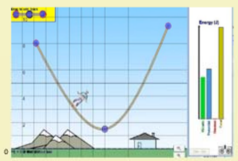
Reconciling “Energy” and “Free Energy”

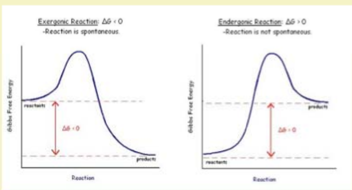
Benjamin Geller[1], Abigail Daane[2], Vashti Sawtelle[1]
[1]Department of Physics, University of Maryland, College Park
[2]Physics Education Research Group, Seattle Pacific University School of Education

Motivation: Bridging Disciplinary Perspectives about Energy

Biology and pre-health science students encounter a disconnect between "energy" as described in introductory physics courses and "free energy" as described in their biology and chemistry classes. Physics courses often employ “energy bar charts” or other such representations to convey the transfer of energy from one form to another, while biology and chemistry courses make frequent use of “reaction coordinate diagrams” that track changes in Gibbs free energy:



Physics Land[1]



Biochemistry Land[2]

Since the concept of free energy plays a central role in the description of biochemical processes, we are exploring how students reason about the relationship between energy and free energy in our Physics for Biologists course at the UMd, College Park.

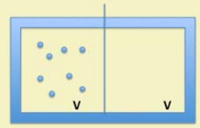
The 1st Law of Thermodynamics expresses the conservation of ENERGY. On the other hand, FREE ENERGY is not conserved, and the decrease in a system’s free energy coincides with an increase in the entropy of the universe:

$$\Delta G = \Delta H - T\Delta S$$

$-T\Delta S_{total}$ $\quad$ $-T\Delta S_{surroundings}$ $\quad$ $T\Delta S_{system}$

The requirement that the system’s Gibbs Free Energy must decrease in a spontaneous process is a proxy for the 2nd Law of Thermodynamics, since $\Delta G_{sys} < 0$ is equivalent to $\Delta S_{total} > 0$

Student Perspective 1: (Free) Energy and the Capacity to do Work



Thermally Isolated Container

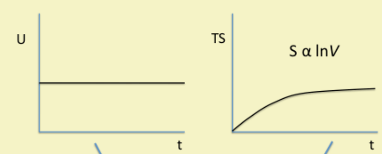
When the partition separating the two halves of the box is removed and the system reaches equilibrium again, how does the new energy of the gas compare to the energy of the original system?

1. The energy of the gas becomes larger
2. The energy of the gas becomes smaller
3. The energy of the gas remains the same
4. There is not enough information

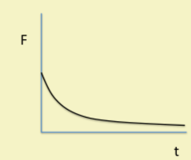
“I said the energy would decrease and I was kinda confused on this one, but **I sort of thought of energy as the ability to perform work on other objects**, and I thought well let's just say a compressed air can next to another compressed air can... normally if you shoot the air out it would, with an object right next to it would send the block flying, but if you let it kind of disperse a little bit, the air molecules kind of have more room to bounce around so the air pressure decreases and when you put it next to the block the block isn't going to go as fast. .” – Sameer, 02/2012

Sameer, by reasoning about the system’s capacity to do work, makes an argument that would be correct if describing what happens to the *free* energy upon expansion.

This got us thinking… how would one tell the *free* energy story for this scenario?

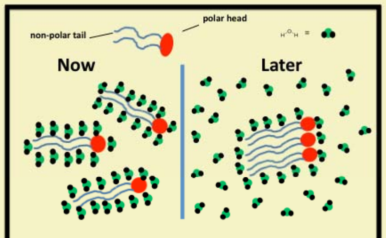


F = U - TS



If one thinks of the *TS* term as “degraded” energy, the free energy can be built up directly as the **total energy minus the degraded energy**.

Student Perspective 2: (Free) Energy is Reduced in a Spontaneous Process



Describe what you see in the pictures above. Explain what is happening.[3]

“Yes, I think that [lipid/water] would be a stronger interaction than [lipid/lipid], but I can’t picture what that’s what would happen… that they would stay [dispersed throughout the water]. **Because I know that they don’t [spontaneously stay dispersed throughout the water]**” – Elena, 12/2012

When asked directly, Elena correctly reasoned that the lipid-water interaction is stronger than the lipid-lipid interaction. This troubles her, however, because she knows that the lipids spontaneously cluster together when placed in water. Elena’s instinct about bonding interactions conflicts with her instinct about spontaneity – a conflict that would be resolved by clearly distinguishing energy from free energy.

<u>Conclusion</u>: Students have valuable resources for distinguishing energy from free energy, but lack a coherent conceptual framework for doing so.

Elena’s biological insight that bilayer formation is spontaneous conflicts with her view that the lipid-water interaction should be stronger than the lipid-lipid interaction. Her sense that the stronger interaction must be associated with spontaneity is a valuable resource, but leads to the wrong conclusion if one does not also grapple with the role that entropy plays in determining spontaneity (something that Elena fails to do).

While Sameer’s answer to the clicker question was not the one we anticipated, his intuition is a valuable resource, as it allows for the distinguishing of energy and free energy on the basis of a system’s capacity to do work. This distinction has the added benefit of requiring that one understand what free energy *means*, not just how to calculate it.

References

1. Image from University of Colorado, Boulder PhET. 2. Image adapted from humanthermodynamics.com 3. Image courtesy of Chris Bauer, University of New Hampshire

Acknowledgements

This work is supported by NSF-TUES DUE 11-22818, and the HHMI NEXUS grant. Many thanks to the University of Maryland Physics Education Research Group (PERG) and Biology Education Research Group (BERG). Thanks to Rachel Scherr for her valuable input.

Contact: geller@umd.edu