RULES OF THUMB

FOR ENGINEERS AND SCIENTISTS

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Preface

In science, rules of thumb are the poor relations of laws and, although useful, cannot always be depended upon. Perhaps because of this, there tends to be a marked reluctance to disseminate them widely. At the same time, they are frequently proposed in the literature. The present compilation is an attempt to begin to bridge this gap between supply and demand. It should not be assumed to be an exhaustive list of all the rules of thumb that have been discovered. Rather, it should be regarded as a "sampler" of such rules and is a miscellany of those I have found particularly useful or surprising.

Thanks are due to the few who replied to the compiler's published appeals for rules of thumb. The aid of Professor F. Bénière, Professor A. A. Berezin, Dr. D. C. Robie, and Dr. A. M. Stoneham is hereby acknowledged.

David J. Fisher, D. Sc.

Introduction

I make no apology for the fact that this is a rather idiosyncratic reference work. It originated from a need to know the properties of an unusual class of organic compounds known as "plastic" crystals. It quickly became apparent that, although the properties important to organic chemists (melting point, boiling point) had invariably been determined, those important to a metallurgist (heat and solute diffusivities in the liquid and solid state, surface energies) had not. I was eventually forced to measure most of the required properties myself but, while searching fruitlessly for such data in *Chemical Abstracts* and other sources, I discovered many intimate correlations that existed between different properties and different substances. A particularly inspiring influence at this time was a paper by K. G. McNeill (*American Journal of Physics*, 1960, **28**, 375), in which the author predicts the properties of copper and lead on the basis of a few simple relationships. A later inspiration was E. M. Purcell, of the *American Journal of Physics*, and his "Back of the Envelope" column. For the record, one work that did *not* inspire the present one was the book *Rules of Thumb*, by T. Parker (Houghton Mifflin). Preparation of the present book was well under way when the latter work appeared. No doubt it is a rule of thumb in itself that when one finds a book title that appears never to have been used before, someone else has the same idea and gets to use it first.

Chance comments by colleagues also revealed that even "well-known" approximate correlations were not, in fact, well known. This lack of dissemination appeared to arise mainly from the false assumption that everyone else already knew them. The latter fact immediately became clear when, after deciding to collect as many newly proposed correlations as possible, I became aware of the many "classic" correlations of which I had hitherto been ignorant.

Consequently, this first compilation is a mixture of those correlations (identified by asterisks*) that I believe should become accepted as "rules of thumb," and those correlations that have already been acclaimed as rules of thumb by others. It is not easy to find the "classic" rules of thumb, and the present list is certainly incomplete. The difficulty stems from the fact that very few authors index the rules under "rules of thumb" or even under rules, again probably assuming that the reader already knows the name of the rule. Moreover, normally trusty sources such as *Chemical Abstracts* and *Science Citation Index* make a point of *not* indexing the word "rule" or indeed any likely synonym such as "correlation," "relationship," etc.

The question arises as to what constitutes a rule of thumb. I gave a great deal of thought to this problem and developed many sets of guidelines that limited how complicated a rule was allowed to be and what subjects it should cover. Unfortunately, adhering to any set of guidelines would have necessitated missing out on one or another particularly interesting rule. Finally, it was decided simply to include anything I felt like including—hence the idiosyncrasy.

One reason why the rule of thumb is less popular in science than in certain other professions may be that scientists are less likely to have to "think on their feet." On the other hand, the medical world is particularly rife with heuristics, so much so that when a doctor diagnoses, with great profundity, that a patient is suffering from gallstones, one cannot be sure whether this is the fruit of much weighing of the physiological evidence or the simple application of the rule "fat-fertile-female-fifty," as a handy guide to the probable incidence of the condition (*New Scientist*, 21st March, 1985). When judging the "correct weight" for a given height, a medic may simply subtract 100 from the patient's height (in centimeters) to give the permissible number of kilograms. If he is feeling particularly dedicated, he may use the "ponderal index," which is the weight (in kilograms) divided by the square of the height (in meters). The resultant value (which appropriately has the units of pressure) should be between 20 and 25. It is also reported that students of forensic medicine were once routinely vouchsafed the advice that, "if the number of bullet holes in a patient is odd, that patient has an odd number of bullets in him" (*British Medical Journal*, volume 292, p. 1399). Rather more cynical is the rule of thumb attributed to pharmaceutical manufacturers that, "there must be 10^5 victims of a disease before it becomes profitable to market a drug to treat it" (*Scientific American*, January, 1983, p. 54).

More seriously, there are several reasons why the collection of rules of thumb should be useful:

1. The first is the previously mentioned ability to "think on one's feet." The universal use of computers has already produced students who are rather out of touch with reality. If one asks such a student what the order of magnitude of a given quantity is likely to be, the result will probably not be an educated guess but a request to visit the ... computer terminal. This is not because the ability to perform simple calculations has been lost, but rather because the simulation mania has percolated downwards to the student level. Unfortunately, we live in a world that is increasingly ruled by the media and by mammon; one in which the

smart answer is a *sine qua non* of credibility. The person who can deliver the "technical fix" on the spot as well as do the real work later will get the attention or the funding.

2. Purcell, an editor of the *American Journal of Physics*, recognized this insidious loss of what might be termed "physical intuition" some years ago and started his "Back of the Envelope" column, which seeks to inculcate this lost art of approximation. One aim of *Rules of Thumb* is to perform the same service, although it does not duplicate the efforts of Purcell. Purcell's examples involve fitting approximate values into accepted physical laws. In contrast, the present work provides a wealth of sometimes surprising correlations whose accuracy can be questioned but into which one may as well fit the best data available and, again, obtain an order of magnitude estimate.
3. Recalling and naming rules can be useful, even if the principle is obvious, because this facilitates discussion and avoids a lot of hand-waving. See, for example, the Sidgwick-Powell rules, which "everyone" has been taught but few could name.
4. Having a rough estimate of how a material should behave can quickly eliminate anomalous results. See, for example, Sirdeshmukh and Subhadra (*Journal of Applied Physics*, 1986, **59**, 276) for a typical example.
5. Recalling a rule can help to avoid "re-inventing the wheel": a process that is increasingly wasting space in scientific journals, as pointed out by Dienes and Welch (*Physical Review Letters*, 1987, 59, 843).
6. Rules of thumb can help to maintain links between science and technology and avoid a rift appearing between them. As Van Uitert has stated (*Journal of Applied Physics*, 1981, **52**, 5547): "as the complexity ... increases, so does the likelihood that the technology-oriented reader will gain little from it. Hence, there are good reasons for presenting physical relations in a way that is easily understood and reducible to rules of thumb."
7. Although the use of computers was criticized, the computer programming industry is itself now a prime consumer of vague correlations. That is, the growing fields of "fuzzy logic" and "expert systems" are not averse to gathering together the vaguest of correlations and, nevertheless, obtaining valuable results.

However, there are some fields in which the use of rules of thumb is counterproductive. In mathematics, for example, it has been found that rules are no substitute for principles (T. H. Logan, *American Journal of Physics*, 1968, **36**, 79).

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* *See page xii for explanation of asterisks.*

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A

ABEGG'S RULE

> The sum of the maximum positive valency exhibited by an element and of its maximum negative valency is 8.

A corollary is that the tendency to form compounds increases with increasing heteropolarity of the two elements involved. Nowadays, this is enshrined in the electronegativity concept. The above rule (Abegg, 1904) is generally true for groups 4 to 7, and is related to the 8-N and Octet rules (qv).

ADAMS' RULE

This useful rule serves to predict whether a given organic biphenyl compound (Figure 1) can be resolved. According to the rule:

> A substituted biphenyl can be resolved if, and only if, the sum of the "hanging bond" lengths is greater than 0.29nm.

The definition of the "hanging bonds" is easily seen from the figure. The seemingly arbitrary value of 0.29nm is, in fact, the distance between the C atoms in the ortho position. Of course, the question of resolution (separation of racemates) also depends upon the temperature, experimental method, and other factors. Nevertheless, for simple compounds at temperatures of between 0° and 25°C, the rule is a useful guide. Basically, it works because it neglects the Van der Waals radii and the activation energy.

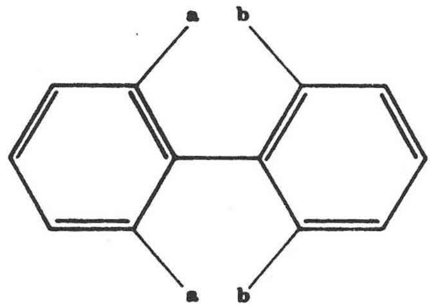

Figure 1. Adams' rule for the resolution of substituted biphenyls. The biphenyl can be resolved only if the sum of the C-a and C-b bond lengths is greater than 0.29nm.

ADJACENT CHARGE RULE

It is possible to write formal electronic structures for some molecules in which adjacent atoms have formal charges of the same sign. This rule states that such structures will not be important, due to instability resulting from the charge distribution. See also Pauling's rules.

AKHIEZER-DAVYDOV RULE*

Only those alloys which cluster can swell much less than the corresponding pure metals, and only those alloys which order can swell much more than the pure metals.

This rule (Akhiezer & Davydov, 1981) neatly summarizes the response of metallic alloys to the void swelling effect which is produced by neutron irradiation.

AL-BAYYATI RULE*

It is often desirable to have a short-cut method for choosing a sample size which is large enough to detect a significant difference between two sample groups or methods. Such a method was suggested (Al-Bayyati, 1971) for finding the sample size which is necessary to detect a difference in the true long-run proportions of two groups. It is assumed that nothing is known about the latter proportions; save that one wishes their difference to have a certain value. On this basis, it can be stated that: