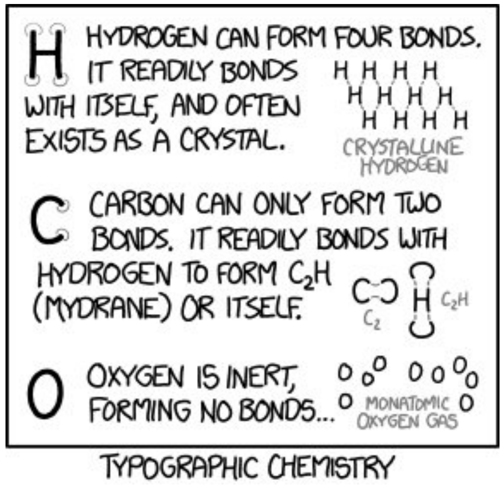
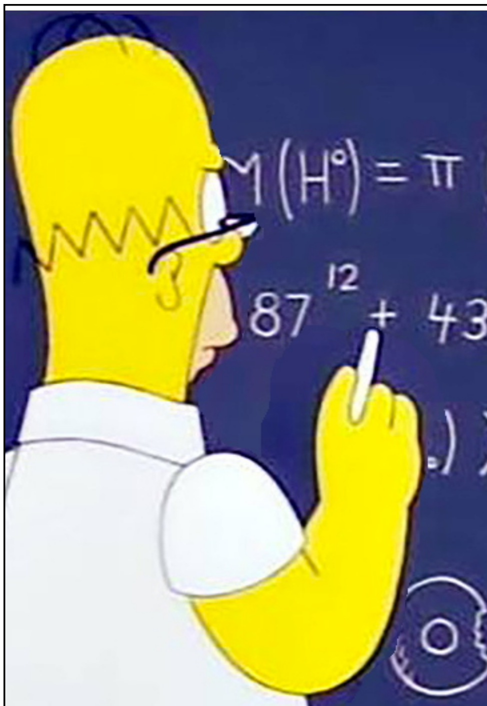
February 1, 2017 Physics 132 Prof. E. F. Redish

- **Theme Music:**
  Phish
  I am hydrogen
- **Cartoon:**
  Randall Munroe
  xkcd



2/1/16 Physics 132 **1**



The Equation of the Day

Energy conservation with chemical reactions

$$\Delta U_{\text{internal}} = \Delta U_{\text{thermal}} + \Delta U_{\text{chemical}}$$

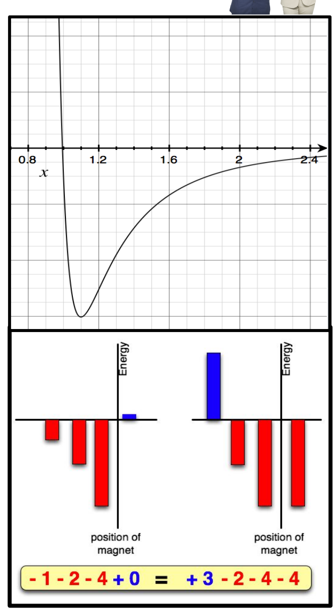
Physics 132

The Gauss Gun: A classical analog of an exothermic reaction

1/30/17 9 **Physics 132**

Sketch

1. What the potential energy curve must look like between the magnet and a metal sphere as a function of distance. (Hint: think about the WEΘ)
2. Energy bar graphs that show the initial and final energies of each of the 4 spheres (when the moving one is far from the magnet)



1/30/17 Physics 132

Energy conservation with chemical reactions: 1

- Consider the collision of two molecules in isolation $A + B \rightarrow A + B$

$$K_A + K_B + U_{AB} = \text{ constant}$$

- If the initial and final states both have the two molecules far apart, $U_{AB} \sim 0$.

$$K_A + K_B = \text{ constant}$$

2/1/16 Physics 132 **11**

We have to refine our definition of "internal energy"

- When we talked about molecular motion last term, we ignored the possibility of chemical reactions.
- "Internal energy" was the sum of the KE of the molecules (for a gas) or the sum of the KE and (interaction) PE of the molecules (for a liquid or solid).
- If chemical reactions can take place, we have to take changes in binding energy into account.
- Define: U_{thermal} = sum of KE (and PE) of molecules
  U_{chemical} = sum of BEs of molecules
  $U_{\text{internal}} = U_{\text{thermal}} + U_{\text{chemical}}$

2/1/16 Physics 132 **12**

Energy conservation with chemical reactions: 2

- Consider the reaction of two molecules in isolation A + B → C + D

$$(K_A + E_A) + (K_B + E_B) + U_{AB} = (K_C + E_C) + (K_D + E_D) + U_{CD}$$

- If the initial and final states both have the two molecules far apart, $U_{AB} \sim U_{CD} \sim 0$.

$$(K_A + E_A) + (K_B + E_B) = (K_C + E_C) + (K_D + E_D)$$

Note: The "*E*"s here are **molecular internal energies** and are negative since the molecules are bound. The (positive) **bond energies** from chemistry are given by $\mathcal{E} = -E > 0$.

2/1

Energy conservation with chemical reactions: 3

- Consider as gas consisting of a mixture of two molecules A, and B that are colliding with each other but not reacting.
- In a gas, most of the time any two molecules are far enough apart that their mutual PE, U_{AB}, can be neglected.

$$\sum_{\text{all A mols.}} K_A + \sum_{\text{all B mols.}} K_B = \text{constant}$$

- This is the thermal energy of the gas, $U_{thermal}$

2/1/16 Physics 132 **14**

Energy conservation with chemical reactions: 4

- Consider the reaction of a gas of A and B molecules that react (fully) to C and D molecules A + B → C + D
  - If the initial and final states both have the two molecules far apart, $U_{AB} \sim U_{CD} \sim 0$.

$$\sum_A (K_A + E_A) + \sum_B (K_B + E_B) = \sum_C (K_C + E_C) + \sum_D (K_D + E_D)$$

- Let's make sense of this (and connect back to chemistry) by rearranging.

2/1/16 Physics 132 **15**

Let's do the math!

$$\sum_A (K_A + E_A) + \sum_B (K_B + E_B) = \sum_C (K_C + E_C) + \sum_D (K_D + E_D)$$

$$\left(\sum_{AB} (K_A + K_B)\right) + \left(\sum_{AB} (E_A + E_B)\right) = \left(\sum_{CD} (K_C + K_D)\right) + \left(\sum_{CD} (E_C + E_D)\right)$$

$$U^i_{thermal} + U^i_{chemical} = U^f_{thermal} + U^f_{chemical}$$

$$U^i_{chemical} - U^f_{chemical} = U^f_{thermal} - U^i_{thermal}$$

$$-\Delta U_{chemical} = \Delta U_{thermal}$$

$$\Delta U_{thermal} + \Delta U_{chemical} = 0$$

2/1/16 Physics 132 **16**