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Supporting Information for:

Understanding Thio-Effects in Simple Phosphoryl Systems: Role of Solvent Assistance and Nucleophile Charge

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Table S1: Breakdown of Different Contributions to the Total Calculated Free Energies for the Different Reactions Examined in This Work[a]

System	ΔE_{gas}	$\Delta\Delta G_{solv}$	ΔZPE	$-T\Delta S$	ΔG_{calc}	ΔG_{exp}
Water Reaction						
Phosphodichloridate						
Reactant State	0.0	0.0	0.0	0.0	0.0	
Transition State	32.7	-13.8	0.6	3.0	22.5	20.5
Product State	80.0	-77.0	1.7	1.0	5.7	
Thiophosphodichloridate						
Reactant State	0.0	0.0	0.0	0.0	0.0	
Transition State	35.4	-14.7	0.5	2.7	23.9	20.8
Product State	79.4	-76.2	1.3	1.0	5.5	
Hydroxide Reaction						
Phosphodichloridate						
Reactant State	0.0	0.0	0.0	0.0	0.0	
Transition State	-3.6	17.9	0.1	2.4	16.8	19.2
Product State	-60.5	23.8	2.3	0.5	-34.0	
Thiophosphodichloridate						
Reactant State	0.0	0.0	0.0	0.0	0.0	
Transition State	-2.1	20.3	-0.7	1.6	19.1	>21.2
Product State	-54.1	19.5	2.3	1.1	-31.2	

[a] All energies are given in kcal/mol, normalized relative to the reactant complex. ΔE_{gas} denotes the gas-phase energy of the system obtained by performing single point calculations in vacuum, $\Delta\Delta G_{solv}$ denotes the contribution from including implicit solvation, ΔZPE and $-T\Delta S$ denotes the differences in zero-point energies and entropies calculated from the vibrational frequencies, and ΔG_{calc} and ΔG_{exp} denote calculated and experimental activation and reaction free energies respectively.

Table S2: Absolute energies for all key stationary points involved in the hydrolysis of phosphodichloridates 1 and 2 by water and hydroxide nucleophiles.[a]

System	E_{el} (a.u.)	E_{ZPE} (kcal/mol)	S (kcal/mol/K^{-1})
Water Reaction			
Phosphodichloridate			
Reactant State	-1641.7841620	53.50848	120.785
Transition State	-1641.7539374	54.08691	110.657
Product State	-1641.7798808	55.21652	117.340
Thiophosphodichloridate			
Reactant State	-1964.7320745	52.38140	123.104
Transition State	-1964.6991038	52.91553	113.955
Product State	-1964.7269412	53.70855	119.771
Hydroxide Reaction			
Phosphodichloridate			
Reactant State	-1641.2903666	44.58200	118.732
Transition State	-1641.2791418	44.43013	111.669
Product State	-1641.3604718	46.93260	116.812
Thiophosphodichloridate			
Reactant State	-1964.2385996	43.24047	121.140
Transition State	-1964.2211342	42.85152	115.626
Product State	-1964.3053846	45.60506	117.578

[a] Shown here are the absolute atomic energy (E_{el}, in atomic unites), zero-point energy contribution (E_{ZPE} in kcal/mol) and entropies (S, in cal/mol/K^{-1}) for all relevant stationary points.

Cartesian Coordinates of Key Stationary Points

Water Reaction

Phosphodichloridate

Reactant State

P	-0.229603	-0.510021	-0.273870
O	-0.171703	0.811871	-0.978063
Cl	-0.092342	-0.134164	1.748625
Cl	-2.155840	-1.211398	-0.427523
O	0.707334	-1.629172	-0.593730
O	2.432650	1.917049	-0.405852
H	1.505389	1.740972	-0.651804
H	2.822306	1.021451	-0.310222
H	3.562733	-0.901826	0.759541
O	3.366513	-0.749634	-0.178401
H	2.497714	-1.177290	-0.326171
H	-2.754285	2.329363	0.048516
O	-1.920504	2.818448	-0.029944
H	-1.285044	2.163706	-0.382618

Transition State

P	0.160178	-0.029551	0.440039
O	-0.746460	-0.974018	1.161450
Cl	0.246934	-0.369961	-1.598337
Cl	-1.758755	1.529002	-0.026807
O	1.001017	1.111978	0.907757
O	1.690066	-1.249267	0.649075
H	1.611860	-2.126216	0.228442
H	2.532052	-0.806918	0.321075
H	3.703006	0.438697	-1.035945
O	3.620271	0.390197	-0.069177
H	3.009355	1.113974	0.167623
H	-3.314607	-0.359589	-0.259807
O	-3.291524	-1.298977	-0.005385
H	-2.430339	-1.359675	0.455732

Product State

P	0.880249	0.331862	-0.461395
O	-0.068746	1.483141	-0.577728
Cl	0.327005	-0.734454	1.233104
Cl	-4.114497	-0.868363	-0.348870
O	1.133782	-0.654289	-1.551014
O	2.356842	0.889468	-0.009854
H	2.349201	1.639107	0.616854
H	3.535537	-0.057552	0.082730
H	4.313842	-1.191185	0.966583
O	4.316299	-0.735370	0.097579
H	4.142618	-1.417887	-0.586475
H	-3.038531	0.849921	0.446243
O	-2.543267	1.624574	0.794014
H	-1.678311	1.587367	0.339020

Thiophosphodichloridate

Reactant State

P	-0.596390	-0.296260	-0.226839
O	-0.043907	0.815739	-1.077636
Cl	-0.062219	0.167344	1.731209
Cl	-2.640748	0.022104	-0.108540
S	-0.209584	-2.168164	-0.620776
O	2.769726	1.153982	-0.679532
H	1.825585	1.133331	-0.927015
H	2.938262	0.252449	-0.332597
H	2.991444	-1.427636	1.242819
O	3.036440	-1.501179	0.275634
H	2.157435	-1.835041	0.014903
H	1.073683	3.541174	0.030541
O	0.142863	3.491912	-0.237088
H	0.022244	2.566004	-0.530043

Transition State

P	-0.028702	0.140672	-0.403378
O	0.868299	-0.435504	-1.460364
Cl	-0.146113	-1.074568	1.291651
Cl	1.983886	1.199827	0.722644
S	-1.095928	1.783414	-0.378665
O	-1.554531	-0.942054	-1.128966
H	-1.331315	-1.888276	-1.229832
H	-2.386832	-0.884431	-0.562499
H	-3.503448	-1.022111	1.280183
O	-3.654370	-0.578309	0.428613
H	-3.586203	0.371045	0.629878
H	3.357472	-0.746555	0.140387
O	3.303237	-1.464401	-0.515346
H	2.472484	-1.241631	-0.983321

Product State

P	-0.734456	-0.172678	-0.519355
O	0.106421	-1.098066	-1.353929
Cl	-0.346010	-0.700194	1.473660
Cl	3.942182	0.902942	0.479445
S	-0.712125	1.764095	-0.723476
O	-2.304141	-0.682852	-0.626525
H	-2.390386	-1.652186	-0.737996
H	-3.445907	-0.098978	0.199998
H	-4.074996	0.151929	1.689959
O	-4.223666	0.319858	0.734300
H	-4.187827	1.292796	0.606576
H	3.106620	-0.972020	-0.236039
O	2.727276	-1.816424	-0.567081
H	1.821283	-1.583739	-0.853453

Hydroxide Reaction

Phosphodichloridate

Reactant State

P	0.177679	-0.480142	-0.075243
Cl	2.047199	-1.350195	-0.225516
O	-0.830776	-1.575692	0.018472
O	0.108501	0.607906	-1.098414
Cl	0.324471	0.416960	1.779881
O	-3.010484	1.336234	0.475990
H	-2.586052	0.920696	1.241695
O	-3.277158	-0.561821	-1.218432
H	-3.174499	0.207950	-0.530580
H	-2.505383	-1.124141	-1.032787
H	2.949495	2.076116	-1.109358
O	2.124474	2.578604	-1.025611
H	1.416399	1.904645	-1.080574

Transition State

P	0.129755	0.106783	-0.236097
Cl	-1.751848	0.168680	-1.340514
O	1.095455	0.353538	-1.349690
O	-0.099033	-1.151467	0.548583
Cl	-0.290542	1.825037	0.844859
O	2.143991	0.177630	1.187512
H	2.523933	1.054148	1.023577
O	3.255006	-1.446545	-0.424028
H	2.827078	-0.770991	0.240406
H	2.744844	-1.300230	-1.235979
H	-3.237872	-1.509733	0.602882
O	-2.684811	-1.852265	1.321974
H	-1.768536	-1.615252	1.061897

Product State

P	-0.986583	0.319017	-0.352868
Cl	3.853119	-1.167862	-0.131195
O	-1.100792	-1.091630	-0.859138
O	-0.087593	1.328716	-1.005162
Cl	-0.333942	0.172492	1.631729
O	-2.440405	0.973090	-0.164068
H	-3.129515	0.263695	-0.052096
O	-3.823918	-1.354130	-0.056665
H	-4.484057	-1.414901	-0.765816
H	-2.999800	-1.712481	-0.441819
H	2.966603	0.817787	-0.183670
O	2.574838	1.719078	-0.202791
H	1.642441	1.580942	-0.470088

Thiophosphodichloridate

Reactant State

P	0.145967	-0.587930	-0.221967
Cl	2.030210	-1.472231	-0.216804
O	-0.849592	-1.696344	-0.381888
S	0.139040	0.973865	-1.402222
Cl	0.060668	0.009603	1.768624
O	-2.997907	1.763960	0.204304
H	-2.091494	1.813912	-0.138047
O	-3.578425	-0.720399	-0.137430
H	-3.335938	0.275090	-0.003117
H	-2.720584	-1.169754	-0.243868
H	3.438115	1.645383	0.233024
O	2.767192	2.344145	0.287226
H	2.020695	2.006242	-0.241569

Transition State

P	-0.198651	0.219382	0.188336
Cl	1.744554	0.823394	1.038825
O	-1.003003	0.195026	1.453650
S	0.321191	-1.319989	-0.932796
Cl	-0.405503	2.036958	-0.824155
O	-2.474131	-0.067569	-0.865838
H	-2.927744	0.731760	-0.555078
O	-3.040488	-1.854113	0.832205
H	-2.814533	-1.118026	0.121738
H	-2.416750	-1.651020	1.546787
H	3.868928	-0.975076	0.256433
O	3.607932	-1.568274	-0.465153
H	2.644436	-1.425081	-0.558472

Product State

P	-0.916204	0.371619	-0.020681
Cl	3.474632	-1.179188	0.300395
O	-0.200068	-0.610765	-0.913107
S	-0.286763	2.227800	0.139734
Cl	-0.918347	-0.527195	1.890236
O	-2.498449	0.362996	-0.329460
H	-2.768488	-0.529709	-0.684823
O	-2.577564	-2.140164	-1.343455
H	-2.962208	-2.158842	-2.234514
H	-1.619943	-1.998290	-1.479645
H	2.777469	0.439100	-0.951053
O	2.497957	1.203425	-1.505201
H	1.672592	1.513234	-1.086440