• Theme Music: Simon & Garfunkel

*Homeward Bound*

• Cartoon: S. Harris

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**Quiz 11**

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Avg. = 7.3
Foothold ideas:
Energies between charge clusters

- Atoms and molecules are made up of charges.
- The potential energy between two charges is
  \[ U_{12}^{\text{elec}} = \frac{k_e Q_1 Q_2}{r_{12}} \]  
  **No vectors!**
- The potential energy between many charges is
  \[ U_{12...N}^{\text{elec}} = \sum_{i<j=1}^{N} \frac{k_e Q_i Q_j}{r_{ij}} \]  
  **Just add up all pairs!**

Moving to molecules

- Apply our Newtonian framework and results to atoms and molecules.
- See what goes over directly, what we have to add.
- Can we integrate what we know about atoms and molecules from chemistry with the physics we have learned?
Molecular forces

Sketch a graph of the extra potential energy from adding $Q$ as a function of position $r$ of charge $Q$

$$\Delta U = k_c Q \sum_{i=1}^{3} \frac{q_i}{r_{Q-q_i}} = k_c Q \left( \frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} \right)$$
What if we move in 2D instead of 1D?

Foothold ideas:
Forces from PE

- For conservative forces, PE can be defined by
  \[ \vec{F} \cdot \Delta \vec{r} = -\Delta U \]

- If you know \( U \), the force can be gotten from it via
  \[ F_{\text{type}} = -\frac{\Delta U_{\text{type}}}{\Delta r} = -\frac{dU_{\text{type}}}{dr} \]

- In more than 1D need to use the gradient
  \[ \vec{F}_{\text{type}} = \left( \frac{\partial U_{\text{type}}}{\partial x} \hat{i} + \frac{\partial U_{\text{type}}}{\partial y} \hat{j} + \frac{\partial U_{\text{type}}}{\partial z} \hat{k} \right) = -\nabla U_{\text{type}} \]

- The force always points down the PE hill.
Foothold ideas:

Bound states

- When two objects attract, they may form a *bound state* – that is, they may stick together.

- If you have to do positive work to pull them apart in order to get to a separated state with KE = 0, then the original state was in a state with negative energy.