# Chemical Energy in Introductory Physics for the Life Sciences

Benjamin W. Dreyfus, Benjamin D. Geller, Julia Svoboda Gouvea, Vashti Sawtelle, Chandra Turpen, and Edward F. Redish
Department of Physics, University of Maryland, College Park

## NEXUS/Physics: Building interdisciplinary coherence

- The NEXUS/Physics course [1] is a two-semester physics course for undergraduate life sciences majors that seeks to help students build stronger connections between physics, biology, and chemistry.
- Students come in with at least 1 year of biology and 1 semester of chemistry.
- For the first two years (2011–13), NEXUS/Physics was run in small pilot classes.
  Starting in 2013–14, it was required for all biology majors at Maryland and taught as a large lecture course with smaller sections for group problem-solving activities.
  Starting in fall 2014, it will be piloted at other institutions.
- **How do we build interdisciplinary coherence around energy?**

## Energy: What are our students bringing with them?

When biology students take introductory physics, they are not arriving as blank slates! They have extensive experience thinking about energy in biology and chemistry, but the context is different from a standard physics class.

**Professor:** You talk about energy in your biology classes and your chemistry classes. So I want to know what you think energy is. *(pause)*
**Irene and Violet**: *(simultaneously)* ATP!!!

NEXUS/Physics class, 11/16/2012

**Sonia:** In biology it's the chemical bonds which hold energy.

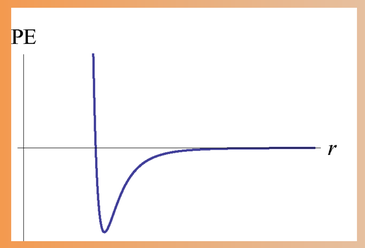
NEXUS/Physics class, 11/16/2012

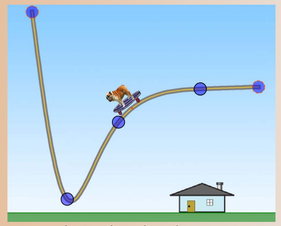
**Irene:** …ATP, which is the biological form of energy.

Interview, 11/1/2012

**Chemical bonds** and **ATP** are central to our students' incoming ideas about energy. However, introductory physics courses typically focus on mechanical energy.

## Curricular design: Bridging "physics energy" and "biology energy"



phet.colorado.edu

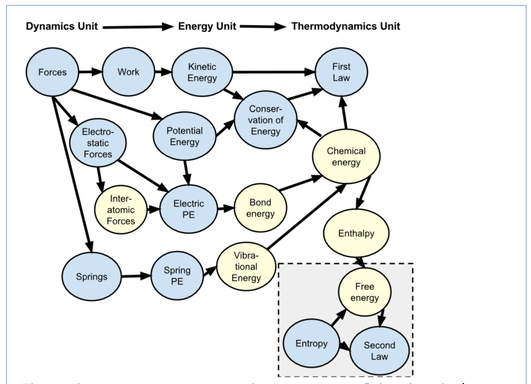
- Chemical energy is a core part of the NEXUS/Physics course's treatment of energy (not just a "miscellaneous" category)
- Chemical bonds are modeled classically, in terms of kinetic and potential energy at the molecular scale
- Microscopic and macroscopic pictures of energy are connected
- Students coordinate multiple representations and reconcile disciplinary ideas

## A chemical energy curricular "thread"

Chemical energy is a thread [2] that runs through the NEXUS/Physics course, providing students with multiple opportunities to make conceptual links, both within physics and across disciplines.


A small section of the chemical energy thread and how it interacts with other threads in the NEXUS/Physics course.

The circles represent example tasks that help students build up the ideas and connections in the thread.




The nodes represent conceptual components of the chemical energy thread, and the arrows represent links between those concepts.

The **blue** nodes represent content typically included in introductory physics. The **yellow** nodes represent content added to build up an integrated treatment of chemical energy.

## Example task: Bound states

Macroscopic mechanical energy as an analogy for molecular interactions

Interpreting negative energy

B. Now suppose that the skateboarder starts *inside the well* at a zero velocity — say at point x = −2.5 units with a total energy as shown by the heavy solid line.

Describe the motion of the skateboarder and how her potential and kinetic energies change as she moves through the well.

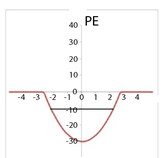
C. Her total energy is shown is the figure as −10 units. How can this be? Is it reasonable for the total mechanical energy to be negative?

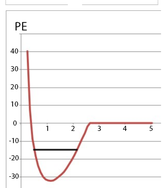
D. If she wants to climb out of the well and be at 0 kinetic energy at the point x = 3 units, how much energy would she need to gain?

E. The skateboarder is actually just an analogy for the cases we are interested in, which are interacting atoms. The potential energy of the interaction looks like the figure at the right.

If the atoms have the energy of −7.5 units as shown by the solid line in the figure, describe their motion and how their potential and kinetic energies change as they move in the well.

F. If the atoms have an energy of −7.5 units as shown by the solid line in the figure, would you have to put energy in to separate the atoms or by separating them would you gain energy? How much? Explain why you think so.




Connecting energy to a physical picture

The same physical principles apply at different scales

## Example task: ATP essay question

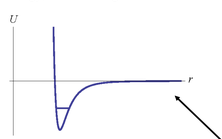
Reconciling ideas from different disciplines

Building on students' biology backgrounds

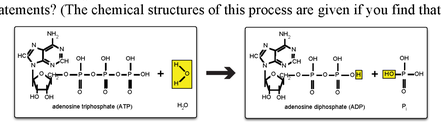
Two students discussing the process of ATP hydrolysis (ATP + $H_2O$ → ADP + $P_i$) make the following comments:

**Justin:** "The O-P bond in ATP is called a 'high-energy bond' because the energy *released* when ATP is hydrolyzed is large. That released energy can be used to do useful things in the body that require energy, like making a muscle contract."

**Kim:** "I thought chemical bonds like the O-P bond in ATP could be modeled by a potential energy curve like this (she draws the picture at the right), where r is the distance between the O and the P. If that's the case, then breaking the O-P bond in ATP would require me to input energy. I might not have to input much energy to break it, if that O-P happens to be a weak bond, but shouldn't I have to input at least *some* energy?"




How did Kim infer from the PE graph that breaking the O-P bond requires an input of energy? Who's right? Or can you reconcile their statements? (The chemical structures of this process are given if you find that useful.)




Multiple correct answers

Coordinating multiple representations

*Note: This is an essay question. Your answer will be judged not solely on its correctness, but for its depth, coherence, and clarity.*

## The chemical energy thread online

All NEXUS/Physics materials are available at:
`http://nexusphysics.umd.edu`

Contact us (or give us your email address) if you're interested in using these materials in your class and would like access to instructor resources.

**Contact:** dreyfus@umd.edu

**References**

[1] E.F. Redish *et al.*, "NEXUS/Physics: An interdisciplinary repurposing of physics for biologists," *Am. J. Phys.* **82**, 368 (2014).
[2] B.W. Dreyfus, J. Gouvea, B.D. Geller, V. Sawtelle, C. Turpen, & E.F. Redish, "Chemical energy in an introductory physics course for the life sciences," *Am. J. Phys.* **82**, 403 (2014).

**Acknowledgments**

This work was supported by the NSF Graduate Research Fellowship (DGE 07-50616), NSF-TUES DUE 11-22818, and the HHMI NEXUS grant. Thanks to Chris Bauer, Melanie Cooper, Catherine Crouch, and Mike Klymkowsky for valuable interdisciplinary conversations on chemical energy and thermodynamics that contributed significantly to this work, to Wolfgang Losert for teaching and developing materials for one of the pilot implementations of the NEXUS/Physics course, and to all of the TAs, LAs, and students who have made NEXUS/Physics possible.