

The object of this column is to enhance our readers' collection of interesting and novel problems in chemical engineering. Problems of the type that can be used to motivate the student by presenting a particular principle in class, or in a new light, or that can be assigned as a novel home problem, are requested, as well as those that are more traditional in nature and which elucidate difficult concepts. Please submit them to Professors James O. Wilkes and Mark A. Burns, Chemical Engineering Department, University of Michigan, Ann Arbor, MI 48109-2136.

THERMODYNAMICS AND COMMON SENSE

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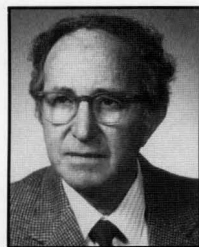
Though it is one of science's grandest pure-logic structures which awes and enraptures its faithful, thermodynamics unfortunately causes much grief for the student who is studying the subject.

Why?

Let's look at a simple situation—that of a batch system of internal energy U going from state 1 to state 2. Here we see written in all texts

$$\Delta U = Q - W \quad (1)$$

But if the system is raised or lowered (potential energy change, ΔE_p), speeded or slowed (kinetic energy change, ΔE_k), or swelled or shrunk (expansion work, W_{pV}) then the above first law expression becomes more generally



Octave Levenspiel is author of four chemical engineering texts. One of them is over thirty years old but is still widely used and has been translated into ten languages. Another, his favorite and funniest, is practically unknown today. Octave is now a retired (emeritus) professor, enjoying himself and struggling to understand thermodynamics.

$$\Delta U + \Delta E_p + \Delta E_k = Q - W_{\text{shaft}} - W_{pV} \quad (2)$$

Clear?

Do you accept this?

Yes?

GOOD!

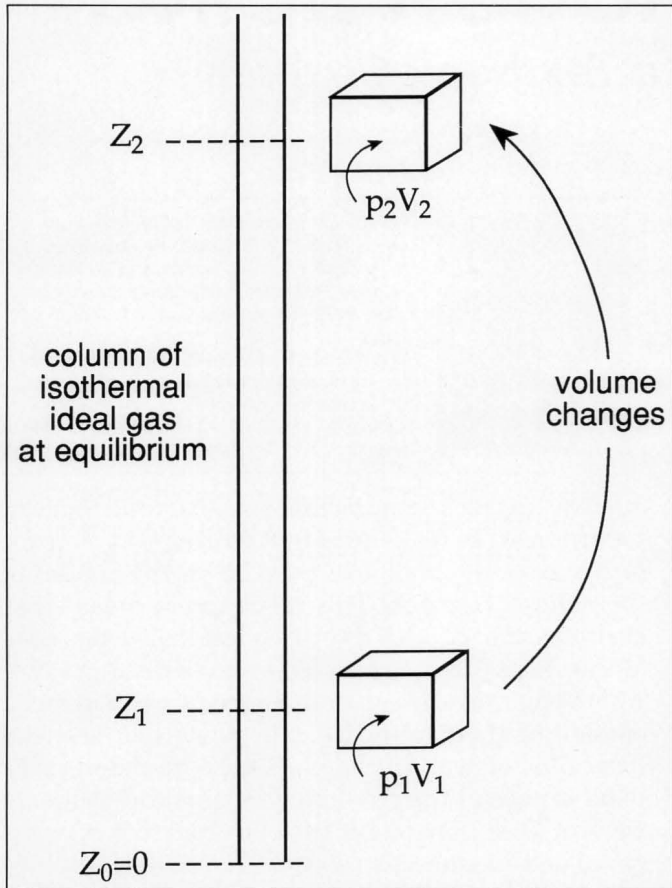
Let us apply this to a column of isothermal ideal gas, such as air, at equilibrium. What happens to the pressure as a chunk of this gas is raised slowly from elevation Z_1 to elevation Z_2 ? Applying the above general first law expression, noting that $\Delta U = 0$ at constant temperature, we find

$$\cancel{\Delta U} + \Delta E_p + \cancel{\Delta E_k} = \cancel{Q} - \cancel{W}_{\text{shaft}} - \int_1^2 p dV \quad (3)$$

Now, for an isothermal ideal gas we can write

$$p = \frac{nRT}{V} \quad \text{and} \quad \frac{V_2}{V_1} = \frac{p_1}{p_2}$$

so for a mass m (or n moles) of gas raised from Z_1 to Z_2 we get



$$\frac{mg(Z_2 - Z_1)}{g_c} = - \int_1^2 \frac{nRT}{V} dV$$

and, since the molecular mass

$$\overline{mw} = \frac{m}{n}$$

rearranging gives, finally

$$g(Z_2 - Z_1) = \frac{g_c RT}{mw} \ln \frac{p_2}{p_1} \quad (4)$$

This is an interesting expression. Look at the left-hand side. It is positive, so the right-hand side must also be positive.

This means that $p_2 > p_1$!!

What this says is that as you climb a mountain the air gets thicker, contrary to experience.

What kind of nonsense is this?

Results like this remind me of the story^[1] of the great physicist Arnold Sommerfeld, who had written a series of books on various topics in physics. When asked why he hadn't written one on thermodynamics, he is supposed to have said

It's a funny subject. The first time you go through it you don't understand it at all. The second time through you think you do except for one or two minor points. The third time you know you don't understand it, but by then you are so used to it, it doesn't bother you.

At the time he was killed in an accident, the physicist was in the middle of writing a book on ... guess what? Yes—thermodynamics!

To get back to the problem, though—where is the error? Please help me straighten out this curious conclusion.

REFERENCE

1. Angrist, S.W., and L.G. Helper, *Order and Chaos*, Basic Books, page 215 (1967) This gem of a book is unique, contains only three equations, and makes thermo almost fun.

The author welcomes comments and solutions to this problem.

A later issue of CEE will list those who have saved thermodynamics from disgrace.