Supplementary Information

for

Calculations of the Electric Fields in Liquid Solutions

Stephen D. Fried[1], Lee-Ping Wang[1], Steven G. Boxer[1], Pengyu Ren[2], Vijay S. Pande[1]*

[1.] Department of Chemistry, Stanford University; Stanford, California
[2.] Department of Biomedical Engineering, University of Texas; Austin, Texas

I. Supplementary Figures

II. Supplementary Tables

III. Supplementary Methods

V. Parameters

I. Supplementary Figures

Figure S1: Sample electric field trajectories

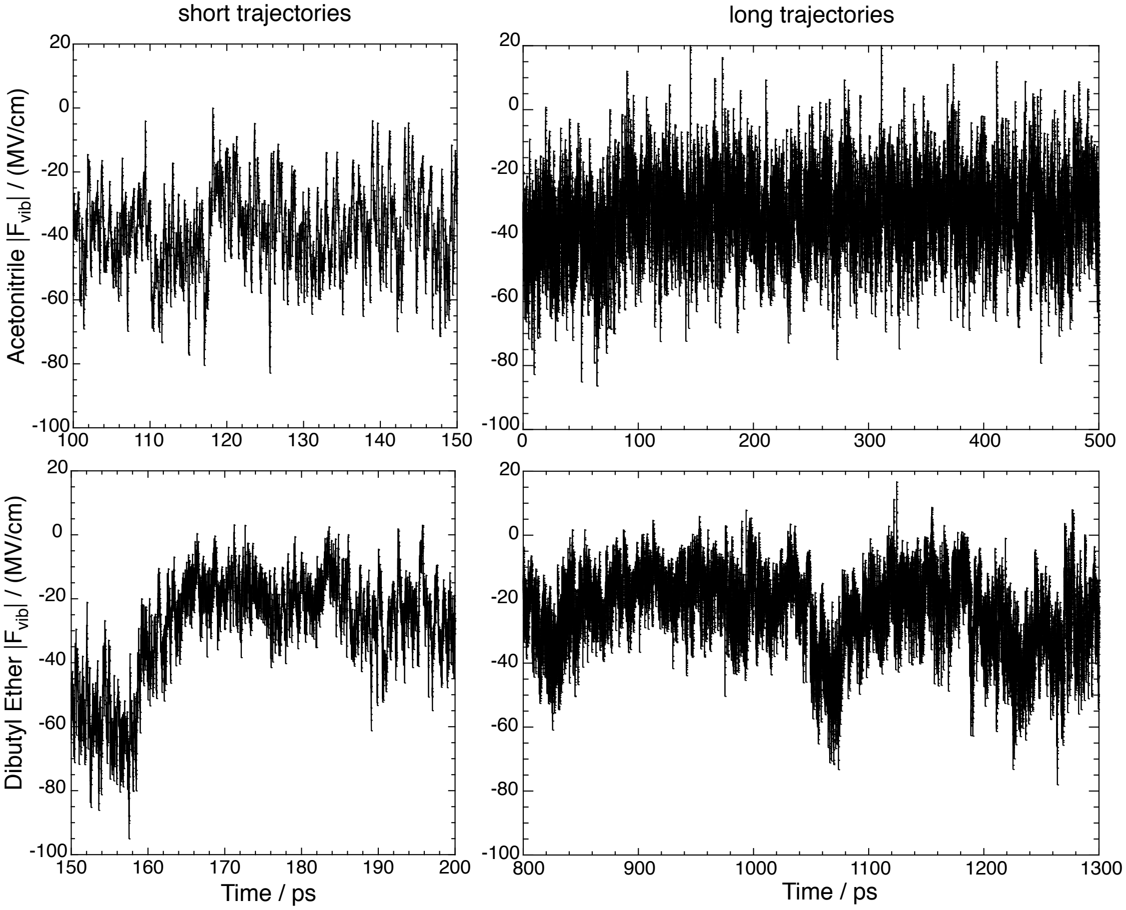

Figure S1. Segments of the electric field trajectories for long (right side) and short (left side) simulations of acetonitrile (top half) and dibutyl ether (bottom half). 50-ps segments were selected from the short trajectory and 500-ps segments from the long trajectories.

Inspection of acetonitrile's trajectories (top) shows that the electric field displays slight memory on the picosecond timescale, but little memory on the tens or hundreds of picoseconds timescales, in agreement with the time constants from the autocorrelation functions. Acetonitrile's field trajectory is representative of all the other solvents studied, except for dibutyl ether (bottom), which alone displayed slow dynamics on the tens (or even hundreds) of picoseconds timescales.

The 50-ps segment (bottom left) shows a close-up of one of the slow process, of which there are a number examples in the 500-ps segment. These types of dynamics imply that dibutyl ether would require longer equilibration in order to reach the equilibrium ensemble, and longer production dynamics to converge ensemble-average properties.

Figure S2: Sample electric field histograms

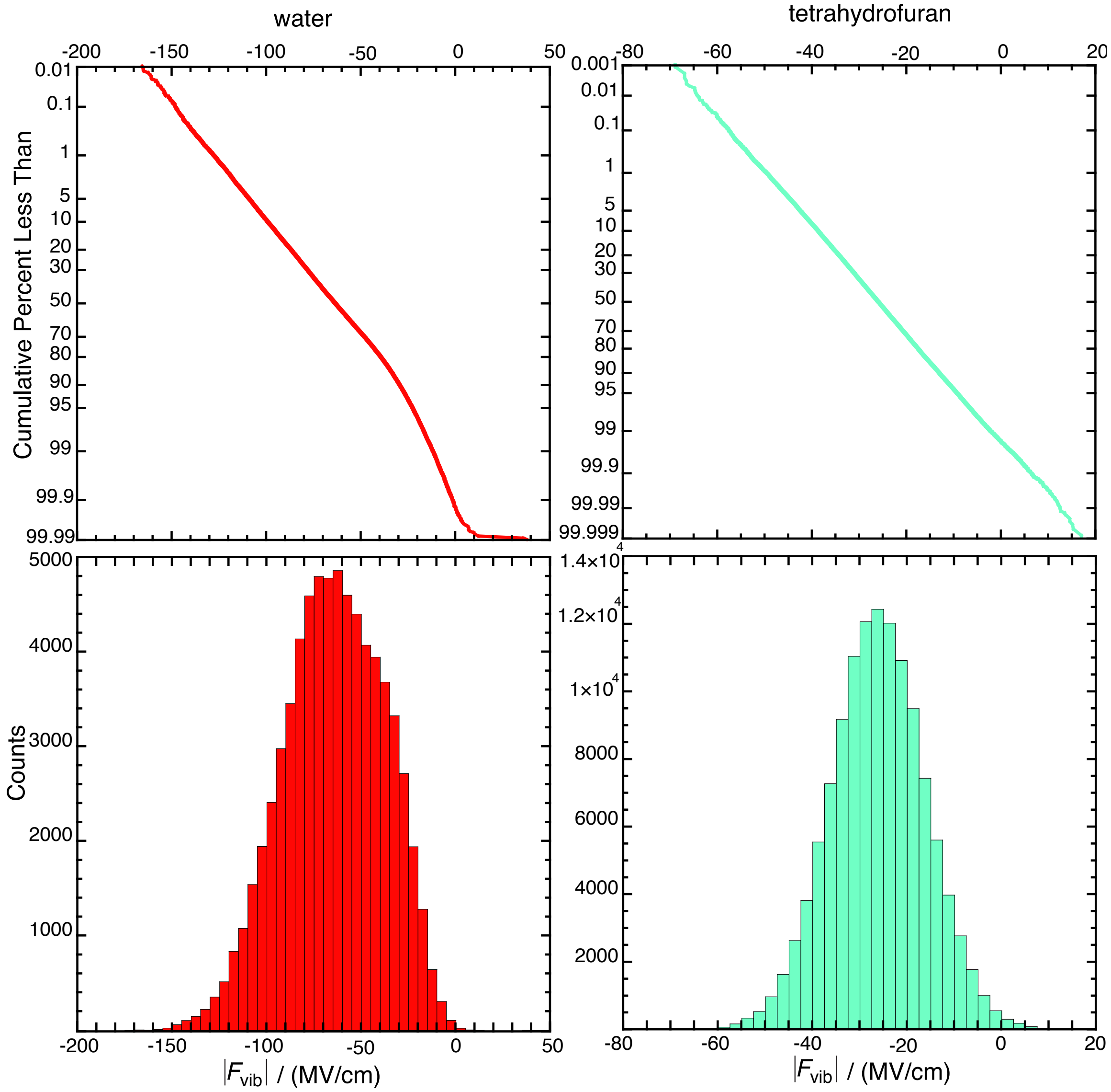

Figure S2. Electric field histograms (bottom half) and cumulative distribution functions (top half) for the long simulations of water (left side) and tetrahydrofuran (right side). The vertical axis of the histograms use a linear scale to illustrate the preponderance of the probability mass, whereas the cumulative distribution functions use a logarithmic scale to illustrate how far out the tails extend.

Tetrahydrofuran is representative of most of the solvents examined. Its electric field distribution is described almost perfectly by the normal distribution. The electric field is positive (the overall interaction between the solvent and C=O is unfavorable) about 1% of the time.

Water's electric field distribution is different – it conforms to the normal distribution less strictly. The histogram shows a larger-than-expected tail on the negative end (to more favorable electric fields), and the positive end has a sharper drop-off. Non-normal behavior is evinced clearly by the non-linearity in the log cumulative plot (top). Hexane was the only other solvent that displayed this skew to its distribution.

Due to water's skew toward negative electric fields, it very infrequently sampled electric fields greater than zero (< 0.1%) and was capable of appreciably sampling electric fields more than twice its mean (~ 1%).

Figure S3: *Ab initio* field-frequency curve for acetophenone

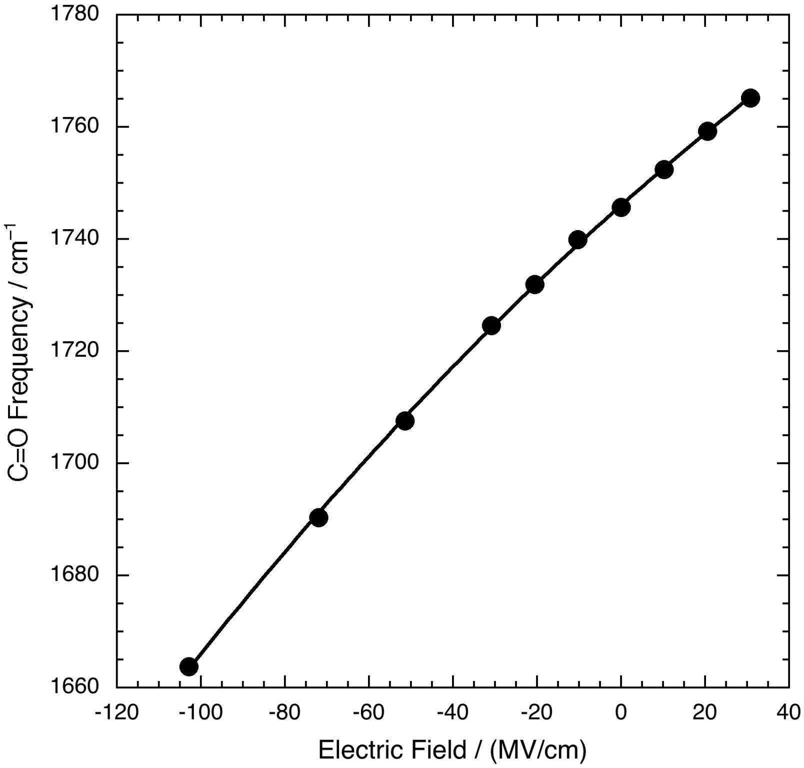

Figure S3. The calculated harmonic frequency of the C=O stretch of acetophenone after being geometry optimized in the presence of a uniform electric field oriented along the C=O bond axis. Calculations were carried out by density functional theory at the B3LYP/6-311++G(d,p) level. The field-induced frequency shifts are well described by the model $\bar{\nu} = 1746 + 0.668F - 0.00133F^2$ with an R^2 of 0.9998.

The linear sensitivity term (corresponding to the difference dipole in cm^{-1}/(MV/cm)) is within the estimated range for the microscopic Stark tuning rate (0.58 – 0.75 cm^{-1} /(MV/cm)) assuming a local field correction factor, $1.4 < f < 1.8$. The quadratic sensitivity term corresponds to one half the difference polarizability in cm^{-1}/(MV/cm)^2.

Although the parabolic shape of the curve is slightly apparent at high electric fields, in the range of electric fields accessible to solvents (between –10 and –70 MV/cm) the trend is essentially linear (a least squares regression line in this range has an R^2 of 0.999), consistent with the strong linear trends in Figure 1A from the main text. In Stark spectroscopy, small external fields are applied relative to the solid solution's environment field, implying the Stark tuning rate is well described by the derivative expression: $|\Delta\vec{\mu}| = d\bar{\nu}/dF = 0.668 - 0.00266F$, where the first term corresponds to $\Delta\vec{\mu}_M$ and the second to $\Delta\vec{\mu}_{ind}$ using the notation from the main text. At the large environment fields present in a cold organic glass (–50 to –70 MV/cm), the induced term would contribute an additional 20–30 % of the intrinsic difference dipole to the total difference dipole.

II. Supplementary Tables

Table S1: Electric field data from the short trajectories[a]

solvent		aceto-nitrile	DMSO	hexane	valero-nitrile	THF	water	dibutyl ether
n [b]		24050	17184	18140	18159	15098	11069	10619
$\lvert F^C \rvert$ [c]	mean	-23.56 ± 0.69	-29.60 ± 1.13	-7.42 ± 0.27	-24.14 ± 0.71	-21.37 ± 0.81	-43.56 ± 1.18	-15.86 ± 1.57
	std.	10.82	11.36	3.42	9.45	9.21	17.82	8.88
$\lvert F^O \rvert$ [c]	mean	-48.66 ± 0.98	-56.10 ± 1.67	-14.40 ± 0.47	-47.31 ± 2.42	-39.90 ± 2.43	-95.44 ± 4.97	-32.46 ± 2.08
	std.	16.82	17.58	7.08	17.42	12.99	36.87	14.2
$\lvert F_{vib} \rvert$ [c]	mean	-36.11 ± 0.82	-42.85 ± 1.38	-10.91 ± 0.37	-35.73 ± 1.54	-30.63 ± 1.47	-69.5 ± 3.04	-24.16 ± 1.74
	std.	12.69	13.39	4.91	12.49	9.95	26.12	10.49
$\lvert \Delta F_{vib} \rvert$ [c]	Mean	-25.1 ± 0.45	-26.49 ± 0.70	-6.98 ± 0.21	-23.16 ± 1.76	-18.53 ± 2.13	-51.88 ± 3.89	-16.60 ± 1.25
	std.	12.49	12.60	5.20	12.72	10.56	25.00	10.98

[a] Some of these data also appeared in Table 1. They are reproduced here to ease comparisons. [b] The number of electric field data points recorded for this trajectory, each taken 10 fs after one another. [c] $\lvert F^C \rvert$ and $\lvert F^O \rvert$ are abbreviations for $\vec{F}^C \cdot \hat{u}_{CO}$ and $\vec{F}^O \cdot \hat{u}_{CO}$ respectively. $\lvert F_{vib} \rvert$ and $\lvert \Delta F_{vib} \rvert$ are the electric field experienced by the C=O vibration and the electric field drop along C=O respecitlvely, as defined by Eq. 5 and Eq. 6 in methods section 2.4. All electric fields are in units of MV/cm.

Table S2: Electric field data from the long trajectories [a]

solvent		aceto-nitrile	DMSO	hexane	valero-nitrile	THF	water	dibutyl ether
n [b]		189489	136069	100767	98631	124246	69979	140186
$\left\|F^C\right\|$ [c]	mean	-19.98 ± 0.34	-26.28 ± 0.37	-5.34 ± 0.19	-20.08 ± 0.35	-17.72 ± 0.39	-40.65 ± 1.57	-16.62 ± 0.81
	std.	9.97	10.60	3.44	9.88	9.23	17.77	8.98
$\left\|F^O\right\|$ [c]	mean	-42.28 ± 0.45	-51.75 ± 0.56	-11.35 ± 0.28	-42.61 ± 0.85	-34.54 ± 0.69	-88.41 ± 2.82	-31.65 ± 1.39
	std.	16.38	15.86	6.87	17.93	12.92	37.66	14.85
$\left\|F_{vib}\right\|$ [c]	mean	-31.13 ± 0.38	-39.02 ± 0.41	-8.34 ± 0.23	-31.35 ± 0.56	-26.13 ± 0.51	-64.53 ± 2.18	-24.13 ± 1.08
	std.	12.28	11.95	4.83	13.07	10.07	26.62	11.16
$\left\|\Delta F_{vib}\right\|$ [c]	Mean	-22.30 ± 0.27	-25.47 ± 0.48	-6.01 ± 0.12	-22.53 ± 0.66	-16.82 ± 0.44	-47.76 ± 1.35	-15.03 ± 0.68
	std.	11.51	12.52	4.97	12.44	9.91	25.14	10.16

[a] Electric fields from the longer trajectories, simulated with the settings described in methods section II.C. [b] The number of electric field data points recorded for this trajectory, each taken 10 fs after one another. [c] $\left|F^C\right|$ and $\left|F^O\right|$ are abbreviations for $\vec{F}^C \cdot \hat{u}_{CO}$ and $\vec{F}^O \cdot \hat{u}_{CO}$ respectively. $\left|F_{vib}\right|$ and $\left|\Delta F_{vib}\right|$ are the electric field experienced by the C=O vibration and the electric field drop along C=O respecitlvely, as defined by Eq. 5 and Eq. 6 in methods section 2.4. All electric fields are in units of MV/cm.

The following tables present electric fields calculated by solving the PB equation with different dielectric constants than that used in the main text (Table 2). Using the conventions in APBS, 'pdie' refers to the internal dielectric of the solute, and 'sdie' refers to the external dielectric of the solvent continuum. 'sys' refers to the calculation in which sdie is set equal to the static dielectric constant of the solvent under consideration, and 'ref' refers to the reference calculation designed to represent the solute in the gas phase. Note that the setting in the main text is pdie(sys) = 2, pdie(ref) = 2, and sdie(ref) = 1.

Table S3: Electric fields calculated by solving PB with pdie(sys) = 1, pdie(ref) = 1, and sdie(ref) = 1[a]

Solvent (static dielectric)	$\lvert F_{vib} \rvert$ / (MV/cm)	$\lvert \Delta F_{vib} \rvert$ / (MV/cm)
Hexane (1.78)	-14.88	-0.02
Dibutyl Ether (3.08)	-25.33	0.66
Tetrahydrofuran (7.43)	-36.13	2.49
Valeronitrile (20.04)	-42.69	5.03
Acetonitrile (37.50)	-45.32	6.42
Dimethyl Sulfoxide (46.84)	-46.16	6.73
Water (78.54)	-48.15	6.79

[a] Solvent fields in which the internal dielectric is set to 1. While this setting produces an estimate for water's electric field that is closer to that of the all-atom models (which is perhaps why it was recommended by Swanson et al.), the electric fields are on the whole too large, leading to a field-frequency slope of 0.329 cm^{-1}/(MV/cm) and overall worse agreement with the all-atom models.

Table S4: Electric fields calculated by solving PB with pdie(sys) = 2, pdie(ref) = 2, and sdie(ref) = 2[a]

Solvent (static dielectric)	$\lvert F_{vib} \rvert$ / (MV/cm)	$\lvert \Delta F_{vib} \rvert$ / (MV/cm)
Hexane (1.78)	1.76	0.08
Dibutyl Ether (3.08)	-5.77	-0.06
Tetrahydrofuran (7.43)	-14.09	0.50
Valeronitrile (20.04)	-19.28	1.61
Acetonitrile (37.50)	-21.18	2.43
Dimethyl Sulfoxide (46.84)	-21.70	2.71
Water (78.54)	-22.75	3.25

[a] Solvent fields in which the reference calculation is carried out on a homogeneous dielectric (as per custom) with pdie = sdie = 2. This setting produces the same *relative* fields as the setting in the main text, but in absolute terms, the fields are all shifted up by ca. 12 MV/cm. As hexane is assigned a positive (unfavorable) solvation field, this reference state is clearly unphysical.

The following tables present electric fields calculated by solving the PB equation with a different charge assignment for the solute than that used in the main text (Table 2). To ease comparisons, we kept the dielectric settings (pdie(sys) = 2, pdie(ref) = 2, sdie(ref) = 1) and the radius parameters (ref. 54 from main text) the same.

Table S5: Electric fields calculated by solving PB with CHELPG charges[a]

Solvent (static dielectric)	$\lvert F_{vib} \rvert$ / (MV/cm) [b]	$\lvert \Delta F_{vib} \rvert$ / (MV/cm) [c]
Hexane (1.78)	-8.30	-2.80
Dibutyl Ether (3.08)	-14.64	-4.53
Tetrahydrofuran (7.43)	-21.71	-5.97
Valeronitrile (20.04)	-26.39	-6.73
Acetonitrile (37.50)	-28.27	-7.11
Dimethyl Sulfoxide (46.84)	-28.80	-7.23
Water (78.54)	-29.85	-7.51

[a] The charges for acetophenone were obtained by optimizing acetophenone by DFT at the B3LYP/6-311+G(d,p) level, and utilizing the CHELPG population scheme of Breneman and Wiberg. [b] The electric fields are overall 15% smaller, which is consistent with the charges' magnitudes being 6–72% smaller than GAFF (36% on average). The fact that GAFF charges give results that agree better with MD attests to the importance of weighting polarization effects into the charges. [c] The electric field drops are significantly different from those found with GAFF charges, which were all close to zero. This demonstrates that GAFF charges produce unusually smooth reaction fields, which is not intrinsic to PB methods in general.

Table S6: Electric fields calculated by solving PB with PCM/CHELPG charges[a]

Solvent (static dielectric)	$\lvert F_{vib} \rvert$ / (MV/cm) [b]	$\lvert \Delta F_{vib} \rvert$ / (MV/cm) [c]
Hexane (1.78)	-15.63	-23.39
Dibutyl Ether (3.08)	-27.24	-38.33
Tetrahydrofuran (7.43)	-41.46	-55.58
Valeronitrile (20.04)	-50.58	-66.35
Acetonitrile (37.50)	-53.36	-68.28
Dimethyl Sulfoxide (46.84)	-54.30	-69.21
Water (78.54)	-55.92	-70.53

[a] The charges were assigned in a way designed to reflect self-polarization effects. For each solvent, solvent-induced CHELPG charges were obtained by running a DFT optimization in the presence of a PCM with a dielectric constant equal to that of the solvent. The charges put into the PB model were the gas-phase CHELPG charges (from above) plus one half the polarization charge for each atom, defined as the difference between the gas-phase charge and the PCM charge for that atom. During the reference calculation, the gas-phase CHELPG charges were used. [b] Including explicit solute polarization results in larger fields, resulting in better agreement for water, but worse overall agreement. [c] The large field drops suggest that artifacts may result from not conserving the solute charges in the reference state.

Table S7: Electric fields calculated by solving PB with a cubic-spline smoothed dielectric boundary[a]

Solvent (static dielectric)	$\lvert F_{vib} \rvert$ / (MV/cm)	$\lvert \Delta F_{vib} \rvert$ / (MV/cm)
Hexane (1.78)	-9.78	-0.92
Dibutyl Ether (3.08)	-17.37	-1.05
Tetrahydrofuran (7.43)	-26.09	-0.50
Valeronitrile (20.04)	-32.12	0.13
Acetonitrile (37.50)	-34.78	0.06
Dimethyl Sulfoxide (46.84)	-35.60	-0.08
Water (78.54)	-37.32	-0.65

[a] Dielectric settings are pdie(sys) = 2, pdie(ref) = 2, sdie(ref) = 1, same as the main text. The only difference is the method for smoothing the dielectric boundary (srfm) is set to be the same as that used by Swanson et al. For the electric fields, the difference is negligible; however, the cubic-spline smoothed boundary produces electric field drops that are closer to zero.

Table S8: Electric fields calculated by solving PB with 0.1 Å grid spacings[a]

Solvent (static dielectric)	$\lvert F_{vib} \rvert$ / (MV/cm)	$\lvert \Delta F_{vib} \rvert$ / (MV/cm)
Hexane (1.78)	-9.87	-0.93
Dibutyl Ether (3.08)	-17.39	-1.04
Tetrahydrofuran (7.43)	-25.75	-0.55
Valeronitrile (20.04)	-31.21	0.04
Acetonitrile (37.50)	-33.33	0.29
Dimethyl Sulfoxide (46.84)	-33.92	0.35
Water (78.54)	-35.05	0.49

[a] Dielectric settings are pdie(sys) = 2, pdie(ref) = 2, sdie(ref) = 1, same as the main text. The only difference is finer grid spacings are used.

III. Supplementary Methods

The following sections are designed to help readers carry out electric field calculations in TINKER according to the methods section 2.4 from the main text. To understand conceptually what is going on, please refer to the main text; the following sections are focused on walking through the implementation.

Some initial notes:

1. The following source code modifications were made on TINKER version 6.2, available online at `http://dasher.wustl.edu/ffe/`, and released in February 2013. Although it is probable the same modifications will work on future versions of TINKER, we cannot predict the future.
2. The electric field calculations described in the following are designed to be used in conjunction with a polarizable force field using a site-based point inducible dipole model (such as AMOEBA). Otherwise, the methods described below will not work.
3. The modified TINKER source code is also available online at `http://www.stanford.edu/~sdfried/take-aways/tinker-2_src.tar.gz`

1. Modifications to and compilation of TINKER.

Download the TINKER source code from `dasher` as a GNU zip, and un-tar. cd into the `source` directory. Here you will find a large number of files ending in `.f` – these are FORTRAN 95 programs. At this point, either make the following changes to the source code by hand (*vide infra*), OR rm the `source` directory and replace it with the one available from my website, which has the modified source code files. This modified version of TINKER is later referred to as `tinker-2`. The changes are each given a brief explanation.

`(1) dyanamic.f` – electric field calculations require the ability to evaluate the induced dipoles on atoms of interest for particular configurations without running dynamics. We introduce the 0-time-step flag to indicate this option. These induced dipole evaluations are done snapshot-by-snapshot, and therefore automation is handled at the scripting level. Setting `nstep` to 0, calls `verlet`, supplying it with `istep = 0` (the flag for the further subroutines), and an infinitesimally small time-step (10 attoseconds).

```
   10 continue
      if (query) then
         write (iout,20)
   20    format (/,' Enter the Number of Dynamics Steps to be',
     &            ' Taken (0 to perform single-pt rerun):  ',$)
         read (input,30)  nstep
   30    format (i10)
c
c     flag to perform a single-point force evaluation of a given input
c     snapshot (added by SDF)
c
```

```
            if (nstep .eq. 0) goto 500
         end if


...

c
c     perform a single-pt force evaluation (added by SDF)
c
  500 continue
      call verlet (0,0.001d0)

c
c     perform any final tasks before program exit
c
  510 continue
      call final
      end
```

(2) `verlet.f` – verlet proceeds as usual, altering coordinates infinitesimally from the snapshot, calls mdsave, and then quits. Skipping Verlet recursion entirely (as opposed to performing it with an infinitesimal time-step) appeared to produce artifacts.

```
c
c     store the current atom positions, then find half-step
c     velocities and full-step positions via Verlet recursion
c
      do i = 1, n
         if (use(i)) then
            do j = 1, 3
               v(j,i) = v(j,i) + a(j,i)*dt_2
            end do
            xold(i) = x(i)
            yold(i) = y(i)
            zold(i) = z(i)
c
c     THIS ONLY HAPPENS IF ISTEP NEQ 0 (added by SDF)
c
            if (istep .ne. 0) then
               x(i) = x(i) + v(1,i)*dt
               y(i) = y(i) + v(2,i)*dt
               z(i) = z(i) + v(3,i)*dt
            end if

         end if
      end do

...

c
c     if performing a single-pt force evaluation, skip over mdstat and
c     mdrest (added by SDF)
c
      if (istep .eq. 0) then
```

```
            call mdsave (istep,dt,epot)
            goto 500
         end if
c
c        compute statistics and save trajectory for this step
c
         call mdstat (istep,dt,etot,epot,eksum,temp,pres)
         call mdsave (istep,dt,epot)
         call mdrest (istep)
  500 continue
      return
      end
```

(3) `mdsave.f` – at the beginning, mdsave checks to see if we are performing a single-point induced dipole evaluation. If so, it immediately runs the code that would *normally* be run if the save-induced option were included in the key file. The format has been altered so that higher floating-point precision is recorded.

```
c
c
c     send data via external socket communication if desired
c
      if (.not.skt_init .or. use_socket)  call sktdyn (istep,dt,epot)
c
c     if performing a single-pt induced dipole evaluation, output high-
c     precision dipoles and quit (added by SDF)
c
       if (istep .eq. 0) then
         iind = freeunit ()
         indfile = filename(1:leng)//'.u'
         call version (indfile,'new')
         open (unit=iind,file=indfile,status='new')
         write (iind,540)  n,title(1:ltitle)
  540    format (i6,2x,a)
         do i = 1, npole
            if (polarity(i) .ne. 0.0d0) then
               k = ipole(i)
               write (iind,550)  k,name(k),(debye*uind(j,i),j=1,3)
c 550          format (i6,2x,a3,3f12.6)
  550          format (i6,2x,a3,3f18.12)
            end if
         end do
         close (unit=iind)
         goto 560
      end if

...

  560 continue
      return
      end
```

(4) `archive.f` – the `archive` program is invoked a number of times in the electric field calculations in order to extract snapshots from archives (as noted in (1) the re-run is done one snapshot at a time) and to automate the creation of the solute-only reference trajectory. In particular, the latter task involves executing `archive` with the `trim` option. Natively, `trim` is designed to remove only a few atoms, so a few variables must be altered so that `trim` can remove 1000's of atoms (i.e., the whole solvent).

```
      integer freeunit
      integer list(20000)
      real*8 xr,yr,zr
...
      character*120 record
      character*100000 trimrecord
      character*120 string

...

c
c     decide whether atoms are to be removed from each frame
c
      if (modtyp .eq. 'TRIM') then
         call active
         if (nuse .eq. n) then
            do i = 1, 20000

...

  140       format (/,' Numbers of the Atoms to be Removed :  ',$)
            read (input,150)  trimrecord
  150       format (a100000)
            read (trimrecord,*,err=160,end=160)  (list(i),i=1,20000)
  160       continue
```

For installation, we used the `intel-13 FORTRAN` compilers configured for the linux architecture. Using a bash command line, cp the `.make` files from `/linux/intel` into `/source`. You will also need to acquire the relevant FFTW3 libraries for your system's architecture and make sure they are in the /source directory as well. If all goes well, it should be as simple as:

```
./compile.make
./library.make
./link.make
mkdir ../bin
./rename.make
```

2. Settings for running production runs

A typical production run would be initiated with files with names such as `acp_hex_md.xyz` and `acp_hex_md.key`, where the naming convention goes `solute_solvent_md.fileType`. The naming convention is not of paramount importance, but should be maintained if the reader desires to use the electric field calculation script as is without modification.

The file `solute_solvent_md.xyz` is a standard `xyz` starting coordinates file, except the solute molecule must come first before the entries corresponding to solvent atoms.

The file `solute_solvent_md.key` defines the functional form of the force field, simulation control settings, and (in our case) all the force field parameters as well. The control settings were as follows:

```
# Electrostatics and vdW
ewald
vdw-correction
ewald-cutoff            10.0
vdw-cutoff              10.0
polar-eps               0.00001

# Dynamics
integrator             beeman
thermostat             bussi
barostat               montecarlo
friction               1.0
volume-scale           molecular

# Output
archive
openmp-threads                  8
mpole-list
save-induced
```

where the options in red are essential.

3. Python script to calculate electric fields

```
#!/usr/bin/env python
#This is a script that obtains the electric fields from a TINKER
trajectory
#stored in the format of an arc file.  Created by SDF 20121030.

#Prerequisites:
#  -1- A flat-text trajectory with fn format solute_solvent.arc (no
numbers)
#  -2- A key file with the same base filename as the arc file
#  -3- A flat-text uind file

#Call the script as:
#  python get_fields.py system.arc system.key system.uind

import sys
import re
import numpy as np
import os

def create_perturbed_key(old_kn, new_kn, dq, delbox=False):
    old_key = open(old_kn)
    new_key = open(new_kn,'w')
    omp_flag = False
    for line in old_key:
        if delbox and 'a-axis' in line: continue
        if delbox and 'b-axis' in line: continue
        if delbox and 'c-axis' in line: continue
        if re.search(r'multipole\s+%s' %(atomTypeC), line) or
re.search(r'multipole\s+%s' %(atomTypeO), line):
            atomInfo = line.split()
            whitespace = re.split(r'\S+', line)
            newline = ''
            atomInfo[-1] = str( float(atomInfo[-1]) + dq)
            for i in range( len(atomInfo) ):
                newline += whitespace[i]
                newline += atomInfo[i]
            newline += '\n'
            new_key.write( newline )
        else:
            new_key.write( line )
        if "openmp-threads" in line:
            new_key.write("openmp-threads 1")
            omp_flag = True
    if not omp_flag:
        new_key.write("openmp-threads 1")
    new_key.close()
    old_key.close()

def getInfo(arc_fn):
    solute = arc_fn.split('.')[0].split('_')[0]
    solvent = arc_fn.split('.')[0].split('_')[1]
    return solute, solvent

def getSystemInfo(arc_fn):
    arc_file = open( arc_fn, 'r' )
    first_line = arc_file.next()
```

```
    numAtoms = int( first_line.split()[0] )
    numLines = sum(1 for line in arc_file)
    numSnapshots = (numLines/numAtoms)
    arc_file.close()
    return numSnapshots, numAtoms

def getSoluteInfo(solute):
    if solute == 'acp':
        return 17, 5, 6
    else:
        print "How many solute atoms are there?"
        numSoluteAtoms = raw_input()
        print "What is the index of the C atom?"
        indexC = raw_input()
        print "What is the index of the O atom?"
        indexO = raw_input()
        return int(numSoluteAtoms), int(indexC), int(indexO)

def getAtomTypes(solute_fn):
    solute_file = open( solute_fn, 'r')
    for line in solute_file:
        infoInLine = line.split()
        if len(infoInLine) >= 6:
            if infoInLine[0] == str(indexC):
                atomTypeC = infoInLine[5]
            if infoInLine[0] == str(indexO):
                atomTypeO = infoInLine[5]
    solute_file.close()
    return atomTypeC, atomTypeO

def whichSnapshot(filename):
    ss = int( (re.search(r'\d+', filename)).group() )
    return ss

def convert(x):
    try:
        float(x)
        return float(x)
    except ValueError:
        mantissa = float( x.split('D')[0] )
        expo = int( x.split('D')[1] )
        return mantissa * 10**expo

#MAIN STARTS HERE
#Get the filenames from the command
arc_fn = sys.argv[1]
key_fn = sys.argv[2]
uind_fn = sys.argv[3]

#find out the identity of the solute and solvent
solute, solvent = getInfo(arc_fn)

#find out the number of snapshots and the number of atoms by peeking
into the arc file
numSnapshots, numAtoms = getSystemInfo(arc_fn)
numSoluteAtoms, indexC, indexO = getSoluteInfo(solute)

#create solute-only archive
```

```
trim = open('trim.in', 'w')
trim.write( '%s \n' %(arc_fn) )
trim.write( '3 \n' )
trim.write( ' '.join(str(n) for n in range(numSoluteAtoms+1,
numAtoms+1)) + '\n')
trim.write( '1 %d 1 \n' %(numSnapshots) )
trim.close()
command = 'cat trim.in | ~/Programs/tinker-2/bin/archive'
os.system(command)
os.rename('%s_2' %(arc_fn) , '%s.arc' %(solute) )

#extract solute-only snapshots, place in a temp dir
os.mkdir('%s_xyzs' %(solute))
os.chdir('./%s_xyzs' %(solute)) #go into solute_xyzs

extract = open('extract.in', 'w')
extract.write( '../%s.arc \n' %(solute) )
extract.write( '2 \n' )
extract.write( '1 %d 1 \n' %(numSnapshots) )
extract.close()
command = 'cat extract.in | ~/Programs/tinker-2/bin/archive'
os.system(command)
for fn in os.listdir('.'):
    if fn != 'extract.in':
        fn_new = fn.translate(None, '.') + '.xyz'
        os.rename(fn, fn_new)

#Get the atom-types for the probeC and probeO atoms
atomTypeC, atomTypeO = getAtomTypes( '%s001.xyz' %(solute) )

#Make a kew file for the single-pt uind evaluations for the solute
solutekey_fn = '%s.key' %(solute)
create_perturbed_key('../%s' %(key_fn), solutekey_fn, 0, delbox=True)

#perform single-pt uind evaluations on the solute snapshots
for fn in os.listdir('.'):
    if fn.endswith('.xyz'):
        print "getting induced dipoles from %s" %(fn)
        command = '~/Programs/tinker-2/bin/dynamic %s %s 0' %
(fn,solutekey_fn)
        os.system(command)


#copy all of the data from files into an array
#rawData[i,j,k,l] stores
      #for the i^th snapshot (0 to numSnapshots-1)
      #for the j^th atom (C=0, O=1)
    #for the k^th component (x=0, y=1, z=2)
      #  the l^th information (coord=0, uindTot=1, uindRef=2)
rawData = np.zeros( (numSnapshots, 2, 3, 3) )

#we're still in solute_xyzs
for fn in os.listdir('.'): #loop thru all files in this directory,
garnering the relevant data
    if fn.endswith('.xyz'): #if an xyz file, grab coordinates, l=0
        ss = whichSnapshot( fn )
        xyz = open( fn , 'r')
        for line in xyz:
```

```
            infoInLine = line.split()
            if len(infoInLine) >= 6:
                if infoInLine[0] == str(indexC):
                    rawData[ss-1,0,0:3,0] = [convert(x) for x in
infoInLine[2:5]]
                if infoInLine[0] == str(indexO):
                    rawData[ss-1,1,0:3,0] = [convert(x) for x in
infoInLine[2:5]]
        xyz.close()
    elif fn.endswith('.u'): #if an u file, grab reference induced
dipoles, l=2
        ss = whichSnapshot( fn )
        u = open( fn , 'r')
        for line in u:
            infoInLine = line.split()
            if len(infoInLine) >= 5:
                if infoInLine[0] == str(indexC):
                    rawData[ss-1,0,0:3,2] = [convert(x) for x in
infoInLine[2:5]]
                if infoInLine[0] == str(indexO):
                    rawData[ss-1,1,0:3,2] = [convert(x) for x in
infoInLine[2:5]]
        u.close()
    else:
        pass

#now go into the original uind archive file
os.chdir('..')
uind = open( uind_fn , 'r')
ss = 0
for line in uind:
    infoInLine = line.split()
    if len(infoInLine) < 5:
        ss += 1
    else:
        if infoInLine[0] == str(indexC):
            rawData[ss-1,0,0:3,1] = [convert(x) for x in
infoInLine[2:5]]
        if infoInLine[0] == str(indexO):
            rawData[ss-1,1,0:3,1] = [convert(x) for x in
infoInLine[2:5]]
uind.close()


#now we are going to process rawData into procData
#procData[i,j,k,l] stores
      #for the i^th snapshot (0 to numSnapshots-1)
      #for the j^th atom (C=0, O=1)
    #for the k^th component (x=0, y=1, z=2)
      #  the l^th information (field)
polarizaC = 1.3340
polarizaO = 0.8370
procData = np.zeros( (numSnapshots, 2, 3, 1) )
procData[:,0,:,0] = ((rawData[:,0,:,1] - rawData[:,0,:,2])) * 0.2082 *
1439 / polarizaC
procData[:,1,:,0] = ((rawData[:,1,:,1] - rawData[:,1,:,2])) * 0.2082 *
1439 / polarizaO
```

```
#now we are going to finalize procData into finalData
#finalData[i,j] stores
      #for the i^th snapshot (0 to numSnapshots-1)
      #  the j^th field (field@C=0, field@O=1, fieldAve=2, fieldDrop=3)
finalData = np.zeros( (numSnapshots, 4) )

for i in range(numSnapshots): #for each snapshot
    #get the C & O coordinates
    #calculate the CO bond length and CO unit vector
    x_C = rawData[i,0,:,0]
    x_O = rawData[i,1,:,0]
    COvec = x_O - x_C
    COlen = np.linalg.norm( COvec )
    COunitvec = COvec / COlen

    #project the electric field onto the bond vector
    field_C = procData[i,0,:,0]
    field_O = procData[i,1,:,0]
    fieldproj_C = np.dot( field_C , COunitvec )
    fieldproj_O = np.dot( field_O , COunitvec )

    #calculate the average field and field drop
    fieldproj_ave = (fieldproj_C + fieldproj_O)/2
    fieldproj_drop = (fieldproj_O - fieldproj_C)

    #fill into finalData
    finalData[i,:] = fieldproj_C, fieldproj_O, fieldproj_ave,
fieldproj_drop


#save finalData to file
print rawData
print procData
print finalData
np.savetxt( '%s_%s_FIELDS.txt' %(solute,solvent) , finalData )
print "calculation of fields for %s_%s completed." %(solute,solvent)
print "Terminating normally."
```

IV. Supplementary Discussion on the local field correction

When an *external* (Maxwell) field, $\vec{F}_{ext}$, is applied to a dielectric material, the *local* field, $\vec{F}_{loc}$, at a given position inside the dielectric is not necessarily the same as $\vec{F}_{ext}$. The differences arise from the polarization of the dielectric by the field. A number of strategies have been devised to evaluate the local field factor, *f*, defined as

$$\vec{F}_{loc} = f\,\vec{F}_{ext} \tag{S1}$$

where *f* is formally a tensor-quantity and position-dependent, although it is generally assumed to be scalar and constant for isotropic systems.[68] The local field effect impinges on a large range of experiments in which external fields are applied to condensed phase systems; it is relevant to the present discussion on vibrational Stark spectroscopy, since *f* affects the absolute magnitude of the difference dipole, $|\Delta\vec{\mu}|$, which in turn affects the scale of the electric fields assigned to vibrational frequency shifts. Beginning with early work on photosynthetic pigments,[80] a tentative value of 1.2 was assigned to *f* by Lockhart and Boxer, and in general the range of 1.1–1.4 has been assumed in following work.[18]

In light of recent results, a brief review of the local field factor, its derivation, and evaluation is merited. The most common equation used to model the local field factor is given by the spherical cavity approximation[68]

$$\vec{F}_{loc} = \left(\frac{3\varepsilon}{2\varepsilon+1}\right)\vec{F}_{ext} \tag{S2}$$

where ε is the static dielectric constant (relative permittivity) of the prevailing medium. The spherical cavity approximation is a special case of a classic problem in electrostatic theory concerning a sphere of dielectric ε_2 embedded in a second medium (of dielectric constant ε) extending to infinity. When an external field is applied to this system, the electric field *inside* the sphere is $3\varepsilon/(2\varepsilon + \varepsilon_2)$ times the external field.[68] Eq. S2 follows from setting $\varepsilon_2 = 1$, which effectively makes the sphere a cavity. Note that if $\varepsilon_2 < \varepsilon$, the electric field inside the sphere will be larger than that in the prevailing medium.

To evaluate *f* from Eq. S2, one must choose a value for the dielectric constant for organic glasses, the medium in which Stark spectroscopy was obtained on acetophenone[23] as well as on many small molecules.[14,18,19,21,22,78] A typical range that is suggested for this is 2–4.[18,80] Organic glasses evince rich dielectric phenomena near their glass-transitions,[81] such as sharp reduction of the dielectric constant at the freezing point and hysteresis upon thawing and re-vitrifying. Nevertheless, in the cold limit ($T \ll T_g$) most non-hydrogen-bonding organic glasses have a non-hysteretic dielectric constants between 2–4,[81] and the value is generally higher (5–6) for glasses made of hydrogen bonding molecules such as glucose or glycerol.[82] By combining the range $2 < \varepsilon_{glass} < 5$ with Eq. S2, one obtains $1.2 < f < 1.4$, the range that has been reported in most work by Boxer and coworkers.

The principal conceptual problem with the spherical cavity approximation for the local field correction is that it assumes the cavity is empty; i.e., it ignores the solute. When an external field is applied, Eq. S2 accounts for the additional field in the cavity due to the polarization of the dielectric environment around the cavity, but does not consider the additional field due to the polarization of the solute (inside the cavity). In this case, the

Lorentz local field approximation provides a different approach based on a hypothetical virtual cavity and the field induced by apparent charges on the boundary of the cavity.[68,75]

$$\vec{F}_{loc} = \left(\frac{2+\varepsilon}{3}\right)\vec{F}_{ext} \tag{S3}$$

For the same range of glass dielectric ($2 < \varepsilon_{\text{glass}} < 5$), with Eq. S3 we now obtain $1.3 < f < 2.3$, a much larger range. It has long been known however that the Lorentz local field is inappropriate when the system consists of polar molecules possessing permanent dipole moments[83]; indeed, it was derived prior to Debye's pioneering work that demonstrated molecules could even possess permanent dipoles.

It is apparent then that a new equation for the local field correction is needed that both accounts for the presence of a solute in the cavity and applies to polar molecules; we shall derive an expression for such in the following. To begin, we consider a solute (which is modeled as a polarizable point-dipole with polarizability, α) in a spherical cavity (of radius, *a*) in a dielectric medium (with dielectric constant, ε). We take the approach that Onsager took[1] of breaking down the total field in the cavity, $\vec{F}$, into two components: the cavity field, $\vec{F}_C$, and the reaction field, $\vec{R}$:

$$\vec{F} = \vec{F}_C + \vec{R} \tag{S4}$$

The cavity field is the portion of the total field that is present even when there is no point-dipole (solute) present, but requires an external field (amplified as according to Eq. S2). The reaction field is the portion of the total field that is present even when no external field is applied, but requires the presence of a point-dipole. The reaction field is analogous to what was referred to as the solvent field in this paper, and it can be calculated according to Eq. 7 from the main text. It is important to point out that in a model where reaction fields are included, the *local* field must be carefully defined as the *difference* in the total electric field at a point upon applying an external field.[75]

When an external field is turned on, $\vec{F}$ will change in two ways. First, the cavity field will change from zero to $3\varepsilon/(2\varepsilon+1)\times\vec{F}_{ext}$. Secondly, the reaction field will change because the solute is polarizable and also responds to the external field. Mathematically, this is:

$$\begin{aligned}\vec{F}_{loc} &= \Delta\vec{F} = \vec{F}_{ext\,field\,on} - \vec{F}_{ext\,field\,off} = \left(\vec{F}_C + \vec{R}_{ext\,field\,on}\right) - \vec{R}_{ext\,field\,off}\\ &= \vec{F}_C + \Delta\vec{R}\end{aligned} \tag{S5}$$

$\Delta\vec{R}$ can be evaluated according to the following:

$$\begin{aligned}\Delta\vec{R} &= \left(\frac{1}{a^3}\frac{2(\varepsilon-1)}{2\varepsilon+1}\right)\left(\textit{dipole due to ext field}\right)\\ &= f\left(\alpha\vec{F}_C + \alpha\Delta\vec{R}\right)\end{aligned} \tag{S6}$$

The first factor is the Onsager factor[1] which when multiplied by a molecule's dipole gives the reaction field. It is traditionally abbreviated f; note that it is not the same as the local field factor, *f*. The second factor is the total dipole moment induced by the external field, which depends on the molecule's polarizability, the cavity field, and also on the reaction field itself (which additionally induces the dipole moment). The permanent dipole does not appear in Eq. S6, since we are only interested in the *change* in reaction field upon applying an external field. The self-consistent equation can be solved for $\Delta\vec{R}$ to give

$$\Delta\vec{R} = \vec{F}_C\left(\frac{f\alpha}{1-f\alpha}\right).$$

Inserting this result back into Eq. S5, we obtain:

$$\begin{aligned}\Delta\vec{F} &= \vec{F}_C + \Delta\vec{R} = \vec{F}_C\left(\frac{1}{1-f\alpha}\right)\\ &= \left(\frac{3\varepsilon}{2\varepsilon+1}\right)\vec{F}_{ext}\left(\frac{1}{1-\dfrac{\alpha}{a^3}\dfrac{2(\varepsilon-1)}{2\varepsilon+1}}\right)\\ &= \left(\frac{3\varepsilon}{2\varepsilon+1-2\alpha(\varepsilon-1)/a^3}\right)\vec{F}_{ext}\end{aligned}$$

In the second line, we have inserted the expression for the cavity field in terms of the external field (Eq. S2) and the Onsager factor (Eq. S6). The quantity in parentheses on the final line corresponds is the local field factor. We can remove the microscopic parameters (polarizability and molecular volume) by invoking the Lorentz-Lorenz equation (which relates polarizability to refractive index) and Onsager's ansatz that molecular volume is trivially related to formula weight and density, to give the final result:

$$\vec{F}_{loc} = \left(\frac{3\varepsilon}{2\varepsilon+1-2\left(\dfrac{n^2-1}{n^2+2}\right)(\varepsilon-1)/a^3}\right)\vec{F}_{ext} \qquad \text{(S7)}$$

where one must be careful to note that *n* is the refractive index of the solute. Using Eq. S7 with *n* for acetophenone and the same range of glass dielectric ($2 < \varepsilon_{\text{glass}} < 5$), we obtain $1.4 < f < 1.8$. This range is consistent with the span of values calculated for the diagonal components of the local field tensor of crystalline durene and naphthalene.[84]

In summary, Eq. S7 provides an expression for the local field correction that accounts for a polarizable solute that can respond to an external field as well as the polar environment surrounding the solute. Moreover, the upper value allowed to *f* by Eq. S7 is quite close to that implied by the AMOEBA-calculated solvent fields. Nevertheless, Eq. S7 suffers from the same underlying assumptions of dielectric continuum theory, which neglect the microsopic structure of matter and local interactions.

(80) Lockhart, D. J.; Boxer, S. G. *Biochemistry* **1987**, *26*, 664–668.
(81) Baker, W. O.; Smyth, C. P. *Ann. N. Y. Acad. Sci.* **1940**, *40*, 447–481.
(82) Thomas, S. B. *J. Phys. Chem.* **1931**, *35*, 2103–2111.
(83) Kirkwood, J. G. *Ann. N. Y. Acad. Sci.* **1940**, *40*, 315–320.
(84) Chen, F. P.; Hanson, D. M.; Fox, D. *J. Chem. Phys* **1975**, *63*, 3878–3885.

V. Parameters

5.1 Acetonitrile

```
atom         210   79    C     "Acetonitrile CN"        6    12.011    2
atom         211   80    N     "Acetonitrile CN"        7    14.007    1
atom         212   82    C     "Acetonitrile CH3"       6    12.011    4
atom         213   83    H     "Acetonitrile H3C"       1     1.008    1

vdw           79                3.8200     0.1010
vdw           80                3.5800     0.1100
vdw           82                3.8200     0.1010
vdw           83                2.9100     0.0330      0.900

bond          79   80          1195.00     1.1700
bond          79   82           380.00     1.4570
bond          82   83           390.00     1.0873

angle         80   79   82       65.00     180.00
angle         79   82   83       45.00     109.92
angle         83   82   83       40.00     109.02

strbnd        80   79   82       18.70      18.70
strbnd        79   82   83       11.50      11.50

torsion       80   79   82   83       0.000 0.0 1   0.000 180.0 2   0.000
0.0 3

multipole   210  211    0                   0.50893
                                            0.00000    0.00000    0.00838
                                            0.04512
                                            0.00000    0.04512
                                            0.00000    0.00000   -0.09024
multipole   211  210    0                  -0.64934
                                            0.00000    0.00000   -0.41663
                                            0.40285
                                            0.00000    0.40285
                                            0.00000    0.00000   -0.80570
multipole   212  210    0                  -0.16118
                                            0.00000    0.00000    0.17034
                                           -0.03526
                                            0.00000   -0.03526
                                            0.00000    0.00000    0.07052
multipole   213  212  210                   0.10053
                                            0.00543    0.00000   -0.12249
                                            0.11906
                                            0.00000    0.00913
                                            0.02813    0.00000   -0.12819


polarize    210          1.3340     0.3900    211  212
polarize    211          1.0730     0.3900    210
polarize    212          1.3340     0.3900    210  213
polarize    213          0.4960     0.3900    212
```

5.2 Dibutyl Ether

```
atom          29   27    C     "Alkane CH3-"             6    12.011    4
atom          30   28    H     "Alkane H3C-"             1     1.008    1
atom          31   29    C     "Alkane -CH2-"            6    12.011    4
atom          32   30    H     "Alkane -H2C-"            1     1.008    1
atom          58   36    O     "Methyl Ether O"          8    15.999    2
atom          59   40    C     "Methyl Ether CH3"        6    12.011    4
atom          60   44    H     "Methyl Ether H3C"        1     1.008    1

vdw           27               3.8200     0.1010
vdw           28               2.9600     0.0240      0.920
vdw           29               3.8200     0.1010
vdw           30               2.9800     0.0240      0.940
vdw           36               3.4050     0.1100
vdw           40               3.8200     0.1010
vdw           44               2.8900     0.0240      0.910

bond          27   28          341.00     1.1020
bond          27   29          323.00     1.5247
bond          29   29          323.00     1.5247
bond          29   30          341.00     1.1120
bond          29   40          453.00     1.5247
bond          36   40          465.10     1.4130
bond          40   44          378.00     1.1120

angle         28   27   28      39.57     107.60     107.80     109.47
angle         28   27   29      42.44     109.80     109.31     110.70
angle         27   29   29      48.20     109.50     110.20     111.00
angle         29   29   29      48.20     109.50     110.20     111.00
angle         27   29   30      42.44     109.80     109.31     110.70
angle         29   29   30      42.44     109.80     109.31     110.70
angle         30   29   30      39.57     107.60     107.80     109.47
angle         40   36   40      88.50     106.00
angle         36   40   29      65.71     107.50     107.00     107.90
angle         36   40   44      70.00     110.00     108.90     108.70
angle         44   40   44      43.57     107.60     107.80     109.47
angle         29   29   40      48.20     109.50     110.20     111.00
angle         30   29   40      42.44     109.80     109.31     110.70
angle         29   40   44      42.44     109.80     109.31     110.70

strbnd        28   27   29      11.50      11.50
strbnd        27   29   29      18.70      18.70
strbnd        29   29   29      18.70      18.70
strbnd        27   29   30      11.50      11.50
strbnd        29   29   30      11.50      11.50
strbnd        40   36   40      38.00      38.00
strbnd        36   40   29      38.00      38.00
strbnd        36   40   44      38.00      -4.50

torsion       28   27   29   27      0.000 0.0 1   0.000 180.0 2   0.341
0.0 3
torsion       28   27   29   29      0.000 0.0 1   0.000 180.0 2   0.341
0.0 3
torsion       28   27   29   30      0.000 0.0 1   0.000 180.0 2   0.299
0.0 3
torsion       27   29   29   27      0.854 0.0 1  -0.374 180.0 2   0.108
0.0 3
```

```
torsion      27   29   29   29      0.854 0.0 1  -0.374 180.0 2   0.108
0.0 3
torsion      27   29   29   30      0.000 0.0 1   0.000 180.0 2   0.341
0.0 3
torsion      29   29   29   29      0.854 0.0 1  -0.374 180.0 2   0.108
0.0 3
torsion      29   29   29   30      0.000 0.0 1   0.000 180.0 2   0.108
0.0 3
torsion      30   29   29   30      0.000 0.0 1   0.000 180.0 2   0.299
0.0 3
torsion      40   36   40   44      0.000 0.0 1   0.000 180.0 2   0.597
0.0 3
torsion      36   40   40   40     -1.150 0.0 1   0.000 180.0 2   1.280
0.0 3
torsion      27   29   29   40      0.854 0.0 1  -0.374 180.0 2   0.108
0.0 3
torsion      29   29   40   44      0.000 0.0 1   0.000 180.0 2   0.108
0.0 3
torsion      29   29   40   36     -1.150 0.0 1   0.000 180.0 2   1.280
0.0 3
torsion      29   40   36   40      0.000 0.0 1  -0.837 180.0 2   3.204
0.0 3
torsion      30   29   29   40      0.000 0.0 1   0.000 180.0 2   0.108
0.0 3
torsion      30   29   40   44      0.000 0.0 1   0.000 180.0 2   0.340
0.0 3
torsion      30   29   40   36      0.000 0.0 1   0.000 180.0 2   0.300
0.0 3


multipole    29   31   30                  -0.16638
                                            0.00000    0.00000    0.25069
                                           -0.24574
                                            0.00000   -0.24574
                                            0.00000    0.00000    0.49148
multipole    30   29   31                   0.05546
                                            0.01102    0.00000   -0.10399
                                            0.00247
                                            0.00000   -0.01906
                                            0.00852    0.00000    0.01659
multipole    31   31   29                  -0.12028
                                            0.33700    0.00000    0.22666
                                            0.34191
                                            0.00000   -0.72407
                                           -0.04985    0.00000    0.38216
multipole    31  -31  -31                  -0.12028
                                            0.00000    0.00000    0.27522
                                            0.47728
                                            0.00000   -0.35302
                                            0.00000    0.00000   -0.12426
multipole    32   31   31                   0.06014
                                            0.00606    0.00000   -0.08554
                                           -0.00370
                                            0.00000   -0.01833
                                            0.00546    0.00000    0.02203
multipole    58   59   59                  -0.32494
                                            0.53657    0.00000    0.37202
                                            0.44076
```

```
                                              0.00000   -0.87825
                                              0.00127    0.00000    0.43749
multipole     59   58   59                    0.11615
                                             -0.19923    0.00000    0.19298
                                             -0.23681
                                              0.00000   -0.41373
                                             -0.10899    0.00000    0.65054
multipole     60   59   58                    0.02316
                                              0.04231    0.00000   -0.02407
                                             -0.01587
                                              0.00000   -0.05904
                                              0.03668    0.00000    0.07491

polarize     29          1.3340     0.3900     30
polarize     30          0.4960     0.3900     29
polarize     31          1.3340     0.3900     32
polarize     32          0.4960     0.3900     31
polarize     58          0.8370     0.3900     59
polarize     59          1.3340     0.3900     58   60
polarize     60          0.4960     0.3900     59
```

5.3. Dimethyl Sulfoxide

```
atom       189   72    S     "Dimethyl Sulfoxide S=O" 16    32.066     3
atom       190   73    O     "Dimethyl Sulfoxide S=O" 8    15.999     1
atom       191   74    C     "Dimethyl Sulfoxide CH3" 6    12.011     4
atom       192   75    H     "Dimethyl Sulfoxide H3C" 1     1.008     1

vdw          72               3.9100     0.3850
vdw          73               3.5200     0.1120
vdw          74               3.8200     0.1010
vdw          75               2.9100     0.0245      0.910

bond         72   73          494.20     1.5100
bond         72   74          197.20     1.8062
bond         74   75          388.20     1.0893

angle        73   72   74      57.25     106.88
angle        74   72   74      87.39      92.98
angle        72   74   75      44.07     107.06
angle        75   74   75      38.95     110.07

strbnd       73   72   74      -5.75      -5.75
strbnd       74   72   74      -5.75      -5.75
strbnd       72   74   75      11.50      11.50

torsion      73   72   74   75      0.000 0.0 1   0.000 180.0 2   0.500
0.0 3
torsion      74   72   74   75      0.000 0.0 1   0.000 180.0 2   0.500
0.0 3


multipole   189  190 -191 -191          0.28761
                                        0.34263    0.00000    0.97464
                                       -0.69101
                                        0.00000    0.85372
                                       -0.23783    0.00000   -0.16271
multipole   190  189 -191 -191         -0.63423
                                       -0.03435    0.00000    0.26755
                                       -0.60034
                                        0.00000   -0.57370
                                        0.09678    0.00000    1.17404
multipole   191  189  190              -0.05355
                                       -0.08789    0.00000    0.54241
                                       -0.28219
                                        0.00000   -0.59075
                                       -0.20358    0.00000    0.87294
multipole   192  191  189               0.07562
                                       -0.01297    0.00000   -0.15656
                                        0.08665
                                        0.00000    0.07386
                                        0.01776    0.00000   -0.16051


polarize    189          3.3000     0.3900    190  191
polarize    190          0.8370     0.3900    189
polarize    191          1.3340     0.3900    189  192
polarize    192          0.4960     0.3900    191
```

5.4. Hexanes

```
atom         29   27    C     "Alkane CH3-"          6    12.011    4
atom         30   28    H     "Alkane H3C-"          1     1.008    1
atom         31   29    C     "Alkane -CH2-"         6    12.011    4
atom         32   30    H     "Alkane -H2C-"         1     1.008    1

vdw          27                 3.8200     0.1010
vdw          28                 2.9600     0.0240      0.920
vdw          29                 3.8200     0.1010
vdw          30                 2.9800     0.0240      0.940

bond         27   28            341.00     1.1020
bond         27   29            323.00     1.5247
bond         29   29            323.00     1.5247
bond         29   30            341.00     1.1120

angle        28   27   28        39.57     107.60     107.80     109.47
angle        28   27   29        42.44     109.80     109.31     110.70
angle        27   29   29        48.20     109.50     110.20     111.00
angle        29   29   29        48.20     109.50     110.20     111.00
angle        27   29   30        42.44     109.80     109.31     110.70
angle        29   29   30        42.44     109.80     109.31     110.70
angle        30   29   30        39.57     107.60     107.80     109.47

strbnd       28   27   29        11.50      11.50
strbnd       27   29   29        18.70      18.70
strbnd       29   29   29        18.70      18.70
strbnd       27   29   30        11.50      11.50
strbnd       29   29   30        11.50      11.50

torsion      28   27   29   27       0.000 0.0 1   0.000 180.0 2   0.341
0.0 3
torsion      28   27   29   29       0.000 0.0 1   0.000 180.0 2   0.341
0.0 3
torsion      28   27   29   30       0.000 0.0 1   0.000 180.0 2   0.299
0.0 3
torsion      27   29   29   27       0.854 0.0 1  -0.374 180.0 2   0.108
0.0 3
torsion      27   29   29   29       0.854 0.0 1  -0.374 180.0 2   0.108
0.0 3
torsion      27   29   29   30       0.000 0.0 1   0.000 180.0 2   0.341
0.0 3
torsion      29   29   29   29       0.854 0.0 1  -0.374 180.0 2   0.108
0.0 3
torsion      29   29   29   79       0.854 0.0 1  -0.374 180.0 2   0.108
0.0 3
torsion      29   29   29   30       0.000 0.0 1   0.000 180.0 2   0.108
0.0 3
torsion      30   29   29   30       0.000 0.0 1   0.000 180.0 2   0.299
0.0 3

multipole    29   31   30                  -0.16638
                                            0.00000    0.00000    0.25069
                                           -0.24574
                                            0.00000   -0.24574
                                            0.00000    0.00000    0.49148
multipole    30   29   31                   0.05546
```

```
                                                  0.01102    0.00000   -0.10399
                                                  0.00247
                                                  0.00000   -0.01906
                                                  0.00852    0.00000    0.01659
multipole    31   31   29                        -0.12028
                                                  0.33700    0.00000    0.22666
                                                  0.34191
                                                  0.00000   -0.72407
                                                 -0.04985    0.00000    0.38216
multipole    31  -31  -31                        -0.12028
                                                  0.00000    0.00000    0.27522
                                                  0.47728
                                                  0.00000   -0.35302
                                                  0.00000    0.00000   -0.12426
multipole    32   31   31                         0.06014
                                                  0.00606    0.00000   -0.08554
                                                 -0.00370
                                                  0.00000   -0.01833
                                                  0.00546    0.00000    0.02203


polarize     29          1.3340     0.3900     30
polarize     30          0.4960     0.3900     29
polarize     31          1.3340     0.3900     32
polarize     32          0.4960     0.3900     31
```

5.5. Valeronitrile

```
atom         29   27    C     "Alkane CH3-"            6    12.011    4
atom         30   28    H     "Alkane H3C-"            1     1.008    1
atom         31   29    C     "Alkane -CH2-"           6    12.011    4
atom         32   30    H     "Alkane -H2C-"           1     1.008    1
atom        33   29    C     "Alkane -CH2- next to CN" 6    12.011    4
atom        34   30    H     "Alkane -H2C- next to CN" 1     1.008    1
atom        210   79    C     "Acetonitrile CN"        6    12.011    2
atom        211   80    N     "Acetonitrile CN"        7    14.007    1

vdw          27              3.8200      0.1010
vdw          28              2.9600      0.0240      0.920
vdw          29              3.8200      0.1010
vdw          30              2.9800      0.0240      0.940
vdw          79              3.8200      0.1010
vdw          80              3.5800      0.1100

bond         27   28          341.00     1.1020
bond         27   29          323.00     1.5247
bond         29   29          323.00     1.5247
bond         29   30          341.00     1.1120
bond         79   80         1195.00     1.1700
bond         79   29          380.00     1.4570

angle        28   27   28      39.57     107.60     107.80     109.47
angle        28   27   29      42.44     109.80     109.31     110.70
angle        27   29   29      48.20     109.50     110.20     111.00
angle        29   29   29      48.20     109.50     110.20     111.00
angle        27   29   30      42.44     109.80     109.31     110.70
angle        29   29   30      42.44     109.80     109.31     110.70
angle        30   29   30      39.57     107.60     107.80     109.47
angle        80   79   29      65.00     180.00
angle        79   29   30      45.00     109.92
angle        29   29   79      45.71     111.59

strbnd       28   27   29      11.50      11.50
strbnd       27   29   29      18.70      18.70
strbnd       29   29   29      18.70      18.70
strbnd       27   29   30      11.50      11.50
strbnd       29   29   30      11.50      11.50
strbnd       80   79   29      18.70      18.70
strbnd       79   29   30      11.50      11.50


torsion      28   27   29   27      0.000 0.0 1   0.000 180.0 2   0.341
0.0 3
torsion      28   27   29   29      0.000 0.0 1   0.000 180.0 2   0.341
0.0 3
torsion      28   27   29   30      0.000 0.0 1   0.000 180.0 2   0.299
0.0 3
torsion      27   29   29   27      0.854 0.0 1  -0.374 180.0 2   0.108
0.0 3
torsion      27   29   29   29      0.854 0.0 1  -0.374 180.0 2   0.108
0.0 3
torsion      27   29   29   30      0.000 0.0 1   0.000 180.0 2   0.341
0.0 3
```

```
torsion      29   29   29   29      0.854 0.0 1  -0.374 180.0 2   0.108
0.0 3
torsion      29   29   29   79      0.854 0.0 1  -0.374 180.0 2   0.108
0.0 3
torsion      29   29   29   30      0.000 0.0 1   0.000 180.0 2   0.108
0.0 3
torsion      79   29   29   30      0.000 0.0 1   0.000 180.0 2   0.108
0.0 3
torsion      30   29   29   30      0.000 0.0 1   0.000 180.0 2   0.299
0.0 3
torsion      80   79   29   30      0.000 0.0 1   0.000 180.0 2   0.000
0.0 3
torsion      80   79   29   29      0.000 0.0 1   0.000 180.0 2   0.000
0.0 3


multipole    29   31   30              -0.16638
                                        0.00000    0.00000    0.25069
                                       -0.24574
                                        0.00000   -0.24574
                                        0.00000    0.00000    0.49148
multipole    30   29   31               0.05546
                                        0.01102    0.00000   -0.10399
                                        0.00247
                                        0.00000   -0.01906
                                        0.00852    0.00000    0.01659
multipole    31   31   29              -0.12028
                                        0.33700    0.00000    0.22666
                                        0.34191
                                        0.00000   -0.72407
                                       -0.04985    0.00000    0.38216
multipole    31  -31  -31              -0.12028
                                        0.00000    0.00000    0.27522
                                        0.47728
                                        0.00000   -0.35302
                                        0.00000    0.00000   -0.12426
multipole    32   31   31               0.06014
                                        0.00606    0.00000   -0.08554
                                       -0.00370
                                        0.00000   -0.01833
                                        0.00546    0.00000    0.02203
multipole   210  211    0               0.50893
                                        0.00000    0.00000    0.00838
                                        0.04512
                                        0.00000    0.04512
                                        0.00000    0.00000   -0.09024
multipole   211  210    0              -0.64934
                                        0.00000    0.00000   -0.41663
                                        0.40285
                                        0.00000    0.40285
                                        0.00000    0.00000   -0.80570
multipole   33   210    0              -0.16117
                                        0.00000    0.00000    0.17034
                                       -0.03526
                                        0.00000   -0.03526
                                        0.00000    0.00000    0.07052
multipole   34    33  210               0.15079
                                        0.00543    0.00000   -0.12249
```

```
                                              0.11906
                                              0.00000     0.00913
                                              0.02813     0.00000    -0.12819


polarize     29          1.3340     0.3900     30
polarize     30          0.4960     0.3900     29
polarize     31          1.3340     0.3900     32
polarize     32          0.4960     0.3900     31
polarize     33          1.3340     0.3900    210 34
polarize     34          0.4960     0.3900     33
polarize    210          1.3340     0.3900    211 33
polarize    211          1.0730     0.3900    210
```

5.6. Tetrahydrofuran

```
atom           1    1    C     "thf C next to O     "   6    12.011    4
atom           2    2    O     "thf O               "   8    15.999    2
atom           3    3    C     "thf C               "   6    12.011    4
atom           4    4    H     "thf H next to O     "   1     1.008    1
atom           5    5    H     "thf H               "   1     1.008    1

vdw            1               3.820     0.1010
vdw            2               3.404     0.1100
vdw            3               3.820     0.1010
vdw            4               2.980     0.0240     0.94
vdw            5               2.980     0.0240     0.94

bond           1    2          403.45     1.4325
bond           1    3          337.31     1.5289
bond           1    4          384.37     1.0916
bond           3    3          370.82     1.5343
bond           3    5          380.44     1.0868

angle          2    1    3      44.81      94.14
angle          2    1    4      51.60     113.50
angle          3    1    4      26.91     119.97
angle          4    1    4      18.58     119.92
angle          1    2    1      82.65      85.11
angle          1    3    3      14.63     120.85
angle          1    3    5      34.45     120.15
angle          3    3    5      34.78     120.24
angle          5    3    5      15.90     125.48

strbnd         2    1    3     18.70      18.70
strbnd         2    1    4     18.70      11.50
strbnd         3    1    4     18.70      11.50
strbnd         1    2    1     38.00      38.00
strbnd         1    3    3     18.70      18.70
strbnd         1    3    5     18.70      11.50
strbnd         3    3    5     18.70      11.50


torsion        3    1    2    1       1.000 0.0 1  -0.750 180.0 2   0.445
0.0 3
torsion        4    1    2    1       0.000 0.0 1   0.000 180.0 2   0.355
0.0 3
torsion        2    1    3    3      -0.575 0.0 1   0.000 180.0 2   0.640
0.0 3
torsion        2    1    3    5       0.000 0.0 1   0.000 180.0 2   0.150
0.0 3
torsion        4    1    3    3       0.000 0.0 1   0.000 180.0 2   0.170
0.0 3
torsion        4    1    3    5       0.000 0.0 1   0.000 180.0 2   0.150
0.0 3
torsion        1    3    3    1       0.090 0.0 1   0.085 180.0 2   0.260
0.0 3
torsion        1    3    3    5       0.000 0.0 1   0.000 180.0 2   0.170
0.0 3
torsion        5    3    3    1       0.000 0.0 1   0.000 180.0 2   0.170
0.0 3
```

```
torsion       5    3    3    5      0.000 0.0 1   0.000 180.0 2   0.150
0.0 3


multipole     1    2    3               0.09445
                                        0.02472    0.00000    0.35135
                                       -0.15743
                                        0.00000   -0.34410
                                       -0.27885    0.00000    0.50153
multipole     2   -1   -1              -0.29982
                                       -0.00033    0.00000    0.59272
                                        0.35733
                                        0.00000   -0.67646
                                        0.00000    0.00000    0.31913
multipole     3    1    3              -0.19057
                                        0.24073    0.00000    0.23156
                                        0.21094
                                        0.00000   -0.33542
                                       -0.25214    0.00000    0.12448
multipole     4    1    2               0.03649
                                       -0.01885    0.00000   -0.10133
                                        0.05488
                                        0.00000    0.13188
                                       -0.08609    0.00000   -0.18676
multipole     5    3    1               0.08357
                                        0.00299    0.00000   -0.07326
                                        0.14804
                                        0.00000    0.01303
                                       -0.05098    0.00000   -0.16107


polarize      1          1.3340     0.3900      2    4
polarize      2          0.8370     0.3900      1
polarize      3          1.3340     0.3900      5
polarize      4          0.4960     0.3900      1
polarize      5          0.4960     0.3900      3
```

5.7. Acetophenone

```
atom          101    101    C      "ACPH C4         "   6    12.011    3
atom          102    102    C      "ACPH C3         "   6    12.011    3
atom          103    103    C      "ACPH C2         "   6    12.011    3
atom          104    104    C      "ACPH C1         "   6    12.011    3
atom          107    107    H      "ACPH H3         "   1     1.008    1
atom          108    108    H      "ACPH H2         "   1     1.008    1
atom          111    111    C      "ACPH C(CO)      "   6    12.011    3
atom          112    112    C      "ACPH C(CH3)     "   6    12.011    4
atom          115    115    H      "ACPH H(CH3)     "   1     1.008    1
atom          116    116    O      "ACPH O(CO)      "   8    15.999    1
atom          117    117    H      "ACPH H4         "   1     1.008    1

vdw           101                3.800     0.0910
vdw           102                3.800     0.0910
vdw           103                3.800     0.0910
vdw           104                3.800     0.0910
vdw           107                2.980     0.0260     0.92
vdw           108                2.980     0.0260     0.92
vdw           111                3.800     0.0910
vdw           112                3.820     0.1010
vdw           115                2.960     0.0240     0.92
vdw           116                3.300     0.1120
vdw           117                2.960     0.0260     0.92

bond          101    102           680.0     1.3947
bond          101    117           410.0     1.0822
bond          102    103           680.0     1.3915
bond          102    107           410.0     1.0822
bond          103    104           680.0     1.3992
bond          103    108           410.0     1.0819
bond          104    111           680.0     1.4940
bond          111    112           385.0     1.5085
bond          111    116           680.0     1.2237
bond          112    115           400.0     1.0888

angle         102    101    102     60.00     119.90
angle         102    101    117     32.00     120.05
angle         101    102    103     60.00     120.11
angle         101    102    107     32.00     119.98
angle         103    102    107     32.00     119.91
angle         102    103    104     60.00     120.19
angle         102    103    108     32.00     120.43
angle         104    103    108     32.00     119.37
angle         103    104    103     60.00     119.50
angle         103    104    111     60.00     120.25
angle         104    111    112     60.00     118.35
angle         104    111    116     60.00     120.69
angle         112    111    116     60.00     120.97
angle         111    112    115     38.00     109.91
angle         115    112    115     34.50     109.03

strbnd        102    101    102     18.70      18.70
strbnd        102    101    117     18.70      11.50
strbnd        101    102    103     18.70      18.70
strbnd        101    102    107     18.70      11.50
strbnd        103    102    107     18.70      11.50
```

```
strbnd        102    103    104      18.70      18.70
strbnd        102    103    108      18.70      11.50
strbnd        104    103    108      18.70      11.50
strbnd        103    104    103      18.70      18.70
strbnd        103    104    111      18.70      18.70
strbnd        104    111    112      18.70      18.70
strbnd        104    111    116      18.70      18.70
strbnd        112    111    116      18.70      18.70
strbnd        111    112    115      18.70      11.50

opbend        102    101    0    0             14.40
opbend        117    101    0    0             15.10
opbend        103    102    0    0             14.40
opbend        107    102    0    0             15.10
opbend        104    103    0    0             14.40
opbend        108    103    0    0             15.10
opbend        103    104    0    0             14.40
opbend        111    104    0    0             14.40
opbend        102    103    0    0             14.40
opbend        112    111    0    0             14.40
opbend        116    111    0    0             46.80
opbend        104    111    0    0             14.40
opbend        101    102    0    0             14.40

torsion       102    101    102    103     -0.335 0.0 1   2.000 180.0 2
0.000 0.0 3
torsion       102    101    102    107      0.000 0.0 1   3.050 180.0 2
0.000 0.0 3
torsion       117    101    102    103      0.000 0.0 1   3.050 180.0 2
0.000 0.0 3
torsion       117    101    102    107      0.000 0.0 1   2.035 180.0 2
0.000 0.0 3
torsion       101    102    103    104     -0.335 0.0 1   2.000 180.0 2
0.000 0.0 3
torsion       101    102    103    108      0.000 0.0 1   3.050 180.0 2
0.000 0.0 3
torsion       107    102    103    104      0.000 0.0 1   3.050 180.0 2
0.000 0.0 3
torsion       107    102    103    108      0.000 0.0 1   2.035 180.0 2
0.000 0.0 3
torsion       102    103    104    103     -0.335 0.0 1   2.000 180.0 2
0.000 0.0 3
torsion       102    103    104    111     -0.335 0.0 1   2.000 180.0 2
0.000 0.0 3
torsion       108    103    104    103      0.000 0.0 1   3.050 180.0 2
0.000 0.0 3
torsion       108    103    104    111      0.000 0.0 1   3.050 180.0 2
0.000 0.0 3
torsion       103    104    111    112     -0.305 0.0 1   2.105 180.0 2
0.000 0.0 3
torsion       103    104    111    116      0.000 0.0 1   2.235 180.0 2
0.000 0.0 3
torsion       104    111    112    115      0.000 0.0 1   0.000 180.0 2
-0.045 0.0 3
torsion       116    111    112    115      0.000 0.0 1   0.000 180.0 2
0.150 0.0 3
```

```
multipole     101   -102   -102        -0.02570
                                        0.00768    0.00000   -0.01753
                                        0.21266
                                        0.00000   -0.16041
                                        0.00442    0.00000   -0.05225
multipole     102   -101   -103         0.03891
                                        0.02722    0.00000    0.14297
                                       -0.04801
                                        0.00000   -0.26527
                                       -0.06576    0.00000    0.31328
multipole     103   -102   -104        -0.00467
                                        0.10264    0.00000    0.06877
                                        0.09548
                                        0.00000   -0.16435
                                       -0.13677    0.00000    0.06886
multipole     104    111    103        -0.19836
                                        0.10216    0.00000    0.09151
                                       -0.04074
                                        0.00000    0.02610
                                        0.01242    0.00000    0.01464
multipole     107    102    101         0.01016
                                       -0.00065    0.00000   -0.17629
                                        0.12054
                                        0.00000    0.06309
                                       -0.00762    0.00000   -0.18362
multipole     108    103    102         0.039795
                                       -0.00208    0.00000   -0.13374
                                        0.10762
                                        0.00000    0.02400
                                       -0.10670    0.00000   -0.13162
multipole     111    116    104         0.76904
                                        0.21969    0.00000    0.59927
                                        0.31546
                                        0.00000   -0.31422
                                        0.49622    0.00000   -0.00124
multipole     112    111    113        -0.27307
                                       -0.02897    0.00000    0.21491
                                       -0.11113
                                        0.00000    0.04609
                                        0.02550    0.00000    0.06504
multipole     115    112    111         0.08196
                                       -0.00144    0.00000   -0.08391
                                        0.06581
                                        0.00000    0.00381
                                       -0.04427    0.00000   -0.06962
multipole     116    111    104        -0.69483
                                       -0.15120    0.00000   -0.22092
                                       -0.71841
                                        0.00000    0.46814
                                       -0.20408    0.00000    0.25027
multipole     117    101    102         0.00865
                                        0.00321    0.00000   -0.18157
                                        0.10658
                                        0.00000    0.02986
                                        0.00449    0.00000   -0.13644

polarize      101          1.7500     0.3900      102    117
```

```
polarize      102          1.7500     0.3900      101    103    107
polarize      103          1.7500     0.3900      102    104    108
polarize      104          1.7500     0.3900      103
polarize      107          0.6960     0.3900      102
polarize      108          0.6960     0.3900      103
polarize      111          1.3340     0.3900      116
polarize      112          1.3340     0.3900      113
polarize      115          0.4960     0.3900      112
polarize      116          0.8370     0.3900      111
polarize      117          0.6960     0.3900      101
```