

# Semiempirical AM1 Electrostatic Potentials and AM1 Electrostatic Potential Derived Charges: A Comparison with *Ab Initio* Values

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Electrostatic potentials calculated from AM1 wave functions have been compared with *ab initio* STO-3G values and qualitative agreement has been found. Atomic charges derived from AM1 electrostatic potentials for both experimental and AM1 optimized geometries are of comparable quality with STO-3G potential derived charges. These results suggest that the AM1 electrostatic potential may be useful both in its own right and also for deriving atomic charges for use in molecular dynamics studies.

## INTRODUCTION

The molecular electrostatic potential (MEP) is widely used in many different areas of chemistry.<sup>1-4</sup> It may be used to predict the site of attack of electrophilic agents and the energy of interaction of polar molecules during the early stages of their reaction. Similarities and differences in electrostatic potentials of different molecules may be used to rationalize their different biological activities. Moreover, atomic charges derived to reproduce the electrostatic potential calculated from the wave function (see below) are finding widespread use in molecular dynamics studies.<sup>5,6</sup>

However, the calculation of *ab initio* molecular electrostatic potentials is often prohibited by the size of the molecule or by the large number of points for which the potential is to be calculated. Possible solutions to this problem involve either calculating the potential classically, with the molecule represented by a series of point charges (or multipoles) or calculating the MEP using semiempirical wave functions such as CNDO,<sup>7</sup> INDO,<sup>7</sup> MINDO/3,<sup>8</sup> MNDO,<sup>9</sup> or AM1.<sup>10</sup> A number of different approximations for evaluating the integrals in semiem-

pirical electrostatic potential calculations are possible. Studies on the reliability of potentials obtained from CNDO wave functions with different approximations were reported in references 11 and 12. In these articles the authors concentrated on the power of different methods using CNDO wave functions to reproduce the position and depth of minima of *ab initio* potential maps. It was found that the most sophisticated approximate method (approximation IV of reference 11.) gives quantitatively good results in most cases, but the advantage of low computational cost is lost in this method. Similar results were found for INDO wave functions.<sup>12</sup>

There are two reasons why we wish to reinvestigate the use of semiempirical wave functions in electrostatic potential calculations. Firstly, the recent AM1 method<sup>10</sup> is generally considered to be superior to earlier semiempirical methods and this prompted us to investigate the quality of the AM1 electrostatic potential. Secondly, we wanted to investigate the quality of atomic charges derived from the electrostatic potential calculated on or outside the van der Waals radii of atoms—the region where AM1 potentials are expected to compare most favorably with *ab initio* potentials. Atomic charges designed to reproduce the quantum mechanically derived MEP have been shown to have

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many advantages over the conventional Mulliken charges;<sup>13</sup> for example, such charges reproduce dipole moments more reliably.<sup>14</sup> For large systems the charges may need to be calculated from carefully chosen fragments and modified to ensure electrical neutrality.<sup>15</sup> In such cases it may be preferable to fit the charges to the AM1 MEP calculated for the whole molecule and hence avoid the errors arising during the annealing process. Moreover, because these charges could be derived more readily it would be easier to study effects such as their conformational dependence and so they may find widespread use in molecular mechanics and dynamics studies.

## METHODS

When calculating the electrostatic potential from semiempirical wave functions, it is essential to be consistent with the approximations inherent in the determination of the wave function. In this respect the electron-core and core-core interactions are of primary importance as the first gives guidelines for calculating nuclear attraction integrals and both contain information on how to handle atomic cores. The AM1 method is based on the NDDO approximation—it neglects all three-center nuclear attraction integrals and retains all two-center attraction integrals. To be consistent with this, the contribution to the potential of all one-center charge distributions was calculated and that of two centers was omitted. In the evaluation of the remaining integrals (all of them two center), the approximations used in AM1 were not followed. AM1 uses the usual Goeppert–Mayer–Sklar potential with the neglect of penetration integrals to represent the electron-core attraction and introduces the core repulsion function (CRF) in the calculation of the mutual interaction of atomic cores to compensate the decreased attractive forces between atoms. The adaptation of this treatment to the calculation of the electrostatic potential is not straightforward and provides no advantage with respect to the explicit evaluation of the nuclear attraction integrals. In removing the approximations used to avoid the calculation of these integrals, there is no reason to involve CRFs in the calculation of electrostatic potentials

and the atomic cores are considered as point charges and their potential is calculated accordingly.

The AM1 calculations were carried out using the AMPAC program<sup>16</sup> and the electrostatic potentials were evaluated with a program written by Szaloczy.<sup>17</sup> Atomic charges were fitted to the potentials using a modified version of CHELP.<sup>18</sup>

The AM1 potentials were compared with *ab initio* STO-3G results calculated using Gaussian 86.<sup>19</sup> Although the STO-3G minimal basis set results may be considerably different from those obtained with higher quality basis sets, STO-3G is considered to be sufficiently accurate for many applications. The STO-3G basis set represents the level of quality that may be reproduced by semiempirical methods, since the AM1 method also operates within the framework of a minimal basis set.

## RESULTS AND DISCUSSION

### General Comparison of Electrostatic Potentials

The general agreement between AM1 and reference STO-3G electrostatic potentials may be assessed from Table I. The potentials used in Table I were calculated at points on spherical shells at and beyond the van der Waals surface of the molecules. In each case, the correlation coefficients are larger than 0.980. The regression coefficients and intercepts are near to 1.0 and 0.0 respectively, but the deviations from the ideal values in both directions make it impossible to improve the numerical agreement by the introduction of a scaling factor or an additive term. The results for ions are generally of similar quality to those for neutral molecules, though by far the largest intercept is for the formate anion. The agreement between AM1 and *ab initio* potentials is similar both for molecules involved in and also excluded from the derivation of AM1 parameters.<sup>10</sup> We note, however, that the CNDO potentials, calculated in the same way (approximation III of reference 11.), show similar agreement with the STO-3G values (Table I), though qualitative discrepancies were found between the CNDO and *ab initio* potential maps.<sup>11</sup> Thus

**Table I.** Correlation between AM1 and STO-3G ab initio electrostatic potentials calculated beyond the van der Waals surface<sup>a</sup> of molecules. Data in parenthesis show the correlation between CNDO<sup>b</sup> and STO-3G potentials.

Molecule <sup>c</sup>	Correlation coefficient	Regression coefficient	Intercept of regression line (kJ/mol)
NH <sub>4</sub> <sup>+</sup>	0.994 (0.992)	1.014 (1.053)	-3.861 (5.368)
H <sub>2</sub> O <sup>d</sup>	0.997 (0.992)	1.102 (1.103)	1.299 (1.811)
formamide <sup>d</sup>	0.982 (0.954)	1.310 (1.132)	2.061 (7.444)
H <sub>2</sub> CO <sup>d</sup>	0.992 (0.961)	1.502 (1.128)	0.662 (3.116)
cytosine	0.991 (0.943)	1.163 (1.106)	3.067 (6.660)
HCO <sub>2</sub> <sup>-</sup>	0.987 (0.990)	1.049 (0.987)	25.276 (-0.996)
OCN <sup>-</sup>	0.997 (0.978)	0.997 (0.978)	-0.280 (-4.569)
HCl <sup>e</sup>	0.995	0.858	0.189

<sup>a</sup>van der Waals radii are taken from A. Bondi, *J. Phys. Chem.*, **68**, 441 (1964); approximately 200 points around the molecules.

<sup>b</sup>Potential calculated according to approximation III of reference 11.

<sup>c</sup>AM1 optimized geometries.

<sup>d</sup>Molecule involved in the AM1 parameter fitting.<sup>10</sup>

<sup>e</sup>See reference 21.

the above test gives only a rough idea of the quality of potentials and further studies are required to establish the reliability of AM1 potentials.

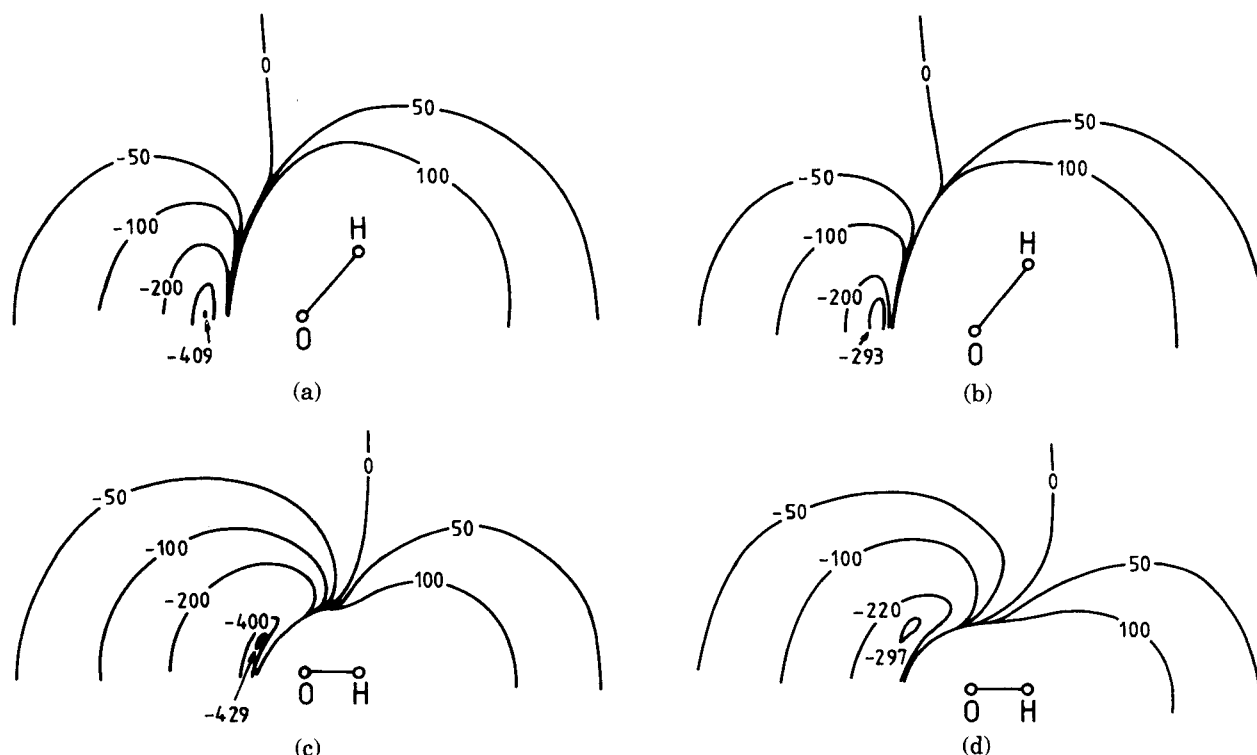
#### Electrostatic Potential Maps of Some Representative Molecules

The AM1 and STO-3G electrostatic potential maps are shown in Figures 1–5. Simi-

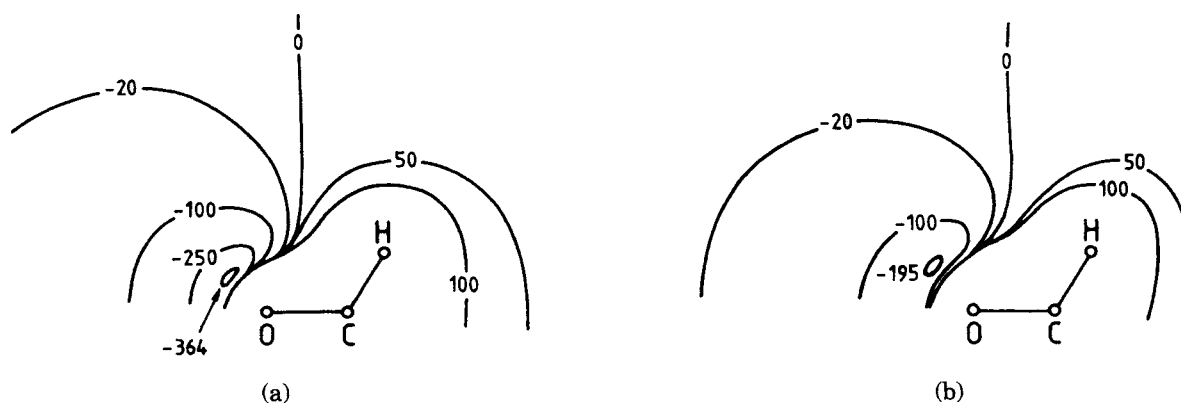
larities and differences between the maps obtained by these two methods are discussed in the following paragraphs.

#### Water

The MEP maps of water (Fig. 1) were calculated in the molecular plane and in a plane perpendicular to the molecular plane containing the symmetry axis of the mole-



**Figure 1.** Electrostatic potential maps for water (kJ/mol); (a) calculated with AM1 in the molecular plane, (b) calculated with STO-3G in the molecular plane, (c) calculated with AM1 in a plane perpendicular to the molecular plane containing the molecular symmetry axis, (d) calculated with STO-3G in a plane perpendicular to the molecular plane containing the molecular symmetry axis.



**Figure 2.** Electrostatic potential maps for formaldehyde in the molecular plane (kJ/mol); (a) calculated with AM1, (b) calculated with STO-3G.

cule. The deepest minima were found above and below the plane of the molecule, by both AM1 and *ab initio* calculations. The minima in both planes are much deeper and slightly closer to the O atom in the AM1 maps.

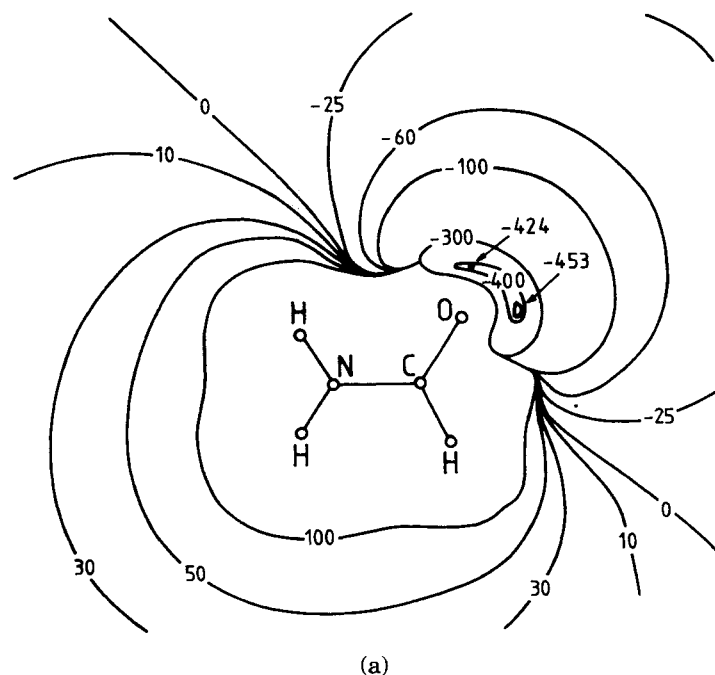
#### Formaldehyde

Similar results were obtained for formaldehyde (Fig. 2). The potential minima can again be attributed to the lone pairs of the O atom. In this case they are in the molecular plane away from the symmetry axis. AM1 predicts the minima to be deeper and

closer to the O atom, as in the case of water, though the results are qualitatively the same as the STO-3G results.

#### Formamide

The shapes of AM1 and STO-3G potential maps of formamide (Fig. 3) are similar both in the molecular plane and in the plane containing the C and N atoms perpendicular to the molecular plane. It should be noted that the AM1 method reproduces the well above the N atom. The minimum near to the O atom is deeper than the one near to



**Figure 3.** Electrostatic potential maps for formamide (kJ/mol); (a) calculated with AM1 in the molecular plane, (b) calculated with STO-3G in the molecular plane, (c) calculated with AM1 in a plane perpendicular to the molecular plane containing the N and C atoms, (d) calculated with STO-3G in a plane perpendicular to the molecular plane containing the N and C atoms.

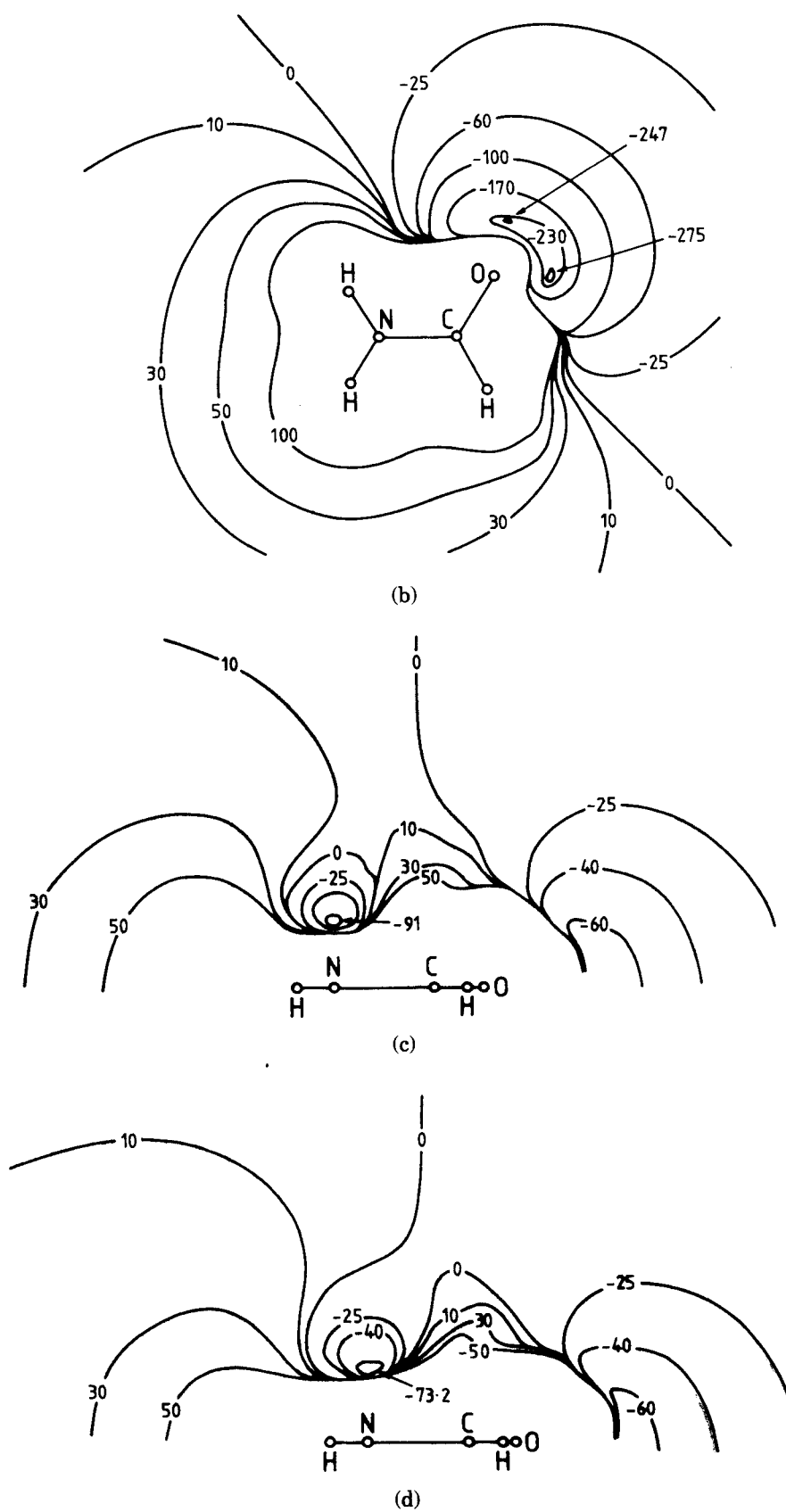
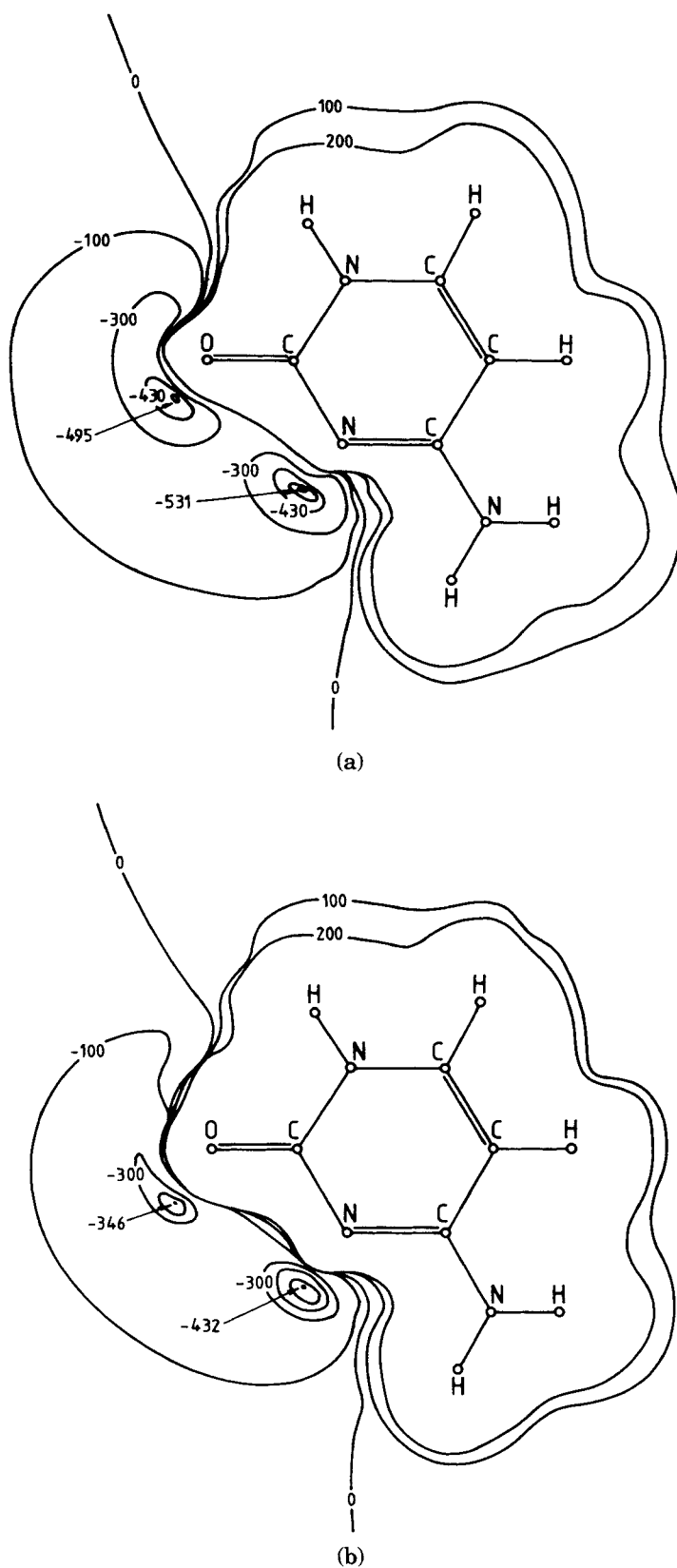
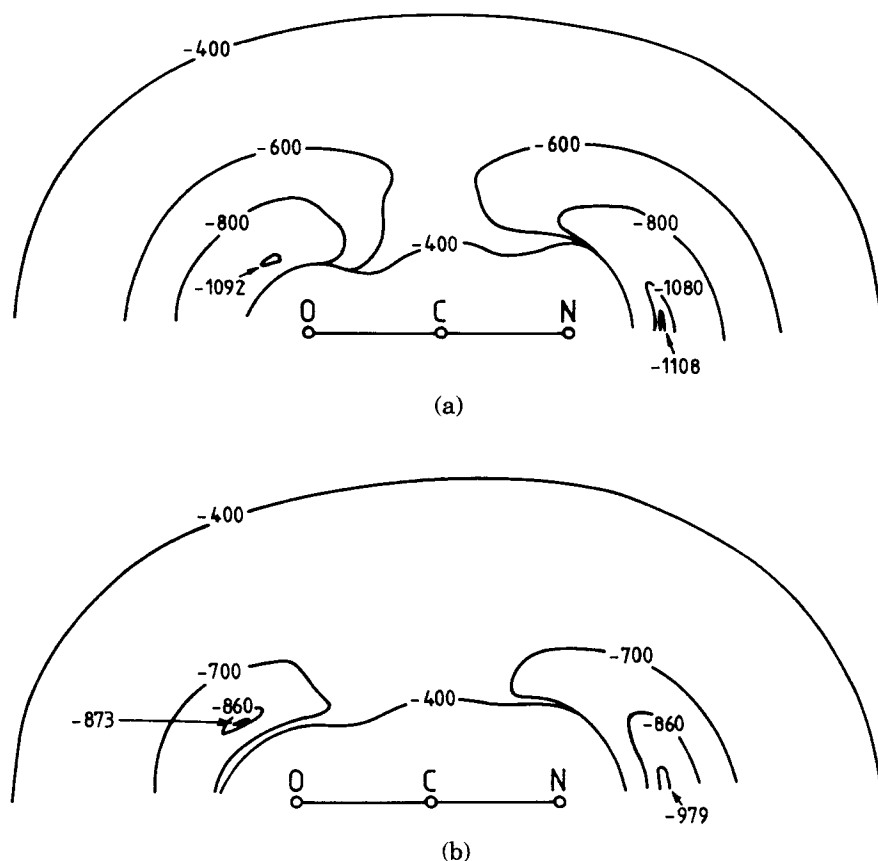


Figure 3. (continued)



**Figure 4.** Electrostatic potential maps for cytosine in the ring plane (kJ/mol); (a) calculated with AM1, (b) calculated with STO-3G.



**Figure 5.** Electrostatic potential maps for  $\text{OCN}^-$  (kJ/mol); (a) calculated with AM1, (b) calculated with STO-3G.

N atom for both methods; the difference is greater with the AM1 method. (The CNDO maps differ qualitatively depending on the approximations used in the potential calculation.<sup>12</sup>)

#### Cytosine

There are two potential wells around the cytosine; one near to the N atom, and another near to the O atom (Fig. 4). The AM1 map—in agreement with the STO-3G case—gives a deeper minimum in the proximity of the N atom, but predicts a smaller difference between the two minima than is shown in the STO-3G map. (We note that while the magnitude of *ab initio* potentials of reference 20. is nearer to our STO-3G results, the difference between the depths of the two minima is closer to our AM1 results.) It is interesting at this point to compare the ability of AM1 and CNDO wave functions to produce correct electrostatic potentials for cytosine. It was reported in reference 12. that approximation IV, which probably gives the best results with CNDO

wave functions, reverses the order of depths of minima around cytosine. Our method of calculating the potential is exactly the same as approximation III of reference 11., but the AM1 potentials seem to be superior not only to the potentials obtained from the CNDO wave function by approximation III, but also to those calculated with the more time-consuming approximation IV.

#### Cyanate

The  $\text{OCN}^-$  ion provides a good test for the quality of the potential since there are two minima around the molecule close to the end atoms (Fig. 5). For both AM1 and STO-3G, the minimum near to the N atom is deeper. The difference between the two minima is quite large for STO-3G but very small for AM1. A similar effect was also observed in the case of cytosine and was also reported in connection with CNDO results.<sup>12</sup>

To summarize, the AM1 potentials are in qualitative agreement with the minimal basis set *ab initio* results in all cases studied. The AM1 method tends to yield deeper min-

ima (which are closer to the nuclei) than the *ab initio* STO-3G method. In the case of molecules with both N and O atoms (cytosine,  $\text{OCN}^-$ , formamide), AM1 predicts the correct order of minima but the depth of the minimum near to the O atom is overestimated with respect to the one near to the N atom.

#### Atomic Charges Derived from Electrostatic Potentials

The good agreement between AM1 and STO-3G electrostatic potentials suggests that AM1 potential derived charges may be of comparable quality to STO-3G potential derived charges. Further evidence that AM1 provides reasonable charge distributions comes from the comparison of AM1 dipole moments with experimental dipole moments. The correlation coefficient is 0.914 for AM1 while 0.850 was obtained with STO-3G. In this section, molecules from reference 14. were used, except for  $\text{SH}_2$  and  $\text{PH}_3$  since no AM1 parameters are available for S and P atoms.<sup>10,21</sup> (According to data in Table I, CNDO is also likely to give reasonable potential derived charges. However, the AM1 method seems to be replacing CNDO in many applications. The advantage of CNDO over AM1 is that it is applicable to more types of atoms, but the balance is due to improve in favor of the AM1 method, so we feel we can restrict our studies to AM1 potential derived charges.)

To obtain atomic charges from electrostatic potentials, the MEP was calculated on extended van der Waals surfaces, as discussed in reference 14. The closest surface was generated by multiplying the van der Waals radii of atoms by a scaling factor varying between 1.0 and 1.5. To assess the effect of this multiplying factor, the dipole moments calculated from the wave function were compared with the dipole moments derived from atomic charges obtained with different scaling factors. These calculations were carried out *ab initio* with a 6-31G\*\*<sup>22</sup> basis. The three scaling factors tested were 1.0, 1.2, and 1.5, and they gave correlation coefficients of 0.997, 0.998, and 0.999 respectively. Since these small differences are not relevant in the study of AM1 potential derived charges, the value of the

scaling factor is not crucial and we chose the value of 1.2 to be used in all further calculations. The results of fitting the charges to reproduce the potential are summarized in Table II. (These charges are not directly comparable to those given in reference 14. due to the use of a different scaling factor.)

Chirlian and Franci<sup>14</sup> propose the 6-31G\*\* basis set<sup>22</sup> to be superior to other Pople-type basis sets,<sup>23</sup> because it yields calculated dipole moments in better agreement with experiment. Therefore, in addition to carrying out a direct comparison between AM1 and STO-3G potential derived charges, we have also compared both the AM1 and STO-3G potential derived charges with 6-31G\*\* potential derived charges.

The results of the comparison of charges fitted to the different electrostatic potentials are presented in Table III. AM1 and STO-3G charges correlate slightly better with the 6-31G\*\* values than they do with one another (last three lines in Table III). However the parameters of the regression line are nearer to the ideal value when the AM1 and STO-3G charges are correlated against each other. The correlation with 6-31G\*\* charges is better for STO-3G than for AM1, but the regression coefficient is slightly nearer to unity in the latter case. It is worth noting that the agreement between AM1 and 6-31G\*\* potential derived charges is better than that found between AM1 Mulliken charges and 6-31G\*\* potential derived charges (Table III).

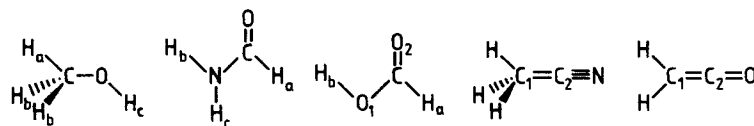
Another way to assess the quality of charges is to compare their dipole moments with experimental values. This was done for AM1, STO-3G, and 6-31G\*\* results (Table IV). The correlation coefficients are 0.912, 0.845, and 0.989, respectively. The comparisons again show the similar quality of AM1 and STO-3G potential derived charges; the AM1 potential derived dipole moments correlate better with the experimental values than do the STO-3G potential derived dipole moments. It should be noted, however, that most of the molecules involved in the calculations were also involved in the AM1 parameter fitting (see Table IV).

Finally, the possibility of using AM1 optimized geometries to derive atomic charges was studied. It was found that at the level of accuracy that can be achieved by AM1,



**Table II.** Potential derived atomic charges. Data in parenthesis are from reference 14.

Atom <sup>a</sup>	AM1 <sup>b</sup>	AM1 <sup>c</sup>	STO-3G <sup>c</sup>	6-31G <sup>***</sup>
HF <sup>e</sup>				
F	-0.442	-0.405	-0.298 (-0.298)	-0.462 (-0.462)
H	0.442	0.405	0.298 (0.298)	0.462 (0.462)
H <sub>2</sub> O <sup>d</sup>				
O	-0.660	-0.667	-0.615 (-0.615)	-0.795 (-0.796)
H	0.330	0.334	0.308 (0.308)	0.398 (0.398)
NH <sub>3</sub> <sup>d</sup>				
N	-1.074	-1.000	-0.976 (-0.953)	-1.052 (-1.014)
H	0.358	0.333	0.325 (0.318)	0.353 (0.338)
CH <sub>4</sub> <sup>d</sup>				
C	-0.233	-0.227	-0.494 (-0.463)	-0.564 (-0.496)
H	0.058	0.057	0.123 (0.116)	0.141 (0.124)
C <sub>2</sub> H <sub>2</sub> <sup>d</sup>				
C	-0.174	-0.176	-0.181 (-0.180)	-0.295 (-0.292)
H	0.174	0.176	0.181 (0.180)	0.299 (0.292)
C <sub>2</sub> H <sub>4</sub> <sup>d</sup>				
C	-0.183	-0.184	-0.162 (-0.159)	-0.355 (-0.339)
H	0.092	0.092	0.081 (0.080)	0.178 (0.169)
CO <sub>2</sub> <sup>d</sup>				
C	0.839	0.886	0.831 (0.808)	0.924 (0.908)
O	-0.420	-0.443	-0.415 (-0.404)	-0.462 (-0.454)
H <sub>2</sub> CO <sup>d</sup>				
C	0.511	0.497	0.368 (0.549)	0.403 (0.578)
O	-0.431	-0.422	-0.292 (-0.344)	-0.451 (-0.502)
H	0.040	-0.038	-0.038 (-0.102)	0.024 (-0.037)
CH <sub>3</sub> OH <sup>d</sup>				
C	0.133	0.148	0.066 (0.141)	0.105 (0.212)
O	-0.526	-0.534	-0.471 (-0.470)	-0.635 (-0.627)
H <sup>a</sup>	0.047	0.039	0.039 (0.022)	0.074 (0.035)
H <sup>b</sup>	0.012	0.012	0.025 (0.002)	0.023 (-0.005)
H <sup>c</sup>	0.322	0.324	0.315 (0.304)	0.411 (0.390)
H <sub>2</sub> NCHO <sup>d</sup>				
O	-0.530	-0.525	-0.394 (-0.404)	-0.558 (-0.580)
N	-0.628	-0.571	-0.670 (-0.697)	-0.900 (-0.921)
C	0.571	0.561	0.489 (0.523)	0.573 (0.660)
H <sup>a</sup>	0.026	0.009	-0.011 (-0.026)	0.058 (0.017)
H <sup>b</sup>	0.297	0.267	0.300 (0.295)	0.399 (0.401)
H <sup>c</sup>	0.264	0.259	0.286 (0.307)	0.427 (0.423)
HCOOH <sup>d</sup>				
O <sub>1</sub>	-0.607	-0.587	-0.540 (-0.531)	-0.639 (-0.671)
O <sub>2</sub>	-0.543	-0.535	-0.410 (-0.403)	-0.547 (-0.598)
C	0.726	0.731	0.622 (0.597)	0.620 (0.781)
H <sup>a</sup>	0.033	0.016	-0.027 (-0.021)	0.092 (0.027)
H <sup>b</sup>	0.392	0.375	0.356 (0.358)	0.474 (0.461)
CH <sub>3</sub> CN				
N	-0.361	-0.359	-0.451 (-0.448)	-0.514 (-0.430)
C <sub>1</sub>	-0.341	-0.320	-0.563 (-0.497)	-0.597 (-0.390)
C <sub>2</sub>	0.340	0.329	0.501 (0.475)	0.489 (0.430)
H	0.121	0.116	0.171 (0.156)	0.207 (0.130)
H <sub>2</sub> C=C=O <sup>d</sup>				
C <sub>1</sub>	-0.825	-0.863	-0.775 (-0.768)	-1.111 (-1.076)
C <sub>2</sub>	0.718	0.740	0.654 (0.652)	0.759 (0.774)
O	-0.379	-0.370	-0.314 (-0.315)	-0.396 (-0.411)
H	0.243	0.246	0.218 (0.216)	0.374 (0.357)
HCl <sup>e</sup>				
Cl	-0.235	-0.234	-0.281 (-0.288)	-0.233 (-0.246)
H	0.235	0.234	0.281 (0.288)	0.233 (0.246)

<sup>a</sup>Atomic labels refer to the following diagrams:<sup>b</sup>AM1 optimized geometry.<sup>c</sup>Experimental geometries as in reference 14.<sup>d</sup>Molecule involved in AM1 parameter fitting<sup>10</sup><sup>e</sup>See reference 21.

**Table III.** Correlation between AM1, STO-3G and 6-31G\*\* potential derived atomic charges.

			Correlation coefficient	Regression coefficient	Intercept of regression line (kJ/mol)
AM1//AM1 <sup>a</sup>	vs.	AM1//exp <sup>b</sup>	0.999	1.008	-0.005
AM1//AM1	vs.	STO-3G//exp <sup>b</sup>	0.978	1.040	0.009
AM1//AM1	vs.	6-31G**//exp <sup>b</sup>	0.980	0.873	0.033
AM1//AM1 <sup>c</sup>	vs.	6-31G**//exp <sup>b</sup>	0.917	0.416	-0.024
AM1//exp <sup>b</sup>	vs.	STO-3G//exp <sup>b</sup>	0.977	1.030	0.015
AM1//exp <sup>b</sup>	vs.	6-31G**//exp <sup>b</sup>	0.980	0.865	0.038
STO-3G//exp <sup>b</sup>	vs.	6-31G**//exp <sup>b</sup>	0.990	0.828	0.021

<sup>a</sup>String preceding "//" refers to the method or basis set used in electrostatic potential calculation; string following // refers to the geometry used; e.g., AM1//exp means that charges were derived from AM1 potentials calculated in experimental geometry.

<sup>b</sup>Experimental geometries as in reference 14.

<sup>c</sup>Mulliken charges.

**Table IV.** Dipole moments (in Debye units) calculated from potential derived charges. Experimental geometries<sup>a</sup> were used except as noted. Data in parenthesis are from reference 14.

Molecule	Exp <sup>b</sup>	AM1 <sup>c</sup>	AM1	STO-3G	6-311G**
HF <sup>d</sup>	1.820	1.754	1.784	1.288 (1.311)	2.033 (2.033)
H <sub>2</sub> O <sup>e</sup>	1.850	1.886	1.854	1.746 (1.746)	2.258 (2.258)
NH <sub>3</sub> <sup>e</sup>	1.470	1.751	1.832	1.786 (1.739)	1.926 (1.850)
H <sub>2</sub> CO <sup>e</sup>	2.330	2.315	2.226	1.478 (1.421)	2.736 (2.695)
CH <sub>3</sub> OH <sup>e</sup>	1.700	1.621	1.712	1.544 (1.440)	1.968 (1.864)
H <sub>2</sub> NCHO <sup>e</sup>	3.730	3.683	3.768	2.905 (2.885)	4.472 (4.458)
HCOOH <sup>e</sup>	1.410	1.456	1.303	0.709 (0.745)	1.549 (1.505)
CH <sub>3</sub> CN	3.920	2.835	2.819	3.062 (3.137)	4.130 (4.137)
H <sub>2</sub> CCO <sup>e</sup>	1.420	1.381	1.036	0.698 (0.684)	1.549 (1.790)
HCl <sup>d</sup>	1.110	1.449	1.435	1.721 (1.766)	1.427 (1.509)

<sup>a</sup>Experimental geometries as in reference 14.

<sup>b</sup>Experimental dipole moments are from reference 14.

<sup>c</sup>AM1 optimized geometry.

<sup>d</sup>See reference 21.

<sup>e</sup>Molecule involved in AM1 parameter fitting.<sup>10</sup>

the experimental and AM1 optimized geometries may be used with equal certainty. Charges calculated with AM1 optimized geometries show a similar correlation with 6-31G\*\* charges to those derived using experimental geometries (Table III). For the dipole moments calculated from potential derived charges, the correlation coefficient between AM1 and 6-31G\*\* is 0.912 using experimental geometries, and 0.937 using AM1 optimized geometries. The correlation coefficient between AM1 dipole moments calculated from potential derived charges obtained with the two sets of geometries is 0.988.

## CONCLUSION

Electrostatic potentials based on AM1 wave functions correlate well with STO-3G results. Excellent qualitative agree-

ment was observed for all molecules, but the numerical values may differ from the STO-3G values. Atomic charges derived from AM1 or STO-3G potentials may be used with a similar degree of confidence for both optimized and experimental geometries. The AM1 charges correlate well with 6-31G\*\* charges and the dipole moments derived from these charges correlate well with quantum mechanical and experimental dipole moments. Thus the AM1 calculations may replace minimal basis set *ab initio* calculations if the shape of the potential map is of interest or if potential derived atomic charges are to be determined. The AM1 potential derived charges are vastly superior to the AM1 Mulliken charges, and should find widespread use in molecular mechanics and molecular dynamics studies.

This makes it possible to investigate the electrostatic properties of molecules that

cannot be treated at the *ab initio* level. The applications of AM1 electrostatic potentials are likely to be extended as AM1 parameters become available for a larger variety of atoms.

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