Molecular structure of noradrenaline according to gas-phase electron diffraction and quantum chemical calculations

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Two nozzle-plate distances, a 193.94 mm over the range 3.6–17.8 $Å^{-1}$ and other 362.28 mm over the range 6.6–32.4 $Å^{-1}$, were used. The measurements were taken in steps of 0.2 $Å^{-1}$ along the *s* scale. The films obtained for CCl_4 as the reference compound and for substance under study were turned to an image on an Epson perfection 4870 scanner. The images were processed using the UNEX program. The electron wavelength was estimated using CCl_4 resulting in 0.05023 Å for long and 0.0499 Å for short nozzle–plate distances, respectively.

The diffractograms were recorded on the Maco EM-Films EMS photo films. The films were digitized and averaged to obtain mean electron diffraction intensities I(s) for each nozzle–plate distance. The background lines were constructed by approximation with cubic splines.

The molecular model included the 63 independent parameters (*r* stands for the refined parameter) – bond distances: C2C1(r), C3-C2(r), C3-C4(r), C4-C5(r), C5-C6(r), C1-C6(r), C2-H(r), C4-H(r), C5-H(r), C6-O1(r), H-O1(r), O2-C1(r), H-O2(r), C7-C3(r), H-C7(r), C8-C7(r), H-C8(r), H-C8(r), C8-N1, N1-H(r), H-N1(r), C7-O3(r), O3-H(r); valence angles: C1C2C3(r), C2C3C4(r), C3C4C5(r), C1C2H, C3C4H, C4C5H, C5C6O1(r), C6O1H, C2C1O2(r), C1O2H, C2C3C7(r), C3C7H, C3C7C8(r), C7C8H, C7C8H, C7C8N1, C8N1H, C8N1H, C8C7O3, C7O3H; torsional angles: C1C2C3C4, C2C3C4C5, C4C3C1C5, C6C1C2H, C2C3C4H, C3C4C5H, C4C5C6O1, C5C6O1H, C3C2C1O2, C2C1O2H, C1C2C3C7, C2C3C7H, C2C3C7C8(r), C3C7C8H, C3C7C8H, C3C7C8N1, C7C8N1H, C7C8N1H, N1C8C7O3 (r), C3C7O3H.

      The C–H bond lengths were refined together with N–H and O–H distance by constraining the differences between them to the MP2/cc-pVTZ calculated values. Because of strong correlation between independent structural parameters, it had to reduce the number of groups involved in refinement procedure. The C8-N1 bond length were constrained to the theoretical MP2/cc-pVTZ values and not refined during GED analysis.

The differences between bond lengths and valence angles, refined in one groups, were taken from MP2/cc-pVTZ calculations and kept fixed at the least-square procedure.
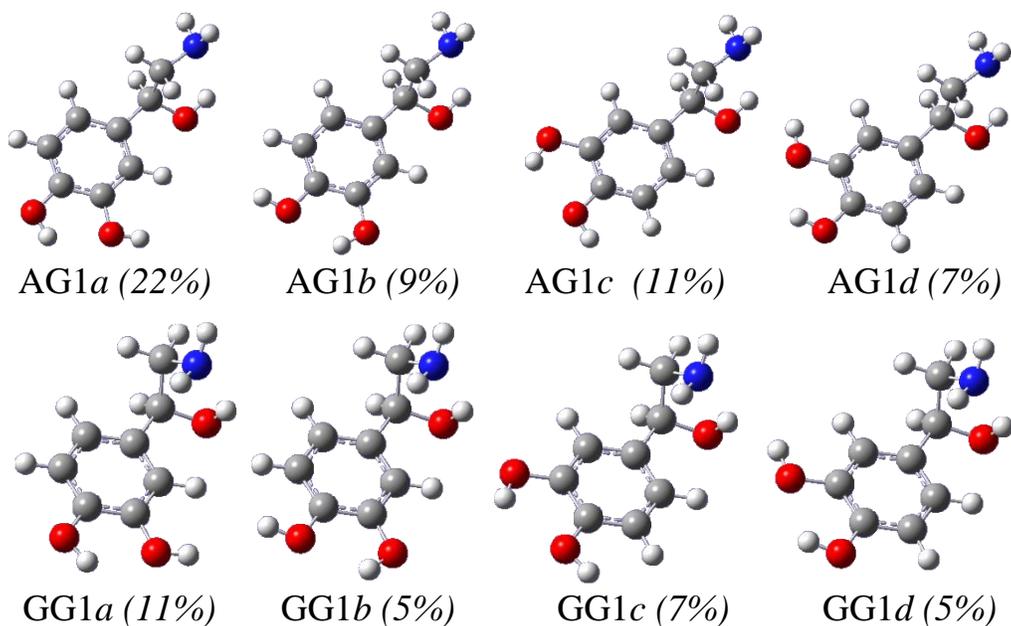
AG1*a (22%)*   AG1*b (9%)*   AG1*c (11%)*   AG1*d (7%)*

GG1*a (11%)*   GG1*b (5%)*   GG1*c (7%)*   GG1*d (5%)*

Figure S1 DFT/B3LYP/cc-pVTZ optimized geometries of GG1(a-d) and AG1(a-d) noradrenaline conformers and their contributions at 458 K.
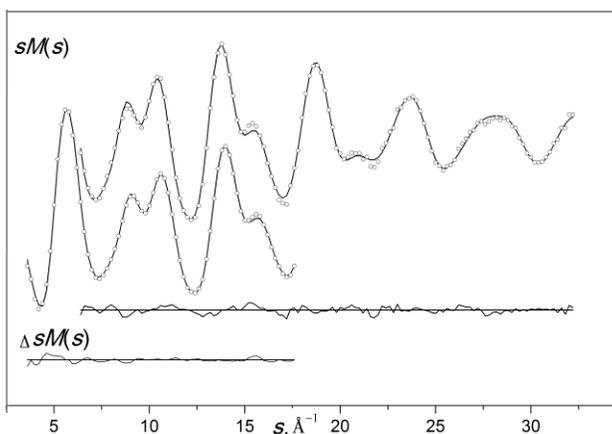
Figure S2 Experimental (dots) and theoretical (line) molecular scattering intensities sM(s) and the differences $\Delta sM(s) = sM_{exp}(s) - sM_{th}(s)$ of NA.

Table S1 The relative free Gibbs energies (in kJ/mol) and mole fractions (%) of 20 most abundance NA conformers calculated at 457 K according to $p_T(i) = [exp(\Delta G_T(i)/RT)]/[\sum[exp(\Delta G_T(i)/RT)]$.

	ΔG, B3LYP/cc-pVTZ	p_i	ΔG, MP2/ cc-pVTZ	p_i
AG1a	**0.00**	**22**	**1.06**	**15**
AG1b	**3.28**	**9**	**4.53**	**6**

AG1c	**4.18**	**7**	**3.61**	**7**
AG1d	**2.41**	**11**	**5.33**	**5**
GG1a	**2.53**	**11**	**0.00**	**20**
GG1b	**5.53**	**5**	**3.16**	**8**
GG1c	**4.18**	**7**	**1.74**	**12**
GG1d	**6.02**	**4**	**3.28**	**8**
AG2a	6.63	4	8.59	2
AG2b	8.29	2	10.42	1
AG2c	7.97	2	10.20	1
AG2d	8.99	2	11.13	1
GG2a	9.21	2	7.80	2
GG2b	9.74	2	8.49	2
GG2c	9.65	2	8.26	2
GG2d	10.21	1	8.69	2
AG3a	7.61	3	8.90	2
AG3b	9.03	2	10.43	1
AG3c	9.07	2	10.58	1
AG3d	9.34	2	10.70	1

Table S2 Experimental total intensity curves I(s) and background lines B(s).

a) long distance $L = 362.2$ mm

3.60000000	0.25246543	0.27935397
3.80000000	0.24997939	0.28367475
4.00000000	0.24386162	0.28799554
4.20000000	0.24392396	0.29207308
4.40000000	0.25208911	0.29571526
4.60000000	0.26664868	0.29868319
4.80000000	0.28662959	0.30078748
5.00000000	0.31064712	0.30194162
5.20000000	0.33199304	0.30213948
5.40000000	0.34563635	0.30142833
5.60000000	0.34869172	0.29989480
5.80000000	0.34353485	0.29765240
6.00000000	0.32944908	0.29481837
6.20000000	0.31248206	0.29149988
6.40000000	0.29536005	0.28777179
6.60000000	0.28064277	0.28368144
6.80000000	0.26891896	0.27927135
7.00000000	0.25985687	0.27460059
7.20000000	0.25325084	0.26974815
7.40000000	0.24868512	0.26479969
7.60000000	0.24544444	0.25983378
7.80000000	0.24299459	0.25491598

8.00000000	0.24089019	0.25009883
8.20000000	0.23918243	0.24542730
8.40000000	0.23791478	0.24094594
8.60000000	0.23718539	0.23670100
8.80000000	0.23648907	0.23273120
9.00000000	0.23444293	0.22905575
9.20000000	0.23097463	0.22567124
9.40000000	0.22641323	0.22255619
9.60000000	0.22189610	0.21968266
9.80000000	0.21875713	0.21702484
10.00000000	0.21753115	0.21455882
10.20000000	0.21733428	0.21225934
10.40000000	0.21718326	0.21010002
10.60000000	0.21586860	0.20805434
10.80000000	0.21296184	0.20609721
11.00000000	0.20871983	0.20420458
11.20000000	0.20362383	0.20235290
11.40000000	0.19851846	0.20052140
11.60000000	0.19355458	0.19869564
11.80000000	0.18964638	0.19687065
12.00000000	0.18660258	0.19504681
12.20000000	0.18446900	0.19322689
12.40000000	0.18274823	0.19141480
12.60000000	0.18168175	0.18961845
12.80000000	0.18116951	0.18785140
13.00000000	0.18196076	0.18613268
13.20000000	0.18358724	0.18448167
13.40000000	0.18560408	0.18291604
13.60000000	0.18729007	0.18145023
13.80000000	0.18771373	0.18009526
14.00000000	0.18674739	0.17886009
14.20000000	0.18457961	0.17775058
14.40000000	0.18164987	0.17676840
14.60000000	0.17880485	0.17591076
14.80000000	0.17631309	0.17517035
15.00000000	0.17477822	0.17453680
15.20000000	0.17422822	0.17399596
15.40000000	0.17405162	0.17353174
15.60000000	0.17392551	0.17313151
15.80000000	0.17337072	0.17278978
16.00000000	0.17234991	0.17250917
16.20000000	0.17128951	0.17229633
16.40000000	0.17010849	0.17215574
16.60000000	0.16915819	0.17208735
16.80000000	0.16852128	0.17208571
17.00000000	0.16800063	0.17214208

17.20000000	0.16788732	0.17224751
17.40000000	0.16824319	0.17239216
17.60000000	0.16917820	0.17256411
17.80000000	0.17089545	0.17273607

b) Short distance $L = 193.9$ mm

6.60000000	0.25724701	0.26262719
6.80000000	0.24859713	0.25929130
7.00000000	0.24066298	0.25595541
7.20000000	0.23558529	0.25261142
7.40000000	0.23199777	0.24926865
7.60000000	0.22971937	0.24594206
7.80000000	0.22948937	0.24264653
8.00000000	0.22967298	0.23939228
8.20000000	0.23010242	0.23618838
8.40000000	0.23036598	0.23304852
8.60000000	0.23113144	0.22999389
8.80000000	0.23072905	0.22704939
9.00000000	0.22968971	0.22423708
9.20000000	0.22682751	0.22156864
9.40000000	0.22291268	0.21904457
9.60000000	0.21912193	0.21665741
9.80000000	0.21584343	0.21439621
10.00000000	0.21543350	0.21224868
10.20000000	0.21597207	0.21019878
10.40000000	0.21657107	0.20822788
10.60000000	0.21555865	0.20631659
10.80000000	0.21319617	0.20444664
11.00000000	0.20832520	0.20260208
11.20000000	0.20273200	0.20077185
11.40000000	0.19701441	0.19894979
11.60000000	0.19144796	0.19713547
11.80000000	0.18701354	0.19533453
12.00000000	0.18388665	0.19355652
12.20000000	0.18154304	0.19181272
12.40000000	0.17976747	0.19011555
12.60000000	0.17868341	0.18847806
12.80000000	0.17871521	0.18691273
13.00000000	0.17988310	0.18542978
13.20000000	0.18269975	0.18403564
13.40000000	0.18578906	0.18273154
13.60000000	0.18780688	0.18151516
13.80000000	0.18909690	0.18038153
14.00000000	0.18879680	0.17932187
14.20000000	0.18654016	0.17832489

14.40000000	0.18345782	0.17737897
14.60000000	0.18035812	0.17647276
14.80000000	0.17711430	0.17559604
15.00000000	0.17512249	0.17474078
15.20000000	0.17428708	0.17389941
15.40000000	0.17397637	0.17306460
15.60000000	0.17336261	0.17223131
15.80000000	0.17223308	0.17139878
16.00000000	0.17059887	0.17057052
16.20000000	0.16886522	0.16975272
16.40000000	0.16670365	0.16895258
16.60000000	0.16487912	0.16817770
16.80000000	0.16329754	0.16743498
17.00000000	0.16167468	0.16673058
17.20000000	0.16084651	0.16606980
17.40000000	0.16022304	0.16545519
17.60000000	0.16113922	0.16488580
17.80000000	0.16196665	0.16435670
18.00000000	0.16278358	0.16386271
18.20000000	0.16473330	0.16339957
18.40000000	0.16598633	0.16296300
18.60000000	0.16676881	0.16255094
18.80000000	0.16699686	0.16216329
19.00000000	0.16663501	0.16180047
19.20000000	0.16574490	0.16146222
19.40000000	0.16419512	0.16114743
19.60000000	0.16256754	0.16085467
19.80000000	0.16114547	0.16058212
20.00000000	0.15954180	0.16032801
20.20000000	0.15897661	0.16009119
20.40000000	0.15842091	0.15986995
20.60000000	0.15833733	0.15966312
20.80000000	0.15843362	0.15946999
21.00000000	0.15822187	0.15929101
21.20000000	0.15808468	0.15912839
21.40000000	0.15759423	0.15898548
21.60000000	0.15763506	0.15886607
21.80000000	0.15698867	0.15877310
22.00000000	0.15689200	0.15870908
22.20000000	0.15719116	0.15867383
22.40000000	0.15796570	0.15866392
22.60000000	0.15827580	0.15867431
22.80000000	0.15893545	0.15870103
23.00000000	0.15919034	0.15874132
23.20000000	0.16025531	0.15879359
23.40000000	0.16040198	0.15885636

23.60000000	0.16085989	0.15892973
23.80000000	0.16103602	0.15901414
24.00000000	0.16121261	0.15911006
24.20000000	0.16109122	0.15921789
24.40000000	0.16066307	0.15933863
24.60000000	0.16012793	0.15947414
24.80000000	0.15955580	0.15962670
25.00000000	0.15901252	0.15979853
25.20000000	0.15863937	0.15999127
25.40000000	0.15869998	0.16020549
25.60000000	0.15870406	0.16044050
25.80000000	0.15918302	0.16069513
26.00000000	0.15952111	0.16096770
26.20000000	0.16006180	0.16125675
26.40000000	0.16093017	0.16156078
26.60000000	0.16150332	0.16187848
26.80000000	0.16208744	0.16221013
27.00000000	0.16273444	0.16255766
27.20000000	0.16319287	0.16292433
27.40000000	0.16393417	0.16331444
27.60000000	0.16443193	0.16373255
27.80000000	0.16474507	0.16418375
28.00000000	0.16534084	0.16467286
28.20000000	0.16603563	0.16520302
28.40000000	0.16663574	0.16577565
28.60000000	0.16713130	0.16639118
28.80000000	0.16788623	0.16704921
29.00000000	0.16848435	0.16774820
29.20000000	0.16895297	0.16848623
29.40000000	0.16962659	0.16926104
29.60000000	0.16998393	0.17006993
29.80000000	0.17053187	0.17091030
30.00000000	0.17098557	0.17177935
30.20000000	0.17169345	0.17267420
30.40000000	0.17238433	0.17359178
30.60000000	0.17332195	0.17452921
30.80000000	0.17430153	0.17548375
31.00000000	0.17548443	0.17645301
31.20000000	0.17670795	0.17743477
31.40000000	0.17809034	0.17842705
31.60000000	0.17926099	0.17942803
31.80000000	0.18081199	0.18043607
32.00000000	0.18181263	0.18144924
32.20000000	0.18344036	0.18246580
32.40000000	0.18445564	0.18348235

Table S3 Molecular structure of two most favorable conformers of noradrenaline obtained by gas-phase electron diffraction and quantum chemical calculations.

Parameter	AG1a				GG1a				X-ray
	GED, r_{h1}	B3LYP[a]	MP2[a]	CCSD[a]	GED, r_{h1}	B3LYP[a]	MP2[a]	CCSD[a]	
r(C1-C2)	1.387(1)[1]	1.384	1.387	1.384	1.388(1)[1]	1.386	1.388	1.386	1.401
r(C2-C3)	1.396(1)[1]	1.395	1.396	1.395	1.395(1)[1]	1.393	1.395	1.394	1.391
r(C3-C4)	1.394(1)[1]	1.392	1.394	1.391	1.397(1)[1]	1.394	1.397	1.394	1.390
r(C4-C5)	1.394(1)[1]	1.391	1.394	1.394	1.393(1)[1]	1.39	1.393	1.392	1.395
r(C5-C6)	1.389(1)[1]	1.386	1.389	1.385	1.389(1)[1]	1.387	1.39	1.387	1.381
r(C1-C6)	1.398(1)[1]	1.398	1.397	1.397	1.396(1)[1]	1.397	1.398	1.395	1.409
r(C6-O1)	1.362(1)[1]	1.364	1.362	1.362	1.362(1)[1]	1.364	1.361	1.362	1.378
r(C1-O2)	1.376(1)[1]	1.377	1.376	1.375	1.376(1)[1]	1.377	1.376	1.374	1.340
r(C3-C7)	1.504(9)[2]	1.510	1.501	1.508	1.519(9)[2]	1.526	1.516	1.522	1.524
r(C7-C8)	1.532(9)[2]	1.539	1.529	1.530	1.533(9)[2]	1.54	1.530	1.532	1.511
r(C8-N1)	1.466[c]	1.469	1.466	1.467	1.464[c]	1.467	1.464	1.466	1.496
r(C7-O3)	1.414(1)[1]	1.418	1.415	1.412	1.414(1)[1]	1.417	1.414	1.412	1.424
r(C-H)av	1.091(9)	1.087	1.087	1.090	1.090(9)	1.085	1.085	1.089	
r(N⋯H)	1.976(84)	2.121	2.084	2.137	2.209(84)	2.115	2.082	2.134	
r(N-H)av	1.016(9)	1.012	1.012	1.011	1.017(9)	1.012	1.012	1.011	
r(O-H)av	0.972(9)	0.966	0.966	0.961	0.971(9)	0.966	0.967	0.962	
C1-C2-C3	119.6(3)	120.3	120	120.2	119.9(3)	120.6	120.4	120.4	
C2-C3-C4	118.7(3)	118.7	119.1	119.0	118.3(3)	118.4	118.8	118.6	
C3-C4-C5	120.3(3)	120.6	120.8	120.8	120.5(3)	121	120.9	121	
C5-C6-O1	118.9(12)	120.2	120.2	120.1	118.9(12)	120.1	120.2	120.1	
C2-C1-O2	122.9(12)	123.9	124.2	123.9	122.9(12)	123.9	124.2	123.8	
C2-C3-C7	116.6(36)	120.6	120.1	120.4	117.1(36)	120.7	120.6	120.8	
C3-C7-C8	112.2(72)	111.7	110.6	111.1	111.7(72)	112.3	110.1	111.1	
C7-C8-N1	108.2	108.9	108.2	108.6	107.1	108.7	107.1	108	
C3-C7-O3	110.3	110.5	110.3	110.1	112.6	112.6	112.6	112.5	
C-C-C-N	172.7	172.9	172.7	172.3	69.9	73.5	69.7	69.9	
φ (O-C-C-N)	43.4(68)	50.6	51.4	52.7	-62.0(68)	-51.6	-54.0	-54.4	
φ (C2-C3-C7-C8)	-81.0(107)	-96.3	-94.1	-95.4	-99.8(107)	-117.9	-112.8	-115.3	
Rf, [d]	7.0%								

[a] with cc-pVTZ basic set. [b] Values in parentheses are three times the standard deviations. The same numeric superscripts indicate that these parameters were refined in one group; differences between parameters in the group were assumed at the values from MP2/cc-pVTZ calculation. Bond lengths are given in Å, bond angles in degrees. [c] Fixed to the MP2/cc-pVTZ value. [d] The GED model of the same ratio AG1a and GG1a.