Is Entropy Disorder?

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On 27 December 2005, Professor Granville Sewell's essay "Evolution's Thermodynamic Failure" appeared in an opinion magazine titled *The American Spectator*. The second paragraph of that essay conflates "entropy", "randomness", "disorder", and "uniformity". The third paragraph claims that "Natural forces, such as corrosion, erosion, fire and explosions, do not create order, they destroy it." Investigation of this second claim reveals not only that it is false, but also shows the first conflation to be an error.

The corrosion reaction is

$$4\,\mathrm{Fe} + 3\,\mathrm{O_2} \rightarrow 2\,\mathrm{Fe_2O_3}.$$

According to standard tables [1] the entropy (at room temperature 298.15 K and at pressure 10^5 Pa) of one mole of Fe is 27.280 J/K, of one mole of O_2 is 205.147 J/K, and of one mole of Fe_2O_3 is 87.404 J/K. The entropy of the reactants is 724.561 J/K, the entropy of the products is 174.808 J/K, so the reaction results in an entropy *decrease* of 549.753 J/K.

Of course this doesn't mean that during corrosion, the entropy of the universe decreases: although the entropy of the iron plus oxygen decreases, the entropy of the surroundings increases by even more. Yet the same is true when the reaction runs in reverse. In a refinery, iron ore becomes elemental iron plus oxygen: During that process, too, the entropy of the iron plus oxygen plus surroundings increases.

What about fire? The burning of coal is the chemical reaction

$$\mathrm{C} + \mathrm{O_2} \rightarrow \mathrm{CO_2}.$$

The ignition temperature (glow point) for combustion of anthracite coal is about 600°C or 900 K [2]. At that temperature the entropy [3] of one mole of C is 22.286 J/K and of one mole of O_2 is 239.931 J/K, so the entropy of the reactants is 262.217 J/K. Meanwhile the product is one mole of CO_2 with entropy 263.626 J/K. Thus the reaction results in an entropy increase of 1.409 J/K — an *increase*, to be sure, but an increase of only 0.54%. The destructive properties of house fires are certainly *not* due to this minute entropy increase.

What about explosions? The explosion of 2,4,6-trinitrotoluene, more commonly called TNT, is the chemical reaction

$$4\,\mathrm{C_7H_5N_3O_6} + 21\,\mathrm{O_2} \rightarrow 28\,\mathrm{CO_2} + 10\,\mathrm{H_2O} + 6\,\mathrm{N_2}.$$

Data for the entropy of TNT is harder to come by [4] and I could find entropy data only for temperatures of 300 K and below, so I'll use 300 K. (Anyone wishing to perform the calculation under different assumptions is of course welcome to do so.) Combined with information from standard tables [5], again at 300 K, this shows that the reaction results in an entropy increase from 5454.149 J/K to 7846.894 J/K. This modest 44% entropy increase is surely disproportionate to the disorder resulting from a TNT explosion.

Another explosion is the oxidation of gasoline. Gasoline consists largely of the compound C_8H_{18}, and this oxidation reaction is

$$2\,C_8H_{18} + 25\,O_2 \rightarrow 16\,CO_2 + 18\,H_2O.$$

Again referring to standard tables [6], but this time using room temperature (298.15 K), we discover that this reaction results in an 20.02% entropy *decrease* from 5851.085 J/K to 4679.420 J/K. If the gasoline is burned in an automobile engine with the explosions encased within pistons, then this 20.02% entropy decrease results in transportation. If the gasoline explodes instead in a Molotov cocktail, then this 20.02% entropy decrease results in mayhem. But the mayhem cannot be blamed on entropy, since exactly the same entropy change can result in either transportation or mayhem.

Finally, what about erosion? In this case there is no chemical reaction, but there is common experience. Suppose a pile of mixed gravel, sand, and dirt is subject to an intense rainstorm. The sand and dirt wash away into a nearby puddle. The sand settles on the bottom of the puddle, the dirt settles above the sand. Erosion has not "destroyed order", it has instead unmixed the gravel, sand, and dirt. Growing up on a Pennsylvania apple orchard, I often played in mud puddles so I knew about this layering phenomena for years before I learned its technical name of "hydraulic sorting" [7].

"Disorder" is an *analogy* for entropy, not a definition for entropy. Analogies are powerful but imperfect. When I say "My love is a red, red rose", I mean that my love shares *some* characteristics with a rose: both are beautiful, both are ethereal, both are desirable. But my love does not share *all* characteristics with a rose: a rose is susceptible to aphid infection, my love is not; a rose should be fed 6-12-6 fertilizer, which would poison my love.

The conclusion is abundantly clear: It is an error to conflate "entropy", "randomness", "disorder", and "uniformity".

References

[1] Ihsan Barin, *Thermochemical Data of Pure Substances* (VCH Publishers, Weinheim, Germany, 1995) pages 675, 1239, and 702.

[2] Ray W. Arms, "The Ignition Temperature of Coal," University of Illinois Engineering Experiment Station Bulletin number 128, April 1922.

[3] Barin, pages 209, 1239, and 404.

[4] *Military Explosives*, Department of the Army Technical Manual TM 9-1300-214 (September 1984) page 8-76 gives the value of 286.56 J/(mol·K).

[5] From Barin:

O_2	205.329 J/(mol·K)	page 1239;
CO_2	214.000 J/(mol·K)	page 404;
H_2O	70.416 J/(mol·K)	page 795;
N_2	191.789 J/(mol·K)	page 1081.

[6] From Barin:

C_8H_{18}	361.205 J/(mol·K)	page 309;
O_2	205.147 J/(mol·K)	page 1239;
CO_2	213.770 J/(mol·K)	page 404;
H_2O	69.950 J/(mol·K)	page 795.

[7] Rudy Slingerland, "Role of hydraulic sorting in the origin of fluvial placers," *Journal of Sedimentary Petrology* **54**, 137–150 (March 1984). Marwan Hassan, Roey Egozi, and Gary Parker "Experiments on the effect of hydrograph characteristics on vertical grain sorting in gravel bed rivers," *Water Resources Research* **42**, W9408 (September 2006).