

Thermodynamic Nature of *High Energy* Phosphoryl Bonds Originating from the Anomeric Effect.

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Supplementary discussion and figures on cooperative effects concerning the anomeric interaction

As detailed by Alabugin and coworkers³² an analysis of the combined effect of electron density donations to the same antibonding orbital is important when investigating any general trend. This is because anti-cooperative effects i.e. destructive interference between lone pair wavefunctions can remove any correlation. To check that no anti-cooperative effects occur, the deletion method as

implemented in NBO 3.1 is used. Here the combined effect of eliminating all 3 interactions is compared to the effect of individually deleting each interaction and numerically adding all three energy terms. If the combined elimination is less than the numerical addition, then anti-cooperative effects occur. This may change any general trend. Previous work on the same anomeric effect in N—P phosphoryl guanidinium compounds showed that anti-cooperative effects were absent.¹² Likewise, in this work, comparisons between E(2), simultaneous (combined) deletions and summed individual deletions showed that the anomeric effect was on the whole slightly cooperative. More importantly, the general trend between the anomeric effect and hydrolysis free energies was not changed no matter what type of anomeric energy was used, Supplementary Figure 2.

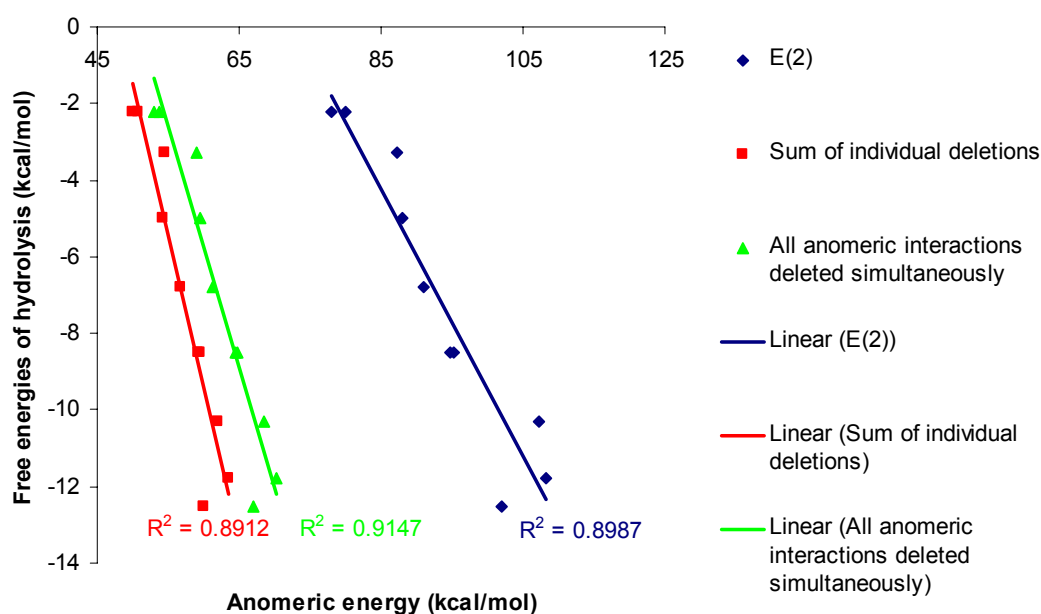
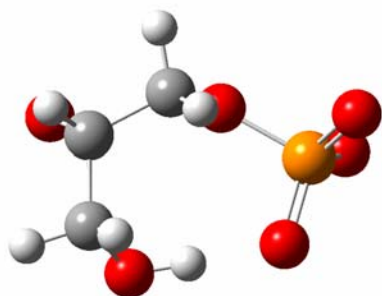
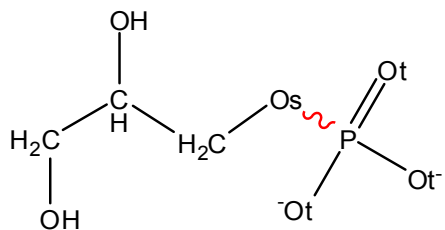


Figure S1. Correlation between free energies of hydrolysis and anomeric energy calculated using second order perturbation (E(2)), by summing individual deletions and deleted simultaneously. The HF/6-311++G(d,p) method on B3LYP/6-311++G(d,p) optimized structures was used for this test due to the inconsistency of deletion operations using DFT as detailed in the NBO manual.¹¹⁰

Archive Files

Glycerol-3-phosphate (1)



The C-C-C-OH and C-Os-P-Ot dihedrals were subjected to conformational searches at the PM3 level of theory. Low energy conformers for C-Os-P-Ot were found at values of 180°, 60° and -60°. Since no difference in energy was obtained the choice made between these three structures was arbitrary. A strong intramolecular hydrogen bond between OH and O was observed. Strong intramolecular hydrogen bonds were observed for this compound no matter what conformation was used.

B3LYP/6-311++G(d,p) optimization in water

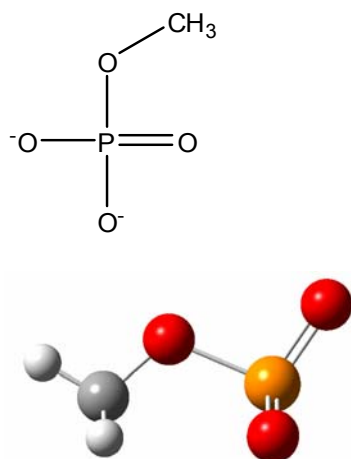
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B3LYP/6-311++G(d,p) frequencies in water

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Methyl monophosphate (2)



The C-O-P-O dihedrals were subjected to conformational searches at the PM3 level of theory. Lowest energy conformers for C-O-P-O were found at values of 180°, 60° and -60°. Since no difference in energy was obtained the choice made between these three structures was arbitrary.

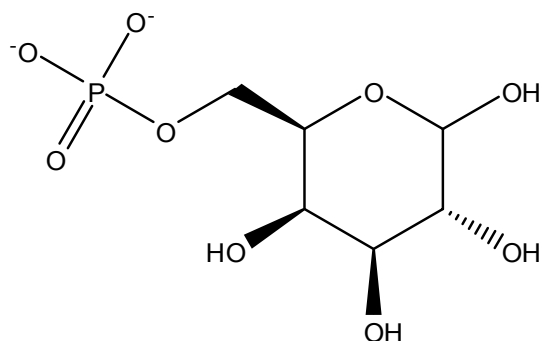
B3LYP/6-311++G(d,p) optimization in water

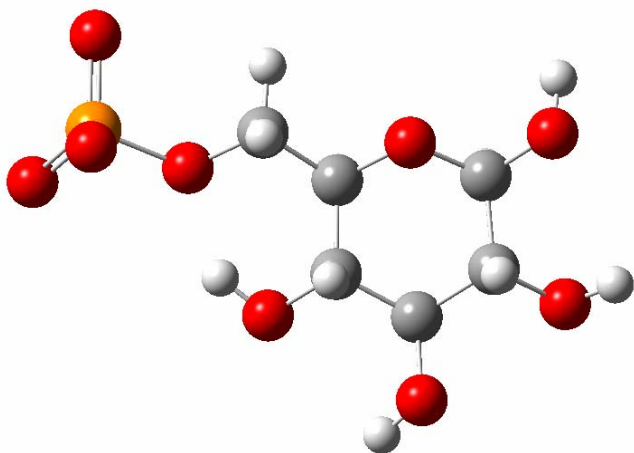
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B3LYP/6-311++G(d,p) frequencies in water

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Glucose-6-phosphate (3)





B3LYP/6-311++G(d,p) optimization in water

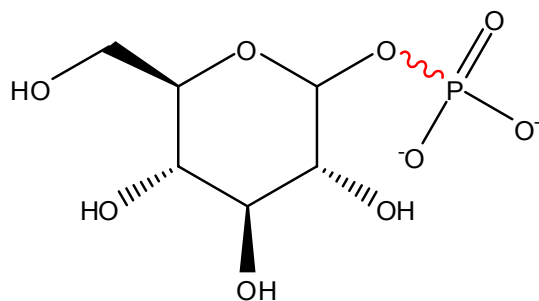
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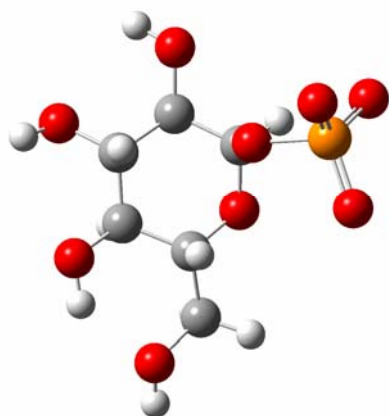
B3LYP/6-311++G(d,p) frequencies in water

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 2. 0132623, 0. 6267827, 0. 2018532, 0. 6307019, -1. 4004539, -0. 3371961, 0. 276119
 1, -0. 3486776, -1. 0711669, -1. 4458372, 0. 1061732, -0. 3421065, 0. 0151692, -0. 6
 563791, -0. 0791184, -0. 3963903, -0. 0595602, -0. 7226124, 3. 5056886, 0. 0504202
 , 0. 0083842, -0. 2262735, 3. 2776488, -0. 0632263, -0. 1113397, -0. 0551052, 3. 315
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 . 1149376, 0. 4403094, -1. 2952075, -2. 2477943, -0. 2610117, -0. 342788, -0. 33981
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 . 021174, -0. 1192608, 0. 0136189, 0. 0466932, 0. 047258, -0. 0078895, 0. 0008818, -
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 , 0. 0336163, 0. 0213328, -0. 0583334, 0. 0351343, -0. 0519762, -0. 0864362, 0. 0637
 954, -0. 0010374, 0. 0282743, -0. 047693, -0. 0558819, -0. 0514141, 0. 004253, -0. 0
 988457, -0. 1202003, 0. 0302882, 0. 0091018, 0. 0397603, 0. 0150749, -0. 0419785, -
 0. 0024996, 0. 0023287, -0. 0886273, -0. 1133007, 0. 0424012, 0. 0074144, 0. 045883
 6, 0. 0093545, -0. 068365, -0. 0504704, 0. 0212434, -0. 1333531, -0. 0973536, 0. 035
 503, 0. 0378974, 0. 0783655, 0. 0269584, -0. 0134949, 0. 0236101, 0. 0004731, 0. 011
 9814, 0. 0485524, 0. 01543, -0. 0990274, 0. 0174738, -0. 1877482, 0. 5262895, -0. 07
 95714, -0. 0613213, -0. 024619, 0. 3293596, -0. 0521141, -0. 0532638, -0. 0479441,
 0. 4447358, 0. 3767627, -0. 0285028, 0. 1187618, -0. 0182637, 0. 4463233, 0. 091232
 4, 0. 0771942, 0. 0623149, 0. 4560421, 0. 4218653, -0. 0938729, -0. 1228773, -0. 109
 882, 0. 4671699, 0. 1316233, -0. 1615115, 0. 1920525, 0. 6950617\Pol ar=196. 52552
 51, -6. 5590627, 176. 2357407, 0. 447104, 3. 2653728, 181. 2990445\PG=C01 [X(C6H
 1109P1)]\NI mag=0\

Glucose-1-phosphate (4)





B3LYP/6-311++G(d,p) optimization in water

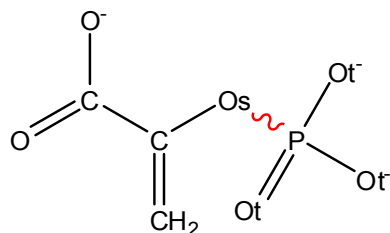
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1.8216071507, -0.8034573429, 1.4494892504\C, 1.7170213317, -0.6767710726,
-0.0813323217\C, 2.4674537514, -1.7780029793, -0.8265556136\H, -0.0767150664,
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0.798917016, -0.0127597962, 3.529203885\O, 3.1465692605, -0.5458792558,
1.9246936332\O, 0.3522748015, -0.8029627788, -0.4818750575\O, 3.8571549221,
-1.6989371999, -0.4794773224\O, -1.7634608049, 0.0721670714, -0.4897005946\H,
-0.9901286275, -0.7996693599, 1.8273301184\H, 1.3039899925, 1.2165264483,
1.9353484226\H, 1.5076830687, -1.8189362592, 1.7389577489\H, 2.1133093619,
0.3063050639, -0.3858207074\H, 2.0537659543, -2.752642806, -0.5406270185\H,
2.3291111136, -1.6408067541, -1.9047480247\H, -1.3602079874,
1.1636379021, 3.0210998256\H, 1.6123577529, 0.3177453205,
3.959536727\H, 3.7575149051, -1.0551651728, 1.3657928861\P, -2.2939087737,
0.8274858769, -1.954639138\H, 4.3215971923, -2.4909383521, -0.8209734718\O,
-2.2196786667, -0.2756612815, -3.0232493849\O, -1.3241749463,
1.9991042927, -2.1791953133\O, -3.7328340722, 1.2363404492, -1.6009174981\
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1)]\
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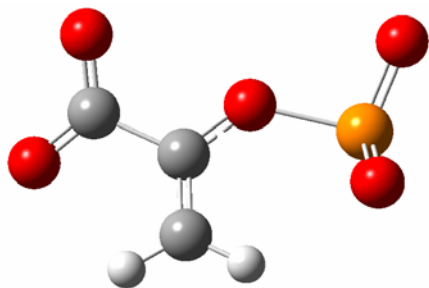
B3LYP/6-311++G(d,p) frequencies in water

```
1\1\GINC-CST204\Freq\RB3LYP\6-311++G(d,p)\C6H1109P1(2-)\RUBEN\18-May-2006\0\#\P
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FREQ\Title Card Required\ -2,1\C, -0.4971205505, 0.252710201, 0.0225923174\C,
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2.1188374639\C, 1.8216071507, -0.8034573429, 1.4494892504\C, 1.7170213317,
-0.6767710726, -0.0813323217\C, 2.4674537514, -1.7780029793, -0.8265556136\H,
-0.0767150664, 1.2166371848, -0.2971539933\O, -1.2976517536, 1.246749884,
2.0506335476\O, 0.798917016, -0.0127597962, 3.529203885\O, 3.1465692605,
-0.5458792558, 1.9246936332\O, 0.3522748015, -0.8029627788, -0.4818750575\O,
3.8571549221, -1.6989371999, -0.4794773224\O, -1.7634608049, 0.0721670714,
-0.4897005946\H, -0.9901286275, -0.7996693599, 1.8273301184\H, 1.3039899925,
1.2165264483, 1.9353484226\H, 1.5076830687, -1.8189362592, 1.7389577489\H,
2.1133093619, 0.3063050639, -0.3858207074\H, 2.0537659543, -2.752642806,
-0.5406270185\H, 2.3291111136, -1.6408067541, -1.9047480247\H, -1.3602079874,
1.1636379021, 3.0210998256\H, 1.6123577529, 0.3177453205, 3.959536727\H,
3.7575149051, -1.0551651728, 1.3657928861\P, -2.2939087737, 0.8274858769,
-1.954639138\H, 4.3215971923, -2.4909383521, -0.8209734718\O, -2.2196786667,
-0.2756612815, -3.0232493849\O, -1.3241749463, 1.9991042927, -2.1791953133\O,
-3.7328340722, 1.2363404492, -1.6009174981\
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Phosphoenolpyruvate (5)





Conformational searches at the PM3 level of theory were performed along both the C-Os-P-Ot dihedral and C(OO)-C-Os-P dihedral. Lowest energy conformers for C-Os-P-Ot were found at values of 180° , 60° and -60° . Since no difference in energy was obtained the choice made between these three structures was arbitrary. The lowest energy conformer for C(OO)-C-Os-P was found at a value of 180° . We note that phosphoenolpyruvate is usually listed as a very high energy with a standard free energy of hydrolysis of -61.9 kJ/mol. However, of this total value only -28.5 kJ/mol is due to hydrolysis of the phosphoryl bond. The remaining -33.6 kJ/mol is due to the tautomerization of the enol form to the keto form (Garrett and Grisham, 3rd edition).

B3LYP/6-311++G(d,p) optimization in water

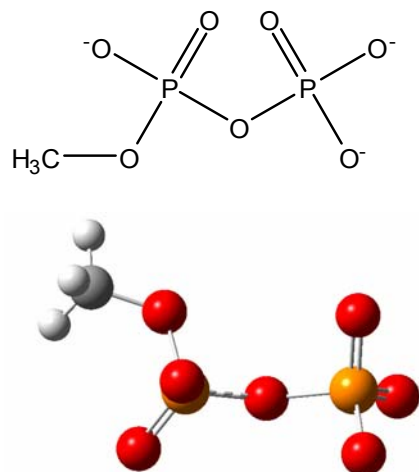
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UESS=READ SCRF(PCM, READ, SOLVENT=WATER)\Title Card Required\ -3, 1\C, 1.
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6404754, 1.0777654073\C, -0.8943495181, -0.0872021107, 1.7562617768\O, 0.38
89773276, 0.0223794749, -0.2725222993\P, -0.8768871264, -0.0144415183, -1.4
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2284607343, -1.1901654562\O, -1.6013408361, -1.3533578523, -1.256426081\H,
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[X(C3H2O6P1)]\@
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B3LYP/6-311++G(d,p) frequencies in water

```
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006\O\#\P GEOM=ALLCHECK GUESS=READ SCRF=CHECK GENCHK RB3LYP/6-311++G(D
,P) FREQ\Title Card Required\ -3, 1\C, 1.6129628633, 0.0462767553, 1.8160
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495181, -0.0872021107, 1.7562617768\O, 0.3889773276, 0.0223794749, -0.27252
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5, 0.0581583, -2.2345296, -1.4750019, 0.5674479, -0.1075815, 0.61287, -1.9658061, 0.0375542, 0.0488122, -0.0964549, -1.1762041, -1.3536846, -0.4992975, -0.125315, -0.5471804, -2.0897926, -0.0913256, 0.0101002, 0.0559822, -1.171633, 0.1139364, -0.0049199, -0.009035, -0.005494, 0.2093527, 0.004838, 0.0160476, 0.0064441, -0.0572479, -0.0392609, -0.0118103, -0.0681137, -0.0117255, 0.2061634, -0.0010673, -0.0674352, -0.0009218, 0.0646065\Pol ar=137.2049077, 2.2367921, 100.5334237, -11.4268649, -1.4249443, 140.6517022\PG=C01 [X(C3H2O6P1)]\NI mag=0\0.60167233, 0.02287574, 0.22329165, -0.10984892, -0.01648388, 0.73561786, -0.10376472, -0.00149320, 0.00507506, 0.11186395, -0.00082351, -0.07668215, 0.00697014, 0.00478832, 0.02991973, -0.02738170, 0.00558086, -0

Methyl diphosphate (6)



The initial conformation for a diphosphate structure was obtained from prior work⁹⁸ (Hwang et al). A conformation search about $\text{Os}\beta\text{-P}\alpha\text{-Os}\alpha\text{-C}$ was performed at the PM3 level to obtain the best dihedral for the methyl group. As detailed by both Hwang et al and Meagher⁹⁹ et al unnaturally strong hydrogen bonds between C-H and O-P are observed in the lowest energy structures. To alleviate this problem, the C-O-P-O dihedral was fixed at 180° .

B3LYP/6-311++G(d,p) optimization in water

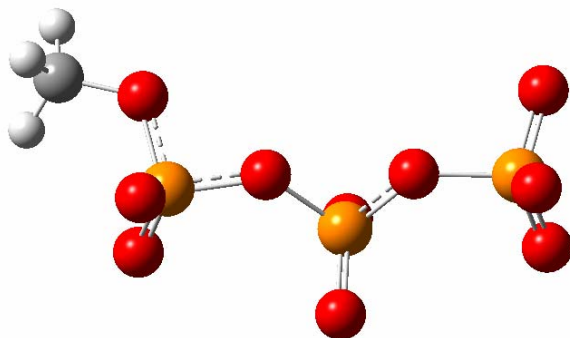
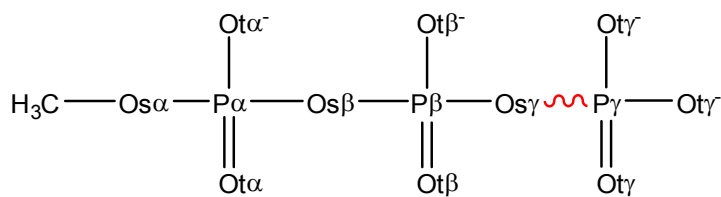
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1\1\GINC-DIRAC\FOpt\RB3LYP\6-311++G(d,p)\C1H307P2(3-)\RUBEN\12-May-200
6\O\#P FREQ RB3LYP/6-311++G(D,P) OPT(MAXCYCLE=900,GDIIS) POP=NB0 SCRF
(PCM,SOLVENT=WATER)\adp_al I \ -3, 1\0, -1.6917835881, 0.7206049278, -1.564
4833397\P, -1.7303841502, 0.8193183749, -0.0334555305\0, -0.1335432585, 0.4
561595206, 0.5147710374\P, 0.946339712, -0.717498134, 0.3079288544\0, 1.640
0741703, -0.9666614912, 1.636522448\0, -1.8998925996, 2.2511495957, 0.50165
50555\0, 1.9966689803, 0.1048767444, -0.683669688\0, 0.4041639871, -1.92319
74447, -0.4320374962\0, -2.6337612115, -0.2153792029, 0.6542863861\C, 3.257
7598076, -0.5018246746, -0.9855816726\H, 3.1226322834, -1.4712561935, -1.47
67753973\H, 3.8540906956, -0.6367165276, -0.0780538784\H, 3.7819729096, 0.1
711959566, -1.6651357716\Versi on=I A64L-G03RevC.01\State=1-A\HF=-1250.0
847727\RMSD=4.910e-09\RMSF=8.668e-05\Di pol e=5.6586531, -0.8261723, -1.12
80312\PG=C01 [X(C1H307P2)]\@
```

B3LYP/6-311++G(d,p) frequencies in water

```
1\1\GINC-DIRAC\Freq\RB3LYP\6-311++G(d,p)\C1H307P2(3-)\RUBEN\12-May-200
6\O\#P GEOM=ALLCHECK GUESS=READ SCRF=CHECK GENCHK RB3LYP/6-311++G(D,P)
) FREQ\adp_al I \ -3, 1\0, -1.6917835881, 0.7206049278, -1.5644833397\P, -1.
7303841502, 0.8193183749, -0.0334555305\0, -0.1335432585, 0.4561595206, 0.5
147710374\P, 0.946339712, -0.717498134, 0.3079288544\0, 1.6400741703, -0.96
```

66614912, 1. 636522448\0, -1. 8998925996, 2. 2511495957, 0. 5016550555\0, 1. 9966689803, 0. 1048767444, -0. 683669688\0, 0. 4041639871, -1. 9231974447, -0. 4320374962\0, -2. 6337612115, -0. 2153792029, 0. 6542863861\C, 3. 2577598076, -0. 5018246746, -0. 9855816726\H, 3. 1226322834, -1. 4712561935, -1. 4767753973\H, 3. 8540906956, -0. 6367165276, -0. 0780538784\H, 3. 7819729096, 0. 1711959566, -1. 6651357716\Version=I A64L-G03RevC. 01\State=1-A\HF=-1250. 0847727\RMSD=3. 305e-09\RMSF=8. 667e-05\Di pol e=5. 6586534, -0. 826172, -1. 1280316\Di pol eDeriv=-1. 1631293, 0. 0492613, -0. 0115698, 0. 01404, -1. 1107661, 0. 0082863, -0. 1538397, 0. 0582314, -2. 3756116, 3. 5891956, -0. 3311148, -0. 1211957, -0. 0115813, 3. 4589495, 0. 0312452, 0. 0672999, -0. 1162623, 3. 3389994, -2. 827842, 0. 9518414, -0. 320199, 1. 0289082, -1. 6927884, -0. 0136366, -0. 2825591, -0. 0324591, -1. 0942279, 3. 5807478, -0. 1857747, 0. 2039949, -0. 2583533, 3. 2588198, -0. 1049762, -0. 1323257, 0. 1738717, 3. 2231026, -1. 3600416, 0. 1259339, -0. 5016595, 0. 1030768, -1. 1110481, 0. 1766095, -0. 4365055, 0. 1846923, -2. 0000706, -1. 1745473, 0. 1947747, 0. 0891738, 0. 2439377, -2. 3315223, -0. 4128881, 0. 1017481, -0. 4262259, -1. 2782016, -1. 8408062, -0. 0498885, 0. 4991136, -0. 1315744, -1. 0446786, 0. 2243737, 0. 59977, 0. 1619965, -1. 14009, -1. 1966251, -0. 1995278, -0. 1551823, -0. 2361793, -1. 8428143, -0. 3764757, -0. 1543419, -0. 4561794, -1. 2601966, -1. 7083112, -0. 4280381, 0. 3687209, -0. 5580622, -1. 5931012, 0. 3490506, 0. 4136418, 0. 3715908, -1. 3696638, 0. 8788142, -0. 1774419, -0. 1264948, -0. 3469839, 0. 4782777, 0. 1468224, -0. 0525893, 0. 0576176, 0. 4228746, -0. 0053518, -0. 0333612, -0. 0132045, 0. 0763606, -0. 1290057, -0. 1377668, 0. 0151809, -0. 1061541, 0. 0148089, -0. 086469, 0. 0386731, -0. 0499279, 0. 0698624, 0. 0605677, -0. 0182183, -0. 1558726, 0. 0192627, -0. 0851898, -0. 0498429, -0. 0268478, 0. 0874306, -0. 0649458, -0. 0137323, 0. 1007064, 0. 1173511, 0. 0787891, -0. 0135136\Pol ar=122. 9377474, -3. 0404799, 118. 1837256, -1. 0542544, 1. 1767369, 118. 1043935\PG=C01 [X(C1H3O7P2)]\NImag=0\0. 05153831, 0. 00890108, 0. 04160694, -0. 00884914, 0. 01345075, 0. 40389540, -0. 06060289, -0. 00030098, 0. 01468567, 0. 35721617, -0. 00090966, -0. 06811390, -0. 01843944, 0. 08145084, 0. 63314014, 0. 02019317, -0. 02615460, -0. 34511

Methyl triphosphate (7)



The initial conformation for a triphosphate structure was obtained from prior work⁹⁸(Hwang et al). A conformation search about Osβ-Pα-Oα-C was performed at the PM3 level to obtain the best dihedral for the methyl group. As detailed by both Hwang et al and Meagher⁹⁹ et al unnaturally strong hydrogen bonds between C—H and O—P are observed in the lowest energy structures. To alleviate this problem, the C-O-P-O dihedral was fixed at 180°.

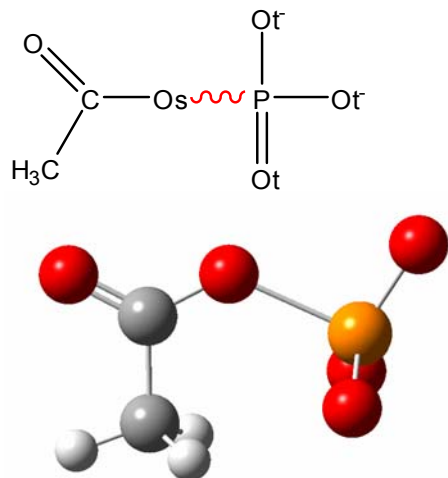
B3LYP/6-311++G(d,p) optimization in water

```
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```

B3LYP/6-311++G(d,p) frequencies in water

```
1\1\GINC-CST215\Freq\RB3LYP\6-311++G(d,p)\C1H3O1OP3(4-)\RUBEN\08-May-2006\0\#\# GEOM=ALLCHECK GUESS=READ SCRF=CHECK TEST GENCHK RB3LYP/6-311++G(D,P) FREQ\Title Card Required\ -4,1\0, -2.5017375935, 0.1672912145, -2.122045395\P, -2.4714207874, 0.1693667596, -0.6118464788\O, -0.9564068824, 0.1635357411, -0.013049306\P, 0.5448248586, -0.2304177842, -0.633660573\O, 1.2921753103, -0.2228711409, 0.7934080647\P, 2.9102450687, -0.5121852031, 1.3220218628\O, 3.2728674079, 0.7994073572, 2.0371631413\O, 2.7548131455, -1.7141150433, 2.2675519762\O, 3.7338211652, -0.7984755431, 0.0602312523\O, 1.0051182003, 0.9096229174, -1.5152401104\O, 0.4671239685, -1.6210127246, -1.2249362956\O, -2.8578107165, 1.6780926118, -0.05567132\O, -3.2910714544, -0.8654817403, 0.1286440235\C, -4.1272735918, 2.2396077247, -0.4143539088\H, -4.0375358459, 3.3228623612, -0.3256403692\H, -4.393165307, 1.9873916069, -1.4447801382\H, -4.9115348029, 1.8826939021, 0.2603735468\Version=IBM64-G03RevC.02\State=1-A\HF=-1817.4730832\RMSD=2.739e-09\RMSF=4.026e-04\Di pol e=-7.7448309, 3.596051, -1.069401\Di pol eDeriv=-1.1480681, -0.0018166, -0.1214859, 0.0287742, -1.027067, 0.0412108, -0.1183883, -0.0382154, -2.0507885, 3.7353832, -0.0120907, -0.1176866, -0.1333102, 3.2168195, -0.1232891, 0.1164003, -0.0563307, 3.1423772, -3.4510308, 0.3458604, -0.0140583, 0.2985491, -0.9871681, -0.0651914, -0.0162114, -0.0505351, -1.1860982, 3.9295886, -0.0232481, 0.2200157, -0.1016771, 3.3088057, -0.040129, 0.2251348, -0.0654517, 3.4318563, -2.5567434, 0.2051164, -1.0377913, 0.2091679, -0.9897011, 0.0885828, -1.1731215, 0.1051805, -2.1497237, 3.5016223, 0.038682, 0.4181973, -0.021274, 3.399023, -0.0749693, 0.0797403, 0.0043116, 3.5069658, -1.2371369, -0.2907304, -0.2400457, -0.3544508, -2.0341623, -0.5766145, -0.2184357, -0.5303482, -1.4867584, -1.1269957, -0.0735481, 0.0007095, -0.0020096, -1.9047528, 0.6947009, -0.015445, 0.6482321, -1.7116541, -1.6950319, 0.159404, 0.5010362, 0.17443, -1.1509479, -0.1650286, 0.6001789, -0.1843622, -1.7810661, -1.2309723, -0.2207809, 0.1511337, -0.287449, -1.7085471, 0.5731903, 0.1867884, 0.5097534, -1.4654348, -1.1284251, -0.0768035, -0.0807671, 0.0082566, -1.9920719, -0.4540484, -0.0428202, -0.4004526, -1.2365475, -1.3907918, 0.5219626, 0.0124723, 0.6642982, -1.735014, -0.2167885, -0.012389, -0.234393, -0.8904833, -1.4909931, -0.4493535, 0.320111, -0.3957584, -1.5581997, 0.3639268, 0.3126103, 0.3985381, -1.3108175, 0.9178859, -0.3105613, 0.0465585, -0.1825558, 0.4363524, -0.0577217, 0.1589304, -0.1515552, 0.4039679, 0.0118241, -0.0033112, -0.0092052, 0.0495212, -0.1730515, -0.0103137, -0.0069511, -0.016947, 0.0939367, -0.004593, 0.0405526, -0.0304096, -0.0121204, 0.0792623, -0.0534994, -0.1085626, 0.005424, -0.1151207, -0.1508813, 0.0405595, 0.0829466, -0.0546696, 0.0323457, 0.0699412, 0.1257264, 0.0532572, -0.0271089\Pol ar=166.0541383, -1.4512759, 162.0535244, 1.4141698, -2.3065663, 161.2688749\PG=C01 [X(C1H3O1OP3)]\NImag=0\0.05214828, 0.00473526, 0.05698219, 0.00027031, 0.00313283, 0.48415947, -0.06327161, -0.00051507, -0.00128207, 0.49452460, -0.00023662, -0.06159239, 0.00182498, 0.09567872, 0.50273910, 0.00613277, 0.00622999, -0.42476433, -0.06079902, -0.09245930, 0.73420158, -0.01163953, -0.00030309, -0.02
```

Acetyl phosphate (8)



Conformational searches at the PM3 level of theory were performed along both the C-Os-P-Ot dihedral and C-C-Os-P dihedral. Lowest energy conformers for C-Os-P-Ot were found at values of 180°, 60° and -60°. Since no difference in energy was obtained the choice made between these three structures was arbitrary. The lowest energy conformer for C-C-Os-P was found at a value of 0°.

B3LYP/6-311++G(d,p) optimization in water

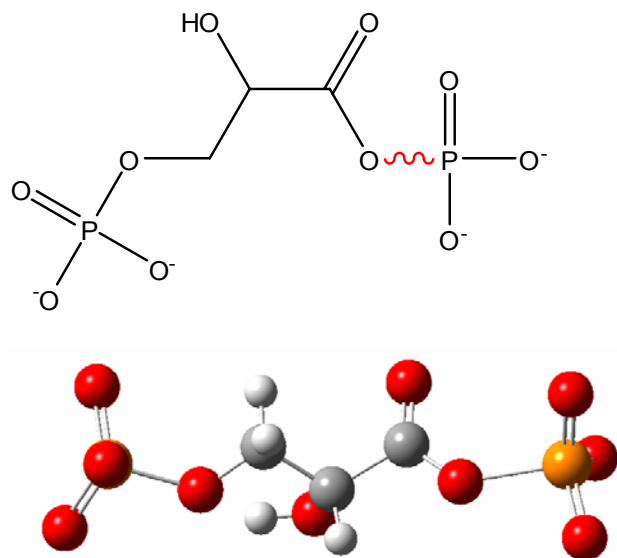
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06\0\#P B3LYP/6-311++G** OPT(MAXCYCLE=900) FREQ POP=NBO SCRF(PCM,SOLV
ENT=WATER)\acetyl_fin gas\ -2,1\C, -1.9947410001, 0.1120409261, -0.90464
51538\C, -1.6047270713, 0.1403632436, 0.5517578332\O, -0.3220924852, 0.0571
307537, 0.8654032168\P, 1.1164097364, -0.090525793, -0.216814171\O, 1.05979
63472, 1.1763937368, -1.0680574333\O, -2.4408857356, 0.2350434132, 1.446409
9382\O, 0.8803413508, -1.4079827431, -0.952519533\O, 2.205440801, -0.117769
9014, 0.8537996501\H, -1.6671739973, -0.8308762063, -1.3487472549\H, -3.072
8065393, 0.2259114752, -1.0015013605\H, -1.4701593062, 0.9059045349, -1.440
5016051\Version=IA64-Linux-G03RevB.05\State=1-A\HF=-796.0952422\RMSD=
2.630e-09\RMSF=4.066e-05\Di pol e=-3.3535525, 0.2118988, -0.8442703\PG=C01
[X(C2H3O5P1)]\@
```

B3LYP/6-311++G(d,p) frequencies in water

```
1\1\GINC-NEWTON\Freq\RB3LYP\6-311++G(d,p)\C2H3O5P1(2-)\RUBEN\21-Apr-20
06\0\#P GEOM=ALLCHECK GUESS=READ SCRF=CHECK GENCHK RB3LYP/6-311++G(D,
P) FREQ\acetyl_fin gas\ -2,1\C, -1.9947410001, 0.1120409261, -0.90464515
38\C, -1.6047270713, 0.1403632436, 0.5517578332\O, -0.3220924852, 0.0571307
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iv=-0.070926, -0.0034281, -0.1105143, -0.0043832, 0.0479423, -0.0253217, -0.
1041035, -0.012871, -0.4563441, 3.1124134, -0.2256446, -0.6340024, -0.212672
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5, 0.3703492, 0.1006067, -0.2146509, 0.0767912, 1.7659875, -3.0700423, 0.2030292, 0.6478288, 0.1815423, -0.6554726, -0.0639454, 0.0023496, -0.01918, -1.1130604, 3.6436661, -0.0190637, 0.1674961, -0.0316195, 3.3319556, -0.0224708, -0.1252773, 0.0010123, 3.1368245, -1.1998218, -0.0309936, 0.0182338, -0.1729477, -1.9059549, 0.5901148, 0.136505, 0.484, -1.4499526, -1.7961908, 0.1183679, 0.6839417, 0.1287131, -0.5687771, -0.084598, 0.9730151, -0.1124816, -1.5152919, -1.1808345, -0.0789686, -0.0625924, 0.0758611, -2.0146194, -0.534143, 0.0639791, -0.4508547, -1.3616585, -1.8391672, 0.023164, -0.5920338, 0.0164695, -1.1344685, 0.0210628, -0.7217304, 0.0312267, -1.6014492, 0.1433173, 0.0448393, -0.0287969, 0.03398, 0.0063552, -0.0505098, -0.0026783, -0.020462, 0.0617857, -0.1358324, 0.0234775, -0.0460908, 0.0259989, 0.1074404, 0.005291, -0.048331, -0.001598, 0.0677921, 0.1337407, -0.0627005, -0.0113705, -0.0490586, 0.0399667, 0.0609556, 0.0086909, 0.0224517, 0.0521734\Pol ar=105.441716, -1.9545666, 81.1408093, -4.1821102, 0.8845545, 93.3016326\PG=C01 [X(C2H3O5P1)]\NI mag=0\0.60781238, -0.00780615, 0.52604114, -0.02538486, -0.00237366, 0.47077584, -0.09147613, -0.00113793, -0.02730728, 0.66056445, -0.00164602, -0.09394955, -0.00072115, -0.03644671, 0.23829514, -0.03552838, 0.00051138, -0.17168350, -0.14389770, 0.02939172, 0.73497422, -0.02070377, 0.00205367, -0

1,3 bisphosphoglycerate (9)



The large number of dihedral angles present in this structure created difficulties in finding the lowest energy structure. Initial conformations were generated from crystal structures of 3-phosphoglyceric acid phosphorylated at alternate oxygen atoms at the acid end. The three different 3-phosphoglyceric acid structures used were each obtained from the pdb database in complex with enzyme structures.

Watson, H.C., Walker, N.P., Shaw, P.J., Bryant, T.N., Wendell, P.L., Fothergill, L.A., Perkins, R.E., Conroy, S.C., Dobson, M.J., Tuite, M.F., et. al. Sequence and structure of yeast phosphoglycerate kinase. *EMBO J.* v1 pp.1635-1640, 1982

Crowhurst, G.S., Dalby, A.R., Isupov, M.N., Campbell, J.W., Littlechild, J.A. Structure of a phosphoglycerate mutase:3-phosphoglyceric acid complex at 1.7 Å. *Acta Crystallogr., Sect.D* v55 pp.1822-1826, 1999

Kovari, Z., Flachner, B., Naray-Szabo, G., Vas, M. Crystallographic and Thiol-Reactivity Studies on the Complex of Pig Muscle Phosphoglycerate Kinase with ATP Analogues: Correlation between Nucleotide Binding Mode and Helix Flexibility *Biochemistry* v41 pp.8796-8806, 2002

In all 6 different structures were used as starting configurations for optimization at higher levels of theory. The lowest energy structure was found was used for Figure 1 in the main text.

B3LYP/6-311++G(d,p) optimization in solvent

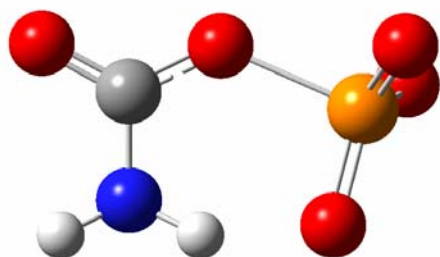
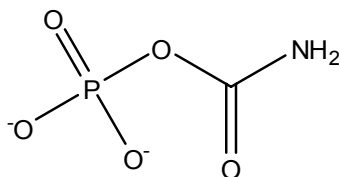
```
1\1\GINC-CST213\FOpt\RB3LYP\6-311++G(d,p)\C3H4O10P2(4-)\RUBEN\06-May-2006\O\#\P B3LYP/6-311++G** OPT(MAXCYCLE=900) FREQ POP=NBO SCRF(PCM, SOLVENT=WATER) GEOM(CHECK, STEP=13) GUESS=READ IOP(1/8=1)\Title Card Required\ -4, 1\0, 2. 1895647978, 0. 4502859557, -0. 0157472128\C, 1. 1823342612, -0. 2789773914, -0. 4340378655\O, 1. 2096630174, -1. 4733791925, -0. 691889426\C, -0. 1101795061, 0. 5348771265, -0. 6500431118\O, -0. 0228364297, 1. 8848829438, -0. 2180601783\C, -1. 2938043601, -0. 1235610745, 0. 0505825651\O, -2. 502641888, 0. 4301847341, -0. 4516903833\P, -3. 9857154786, -0. 1353437386, 0. 1597459989\O, -3. 9854416774, 0. 2077542544, 1. 6628805266\O, -4. 0109424633, -1. 6501483781, -0. 1264865944\O, -4. 9893167738, 0. 6819132707, -0. 6731532086\H, -0. 2938932395, 0. 4933664267, -1. 7368853593\H, 0. 8154381088, 2. 2659712198, -0. 5445801969\H, -1. 2108351138, 0. 0511676429, 1. 1317535491\H, -1. 2614079013, -1. 2010885099, -0. 1345693468\P, 3. 9117579017, -0. 0781382227, 0. 207923599\O, 4. 3249651515, -0. 5596495607, -1. 1800783648\O, 3. 8363369446, -1. 1379001301, 1. 3034257951\O, 4. 4993942495, 1. 2659036875, 0. 6370775287\Version=IBM64-G03RevC. 02\State=1-A\HF=-1552. 831585\RMSD=2. 975e-09\RMSF=8. 194e-05\Di pol e=2. 1753242, 1. 6788858, -1. 7090508\PG=C01 [X(C3H4O10P2)]\@\
```

B3LYP/6-311++G(d,p) frequencies in solvent

```
1\1\GINC-CST213\Freq\RB3LYP\6-311++G(d,p)\C3H4O10P2(4-)\RUBEN\06-May-2006\O\#\P GEOM=ALLCHECK GUESS=READ SCRF=CHECK TEST GENCHK RB3LYP/6-311++G(D,P) FREQ\Title Card Required\ -4, 1\0, 2. 1895647978, 0. 4502859557, -0. 0157472128\C, 1. 1823342612, -0. 2789773914, -0. 4340378655\O, 1. 2096630174, -1. 4733791925, -0. 691889426\C, -0. 1101795061, 0. 5348771265, -0. 6500431118\O, -0. 0228364297, 1. 8848829438, -0. 2180601783\C, -1. 2938043601, -0. 1235610745, 0. 0505825651\O, -2. 502641888, 0. 4301847341, -0. 4516903833\P, -3. 9857154786, -0. 1353437386, 0. 1597459989\O, -3. 9854416774, 0. 2077542544, 1. 6628805266\O, -4. 0109424633, -1. 6501483781, -0. 1264865944\O, -4. 9893167738, 0. 6819132707, -0. 6731532086\H, -0. 2938932395, 0. 4933664267, -1. 7368853593\H, 0. 8154381088, 2. 2659712198, -0. 5445801969\H, -1. 2108351138, 0. 0511676429, 1. 1317535491\H, -1. 2614079013, -1. 2010885099, -0. 1345693468\P, 3. 9117579017, -0. 0781382227, 0. 207923599\O, 4. 3249651515, -0. 5596495607, -1. 1800783648\O, 3. 8363369446, -1. 1379001301, 1. 3034257951\O, 4. 4993942495, 1. 2659036875, 0. 6370775287\Version=IBM64-G03RevC. 02\State=1-A\HF=-1552. 831585\RMSD=2. 592e-09\RMSF=8. 194e-05\Di pol e=2. 1753237, 1. 6788856, -1. 7090506\Di pol eDeriv=-2. 9593829, -0. 441194, -0. 6028073, -0. 3290236, -1. 1938523, -0. 1969985, -0. 6354635, -0. 2221167, -0. 8015075, 2. 0975095, 0. 2764421, 0. 4755373, 0. 742246, 2. 1029412, 0. 5898898, 0. 688346, 0. 4560943, 0. 6012237, -0. 8957419, 0. 1237023, -0. 0481032, -0. 3213639, -1. 9072219, -0. 3865405, -0. 1713231, -0. 3434251, -0. 6250698, -0. 0576067, 0. 2244455, 0. 0228667, 0. 0516894, 1. 022816, 0. 1987573, -0. 087062, 0. 2383973, 0. 4409282, -0. 6388766, -0. 0903084, -0. 09254, -0. 0242771, -1. 4191027, -0. 1459115, -0. 0933282, -0. 1086698, -0. 6378064, 1. 18659, -0. 199009, 0. 1045632, -0. 2272095, 0. 3749208, -0. 0041705, 0. 3060353, 0. 0491043, 0. 443357, -2. 4754568, -0. 0783385, 0. 1623182, -0. 0744201, -0. 921733, 0. 1725265, 0. 1374499, 0. 1693578, -0. 9725715, 3. 4669891, -0. 1931349, 0. 1754851, 0. 0622363, 3. 2834636, 0. 0842906, -0. 0786832, 0. 0991456, 3. 290361, -1. 2108079, 0. 0438335, 0. 0688668, 0. 0264244, -1. 1942264, -0. 3096616, 0. 2175186, -0. 2973072, -2. 3097405, -1. 2290646, -0. 0938141, -0. 0429805, -0. 2415545, -2. 3153269, -0. 2413164, -0. 016317, -0. 2707659, -1. 1752905, -1. 8179257, 0. 4919876, -0. 4911057, 0. 518545, -1. 4778538, 0. 3526634, -0. 5260077, 0. 3599081, -1. 4966263, 0. 0298427, 0. 0137234, -0. 022892, 0. 0176854, -0. 0315078, -0. 0137793, -0. 009001, -0. 0880568, -0. 0953762, 0. 4422566, 0. 0578532, 0. 05685, 0. 0113549, 0. 4878944, -0. 0581242, 0. 0680153, -0. 103288, 0. 3940246, -0. 0419421, 0. 0048897, -0. 0169668, 0. 0266497, 0. 0625242, -0. 0524089, -0. 1049944, -0. 0092316, -0. 1853911, 0. 0194424, -0. 0015011, -0. 0139211, 0. 0940741, -0. 1295989, -0. 0111959, -0. 0325229, -0. 0485665, 0. 0518104, 3. 592817, 0. 4161203, 0. 1491684, -0. 0274884, 3. 1988983, -0. 0477167, 0. 0445481, 0. 0423137, 3. 4151952, -1. 3546226, 0. 0952129, 0. 2954978, 0. 18432
```


88, -1.1448253, -0.2591955, 0.5128098, -0.3152118, -2.0271376, -1.1797685, -0.0257363, -0.0188159, 0.1550721, -1.5835654, 0.6140395, -0.1506406, 0.5980763, -1.7677496, -1.3906058, -0.4917009, -0.1728314, -0.5775617, -2.0378035, -0.3304292, -0.1810862, -0.2971159, -1.2244557\Pol ar=188.9086142, 2.0093474, 176.7412186, 6.6742963, 4.6568113, 163.3331641\PG=C01 [X(C3H4O10P2)]\NI mag=0\0.36360438, 0.10791012, 0.26075083, 0.09670291, 0.07432069, 0.10018934, -0.23827883, -0.07895276, -0.06037901, 0.53830234, -0.03919369, -0.14470267, -0.03010042, -0.00239389, 0.83914220, -0.05278658, -0.03834613, -0.085614

Carbamyl phosphate (10)



B3LYP/6-311++G(d,p) optimization in water

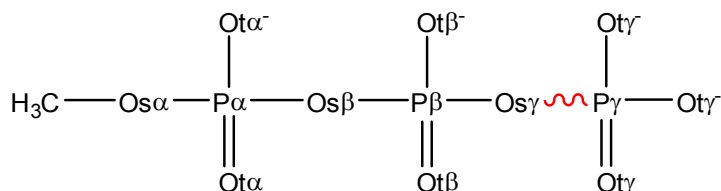
1\1\GINC-CSI T216\F0pt\RB3LYP\6-311++G(d,p)\C1H2N1O5P1(2-)\RUBEN\02-May-2006\0\#\P OPT FREQ B3LYP/6-311++G** POP=NB0 GUESS=READ GEOM=CHECK SCRF(PCM, SOLVENT=WATER)\cphos_fi n_gas\ -2, 1\N, -1.6037215947, 0.1972934907, -1.3217258596\C, -1.6984985901, -0.0685966443, 0.0009114934\O, -0.5546923467, -0.2809128772, 0.6622236658\P, 1.1214099104, 0.0190317163, 0.1281565196\O, 1.3227665969, 1.5018517634, 0.4340934274\O, -2.7748926464, -0.1188391152, 0.6071319385\O, 1.1069073268, -0.3412551664, -1.3649704236\O, 1.8694355496, -0.9553394671, 1.0315736855\H, -2.4606363419, 0.2451900097, -1.8613661463\H, -0.699665451, 0.0558185772, -1.7747879392\Versi on=I BM64-G03RevC.02\State=1-A\HF=-812.1712888\RMSD=6.426e-09\RMSF=3.416e-05\Di pol e=-2.8774212, -0.036292, -2.1801559\PG=C01 [X(C1H2N1O5P1)]\@\

B3LYP/6-311++G(d,p) frequencies in water

1\1\GINC-CSI T216\Freq\RB3LYP\6-311++G(d,p)\C1H2N1O5P1(2-)\RUBEN\02-May-2006\0\#\P GEOM=ALLCHECK GUESS=READ SCRF=CHECK GENCHK RB3LYP/6-311++G(D,P) FREQ\cphos_fi n_gas\ -2, 1\N, -1.6037215947, 0.1972934907, -1.3217258596\C, -1.6984985901, -0.0685966443, 0.0009114934\O, -0.5546923467, -0.2809128772, 0.6622236658\P, 1.1214099104, 0.0190317163, 0.1281565196\O, 1.3227665969, 1.5018517634, 0.4340934274\O, -2.7748926464, -0.1188391152, 0.6071319385\O, 1.1069073268, -0.3412551664, -1.3649704236\O, 1.8694355496, -0.955

3394671, 1. 0315736855\H, -2. 4606363419, 0. 2451900097, -1. 8613661463\H, -0. 699665451, 0. 0558185772, -1. 7747879392\\Version=I BM64-G03RevC. 02\State=1-A\HF=-812. 1712888\RMSD=3. 037e-09\RMSF=3. 416e-05\Di pol e=-2. 8774208, -0. 0362925, -2. 1801558\Di pol eDeri v=-0. 834119, 0. 0095969, -0. 0142585, 0. 0043474, -0. 7814484, 0. 3405174, 0. 1336798, 0. 210243, -1. 5800516, 3. 3335613, -0. 0300866, -0. 3916922, -0. 2254834, 0. 5279104, -0. 3718475, 0. 0280028, -0. 4027917, 2. 6193036, -2. 9811983, -0. 0139467, -0. 1818304, 0. 083009, -0. 685936, 0. 1314242, -0. 4084841, 0. 1186276, -1. 1180234, 3. 5011215, -0. 1122296, 0. 3601929, 0. 0355278, 3. 3532341, 0. 0600952, 0. 0906136, 0. 0612092, 3. 1564638, -1. 1980462, -0. 1173224, -0. 1023842, -0. 3747015, -2. 1868145, -0. 2587722, -0. 0975249, -0. 2502505, -1. 1337734, -2. 2711127, -0. 1152576, 0. 7493576, -0. 0257464, -0. 6158206, 0. 052761, 0. 6202641, 0. 0914494, -1. 2136857, -1. 341555, 0. 0293055, 0. 0097278, 0. 0654324, -1. 1863492, -0. 2946131, 0. 1408516, -0. 2686698, -2. 1097853, -1. 4610253, 0. 3761762, -0. 4007307, 0. 4880004, -1. 6075207, 0. 4360239, -0. 4764439, 0. 4207535, -1. 4962348, 0. 2733215, -0. 0072172, 0. 0982672, -0. 0107826, 0. 4263865, -0. 0474293, 0. 0591863, 0. 0025534, 0. 3092724, 0. 7568904, -0. 0227924, -0. 0130512, -0. 0326653, 0. 3790428, -0. 0396473, -0. 0234922, 0. 0227377, 0. 2486757\Pol ar=100. 5421557, -1. 3021971, 77. 305194, 0. 3986241, -2. 9043723, 90. 6620685\PG=C01 [X(C1H2N105P1)]\NI mag=0\0. 83282200, -0. 07780029, 0. 04442992, 0. 00242818,

Deprotonated methyl triphosphate (11)



B3LYP/6-311++G(d,p) optimization in gas

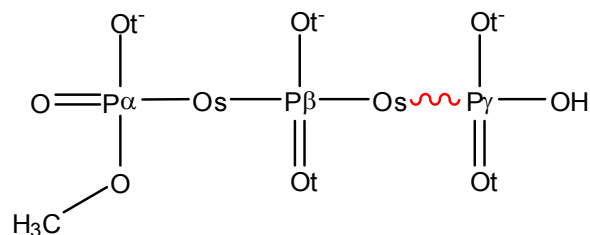
1\1\GINC-CST204\FOpt\RB3LYP\6-311++G(d,p)\C1H3010P3(4-)\RUBEN\28-Oct-2005\0\#\#P B3LYP/6-311++G** OPT(MAXCYCLE=600) FREQ POP=NB0\atp_j ccf_gas_out\ -4, 1\0, -1. 99740487, -1. 0433090398, -3. 0902028443\P, -1. 996252605, -1. 0314528685, -1. 5702853114\0, -0. 5532434051, -1. 0344803272, -0. 8766569128\P, 1. 0417893267, -0. 3061941407, -0. 702583074\0, 0. 8641077777, 0. 2847926817, 0. 7721941409\P, 1. 6808757326, 1. 0386612811, 2. 2119117471\0, 0. 6443311168, 2. 1098192671, 2. 6187832756\0, 1. 8118626656, -0. 1234397075, 3. 2182407003\0, 3. 0202849151, 1. 6002160119, 1. 6978197013\0, 1. 148861782, 0. 7701193133, -1. 7656459631\0, 1. 9736689654, -1. 5025647154, -0. 7850791004\0, -2. 6113764272, 0. 4931989895, -1. 1573237452\0, -2. 8816535985, -2. 0668686192, -0. 8729084325\0, -2. 4786051502, 0. 9115193695, 0. 1960652883\H, -3. 0640577084, 0. 2608768728, 0. 8675844651\H, -1. 4381756613, 0. 9195503076, 0. 5364980007\H, -2. 8778339183, 1. 9353716898, 0. 2601088203\\Version=I BM64-G03RevC. 02\State=1-A\HF=-1816. 4431879\RMSD=4. 997e-09\RMSF=6. 252e-06\Di pol e=-2. 7279597, -0. 0316727, -1. 3582032\PG=C01 [X(C1H3010P3)]\@

B3LYP/6-311++G(d,p) frequencies in gas

1\1\GINC-CST204\Freq\RB3LYP\6-311++G(d,p)\C1H3010P3(4-)\RUBEN\28-Oct-2005\0\#\#P GEOM=ALLCHECK GUESS=READ SCRF=CHECK GENCHK RB3LYP/6-311++G(D,P) FREQ\atp_j ccf_gas_out\ -4, 1\0, -1. 99740487, -1. 0433090398, -3. 0902028443\P, -1. 996252605, -1. 0314528685, -1. 5702853114\0, -0. 5532434051, -1. 0344803272, -0. 8766569128\P, 1. 0417893267, -0. 3061941407, -0. 702583074\0, 0. 8641077777, 0. 2847926817, 0. 7721941409\P, 1. 6808757326, 1. 0386612811, 2. 2119117471\0, 0. 6443311168, 2. 1098192671, 2. 6187832756\0, 1. 8118626656, -0. 1234397075, 3. 2182407003\0, 3. 0202849151, 1. 6002160119, 1. 6978197013\0, 1. 148861782, 0. 7701193133, -1. 7656459631\0, 1. 9736689654, -1. 5025647154, -0. 7850791004\0, -2. 6113764272, 0. 4931989895, -1. 1573237452\0, -2. 8816535985, -2. 066

8686192, -0.8729084325\C, -2.4786051502, 0.9115193695, 0.1960652883\H, -3.0640577084, 0.2608768728, 0.8675844651\H, -1.4381756613, 0.9195503076, 0.5364980007\H, -2.8778339183, 1.9353716898, 0.2601088203\\Versi on=I BM64-G03RevC.02\State=1-A\HF=-1816.4431879\RMSD=4.118e-09\RMSF=6.254e-06\Di pol e=-2.7279597, -0.0316734, -1.3582028\Di pol eDeri v=-0.8951274, -0.0767797, -0.0768692, -0.0415887, -0.7937222, -0.0567509, -0.1897735, -0.1633822, -1.7287933, 2.9019902, 0.4451756, 0.1740824, 0.1741325, 2.2544302, 0.3308859, 0.3847899, 0.2264422, 2.4972375, -2.8182227, -0.5151176, -0.6433715, -0.5167645, -0.8410659, -0.2033062, -0.6738398, -0.174098, -0.9265909, 2.9710447, -0.0617112, 0.0982514, 0.336341, 2.341812, 0.4015905, 0.3484433, 0.3579279, 2.8694288, -1.0017942, -0.1513921, -0.3869369, -0.2905623, -1.0347818, -0.9032524, -0.6857274, -0.9240223, -2.6342226, 2.4296665, 0.1263372, 0.3902288, 0.0256625, 2.334897, 0.2582162, 0.2344522, 0.2652023, 2.8583952, -1.2227332, 0.4049076, 0.1582733, 0.3780087, -1.298903, -0.2856406, 0.1088111, -0.234607, -0.9999317, -0.8655916, 0.0493312, -0.1165694, 0.126226, -1.2543491, 0.5258582, -0.1485023, 0.3678925, -1.3913428, -1.5949028, -0.3604182, 0.0314443, -0.3344109, -0.9804132, 0.0013815, 0.2077435, 0.0808323, -0.9220277, -0.9149644, -0.0280956, 0.045385, -0.1646564, -1.0970225, 0.3411246, 0.0904205, 0.2721713, -1.2742943, -1.2035735, 0.3861505, 0.0863367, 0.4414934, -1.303096, -0.1816548, 0.061962, -0.1063705, -0.8950856, -0.768991, 0.1705566, 0.0167549, 0.2761232, -1.2254624, -0.4333571, 0.103272, -0.4178715, -1.1136903, -1.2648113, -0.4498356, 0.0898815, -0.4330849, -1.2573166, 0.0585304, 0.1994101, 0.2214782, -0.9267462, 0.2041202, -0.0099164, -0.0739557, -0.0193899, 0.5215023, 0.0779659, -0.2214443, 0.2920879, 0.8068905, -0.0998802, -0.0475836, 0.1613428, -0.1374836, -0.0363282, 0.1542318, 0.1402358, 0.0188359, -0.1950117, 0.1628744, -0.0350238, 0.002655, -0.0007033, 0.0245627, 0.0213115, 0.0794938, -0.0273671, 0.0022865, -0.0191038, 0.1534151, 0.0430663, 0.1806572, -0.3547432, -0.1071344, 0.0160189, -0.0551521, -0.0265012\Pol ar=159.8943408, 2.6101218, 141.1270117, 5.8888811, 11.8444645, 158.8451695\PG=C01 [X(C1H3010P3)]\NI mag=0\\0.05270219, 0.00416909, 0.05482295, -0.00744939, 0.00168118, 0.48471255, -0.06

Methyl triphosphate protonated once (12)



Conformational searches at the PM3 level was performed for the P-Os-P-OH dihedral only.

B3LYP/6-311++G(d,p) optimization in gas phase

1\\GINC-CSIT213\FOpt\RB3LYP\6-311++G(d,p)\C1H4010P3(3-)\RUBEN\28-Oct-2005\0\\#P B3LYP/6-311++G** OPT(MAXCYCLE=600) FREQ POP=NB0\\atp_jccf_7_gas_out\\-3,1\\0, -2.5313678287, 0.0658596294, -2.7245647494\P, -2.3394345263, -0.3216934771, -1.2840814839\\0, -0.7681269942, -0.6297739584, -0.8984229569\P, 0.7829275944, -0.0476925911, -0.9265560643\\0, 0.9112369774, 0.4721167878, 0.6447784175\P, 2.059296635, 0.2059898545, 1.8455019365\\0, 2.4824673906, -1.3557924545, 1.5069024239\\0, 3.2444505982, 1.1227301918, 1.6281386858\\0, 1.3441847668, 0.2384391351, 3.1771370149\\0, 0.9168694942, 1.1044442895, -1.8756353654\\0, 1.6860402936, -1.2696408324, -1.0557168829\\0, -2.6353220509, 1.065843825, -0.3901564505\\0, -3.1534013693, -1.446487301, -0.679248525\\C, -2.4390249775, 1.0024702151, 1.0178995709\\H, -3.0550750664, 0.2080127069, 1.4619186877\\H, -1.389650174, 0.8280861745, 1.2726344602\\H, -2.7487245896, 1.9728511809, 1.4288531089\\H, 2.3095039257, -1.5147426466, 0.5405375977\\Versi on=I BM64-G03RevC.02\State=1-A\HF=-1817.3711733\RMSD=6.350e-09\RMSF=5.747e-06\Di pol e=-1.0458402, 0.0812027, 0.4355924\PG=C01 [X(C1H4010P3)]\\@

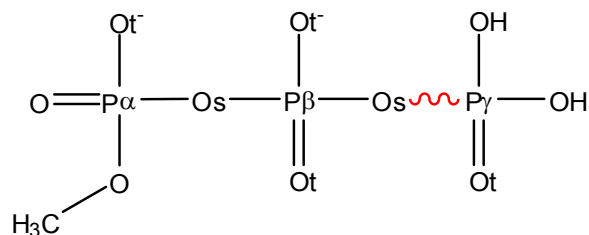
B3LYP/6-311++G(d,p) frequencies in gas phase

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1\1\GINC-CSI T213\Freq\RB3LYP\6-311++G(d,p)\C1H4O10P3(3-)\RUBEN\28-Oct-
2005\0\#P GEOM=ALLCHECK GUESS=READ SCRF=CHECK GENCHK RB3LYP/6-311++G(
D,P) FREQ\atp_jccf_7_gas_out\ -3,1\0, -2.5313678287, 0.0658596294, -2.72
45647494\P, -2.3394345263, -0.3216934771, -1.2840814839\0, -0.7681269942, -
0.6297739584, -0.8984229569\P, 0.7829275944, -0.0476925911, -0.9265560643\
0, 0.9112369774, 0.4721167878, 0.6447784175\P, 2.059296635, 0.2059898545, 1.
8455019365\0, 2.4824673906, -1.3557924545, 1.5069024239\0, 3.2444505982, 1.
1227301918, 1.6281386858\0, 1.3441847668, 0.2384391351, 3.1771370149\0, 0.9
168694942, 1.1044442895, -1.8756353654\0, 1.6860402936, -1.2696408324, -1.0
557168829\0, -2.6353220509, 1.065843825, -0.3901564505\0, -3.1534013693, -1
.446487301, -0.679248525\C, -2.4390249775, 1.0024702151, 1.0178995709\H, -3
.0550750664, 0.2080127069, 1.4619186877\H, -1.389650174, 0.8280861745, 1.27
26344602\H, -2.7487245896, 1.9728511809, 1.4288531089\H, 2.3095039257, -1.5
147426466, 0.5405375977\Version=IBM64-G03RevC.02\State=1-A\HF=-1817.37
11733\RMSD=3.985e-09\RMSF=5.762e-06\Di pol e=-1.0458415, 0.0812029, 0.4355
931\Di pol eDeri v=-0.9344529, -0.0214273, -0.1622178, 0.0509712, -0.773209, 0
.160552, -0.2730488, 0.0969945, -1.5125241, 3.0860228, 0.2671707, 0.1800647,
-0.0174854, 2.0934387, 0.2490316, 0.2713882, 0.0511733, 2.4997469, -3.004173
7, -0.1324218, -0.3460097, -0.2408522, -0.7003138, -0.0353508, -0.3035194, 0.
0262982, -0.7558752, 3.1307167, -0.1394797, 0.261574, 0.2778313, 2.092313, 0.
0126787, 0.3693746, -0.1109768, 2.6001543, -1.3519121, 0.0515236, -0.7095741
, 0.001526, -0.7116656, -0.1990759, -0.8914425, -0.1609895, -2.1738334, 2.518
4686, 0.2759686, 0.427102, 0.1951295, 2.0794417, 0.1675586, 0.2792567, 0.2371
848, 2.7926267, -0.7804426, 0.1384115, -0.1125829, 0.156821, -1.2640325, -0.2
133003, -0.1459463, -0.1914864, -1.0424288, -1.3660517, -0.4017936, -0.10307
29, -0.4346519, -1.0285829, -0.0705229, 0.0307888, 0.0141386, -0.8752161, -0.
9665664, -0.0376014, 0.2620516, -0.0413754, -0.7462572, -0.0085822, 0.165328
5, -0.0573515, -1.5248189, -0.9150776, -0.0337909, 0.0330281, -0.139977, -1.0
65706, 0.4003567, 0.0531953, 0.3002288, -1.1096652, -1.1753858, 0.3232617, -0
.0775076, 0.4131871, -1.1503418, -0.0694928, -0.1374385, -0.0291563, -1.0733
669, -0.6983945, 0.054043, -0.0052588, 0.154358, -0.9936011, -0.4101371, 0.11
25035, -0.4025884, -1.3377578, -1.1804037, -0.3491791, 0.0410007, -0.3904444
, -1.1793451, 0.0329946, 0.1588231, 0.1737799, -0.8927917, 0.2490735, 0.01254
57, -0.0178834, 0.0287549, 0.3841109, -0.0282863, -0.1055725, 0.1872534, 0.82
6816, -0.069881, -0.0739027, 0.118017, -0.129761, -0.0456591, 0.1621755, 0.06
43969, 0.0381171, -0.0949149, 0.08093, -0.0243314, -0.0614762, -0.0088785, 0.
0358605, 0.0229881, 0.0006257, -0.0212591, -0.0212221, 0.0143414, 0.0972435,
0.0583087, 0.122241, -0.2517671, -0.196994, 0.0458763, -0.1344352, -0.101250
7, 0.3631889, -0.0062403, 0.2144367, 0.0026058, 0.2253163, 0.0234067, 0.30541
04, -0.0169254, 0.796322\Pol ar=137.0745011, 1.9151092, 115.4867493, 6.25538
, 2.4930984, 138.5405822\PG=C01 [X(C1H4O10P3)]\NI mag=0\0.05847329, -0.01

```

Methyl triphosphate protonated twice (13)



Conformational searches at the PM3 level was performed for the P-Os-P-OH dihedral only.

B3LYP/6-311++G(d,p) optimization in gas phase

```

1\1\GINC-CSI T202\FOpt\RB3LYP\6-311++G(d,p)\C1H5010P3(2-)\RUBEN\28-Oct-
2005\0\#\P B3LYP/6-311++G** OPT(MAXCYCLE=600) FREQ POP=NB0\atp_jccf_7
_9_gas_out\ -2, 1\0, -1.8536037741, -0.4312031511, -0.7186266991\P, -1.8528
759114, -0.4315638979, 0.7921308661\0, -0.3085648609, -0.4315253316, 1.3753
943585\P, 1.2383353462, -0.5183541827, 0.849622416\0, 1.2651331415, 0.68007
61898, -0.3376753412\P, 1.2502989193, 0.6114217834, -1.9606927337\0, -0.280
9435721, 0.7309402877, -2.3662733421\0, 2.0838342003, 1.6526795193, -2.6135
568916\0, 1.740635261, -0.8830952982, -2.2876006181\0, 1.4610507173, -1.821
9128189, 0.1036947924\0, 2.1168148575, -0.0837920728, 1.9720706169\0, -2.29
13278121, 1.1133947575, 1.2247773866\0, -2.6613619161, -1.4120562137, 1.583
1390259\C, -2.2698565713, 1.4499392639, 2.6016054442\H, -2.8994480728, 0.76
67508851, 3.1852443341\H, -1.2480799376, 1.4163279632, 2.9966745172\H, -2.6
57780632, 2.4701162273, 2.6913578031\H, -0.9256469118, 0.2706806722, -1.722
2967944\H, 1.6403897313, -1.4541138166, -1.4592670578\Versi on=I BM64-G03R
evC. 02\State=1-A\HF=-1818. 1472545\RMSD=3.822e-09\RMSF=5.032e-06\Di pol e
=-0.9839097, 0.7481113, 0.7451716\PG=C01 [X(C1H5010P3)]\@

```

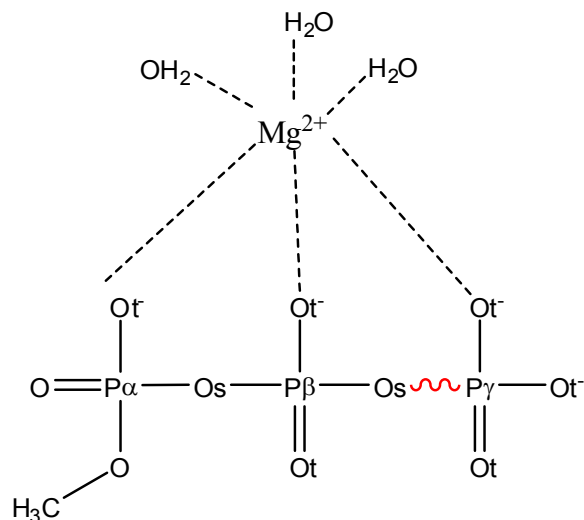
B3LYP/6-311++G(d,p) frequencies in gas phase

```

1\1\GINC-CSI T202\Freq\RB3LYP\6-311++G(d,p)\C1H5010P3(2-)\RUBEN\28-Oct-
2005\0\#\P GEOM=ALLCHECK GUESS=READ SCRF=CHECK GENCHK RB3LYP/6-311++G(
D,P) FREQ\atp_jccf_7_9_gas_out\ -2, 1\0, -1.8536037741, -0.4312031511, -0
.7186266991\P, -1.8528759114, -0.4315638979, 0.7921308661\0, -0.3085648609
, -0.4315253316, 1.3753943585\P, 1.2383353462, -0.5183541827, 0.849622416\0
, 1.2651331415, 0.6800761898, -0.3376753412\P, 1.2502989193, 0.6114217834, -
1.9606927337\0, -0.2809435721, 0.7309402877, -2.3662733421\0, 2.0838342003
, 1.6526795193, -2.6135568916\0, 1.740635261, -0.8830952982, -2.2876006181\
0, 1.4610507173, -1.8219128189, 0.1036947924\0, 2.1168148575, -0.0837920728
, 1.9720706169\0, -2.2913278121, 1.1133947575, 1.2247773866\0, -2.661361916
1, -1.4120562137, 1.5831390259\C, -2.2698565713, 1.4499392639, 2.6016054442
\H, -2.8994480728, 0.7667508851, 3.1852443341\H, -1.2480799376, 1.416327963
2, 2.9966745172\H, -2.657780632, 2.4701162273, 2.6913578031\H, -0.925646911
8, 0.2706806722, -1.7222967944\H, 1.6403897313, -1.4541138166, -1.459267057
8\Versi on=I BM64-G03RevC. 02\State=1-A\HF=-1818. 1472545\RMSD=2.619e-09\
RMSF=5.035e-06\Di pol e=-0.9839092, 0.7481122, 0.7451717\Di pol eDeri v=-1.04
58718, -0.1103071, 0.2882019, -0.15729, -0.7362386, 0.1308338, 0.2493092, 0.0
762788, -1.6516906, 2.8636935, 0.0076275, -0.5098432, -0.0265253, 2.2697865,
0.3744003, -0.1606331, -0.0232545, 2.3813047, -2.6787775, 0.1462449, 0.33362
77, 0.0960233, -0.6196811, -0.0574776, 0.0407764, -0.0123948, -0.8347832, 2.9
098391, -0.1300803, 0.0059531, -0.1256285, 2.0257494, -0.1913167, -0.2216508
, 0.0295329, 2.7231625, -0.7296304, -0.004534, 0.0438139, -0.0596401, -1.0132
949, 0.5517805, 0.1495507, 0.5155184, -2.1358243, 2.4552963, 0.0925559, -0.30
06843, 0.061123, 2.2497857, -0.2925207, -0.2279089, -0.5150094, 2.5973679, -1
.6181557, -0.0877246, 0.2036391, -0.1828291, -0.6819516, 0.2265422, 0.179281
2, 0.2080328, -0.9831963, -0.9670881, -0.2540261, 0.2806286, -0.2674856, -1.0
304559, 0.3252369, 0.2080032, 0.2736377, -0.9610175, -0.7190807, 0.1434913, 0
.1139061, 0.1877961, -1.2431258, 0.1302206, 0.1260546, 0.107715, -1.0460964,
-0.8402775, 0.0962664, 0.0618207, 0.2099359, -1.1568467, -0.1137891, 0.16242
93, -0.155034, -1.2316051, -1.1084024, -0.0255019, -0.3181319, -0.1073354, -0
.7336072, -0.1586465, -0.3204448, -0.0873299, -1.2000663, -0.692189, 0.14797
53, 0.1724408, 0.3097957, -1.2137439, -0.5339935, 0.2394269, -0.4223076, -1.1
480901, -1.0871396, -0.2424156, 0.230101, -0.2904594, -1.0696433, 0.1012979,
0.3075327, 0.2232015, -0.9348021, 0.3257971, -0.0192349, -0.0289373, -0.0278
852, 0.412474, 0.105123, -0.1651402, 0.315153, 0.8065142, -0.0503986, -0.0472
889, 0.115718, -0.108318, 0.0079217, 0.1277969, 0.0898935, 0.0029793, -0.1072
01, -0.0918596, -0.0482932, -0.133177, -0.0048607, 0.0524057, 0.011507, -0.03
74382, -0.0435989, -0.0397614, 0.0136006, 0.1188156, 0.0413164, 0.1347102, -0
.2464603, -0.1196634, 0.0212236, -0.0461866, -0.007681, 0.7847024, 0.2073532
, -0.5295971, 0.3387122, 0.3779768, -0.3334451, -0.5458306, -0.2213088, 0.821
7713, 0.275942, 0.0090764, -0.0707965, 0.0201607, 0.3489495, -0.2838863, -0.0
944348, -0.2256248, 0.9516948\Pol ar=120.3906897, 1.6998014, 107.8100854, -1
1.0686585, -2.0173713, 127.8463052\PG=C01 [X(C1H5010P3)]\NI mag=0\

```

Methyl triphosphate with oxygen atoms on $P\alpha$, $P\beta$ and $P\gamma$ coordinated Mg^{2+} 3 water molecules complete the coordination to Mg^{2+} (14)



This conformation of triphosphate in complex with Mg^{2+} was obtained from the transition state analogue structure of arginine kinase²³ (Zhou et al).

B3LYP/6-311++G(d,p) optimization in gas phase

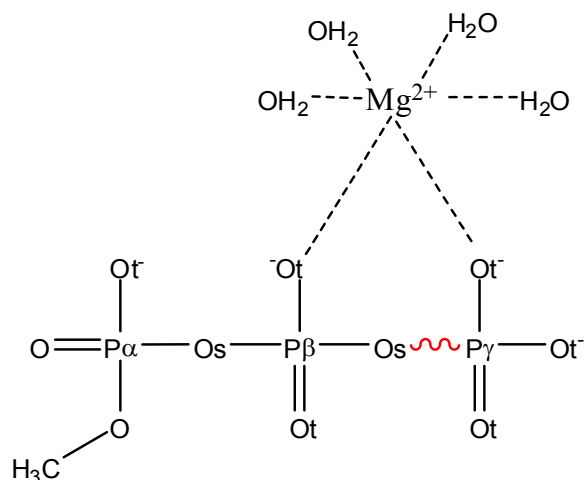
```
1\1\GINC-BOHR\FOpt\RB3LYP\6-311++G(d,p)\C1H9Mg1013P3(2-)\RUBEN\28-Sep-
2005\O\#P B3LYP/6-311++G** OPT(MAXCYCLE=500) FREQ POP=NBO SCF=DAMP GU
ESS=READ GEOM=CHECK\mgatp\ -2, 1\C, -3. 6142540182, 0. 0205819176, -1. 08271
23228\O, -3. 5391038716, 0. 0701624575, 0. 3357302254\P, -2. 0949515683, 0. 0331
26384, 1. 1433897259\O, -1. 3100982566, -1. 1803911982, 0. 3936942874\P, -0. 282
1657363, -1. 3681758884, -0. 9167292267\O, 1. 0751946516, -1. 8520878429, -0. 24
86136203\P, 2. 4093886367, -0. 9919210037, 0. 4929875867\O, 1. 6444944779, 0. 25
64913511, 1. 0963361224\O, 2. 9907902065, -1. 9432462651, 1. 489544326\O, 3. 274
7567266, -0. 5152274553, -0. 6819391184\O, -0. 0970084059, 0. 0805827964, -1. 45
98796809\Mg, 0. 5006408932, 1. 4243920411, -0. 0367416453\O, -0. 879818981, -2.
375831605, -1. 8375633651\O, -0. 8568196022, 2. 7303236273, -1. 3832650154\O, -
1. 3542481558, 1. 348077317, 0. 7975365624\O, 1. 797417029, 2. 8092130646, 1. 103
413259\O, -2. 4051383721, -0. 278220402, 2. 5595189245\O, 2. 134125532, 1. 63510
73552, -1. 5735588895\H, -1. 4705024474, 2. 5273255674, -0. 6586505627\H, -0. 89
9200907, 1. 9098753212, -1. 913342673\H, 2. 4431146434, 3. 0173095748, 0. 405245
7078\H, 2. 0743373915, 1. 901136535, 1. 4239565677\H, 2. 7008338752, 0. 92297629
3, -1. 2730125695\H, -4. 6753245036, -0. 0599976873, -1. 3377881827\H, -3. 07888
10375, -0. 8433482295, -1. 4868544871\H, -3. 2157394762, 0. 9339167054, -1. 5416
461993\H, 1. 5187820418, 1. 0995419395, -2. 2030873488\Versi on=I A64-Li nux-G
03RevB. 05\State=1-A\HF=-2246. 6196233\RMSD=9. 143e-09\RMSF=1. 086e-02\Di p
ole=-1. 7180418, 3. 2224041, -2. 0855995\PG=C01 [X(C1H9Mg1013P3)]\@
```

B3LYP/6-311++G(d,p) frequencies in gas phase

```
1\1\GINC-BOHR\Freq\RB3LYP\6-311++G(d,p)\C1H9Mg1013P3(2-)\RUBEN\29-Sep-
2005\O\#P GEOM=ALLCHECK GUESS=READ SCRF=CHECK GENCHK RB3LYP/6-311++G(
D,P) FREQ\mgatp\ -2, 1\C, -3. 6142540182, 0. 0205819176, -1. 0827123228\O, -3
. 5391038716, 0. 0701624575, 0. 3357302254\P, -2. 0949515683, 0. 033126384, 1. 14
33897259\O, -1. 3100982566, -1. 1803911982, 0. 3936942874\P, -0. 2821657363, -1
. 3681758884, -0. 9167292267\O, 1. 0751946516, -1. 8520878429, -0. 2486136203\P
, 2. 4093886367, -0. 9919210037, 0. 4929875867\O, 1. 6444944779, 0. 2564913511, 1
```

.0963361224\0, 2.9907902065, -1.9432462651, 1.489544326\0, 3.2747567266, -0.5152274553, -0.6819391184\0, -0.0970084059, 0.0805827964, -1.4598796809\Mg, 0.5006408932, 1.4243920411, -0.0367416453\0, -0.879818981, -2.375831605, -1.8375633651\0, -0.8568196022, 2.7303236273, -1.3832650154\0, -1.3542481558, 1.348077317, 0.7975365624\0, 1.797417029, 2.8092130646, 1.103413259\0, -2.4051383721, -0.278220402, 2.5595189245\0, 2.134125532, 1.6351073552, -1.5735588895\H, -1.4705024474, 2.5273255674, -0.6586505627\H, -0.899200907, 1.9098753212, -1.913342673\H, 2.4431146434, 3.0173095748, 0.4052457078\H, 2.0743373915, 1.901136535, 1.4239565677\H, 2.7008338752, 0.922976293, -1.2730125695\H, -4.6753245036, -0.0599976873, -1.3377881827\H, -3.0788810375, -0.8433482295, -1.4868544871\H, -3.2157394762, 0.9339167054, -1.5416461993\H, 1.5187820418, 1.0995419395, -2.2030873488\Version=A64-Linux-G03RevB.05\State=1-A\HF=-2246.6196233\RMSD=9.143e-09\RMSF=1.086e-02\Di pol e=-1.7180418, 3.2224041, -2.0855995\Di pol eDeriv=0.345277, 0.0606374, 0.0446202, 0.04452, 0.2759854, -0.0332613, 0.2465061, -0.0529998, 0.7471256, -1.2062477, 0.0042539, -0.3744967, 0.0230052, -0.510631, -0.0238752, -0.4803411, 0.0342003, -1.2148621, 2.7363645, 0.0517336, -0.0719952, -0.1639164, 2.1487205, 0.1303037, -0.3581488, -0.0242136, 2.5478364, -1.5172315, 0.3484261, 0.5570559, 0.5310984, -1.0835902, -0.3934468, 0.8886545, -0.441459, -1.3078464, 2.9869765, 0.0162397, 0.1039895, -0.1259094, 2.3395007, 0.1240598, -0.0327329, 0.4670386, 2.2328432, -2.1694134, -0.0940709, -0.6070232, -0.1384999, -0.9003301, -0.0941124, -0.7839718, -0.1093366, -0.9064615, 2.8251774, -0.3447028, 0.1649858, 0.0502807, 2.2567964, -0.1505987, 0.3214435, -0.2588315, 2.2201209, -1.1081878, 0.3451441, 0.0582968, 0.2512374, -1.5919558, -0.2406604, -0.0215069, -0.2235663, -0.9009538, -0.9912793, 0.2340824, -0.200604, 0.2732114, -1.0404204, 0.329125, -0.3259204, 0.3620096, -1.0636939, -1.1666274, 0.0416105, 0.1965492, -0.043274, -1.0180025, 0.3140425, 0.318137, 0.2834771, -1.1479202, -1.043246, -0.1337075, 0.0210783, -0.1198535, -1.504227, 0.2547953, 0.0318512, 0.1245543, -0.8827395, 1.702808, 0.088944, 0.0191438, 0.0005351, 1.3784421, 0.0182249, 0.0784309, 0.0051001, 1.1619135, -0.993211, -0.1670633, -0.1881975, -0.1347699, -1.0900059, -0.3417492, -0.1647915, -0.3748158, -0.9932958, -0.6740889, 0.0928538, 0.0001638, 0.1364445, -0.7513031, 0.162822, -0.0177364, 0.1756087, -0.7045787, -1.1785426, -0.2824648, 0.1155745, -0.3186129, -1.3200468, 0.1283169, 0.2530598, 0.2344958, -0.9179595, -0.5531458, -0.0876658, -0.1532081, -0.1634817, -1.1035867, -0.1390511, -0.1572806, -0.0322511, -0.561756, -0.8484044, -0.0392161, 0.1990895, -0.0290746, -0.7157428, 0.1244286, 0.2477887, 0.0880174, -1.3747255, -0.8539877, 0.0831684, 0.0047243, 0.0496084, -0.8418978, 0.2819637, 0.0089629, 0.1742853, -0.7367779, 0.2759494, 0.0139851, -0.0589404, -0.0038343, 0.4092028, -0.1264072, -0.0641042, -0.214188, 0.4492354, 0.3018962, -0.1015084, 0.0138939, -0.1104699, 0.44569, -0.0948728, 0.0019203, -0.0224501, 0.2854477, 0.2252861, 0.0371008, 0.0697478, 0.0713917, 0.3409152, 0.0175863, 0.075624, 0.0679955, 0.276183, 0.2123935, 0.0488853, 0.0403713, 0.0874288, 0.9671905, 0.1236924, 0.0367102, -0.0154868, 0.2830957, 0.3837629, -0.2821217, 0.1502214, -0.1905461, 0.6892162, -0.3342224, 0.0652264, -0.2620591, 0.3680002, -0.2761874, -0.0191619, -0.1374353, -0.0241641, 0.069015, -0.0031256, -0.077613, -0.0014904, -0.0233227, 0.1030218, 0.0283689, 0.0472179, 0.0080165, -0.0117208, -0.0485603, -0.0300762, 0.0019905, -0.0271813, 0.0379966, -0.0885392, 0.0626269, -0.0564566, -0.1296592, 0.1283051, -0.0131311, 0.0616268, -0.0892378, 0.4428909, 0.1447883, -0.07745, 0.0960852, 0.2924454, -0.1137231, -0.0469607, -0.0472519, 0.281511\Pol ar=160.8725258, -0.2962689, 147.2258876, 4.8950643, -2.7976092, 145.8506851\PG=C01 [X(C1H9Mg1013P3)]\NI mag=0

Methyl triphosphate with oxygen atoms on P β and P γ coordinated Mg²⁺, 4 water molecules complete the coordination to Mg²⁺ (15).



This conformation of triphosphate in complex with Mg^{2+} was obtained from the bis(Mg^{2+})-ATP-oxalate complex of the pyruvate kinase³⁴ (Larsen et al).

35) Larsen TM, Benning MM, Rayment I, Reed GH.

Structure of the bis(Mg^{2+})-ATP-oxalate complex of the rabbit muscle pyruvate kinase at 2.1 Å resolution: ATP binding over a barrel.

Biochemistry. 1998 May 5;37(18):6247-55.

B3LYP/6-311++G(d,p) optimization in gas phase

```
1\1\GINC-CSI T204\F0pt\RB3LYP\6-311++G(d,p)\C1H11Mg1014P3(2-)\RUBEN\15-
Mar-2006\0\#\#P B3LYP/6-311++G** OPT(MAXCYCLE=900,MODREDUNDANT) FREQ PO
P=NB0\mgatp_3a_final_check\ -2, 1\P, -0.7329595632, 1.8181613772, 2.05081
01267\0, -0.7592412222, 1.8758379048, 3.5442954156\0, 0.7133314558, 1.79540
7044, 1.3958080438\0, -1.5793836849, 2.8280531542, 1.2474653621\P, -1.46033
11691, -0.5095596023, 0.2281002774\0, -2.8249459742, -1.043087699, -0.01858
53702\0, -0.7946515376, 0.3677086985, -0.8597520709\0, -1.3257708078, 0.258
1372425, 1.6316597538\P, 0.6341717937, -2.6303209879, -0.4507608717\0, 1.69
18696847, -1.6990973935, -1.0748635401\0, 1.1184863078, -3.8390600705, 0.28
11069643\0, -0.3840729152, -1.771287545, 0.4650759163\0, -0.3819922795, -3.
0637620567, -1.6869900182\C, 0.0972786451, -4.0052452122, -2.6278805906\Mg
, 0.8656724472, 1.5067171704, -0.5965109872\H, 0.9526342434, -3.6098126859,
-3.192286225\H, 0.3993971661, -4.9378179936, -2.1364398226\H, -0.722071406
, -4.2104621848, -3.3228748893\0, 1.2073595034, 0.5199036221, -2.5301323372
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B3LYP/6-311++G(d,p) frequencies in gas phase

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Supplementary notes on solvent calculations (dmso vs water).

The DMSO system was made up of a simple methyl monophosphate molecule coordinated to three DMSO molecules and optimized in DMSO using the PCM method. The water system was made up of a simple methyl monophosphate molecule coordinated to three water molecules and optimized in water using the PCM method. This way both the dielectric and stereoelectronic effects of DMSO and water are modeled.

Results

DMSO	Water
O—P bond length = 1.71 Å E(2) $n(\text{O}) \rightarrow \sigma^*(\text{O—P}) = 61 \text{ kcal/mol}$	O—P bond length = 1.68 Å E(2) $n(\text{O}) \rightarrow \sigma^*(\text{O—P}) = 50 \text{ kcal/mol}$

Variations of OH bond lengths with bonding and antibonding orbital occupancy

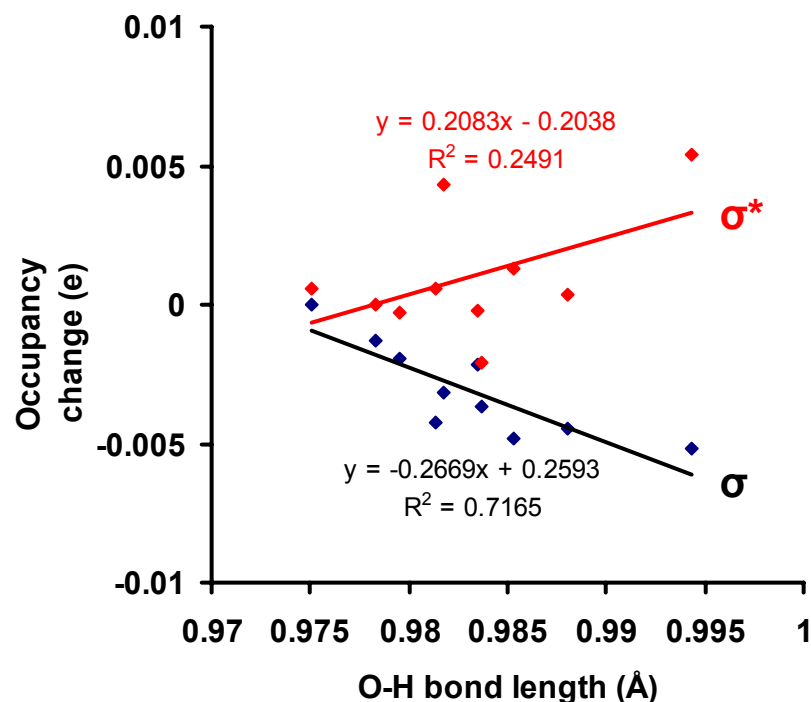


Figure S2 : Decrease in $\sigma(\text{O—H})$ and increase in $\sigma^*(\text{O—H})$ occupancies and their correlation with O—H bond lengths. All calculations were performed using the B3LYP/6-311++G(d,p) level in PCM with Pauling explicit hydrogen radii. All points were calculated using default G03 convergence criteria except for acetic acid which could not reach convergence and so was calculated using a loose optimization.

Full Gaussian reference

Frisch, M. J.; Trucks, G. W.; Schlegel, H. B.; Scuseria, G. E.; Robb, M. A.; Cheeseman, J. R.; Montgomery Jr., J. A.; Vreven, T.; Kudin, K. N.; Burant, J. C.; Millam, J. M.; Iyengar, S. S.; Tomasi, J.; Barone, V.; Mennucci, B.; Cossi, M.; Scalmani, G.; N. Rega; Petersson, G. A.; Nakatsuji, H.; Hada, M.; Ehara, M.; Toyota, K.; Fukuda, R.; Hasegawa, J.; Ishida, M.; Nakajima, T.; Honda, Y.; Kitao, O.; Nakai, H.; Klene, M.; Li, X.; Knox, J. E.; Hratchian, H. P.; Cross, J. B.; Adamo, C.; Jaramillo, J.; Gomperts, R.; Stratmann, R. E.; Yazyev, O.; Austin, A. J.; Cammi, R.; Pomelli, C.; Ochterski, J. W.; Ayala, P. Y.; Morokuma, K.; Voth, G. A.; Salvador, P.; Dannenberg, J. J.; Zakrzewski, V. G.; Dapprich, S.; Daniels, A. D.; Strain, M. C.; Farkas, O.; Malick, D. K.; Rabuck, A. D.; Raghavachari, K.; Foresman, J. B.; Ortiz, J. V.; Cui, Q.; Baboul, A. G.; Clifford, S.; Cioslowski, J.; Stefanov, B. B.; Liu, G.; Liashenko, A.; Piskorz, P.; Komaromi, I.; Martin, R. L.; Fox, D. J.; Keith, T.; Al-Laham, M. A.; Peng, C. Y.; Nanayakkara, A.; Challacombe, M.; Gill, P. M. W.; Johnson, B.; Chen, W.; Wong, M. W.; Gonzalez, C.; Pople, J. A. Gaussian 03; Revision A.1 ed.; Gaussian, Inc.: Pittsburgh, PA, 2003.