of quinolinium ($h = 2$, $\beta^0_{CN} = 1{\cdot}2\beta^0$) as a function of the auxiliary inductive parameter.*

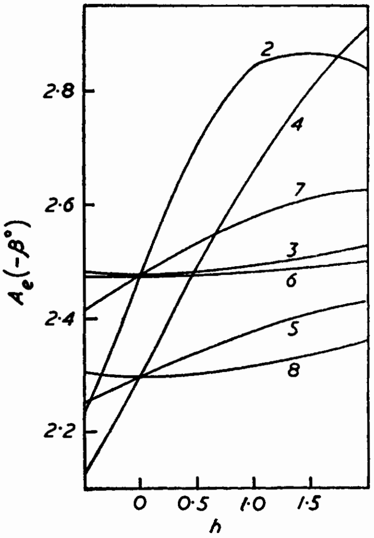


FIG. 8. *Electrophilic localization energies of quinoline as a function of h for $h' = 0$.*

molecule if the auxiliary inductive effect is not too large ($P_2 < P_4$ for $h' < 0{\cdot}090$). However, it is not possible to account for the observations in terms of localization energies for any reasonable values of the Hückel parameters for quinoline.

Other reactions which may amount to attack by nucleophiles on the quinoline molecule[22] also support the order $2 < 4 <$ others for the π-electron densities. However, it is possible that these reactions, and also the amination discussed above, involve initial addition of an electrophile [*e.g.*, Ba^{++} in amination with $Ba(NH_2)_2$] to the nitrogen lone-pair of electrons, followed by nucleophilic attack on the quinolinium system thus formed. The catalysis by Ba^{++} observed in the amination tends to support this proposition.

Evidence for the order of π-electron densities in the quinoline molecule might alternatively be sought in the relative reactivities of methyl substituents towards aldehydes and other reagents. Electrophilic catalysts such as anhydrous zinc chloride are commonly employed, and this again leads to ambiguity as to the nature of the reactive species since the catalyst may attach itself to the nitrogen *n*-electrons, thus producing a quinolinium structure (nitrogen core charge $+2$).* However, in some cases,[23] a basic catalyst or no catalyst has been used. The greater reactivity of a 2- than of a 4-methyl substituent in quinoline under these conditions implies that the π-electron densities increase in the order $2 < 4 <$ others in the free base.†

Several reactions which undoubtedly involve nucleophilic attack on the quinolinium system have been observed when using 1-alkylquinolinium salts and related compounds. They show an interesting variation in the orientation of attack which has been studied particularly by Bradley and Jeffrey.[24] With strong nucleophiles such as R^- or OH^- the attack occurs at the 2-position, while with the weaker nucleophile CN^- the 4-position is attacked. Now vigorous reagents will demand less π-electron rearrangement in formation of the transition state than will weak reagents,[20] so that it might be suspected that the orientation of attack by strong nucleophiles will tend to follow the π-electron distribution whereas with weaker nucleophiles the atom-localization energies will be decisive. The change in orientation can be accounted for in this way. The π-electron densities for the quinolinium system are shown in Fig. 5. For $h' < 0{\cdot}22$ the 2-position has the lowest charge, whereas for $h' > 0{\cdot}09$ the 4-position has the smallest localization energy (Fig. 6), so that for h' in the range 0·09—0·22 the change in orientation can be explained.‡

Some quantitative studies of the ease of displacement of halogen substituents in quinoline by nucleophiles have been made,[25] the activation energies being in the order $2 < 4 <$ others with a weak nucleophile (piperidine), and $4 < 2$ with a strong nucleophile (ethoxide anion). The theoretical interpretation is complicated by the fact that the halogen substituents conjugate with the ring system, which introduces additional coulomb and resonance parameters into any Hückel molecular-orbital calculations. We have, therefore, not attempted detailed calculations for such systems. It is tempting to connect the change in relative reactivities of substituents with strength of nucleophile with the proposition that the π-electron density at the attacked position is decisive for strong nucleophiles, the localization energy at that position in the case of weak nucleophiles. However, at present there is no clear evidence that the relative reactivities of two positions

---

* The alternative rôle of the catalyst commonly assumed in these reactions is attachment to the *n*-electrons of the aldehydic oxygen atom, but both modes of attachment could operate in the heterocyclic reactions.

† If the reaction mechanism consisted of an ionization pre-equilibrium followed by reaction of the aldehyde with the small equilibrium amount of conjugate base formed in the first step, then the relative reactivities of the various methylquinolines would be determined largely by the relative stabilities of their conjugate bases. It is not possible to account for the observed order of reactivities in this way because the conjugate base of 4-methylquinoline is more stable than that of 2-methylquinoline; the difference in π-electron energies (for $h = 0{\cdot}5$, $h' = 0{\cdot}085$) is $0{\cdot}045\beta^0$.

‡ The lower limit depends somewhat on the value adopted for β^0_{CN}, the figure given here applying for $\beta^0_{CN} = \beta^0$. For $\beta^0_{CN} = 1{\cdot}2\beta^0$, however (see Fig. 7), any positive value of h' yields the appropriate order of nucleophilic localization energies.

[22] Bergstrom and McAllister, *J. Amer. Chem. Soc.*, 1930, **52**, 2845; Bergmann and Rosenthal, *J. prakt. Chem.*, 1932, **135**, 267.

[23] Kaslow and Stayner, *J. Amer. Chem. Soc.*, 1945, **67**, 1716.

[24] Bradley and Jeffrey, *J.*, 1954, 2770.

[25] Brower, Samuels, Way, and Amstutz, *J. Org. Chem.*, 1953, **18**, 1648; Chapman and Russell-Hill, *Chem. and Ind.*, 1954, 1298.

in two *different* conjugated systems are solely determined by the relative π-electron densities at these positions (clearly no such simple relation holds for positions in different alternant hydrocarbons) and it does not seem profitable to consider further these substituted quinolines at present.

Attack by Electrophiles.—The orientation of electrophilic substitution in quinoline and its derivatives is often regarded as puzzling [26] because the position preferentially nitrated, for example, can be 3, 5, 6, or 8. It now seems possible to account for all of the observations in terms of molecular-orbital calculations. The key observations concern the parent heterocycle: in a strongly acidic environment quinoline is nitrated,[7,27] brominated,[9,10] and sulphonated [28] at the 8- and the 5-position, whereas in a less acidic environment the order of reactivity of positions in nitration,[8] bromination,[9] and mercuration [29] is 3 > 6,8. It was suggested [5] that in the strongly acidic medium (concentrated sulphuric acid) the unprotonated quinoline is present in too small a concentration to react appreciably with the electrophile, the reaction proceeding through the quinolinium cation. The latter must be relatively unreactive towards cations because it is a cation too. Thus the orientation of electrophilic substitution is likely to follow atom-localization energies rather than π-electron densities, as discussed above for nucleophilic substitution. The localization energies for electrophilic substitution are shown in Figs. 8, 9, and 10 and they are smallest for the 8- and the 5-position.

FIG. 9. *Electrophilic localization energies of quinolinium* ($h = 2$, $\beta^0_{CN} = \beta^0$) *as a function of the auxiliary inductive parameter.*

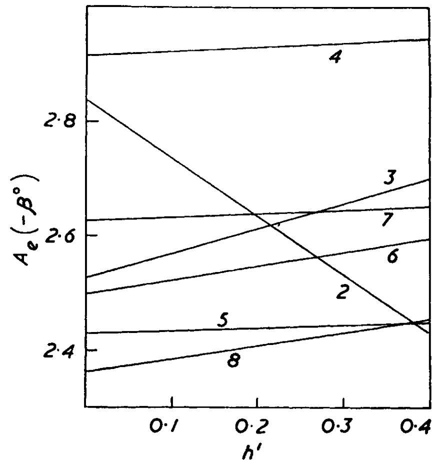
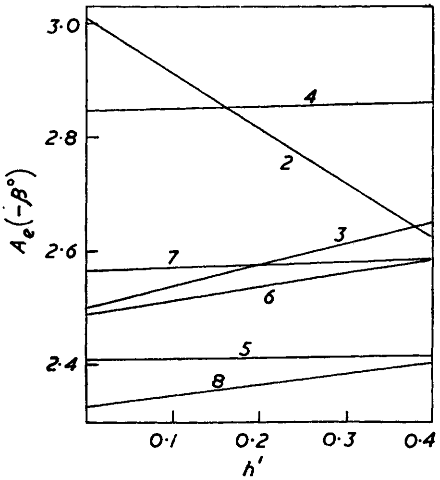


FIG. 10. *Electrophilic localization energies of quinolinium* ($h = 2$, $\beta^0_{CN} = 1{\cdot}2\beta^0$) *as a function of the auxiliary inductive parameter.*



It was also suggested [5] that in acetic anhydride or acetic acid the proportion of unprotonated quinoline is great enough for electrophilic substitution to proceed predominantly through it, the free base being reactive enough for the orientation to be governed by the π-electron densities. The π-electron densities of quinoline are greatest for the 3-, 6-, and 8-positions and although the values available in the literature [2,6] when the suggestion was made did not fall in the order 3 > 6,8 > others, it was thought that this order might be obtained with a more appropriate choice of Hückel parameters. However, the present study (Figs. 1 and 2) shows that for no physically reasonable choice of parameters does the 3-position have the greatest π-electron density.

[26] Campbell, " Chemistry of Carbon Compounds," Elsevier, Amsterdam, 1957, Vol. IVA, p. 597; Elderfield, " Heterocyclic Compounds," Wiley, New York, 1952, Vol. IV, p. 262.

[27] Fieser and Hershberg, *J. Amer. Chem. Soc.*, 1940, **62**, 1640.

[28] McCasland, *J. Org. Chem.*, 1946, **11**, 277.

[29] Ukai, *J. Pharm. Soc. Japan*, 1931, **51**, 542.

Dewar and Maitlis[8] proposed a different explanation to account for the orientation $3 > 6,8 >$ others, involving the initial 1,2-addition of nitronium acetate and subsequent substitution in the dihydroquinoline system. Since this system does not carry a positive charge the orientation of electrophilic substitution would be expected to follow π-electron densities. These are shown in Fig. 11 (the nitrogen core charge in the dihydroquinoline system is $+2$, so that the parameters for quinolinium are appropriate). However, the order of π-electron densities does not coincide with the observed orientation of nitration for any acceptable value of h'.

An alternative mechanism which does account for the observed orientation of nitration, bromination, and mercuration is suggested from the preceding discussion of nucleophilic attack in quinolinium systems. If the nucleophile is as weak as or weaker than CN^-—and the acetate anion is in this category, as judged by its basicity—it attacks the 4-position. The π-electron densities for the resultant 1,4-dihydroquinoline system are shown in Fig. 12.

FIG. 11. *π-Electron densities for* 1,2-*dihydroquinoline* ($h = 2$) *as a function of the auxiliary inductive parameter.*

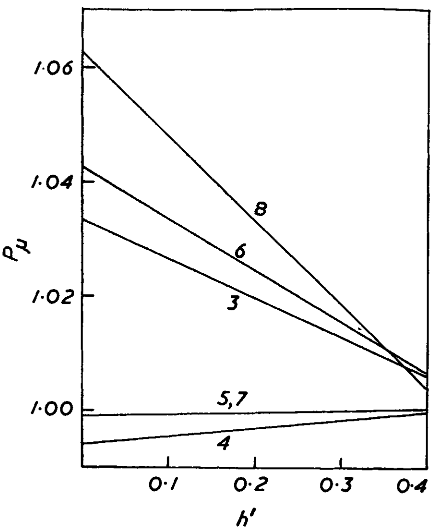
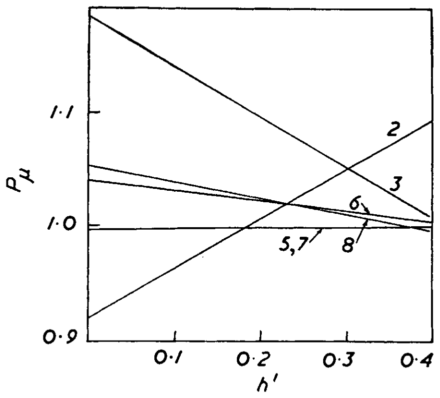
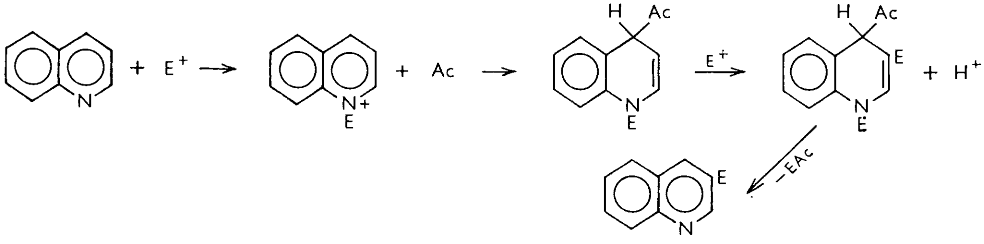


FIG. 12. *π-Electron densities for* 1,4-*dihydroquinoline* ($h = 2$) *as a function of the auxiliary inductive parameter.*



For $h' < 0{\cdot}30$ the 3-position has the greatest π-electron density. We therefore suggest that the preferential attack of the 3-position in bromination or nitration in acetic acid or anhydride occurs by initial " electrophilation " of the nitrogen followed by addition of acetate at the 4-position of this quinolinium system, then by electrophilic substitution in the 1,4-dihdroquinoline system, and finally by elimination of " electrophile acetate: "



The smaller amount of attack at the 6- and the 8-position might be accounted for in a similar way, since these positions are next in order of π-electron densities in 1,4-dihydroquinoline. However, the observation[8] that not even a trace of 3-nitroquinoline could be isolated when nitration was performed in perfluoroacetic anhydride, the products being the 6- and the 8-nitro-derivative, suggests that these isomers are formed by direct electrophilic substitution in the quinoline molecule, trifluoroacetate anion being too weak a nucleophile to form the 1,4-dihydroquinoline system. The 6- and the 8-substituted product in acetic acid or anhydride may thus be formed by attack on the small proportion of "unelectrophilated" quinoline present in these solvents. If this mechanism operates, then the order of reactivities is expected to be (see Fig. 2) $8 > 6$ (for the physically likely range of $0{\cdot}07 < h' < 0{\cdot}16$).* Unfortunately the experimental evidence at present available does not indicate unambiguously the relative reactivites of these two positions. Dewar and Maitlis did not separate the 6- and the 8-nitroquinoline and, although the only major bromination products in acetic acid are [9] 3-, 3,6-, and 3,6,8-substituted quinolines, this does not necessarily imply that the 6-position is more reactive than the 8-position because the trisubstituted product predominates even when only one mol. of brominating agent is used and this product might largely or wholly be formed by way of the 3,8- rather than the 3,6-dibromo-compound. The preponderance of polysubstituted products does, however, support the hypothesis that the second and third substitutions occur in the free base because the explanation of polysubstitution must be sought [5] in the considerable lowering of the basicity of quinoline produced by bromo-substituents.

Mercuration with mercuric acetate in methanol [29] which leads ultimately to 3- and 8-substituted products proceeds through isolable intermediates which may be 1,4-adducts of the type here proposed to account for 3-orientation. Again the available evidence is not sufficiently clear-cut to decide whether the order of reactivities is $8 > 6$ or not.

The orientation of electrophilic substitution in isoquinoline in not too strongly acidic media [9] also can be interpreted by using molecular-orbital calculations [30] and assuming an addition mechanism similar to that described above.

Attack by Radicals.—The phenylation of quinoline with benzoyl peroxide [31] undoubtedly involves attack of the free base by phenyl radicals. The relative yields of phenyl derivatives are in the order $8 > 4 > 3 > 5 > 6,7 > 2$. The isolation of all possible isomers shows that phenyl radicals are not very selective and thus that they are extremely reactive towards quinoline. It might therefore be expected that the orientation would follow the molecular-orbital quantities corresponding to the "isolated molecule" treatment of reactivity [32] rather than radical localization energies. For alternant hydrocarbons the free valencies are the appropriate quantities but these are no longer apposite for non-alternant or heterocyclic systems,[33] and no alternative satisfactory "isolated molecule" quantities have so far been suggested for such systems. Certainly the observed orientations cannot be correlated with the localization energies (Fig. 13).

The high-temperature bromination of quinoline,[34] to yield 2-bromoquinoline, probably involves attack of quinoline by bromine atoms. The more severe discrimination between the quinoline positions, and the gross change in relative reactivities of positions, compared with the phenylation phenomena, suggest that if this reaction involves radical attack then the orientation should be governed by the localization energies. The localization energies for the free base, shown in Fig. 13, do not account for the observed orientation, but those for the quinolinium system (Figs. 14 and 15) do if β^0_{CN} is not greater than β^0.† This suggests that the reaction may proceed through a quinoline–bromine complex involving the *n*-electrons of the quinoline-nitrogen atom, the complex thus resembling the quinolinium system rather than quinoline itself.

---

* In 1,4-dihydroquinoline the order is $8 > 6$ for $h' < 0{\cdot}25$ and $6 > 8$ for $0{\cdot}25 < h' < 0{\cdot}38$.

† For the quinolinium system a value of β^0_{CN} less than that for quinoline would indeed be appropriate because the effective nuclear charge on the quinolinium-nitrogen is greater than that on the quinoline-nitrogen atom, and β^0_{CN} decreases with increasing nuclear charge of either carbon or nitrogen.

[30] Brown and Harcourt, *Tetrahedron*, in the press.
[31] Pausacker, *Austral. J. Chem.*, 1958, **11**, 200.
[32] Brown, *Quart. Rev.*, 1952, **6**, 63.
[33] Brown, *J. Chim. phys.*, 1953, **50**, 109.
[34] Jansen and Wibaut, *Rec. Trav. chim.*, 1937, **56**, 699.

The change in the orientation of vapour-phase bromination of quinoline at low temperatures, when 3-bromoquinoline is produced,[34] cannot be reconciled with the localization energies. However, a homolytic mechanism analogous to the heterolytic mechanism proposed to account for electrophilic substitution at the 3-position may be tentatively proposed. It is possible that at lower temperatures a complex between quinoline and bromine (somewhat similar in type to that suggested to account for the features of electrophilic substitution [35] but with the bromine engaging both the 1- and the 2-position of quinoline) is formed in sufficient concentration for the bromination to proceed by homolytic attack by bromine on this 1,2-dihydroquinoline system. The attack would occur at the 3-position because this is now equivalent to the ω-styrene position.*

FIG. 13. *Radical localization energies for quinoline ($h = 0{\cdot}5$) as a function of the auxiliary inductive parameter.*

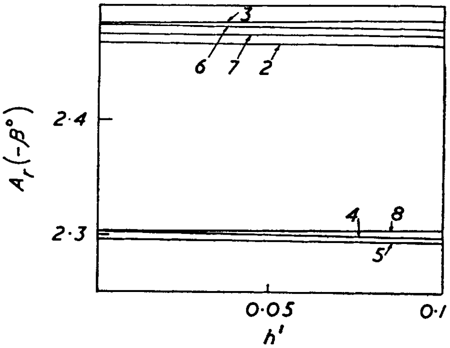
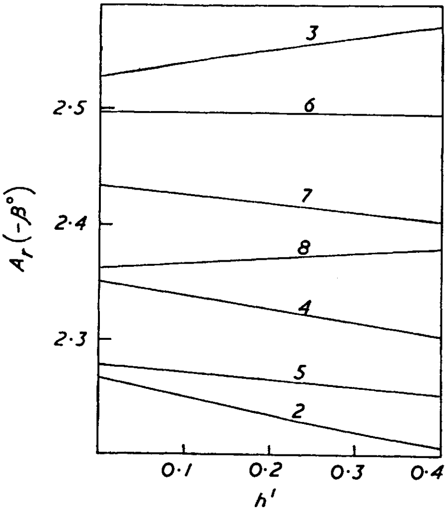


FIG. 14. *Radical localization energies of quinolinium ($h = 2$, $\beta^0_{CN} = \beta^0$) as a function of the auxiliary inductive parameter.*



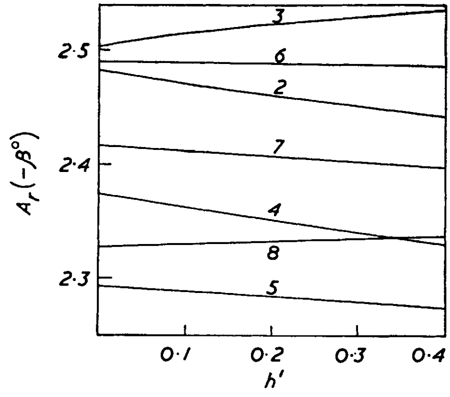


FIG. 15. *Radical localization energies of quinolinium ($h = 2$, $\beta^0_{CN} = 1{\cdot}2\beta^0$) a function of the auxiliary inductive parameter.*

Conclusion.—In the above analysis it has been shown that it is possible to account,

---

* The distinction between a 1,2-complex and a 1,2-adduct is that in the former the Br–Br bond remains intact and the nitrogen atom of quinoline is excluded from the conjugation. In the latter the Br–Br bond is broken and the nitrogen still participates in the conjugation but with a core charge of +2.

[35] Brown, *J.*, 1959, 2224, 2232.

sometimes very speculatively, for many substitutions in quinoline by using simple Hückel molecular-orbital calculations as a basis, with values of parameters close to those indicated by other studies. The analysis suggests that the following is a suitable set of Hückel parameters: $\beta^0_{CN} = \beta^0$; for N (core charge $+1$), $h = 0{\cdot}5$, $h' = 0{\cdot}085$; for NH (core charge $+2$), $h = 2$, $h' = 0{\cdot}2$.

In addition, the study provides further evidence for the principle that when reactions occur readily the orientation tends to follow the charge distribution (for heterolytic reactions), while for more sluggish reactions the orientation tends to follow the localization energies. These values may be compared with previous estimates of coulomb parameters based on comparison of theoretical and experimental data. One method of estimation uses the basicity constants of heterocylic amines.[36-8] The results reported have been $h_{NH} - h_N \approx 1{\cdot}2$,[36] $h_N \approx 0{\cdot}6_5$,[37] $h_{NH} = 2$, $h_N = 0{\cdot}8$;[38] but although these values are reasonably close to those found in the present study there are considerable uncertainties in the method; the variance in the linear correlations used is considerable, a conversion factor, for which widely varying estimates have been proposed, is required to convert from kcal. mole^{-1} into Hückel units (*i.e.*, units of β^0), and the auxiliary inductive effect was neglected.

Another estimate, $h_N = 0{\cdot}6$,[39] has been based on the dipole moments of six-membered-ring heterocycles. This also is now regarded as unsatisfactory because the estimate used for the σ-electron contribution to the dipole moment is now considered to be unsatisfactory and no auxiliary inductive parameter was included.

The value $h_N = 0{\cdot}5$ has been derived from consideration of the proportions of isomers isolated in the phenylation of pyridine.[40] This too is unreliable because (i) it depends upon the assumption that the orientation should be correlated quantitatively with localization energies rather than some " isolated molecule " quantities, (ii) there is some doubt as to the interpretation of phenylation experiments,[31] and (iii) no auxiliary inductive parameter was included.

It must be emphasized that the present study does not furnish a sensitive means of fixing the values for the primary coulomb parameters h_N and h_{NH} because agreement with experiment can be obtained over an appreciable range of these parameters provided that values for the auxiliary inductive parameters are chosen appropriately. The present work primarily demonstrates that, given the values of h_{NH} and h_N, it is possible to account for the chemistry of quinoline for values of h'_{HN} and h'_N which are physically reasonable, lie within narrowly defined numerical ranges, and have also been found suitable in similar studies of other nitrogen heterocycles.

The present investigation strongly suggests that a variety of mechanisms may operate in substitution of quinoline and that these reactions might prove a fertile field for future studies.

University of Melbourne, Carlton, N.3,
Victoria, Australia.

[*Received, March 2nd,* 1959.]

---

[36] Longuet-Higgins, *J. Chem. Phys.*, 1950, **18**, 275.
[37] Hush, *J.*, 1953, 684.
[38] Mason, *J.*, 1958, 674.
[39] Lowdin, *J. Chem. Phys.*, 1951, **19**, 1323.
[40] Brown, *J.*, 1956, 272.