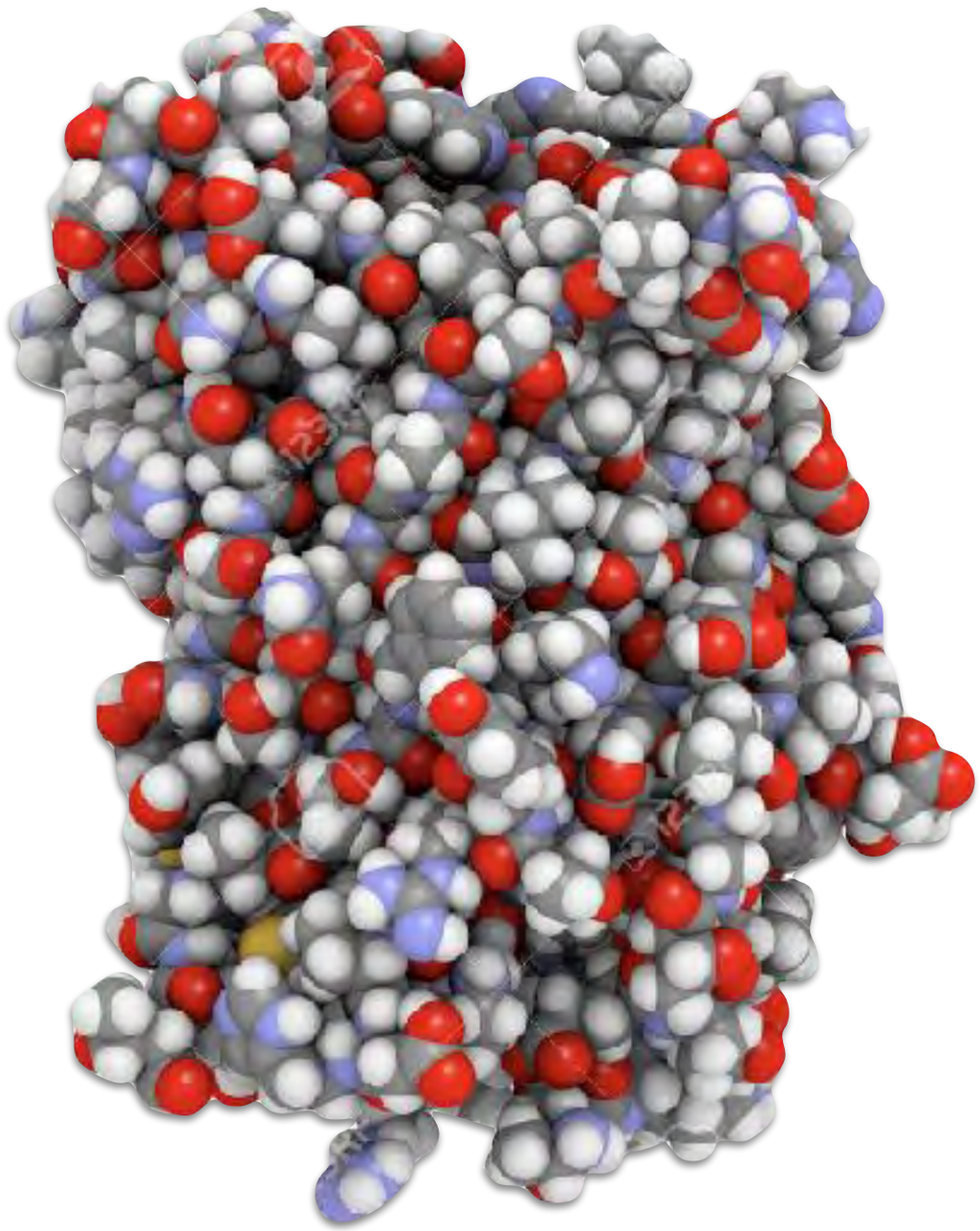
Lecture 2

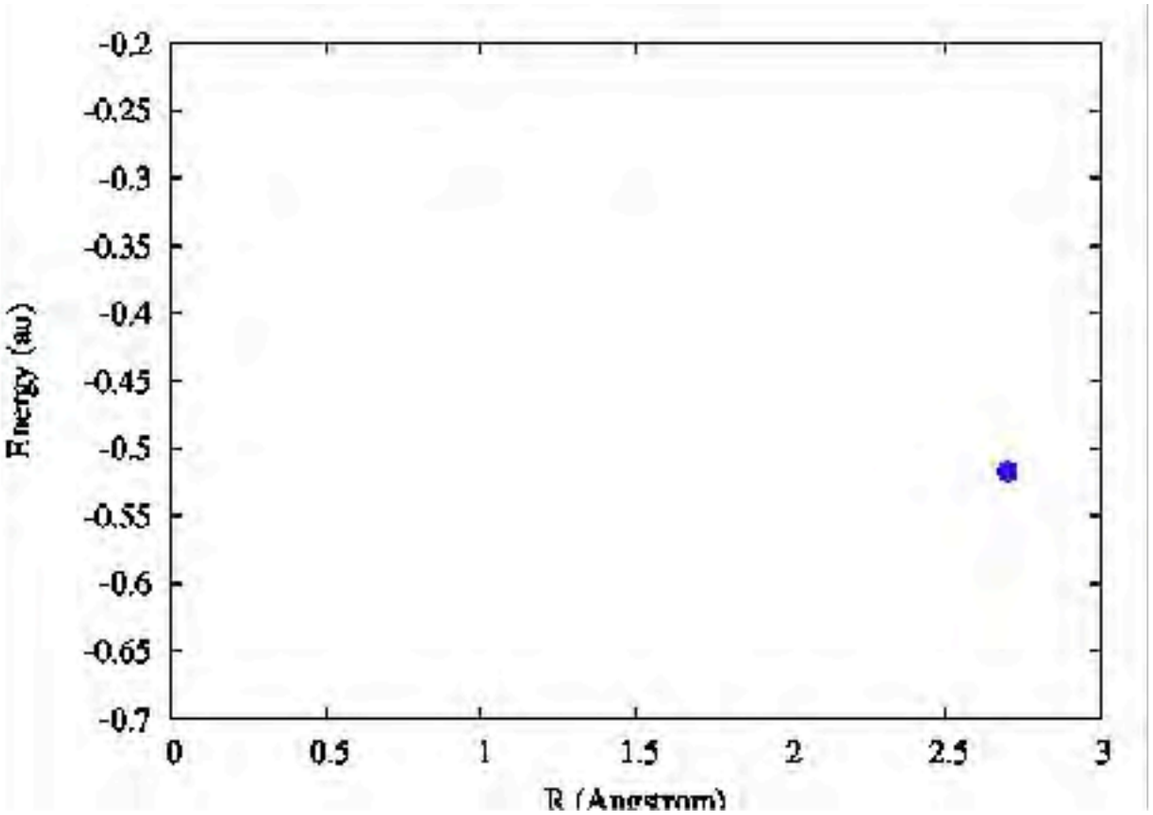
Molecular Mechanics Force Field

How can one build an empirical potential for a complex system like protein?

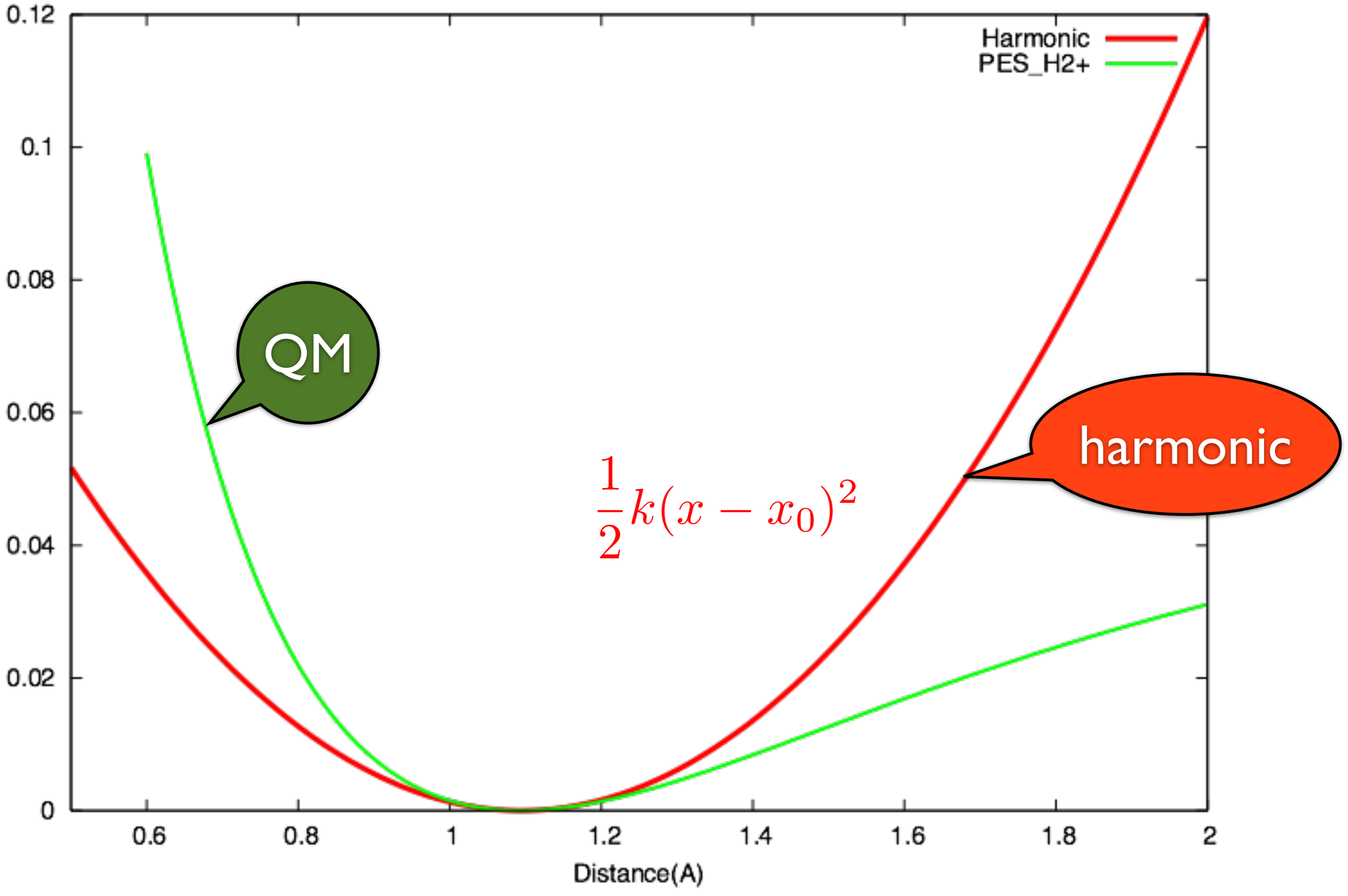


Molecular Mechanics based Force Fields

Empirical ways to define the potential energy function to describe the properties of a molecular system



Potential energy is driven by the complex electronic structural changes

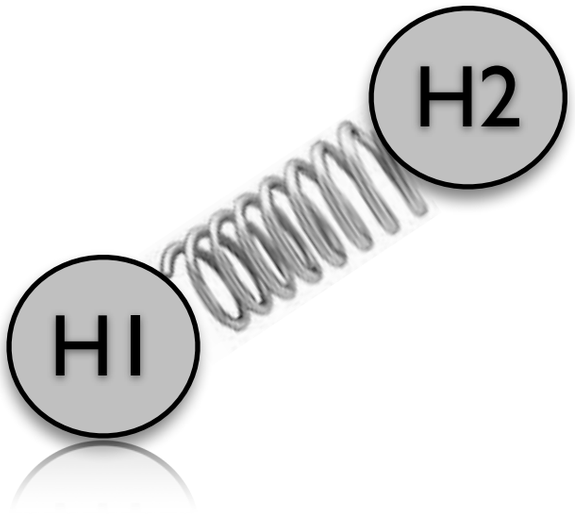

0.12
0.1
0.08
0.06
0.04
0.02
0
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Distance(A)
Harmonic
PES_H2+
QM
harmonic
$\frac{1}{2}k(x-x_0)^2$

Bonding Interactions: to describe bonds

H_2 molecule

$$U(\mathbf{R}^N) = ?$$

Our model should be based on some experimental/ theoretical knowledge about the system



$$U(\mathbf{R}_1, \mathbf{R}_2) = \frac{1}{2} k_{\mathrm{r}} (R - R_0)^2$$

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$$R = |\mathbf{R}_1 - \mathbf{R}_2|$$

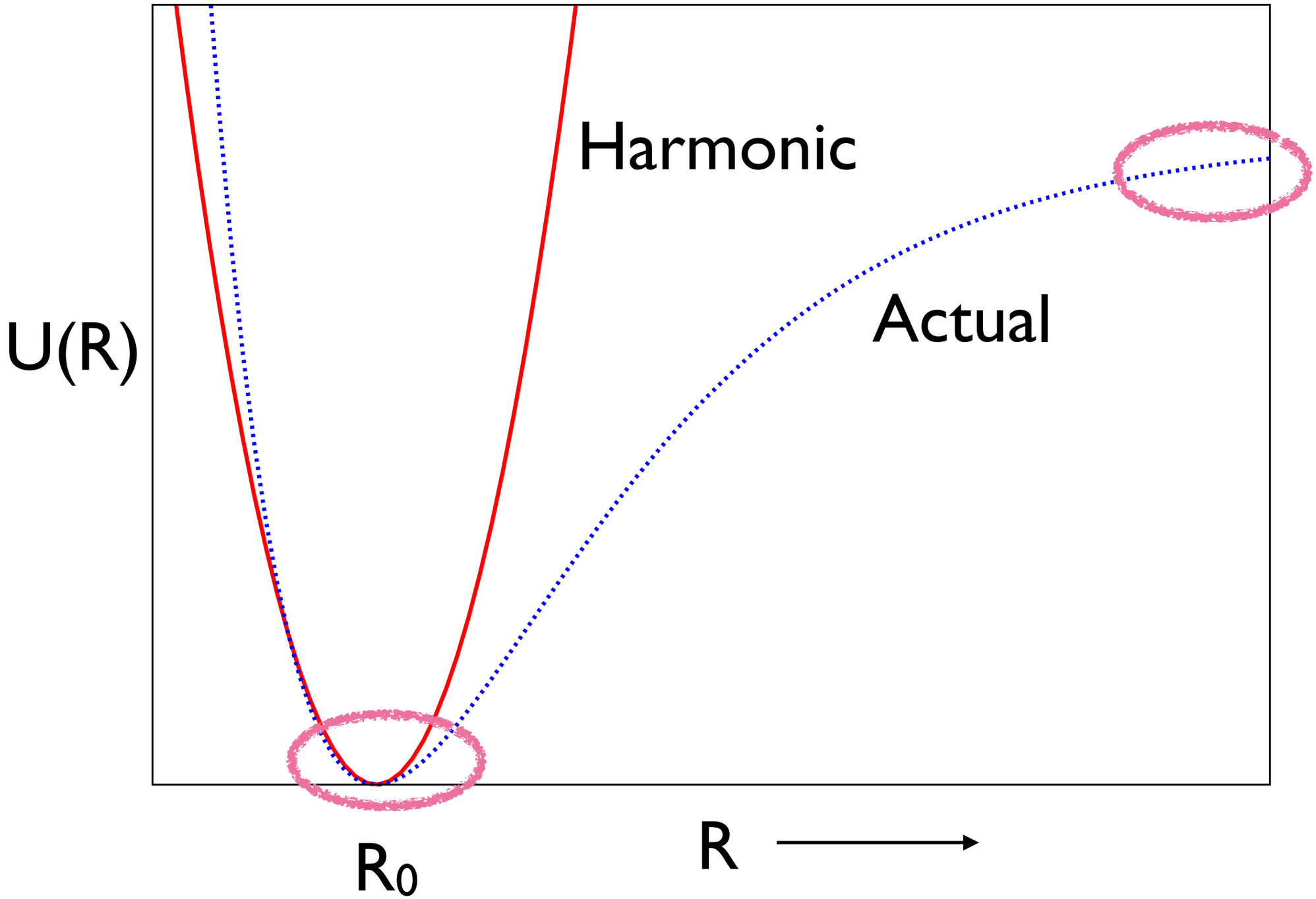
parameters

reproduce experiments/theory

$$\nu = \frac{1}{2\pi} \sqrt{\frac{k}{\mu}}$$

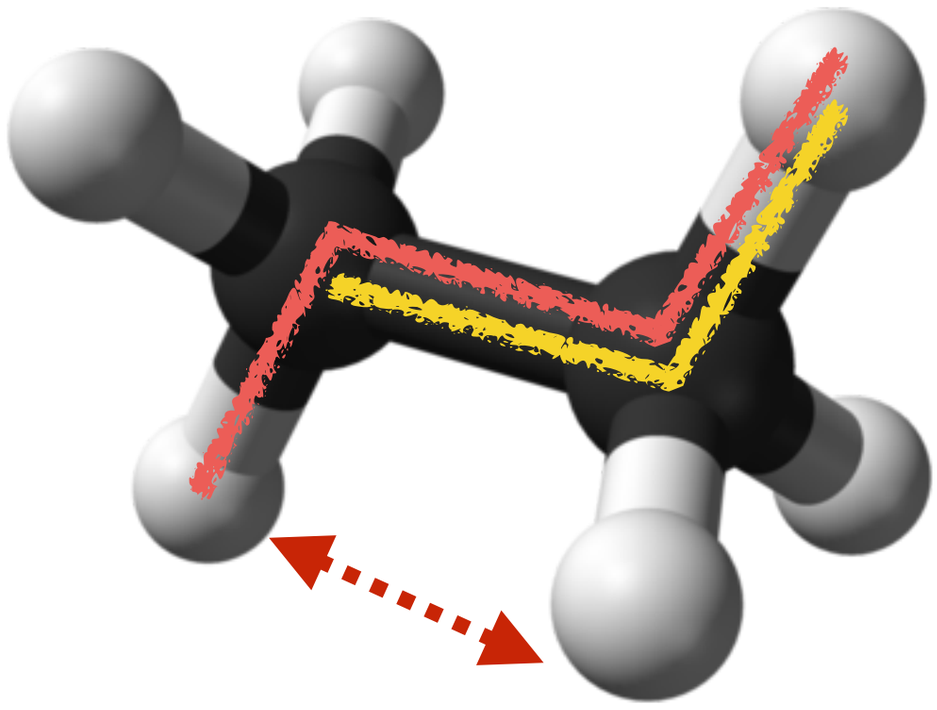
$$k = 4\pi^2 \mu \nu^2 = 4\pi^2 \mu c^2 \overline{\upsilon}^2$$

Expt/theory



IMPORTANT: No dissociation of bonds if described by harmonic potential

For a polyatomic molecule, potential energy depends not just on bond terms



many body terms!

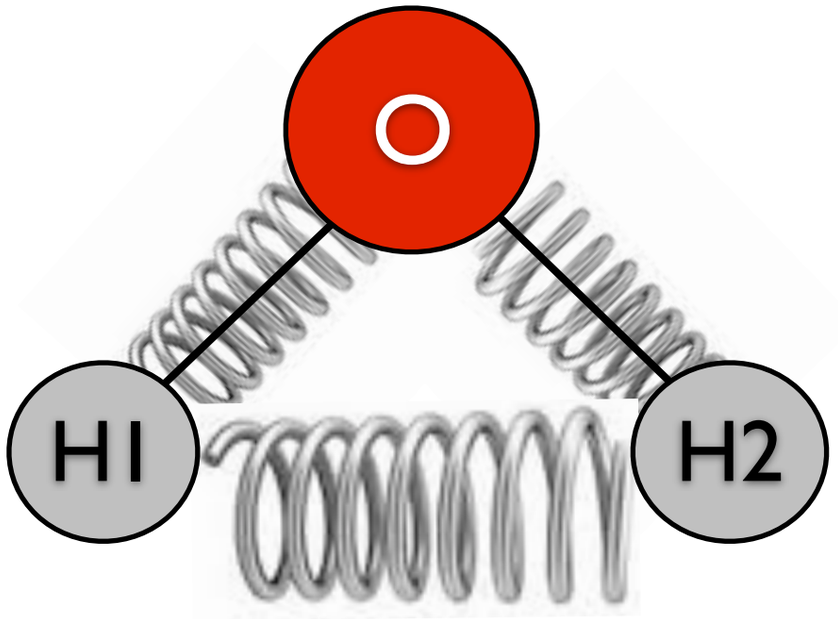
Fortunately, we can systematically build these many-body interaction terms!

H_2O molecule

- OH bonds can be treated by harmonic bonds
- H-H as harmonic

  OR

  H-O-H angle as harmonic



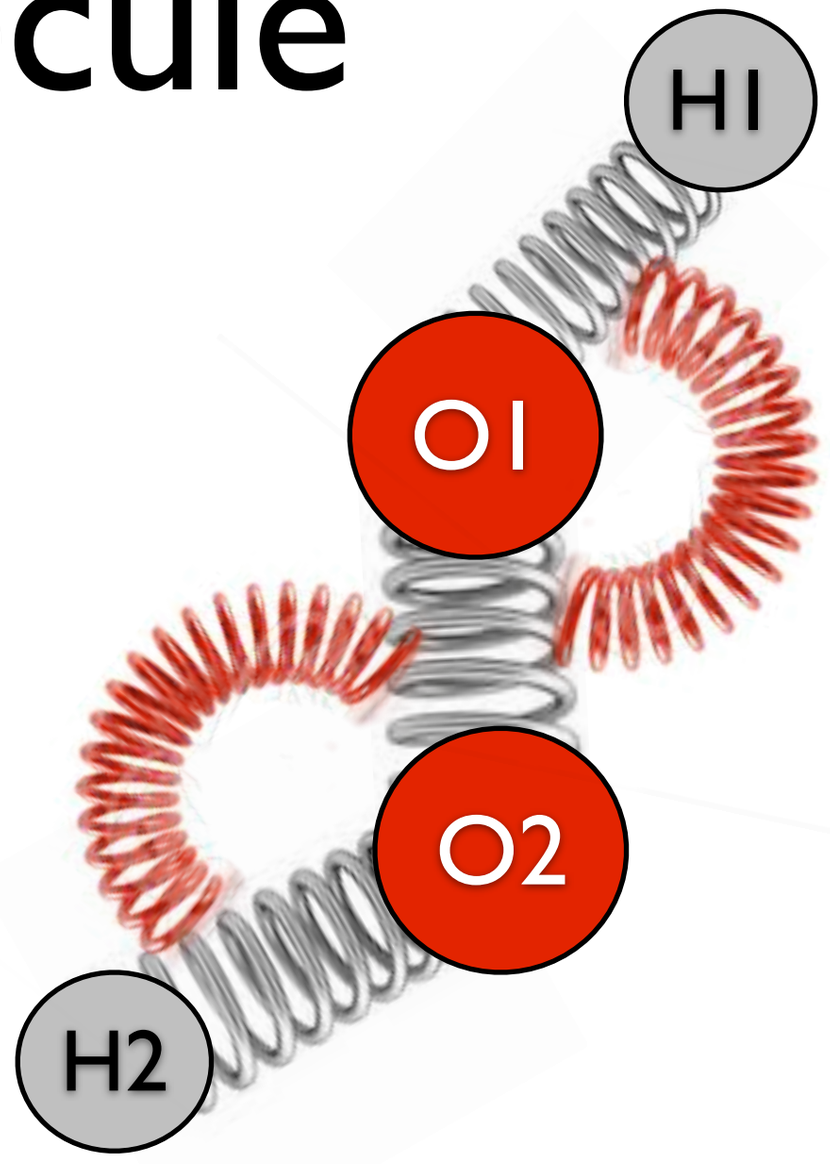
DOF=3x3

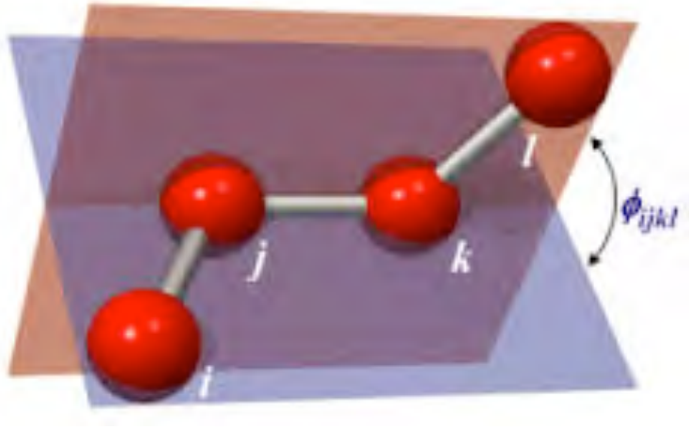
$$U(\mathbf{R}_1, \mathbf{R}_2, \mathbf{R}_3) = \frac{1}{2} k_{\mathrm{OH}} \left(R_{\mathrm{OH1}} - R^0_{\mathrm{OH}}\right)^2 + \frac{1}{2} k_{\mathrm{OH}} \left(R_{\mathrm{OH2}} - R^0_{\mathrm{OH}}\right)^2 + \frac{1}{2} k_{\mathrm{HOH}} \left(\theta_{\mathrm{H1-O-H2}} - \theta^0_{\mathrm{HOH}}\right)^2$$

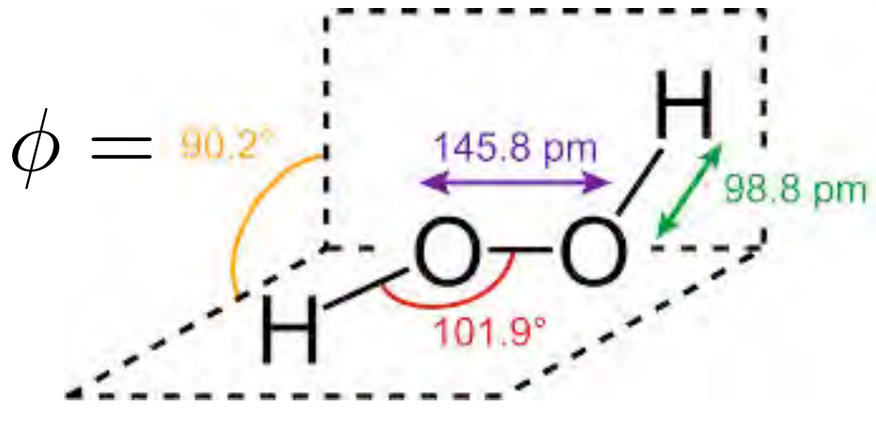
1 2 3 4

H_2O_2 molecule

- 3 distances [2 types]
- 2 angles [1 type]
- 1 torsion [1 type]



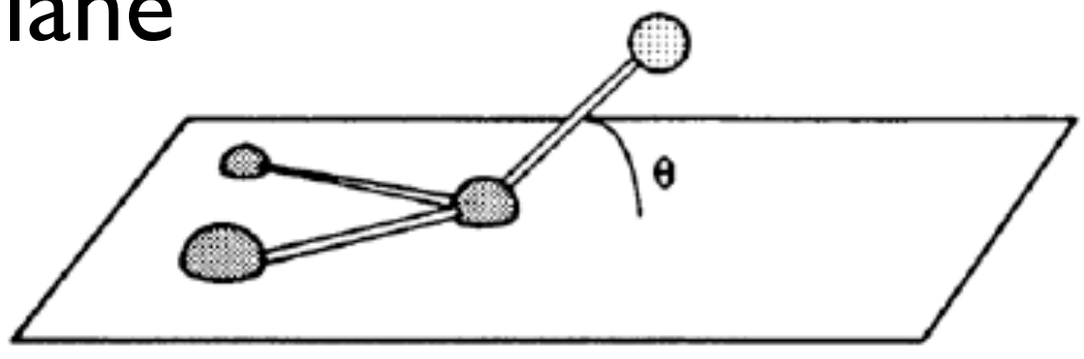




Potential for Torsions: Two kinds

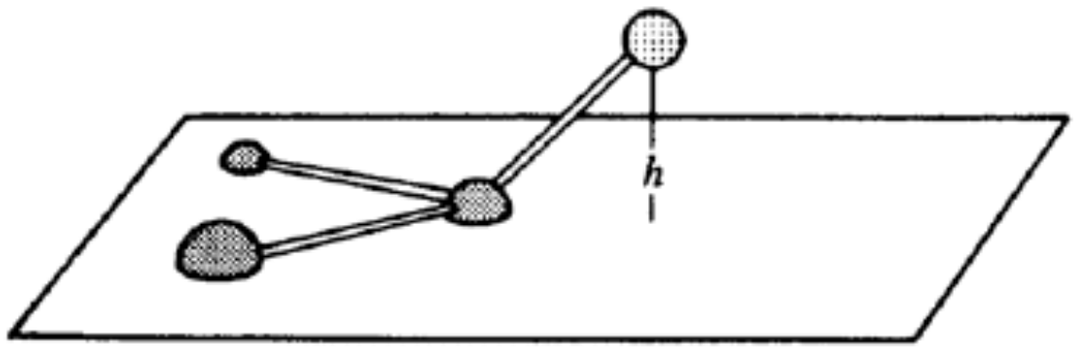
- Improper Torsion/Out-of Plane

$$U(\theta) = \frac{1}{2} k_{\theta,\mathrm{I}}\, \theta^2$$



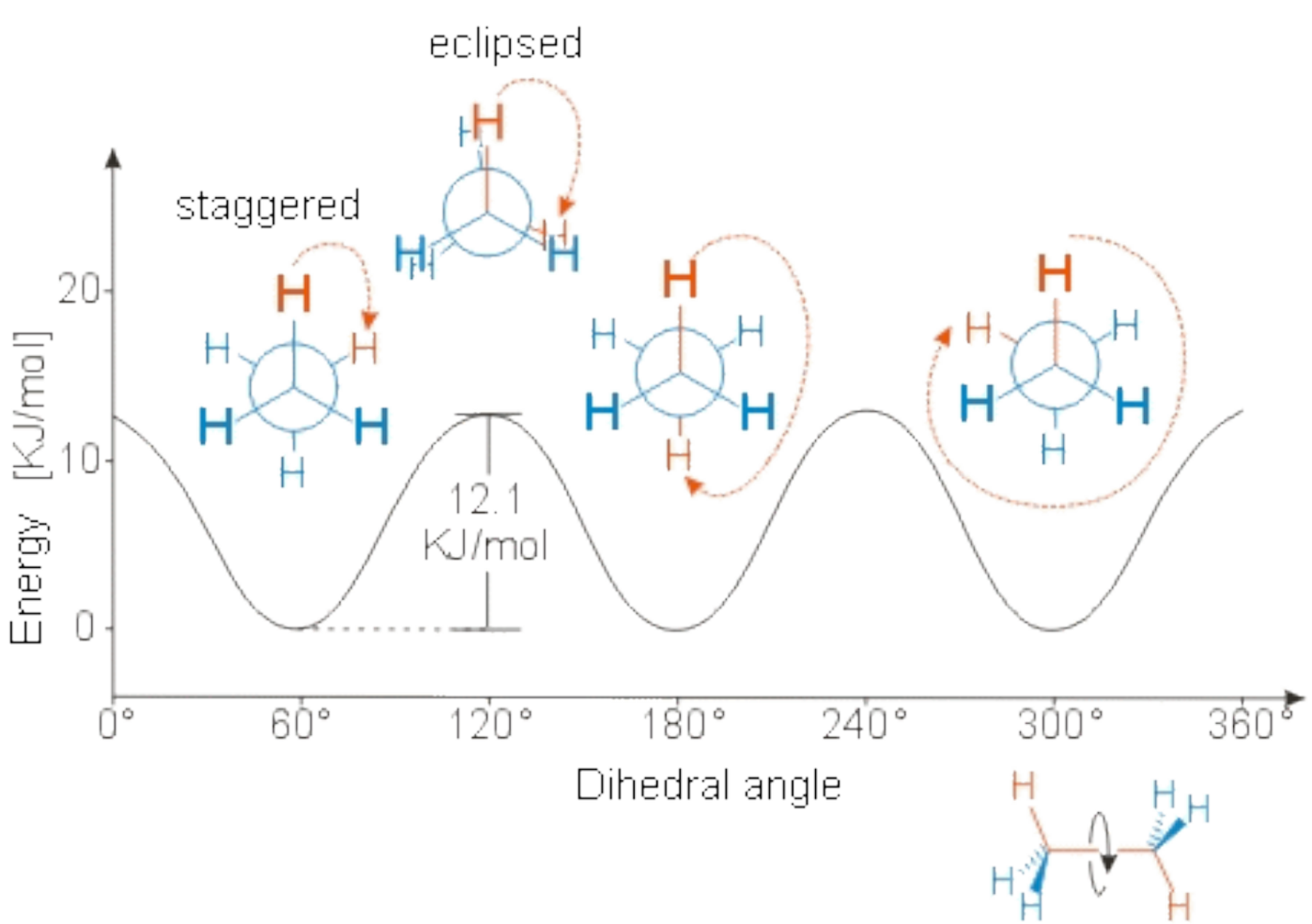
OR

$$U(\theta) = \frac{1}{2} k_{r,\mathrm{I}}\, h^2$$

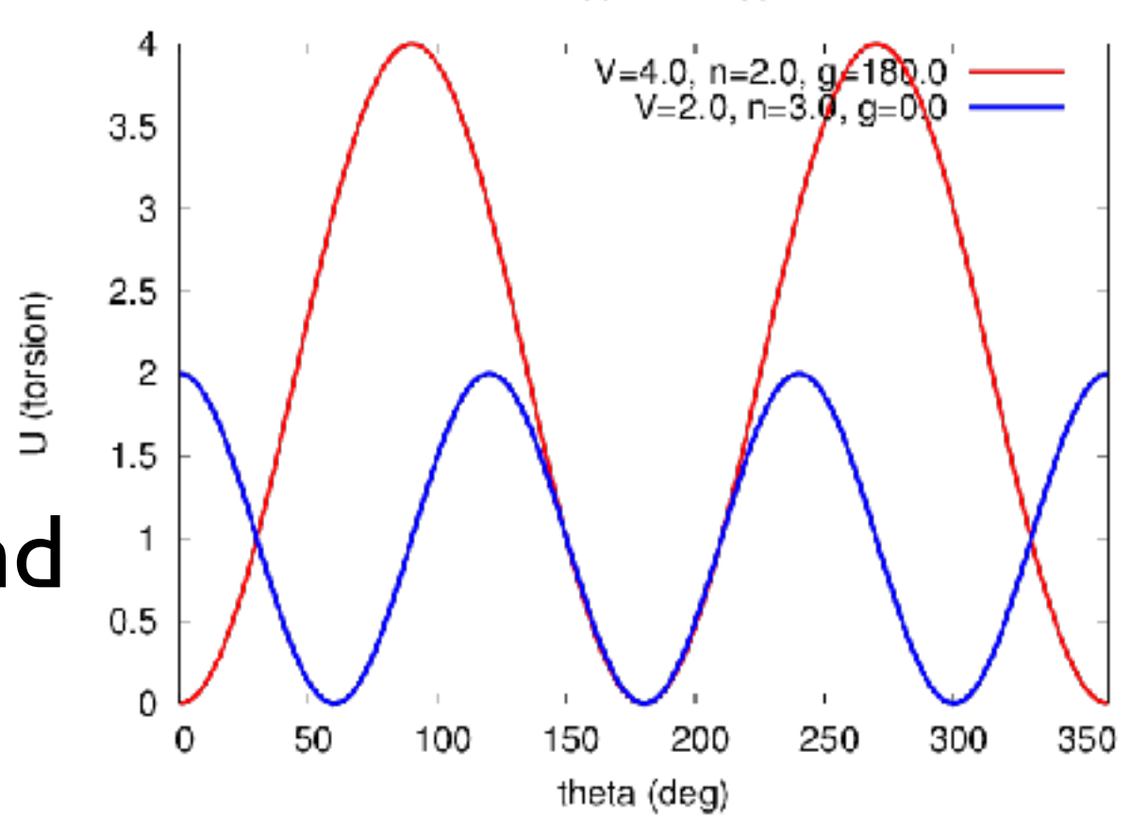


these describe out-of-plane motion

(Proper) Torsion

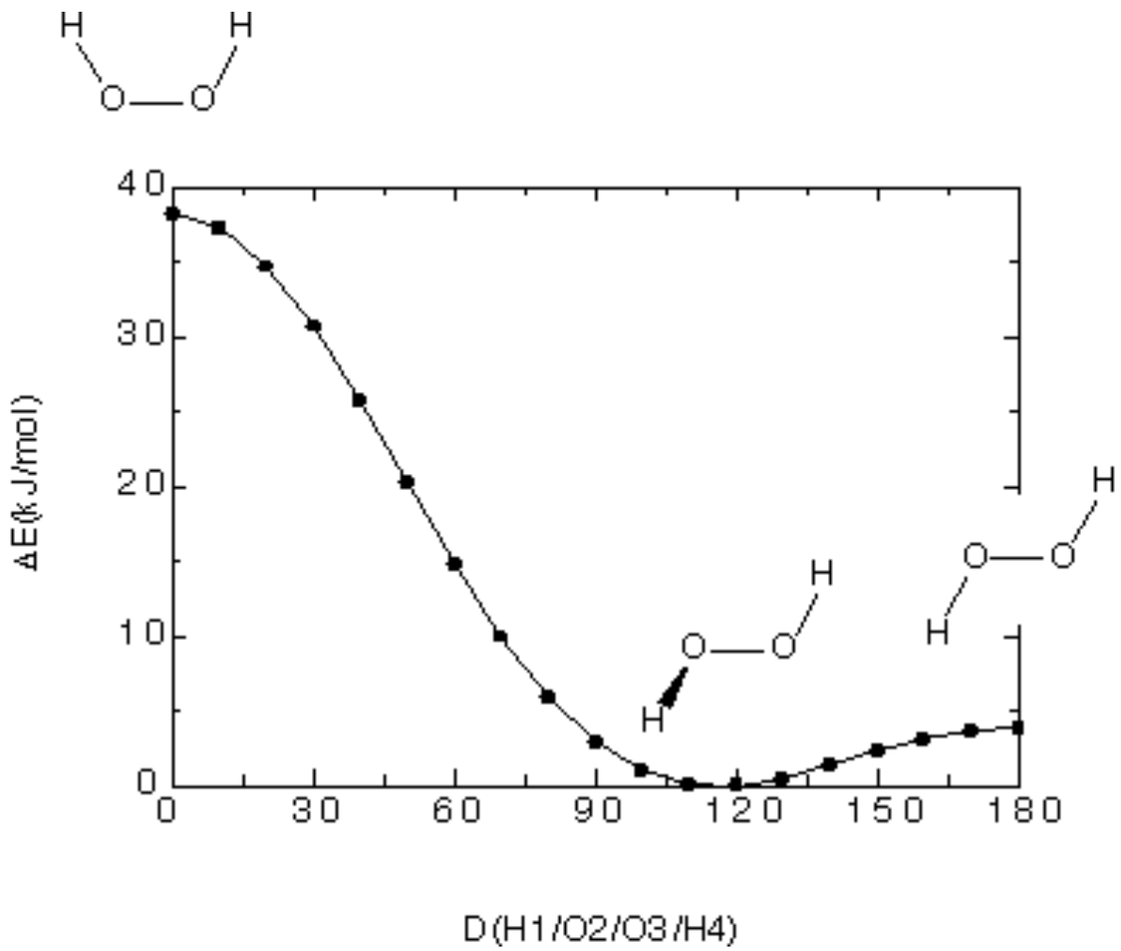


$$U(\phi) = \sum_{n=0}^{N} \frac{V_n}{2} \left[1 + \cos(n\phi - \gamma)\right]$$



What values of N and gamma, and V_n are suitable to mimic ethane potential energy surface?

$$U(\mathbf{R}_1,\mathbf{R}_2,\mathbf{R}_3,\mathbf{R}_4) = \frac{1}{2}k_{\mathrm{OH}}\left(R_{\mathrm{O1H1}} - R^0_{\mathrm{OH}}\right)^2 +$$



$$\frac{1}{2}k_{\mathrm{OH}}\left(R_{\mathrm{O2H2}} - R^0_{\mathrm{OH}}\right)^2 +$$

$$\frac{1}{2}k_{\mathrm{OO}}\left(R_{\mathrm{O1O2}} - R^0_{\mathrm{OO}}\right)^2 +$$

$$\frac{1}{2}k_{\mathrm{HOO}}\left(\theta_{\mathrm{H1-O1-O2}} - \theta^0_{\mathrm{HOO}}\right)^2$$

$$\frac{1}{2}k_{\mathrm{HOO}}\left(\theta_{\mathrm{H2-O2-O1}} - \theta^0_{\mathrm{HOO}}\right)^2$$

$$\sum_{n=0}^{N'}\frac{V_{\mathrm{HOOH}}}{2}\left[1+\cos(n\phi_{\mathrm{H1-O1-O2-H2}} - \gamma_{\mathrm{H1-O1-O2-H2}})\right]$$

Some Other Examples:

- Bond Potentials

Bond	R_0 (Å)	k_r (kcal mol^{-1} Å^{-2})
Csp^3-Csp^3	1.523	317
Csp^3-Csp^2	1.497	317
Csp^2=Csp^2	1.337	690
Csp^2=O	1.208	777
Csp^3-Nsp^3	1.438	367
C-N (amide)	1.345	719

Angle

Angle	θ_0 (deg)	k_θ(kcal mol^{-1} deg^{-2})
Csp^3-Csp^3-Csp^3	109.47	0.0099
Csp^3-Csp^3-H	109.47	0.0079
H-Csp^3-H	109.47	0.007
Csp^3-Csp^2-Csp^3	117.2	0.0099

- pwd
- mkdir nnair
- cd nnair
- mkdir H2PlusPES
- cd H2PlusPES
- kwrite h2plus_d2.0.in

H2+ PE Surface

```
%chk=h2plus_6311Pg
# HF/6-311++G

H2+ 6-311++G

1 2
H 0.0 0.0 0.0
H 0.0 0.0 2.0
```

```
g09 h2plus_d2.0.in h2plus_d2.0.out
```

- repeat the same for distances 1.8, 1.6, 1.4, 1.2, 1.0, 0.8, 0.6, 0.4

```
grep "SCF Done:" h2plus_d*.out
```

- kwrite h2plus_energy.dat

```
0.6    -0.601152743767
0.8    -0.623869030902
[…]
```

- gnuplot

```
f(x) = k*(x-x0)**2 + c

x0=0.7

c=—6.1

k=0.01

fit f(x) ‘h2plus_energy.dat’ using 1:2 via k, x0, c
```

Home Work: what is the value of k in kcal mol^{-1} A^{-2}?