The Thermodynamics of Love

by David Hwang

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Two people who fall in love with one another are often described as having a certain personal "chemistry." Although most people would probably be quite content with accepting this convention at face value, the truth is that the correlation between romance and everyone's favorite branch of the natural sciences runs quite deep.

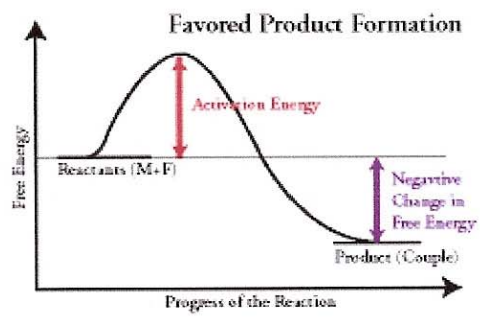
In fact, while the terminology of thermodynamics explains the spontaneity of chemical reactions very well, it also applies directly to various factors determining the success of human relationships.

Let us begin with a theoretical chemical reaction where two elements, "male" (M) and "female" (F), combine to form a new compound called "couple" (M-F):

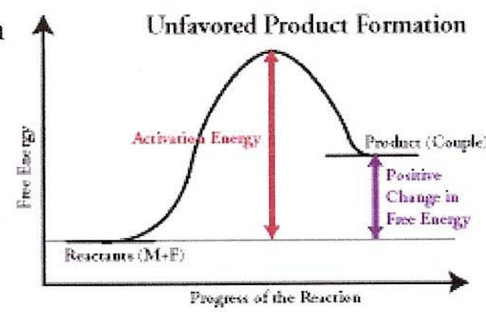
M + F ----> M-F

Usually M is the element with the higher atomic weight, although exceptions do exist.

To predict the likeliness that any given chemical reaction will proceed in the forward direction (and to make themselves feel smart), chemists like to draw simple curves outlining energy considerations:



The y-axis for both of these curves represents a thermodynamic value that chemists call free energy (no, not free love). Individual elements with a collective high free energy (G) value are relatively reactive, while a compound with a low G value is likely to be stable.



Thus, a reaction in which G decreases (-sG) favors formation of product because the products have less free energy than the starting compounds and are more stable. In a reaction in which G increases (+sG), reactants are not likely to make much chemical progress. The x-axis of these graphs usually measures time progression.

We can apply these concepts to our theoretical male-female reaction. Are two people completely natural as a pair, or are they better off apart?

The likeliness that couple formation will succeed is, in part, dependent on the relative stability of the couple versus that of the initial reactants, M and F. If the curve for the reaction looks like the top graph, then chance looks good for a forward reaction and couple formation. If instead, the curve looks like the bottom graph, where "couple" is a very unstable compound, then male and female are likely to remain separate elements.

Free energy (sG) can thus be seen as a measure of how content a person is in his or her current romantic state (i.e., single or part of a couple). If one finds oneself in a position of high free energy, denoting high stress levels, one will probably not remain in that state for very long but will instead attempt to find happiness either by hooking up or breaking up, whatever the case may be.

Further examination of the graphs reveals large middle "humps" in the reaction curves. Chemists have named this energy hump "activation energy," if for no other reason that the term "activation hump" could bear other, less scientific denotations.

Activation energy is defined as the amount of free energy that needs to be added to the reaction in order for the reaction to proceed. Without this activation energy barrier, all chemical reactions in which products are more stable than reactants would occur almost instantaneously. Conversely, even if the reactants of a reaction are less stable than the product, a high activation energy may cause the reaction to take a long time. However, even a very low activation energy cannot overcome the hopelessness of a reaction where the products have a higher G value than the reactants.

Although some people seem to be more conducive to romance than others, couples do not form overnight. Even if two lovers are meant to be together forever, there exists a time period in which they must overcome self-consciousness and get to know one another. This "activation energy" may be large or small, depending on how open the male and the female are to one another initially.

However, just like in chemistry, the presence of a high activation energy in human relationships does not prevent the couple product itself from being very stable. In fact, a man and woman that spend much time in getting to know one another will probably have a very stable relationship. Looking at the top graph, one can see that a chemical reaction with a high forward activation energy has an even larger activation energy for the reverse reaction, the splitting of product (or couple) back into separate reactants (male and female).

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Furthermore, "catalysts" are often added to chemical systems to lower activation energies and facilitate reactions. While chemists have yet to produce a true aphrodisiac (they are working very hard--how else are chemistry majors going to get dates?), everyone knows that certain catalysts do exist that can be used to speed up the development of human relationships.

Encouraging mutual friends and overlapping class schedules are just two real-life catalysts that can speed a romantic reaction simply needing a nudge towards product formation.

Chemists have even analyzed the subfactors that compose a change in free energy (sG) value for any given reaction:

$$sG = sH - TsS$$

where sH is change in enthalpy (internal heat), T is the temperature at which the reaction is performed, and sS is change in entropy (system disorder). Change in enthalpy can be thought of as the internal heat energy released from the reactants or gained during product formation: a positive sH value indicates that heat had to be added from an external source to aid the reaction, whereas a negative sH value indicates that heat was released from the reaction.

Change in entropy (sS) expresses the degree to which the orderliness of the system changes during the passage of time, with disorderliness being favored naturally over orderliness. Thus, a positive sS value for a reaction indicates favorable movement towards the unstructured (e.g., separate reactants), whereas a negative sS value indicates unfavorable movement of a reaction towards the highly structured (e.g., a single product).

Potential conflicts of interest arise, however. Looking at the equation above, we see that while a reaction in which heat is released (-sH) will favor a negative free energy (-sG), a reaction in which the product is more structured than the reactants will yield a negative entropy (-sS) term, causing the sG value to rise.

This bickering among variables applies directly to our male-female couple formation system. That is, when a man and woman fall in love, much "heat" is released in the form of mutual passion. The more passion in a relationship, the more personal warmth, the more heat released--the more negative the enthalpy change value, the more negative the sG value, the more stable product.

In chemistry as in life, there is a natural tendency towards disorder (also know as the second law of thermodynamics). People have a natural tendency to take care of themselves and listen to their own independent concerns. Living or even just staying with the same partner for extended period of time tests one's willingness to sacrifice one's own wants for the benefit of the structured relationship.

Thus, the negative entropy factor comes into play: getting into a relationship with a lover means that one can't simply do what one wants to do all the time, and the orderliness of one's life thus increases. This increase in orderliness can put strain on a relationship or a chemical product, making the free energy larger and the likeliness for a break-up greater.

The passions of love and the desire to do one's own thing often work against each other, just like entropy and enthalpy change in an exothermic M + F ----> M-F reaction.

Even temperature, an external condition in chemical reactions, has relevance in gauging the success of human relationships. The T variable in the free energy equation shown above can be used to represent the environmental factors coming into play in love. Stress at work, lack of money, forbidding parents--all are examples of problems that turn up the heat of one's life, aggravating the effects of an already harmful negative entropy (i.e., greater disorder) factor. A relaxed lifestyle allows lovers to enjoy one another; such low temperature alleviates entropy concerns and allows as much free energy to be released, as much couple stability to be gained as possible.

The beauty of this entire thermodynamics-love model is that the graphs shown above do not represent static, one-way reactions but rather describe a dynamic equilibrium between their reactants (singles) and product (couple). As anyone who has been in love before knows, human relationships are dynamic as well. Being in a couple isn't peachy-keen one hundred percent of the time; even the closest of lovers argue and bicker. Similarly, even the most stable of chemical compounds spend time in their original, separate reactants state.

While a high grade in general chemistry does not guarantee one's success in love, interesting (and scary) correlations between the model of thermodynamics & factors of romance abound.

The model of thermodynamics makes relative judgements of the stability of reactants compared to the product and the energy required to equilibrate between the two extremes. If our given male/female reaction has a very negative free energy, then it is expected that the system will spend most of its time together as a strong couple. Any tendencies for the equilibrium to move backwards towards separate M and F reactants, although inevitable, will always be counteracted by the indefatigable stability of the M-F bond.

While a high grade in general chemistry does not guarantee one's success in love, interesting (and scary) correlations between the model of thermodynamics and factors of romance abound. The author of this article would like to wish all readers good luck in achieving the most negative free energy values possible in love. In addition, don't be discouraged with seemingly insurmountable activation energies.

● Hwang, David. (2001). “The Thermodynamics of Love”, *Journal of Hybrid Vigor*, Issue 1, Emory University.