The Gender of Boyle's Law

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Abstract

Boyle's law is typically considered gender-free or gender-neutral. Here, I adopt a Daoist interpretation of gender and explore the yin and yang dimensions of Boyle's law, the phenomenon it describes and the problems it addresses. The gendered perspective opens analysis of the concept of laws, reductionism, metaphysical frameworks of nature's order, the role of eponymous concepts, and systems of credit and authority—and the contexts in which differently gendered versions function.

Outline:

The Gender of Boyle's Law

There are more things in heaven and earth, Horatio,
Than are dreamt of in your philosophy
Hamlet, I.5.166-167.

Does gender matter to science? I hope in this extended essay to show that it does, even to such apparently simple physical principles as the familiar Boyle's law, PV=k.

For many, contending that science is gendered implies that men and women must inherently do science differently. I might agree that men and women tend to approach science differently, but not "inherently" so. My observations are not about male and female. Rather, in focusing on gender, I consider variations in syle or perspective that might be labeled 'masculine' and 'feminine' (quite apart from an individual's gonads!). Gendered attributes are cultural, not biological. That is, to the extent that men and women may behave or think differently about science, I will regard it as a result of enculturation and contingent social history, not of sex chromosomes or hormones. Indeed, embedded patterns of thinking in our culture render puzzling (or even unnatural) the concept of a "masculine" female or "feminine" male. We are even less inclined to view individuals as *combining* both "feminine" and "masculine" behaviors. I wish to escape the overtones and misinterpretations that occur when one slips unconsciously from *talking about* masculine and feminine to *thinking in terms of* male and female. Towards that end, I adopt here another characterization of gender.
I summon to our aid the traditional Chinese framework for conceiving masculine and feminine: the Daoist (Taoist) principles of yin and yang. The masculine is *yang*. The feminine is *yin*. The distinction of yin and yang (more below) was important to ancient Chinese philosophers for underscoring balance, whereby neither masculine nor feminine attributes assumed precedence or gained exclusive privilege. Politically, Daoists underscored the relevance of yin, or feminine, principles in governance and in interpreting and exercising power, as reflected in many martial arts today. The

Daoist concept of complementarity, rather than of either-or alternatives, is also one that I endorse, and whose substantive consequences in science I hope to ultimately illustrate by discussing the history and contexts of Boyle's law. Thus, to say that Boyle's Law is gendered means, fundamentally, that it embodies a particular, and specifically masculine (or yang), enculturated way of doing science. If so, then there must be other equally legitimate ways of construing and doing science, without abandoning or substantially altering the central aims of science. In what follows, I refrain from abstract arguments about gender or vague thematic possibilities. Rather, using the case of Boyle's law, I hope to illustrate concretely, and then profile in general terms, an alternatively gendered (feminine,

Yang	**Yin**
masculine	feminine
sunlit/light	shadowed/dark
positive	negative
parts	wholes
active/generative	passive/receptive
fire	water
sun	moon
hot	cold
expanding	contracting
- - - - - - - - - - -	- - - - - - - - - - -
internalistic	contextual
reductionistic	holistic
mechanical	ecological
simplified	complex
individual	communal
power	equity
competitive	collaborative

Figure 1. Features characterizing the complementary Daoist principles of yin and ying.

or yin) approach to scientific practice. Ultimately, I hope the reader becomes persuaded that Boyle's law, PV=k, is limited and misleading and, when left unbalanced, even constitutes *bad* science.

A gendered view of science differs markedly from one that considers science transcendental, or universal, and hence gender-neutral. Such views are typically expressed in terms of 'objectivity' or 'rationality', concepts I wish to avoid as unfruitful to a practice-oriented analysis of effective scientific investigation and reliable representations of nature. Thus, one of my early aims is to show how Boyle's law is *not* universal, but contingent and contextual.

Many scientists and philosophers scoff at the claim that science may be shaped by gendered perspectives. Such critics often point to physical laws, such as Boyle’s law relating pressure and volume of gases, as examples of scientific discoveries of immutable truths of the natural world, immune to gender (Potter 2001, p. ix). Sexism may appear perhaps in studies of sexual differences (a marginal science, at best!), they say, but not in the Exact Sciences, the proper models of "good" scientific practice. Thus, who Boyle was or his social setting — the male aristocracy in late 17th-century England — may certainly illustrate the cultural context of science, but (skeptics contend) they are irrelevant to both what he discovered and how he did so. Rather, general principles of investigation and standards of experimental evidence alone are held to determine such findings. Here, I adopt the implicit challenge: to profile the gender in Boyle’s law.

For those familiar with gendered analyses, my work here contrasts with Elizabeth Potter’s earlier analysis of *Gender and Boyle’s Law of Gases* (2001). Potter draws largely on Boyle himself and his historical context: from his writings on the social role of women, in his youthful essay on "Seraphick Love," to his debates about the vacuum and their relation to contemporary views of nature and the politics of women’s rights. My analysis is complementary. My posture is also broader, borrowing from various characterizations of an alternative-gendered science. I am also concerned about the role of Boyle's law in a standard science curriculum and how that instruction supports and contributes to sustaining gendered approaches to science and the broader culture.

Again, my focus is the cultural dimensions of gender—not the politics of male and female. Accordingly, I do not frame this analysis as "feminist," although one may see in it concepts emerging from feminist epistemology. Thus, in lieu of the familiar masculine/feminine dichotomy, my framework for gender comes from the complementary Daoist concepts of yang and yin. Other attributes are aligned with each as a thematic syndrome (dark/light; heaven/earth, and so on; see Figure 1). One may see these echoed in Western images of masculine and feminine, and in ways that our culture conventionally associates (despite recurrent exceptions) with men and women. One virtue of the yin-yang schema is that is comes from a cultural tradition where gender is less politicized. One may freely conceive gender apart from equity among the sexes. Moreover, the conceptual framework emphasizes balance between male and female, while not erasing the distinction. Here, then, I explore the *yang* features of Boyle's law and its possible *yin* alternatives.

As a further prefatory aside, I might add a perhaps deflationary disclaimer to prospective skeptics. A naysayer may interpret a claim that gender shapes Boyle's law to imply that the law must be "wrong" and that a woman scientist studying gas laws would necessarily come up with some different, allegedly better equation for the same phenomenon. This interpretation reflects a notion that all perspective is bias, and that all bias inevitably leads to error. A yin, or feminist, version of Boyle's law would inevitably be wrong, they imagine, because it would not (or could not) match the data, as already simply and accurately documented by Boyle. While some feminist analyses do (importantly) probe errors and demonstrate their gendered roots (e.g., Fausto-Sterling 1986, Schiebinger 1993), one need not deny Boyle's empirical conclusions here, nor propose a different relationship of pressure and volume. Boyle's law need not be "wrong" to exhibit gender. Perspectives may have significant consequences, however, and potentially mislead thinkers, especially where the perspective is masked, or other perspectives are eclipsed. One may still probe deficits in the yang form of Boyle's law.

Gender fundamentally underscores alternatives, not essential error. One asks: what other questions or problems could one pose? What other modes or styles of investigation might one fruitfully pursue? What other data may be relevant to collect? What phenomena may have been overlooked? How else might one interpret the available evidence? How might Boyle's or other scientists' gendered perspective have blinded them from considering or pursuing such alternatives, or from recognizing them as viable? Boyle's law may not be wrong, so much as context-dependent and/or incomplete. Accordingly, gendered alternatives frequently haunt the negative space of common histories or philosophies of science. The form of "proof" is demonstrative, not based on logic or falsification. Still, even the alternatives fully follow the aims of science in the development and justification of reliable (trustworthy) natural knowledge. My analysis, therefore (as in many analyses of gender), aims not to expose error or to sort right from wrong. Rather, I intend to show how science may be gendered — and how its problems, practice and purported solutions may reflect a systematically incomplete view of nature. My analysis may thereby indicate how to enrich a *scientific* understanding of our world by drawing on other (in this case, yin) perspectives.

Historical Interlude

For those not familiar with the historical context of Boyle and his law, here is a brief account of how it originated. Boyle was interested in the "spring of air." It could exert pressure when compressed. Borrowing from a device of Otto Guericke, Boyle enlisted his hired technician, Robert Hooke, to build an "air pump." The pump — functioning like a modern bicycle pump in reverse —

had a vessel for investigating the properties of space largely evacuated of air. If such a ‘Boylean vacuum’ was not a true vacuum, its low residual volume of air at least exhibited extremely low pressure. In 1660 Boyle published his findings on its many effects — on magnets, sound transmission, sealed bladders, burning candles, the life of small animals, and more. In response to criticism, Boyle returned to demonstrate the features of the ‘spring of air’. In one set of experiments he compressed a small amount of air trapped in the end of a glass J-tube with increasing amounts of mercury. In a second set of experiments, he dilated the air in a similar set-up, using his new air-pump to draw up the column of mercury weighing on the trapped air. In both cases, he recorded the volume of the trapped air and the corresponding height of the column of mercury (an indirect measure of its weight, or pressure) (Figures 2a and 2b). Students even today can graph his figures and see the indirect mathematical relationship of pressure and volume (Conant 1957).

There are many ways to express Boyle's law:

$$PV = k$$

The product of gas pressure and gas volume remains constant.

or:

$$P_1V_1 = P_2V_2$$

The product of the pressure and the volume of a confined gas at one time is the same as at another time (even when the volume or pressure change).

The analysis here will be based on the more narrowly explicit version:

$$\Delta P \propto 1/\Delta V$$

The change in pressure [of a confined gas] is inversely proportional to the change in volume. (As the volume increases, the pressure decreases, and vice versa.)

A table of the condenſation of the air.

A	*A*	*B*	*C*	*D*	*E*
48	12	00		$29\frac{2}{16}$	$29\frac{2}{16}$
46	$11\frac{1}{2}$	$01\frac{7}{16}$		$30\frac{9}{16}$	$33\frac{6}{16}$
44	11	$02\frac{13}{16}$		$31\frac{15}{16}$	$31\frac{12}{16}$
42	$10\frac{1}{2}$	$04\frac{6}{16}$		$33\frac{8}{16}$	$33\frac{1}{7}$
40	10	$06\frac{3}{16}$		$35\frac{5}{16}$	35 - -
38	$9\frac{1}{2}$	$07\frac{14}{16}$		37	$36\frac{15}{19}$
36	9	$10\frac{2}{16}$		$39\frac{5}{16}$	$38\frac{7}{8}$
34	$8\frac{1}{2}$	$12\frac{8}{16}$		$41\frac{10}{16}$	$41\frac{2}{17}$
32	8	$15\frac{1}{16}$		$44\frac{3}{16}$	$43\frac{11}{16}$
30	$7\frac{1}{2}$	$17\frac{15}{16}$		$47\frac{1}{16}$	$46\frac{3}{5}$
28	7	$21\frac{3}{16}$		$50\frac{5}{16}$	50 - -
26	$6\frac{1}{2}$	$25\frac{3}{16}$	Added to $22\frac{1}{8}$ makes	$54\frac{5}{16}$	$53\frac{10}{13}$
24	6	$29\frac{11}{16}$		$58\frac{13}{16}$	$58\frac{2}{8}$
23	$5\frac{3}{4}$	$32\frac{3}{16}$		$61\frac{5}{16}$	$60\frac{18}{23}$
22	$5\frac{1}{2}$	$34\frac{15}{16}$		$64\frac{1}{16}$	$63\frac{6}{11}$
21	$5\frac{1}{4}$	$37\frac{15}{16}$		$67\frac{1}{16}$	$66\frac{4}{7}$
20	5	$41\frac{9}{16}$		$70\frac{11}{16}$	70 - -
19	$4\frac{3}{4}$	45 - -		$74\frac{2}{16}$	$73\frac{11}{19}$
18	$4\frac{1}{2}$	$48\frac{12}{16}$		$77\frac{14}{16}$	$77\frac{2}{3}$
17	$4\frac{1}{4}$	$53\frac{11}{16}$		$82\frac{12}{16}$	$82\frac{4}{17}$
16	4	$58\frac{2}{16}$		$87\frac{14}{16}$	$87\frac{3}{8}$
15	$3\frac{3}{4}$	$63\frac{15}{16}$		$93\frac{1}{16}$	$93\frac{1}{5}$
14	$3\frac{1}{2}$	$71\frac{5}{16}$		$100\frac{7}{16}$	$99\frac{6}{7}$
13	$3\frac{1}{4}$	$78\frac{11}{16}$		$107\frac{13}{16}$	$107\frac{7}{13}$
12	3	$88\frac{7}{16}$		$117\frac{9}{16}$	$116\frac{4}{8}$

AA. The number of equal ſpaces in the ſhorter leg, that contained the ſame parcel of air diverſly extended.

B. The height of the mercurial cylinder in the longer leg, that compreſſed the air into thoſe dimenſions.

C. The height of the mercurial cylinder, that counterbalanced the preſſure of the atmoſphere.

D. The aggregate of the two laſt columns *B* and *C*, exhibiting the preſſure ſuſtained by the included air.

E. What that preſſure ſhould be according to the hypotheſis, that ſuppoſes the preſſures and expanſions to be in reciprocal proportion.

Figure 2a. Boyle's table of compressed air.

A table of the rarefaction of the air.

A. The number of equal ſpaces at the top of the tube, that contained the ſame parcel of air.
B. The height of the mercurial cylinder, that together with the ſpring of the included, air counterbalanced the preſſure of the atmoſphere.
C. The preſſure of the atmoſphere.
D. The complement of *B* to *C*, exhibiting the preſſure ſuſtained by the included air.
E. What that preſſure ſhould be, according to the hypotheſis.

A	*B*	*C*	*D*	*E*
1	00 0/8	Subſtracted from 29 3/4 leaves	29 3/4	29 3/4
1 1/2	10 5/8		19 1/8	19 5/6
2	15 3/8		14 3/8	14 7/8
3	20 2/8		9 4/8	9 15/12
4	22 5/8		7 1/8	7 7/16
5	24 1/8		5 5/8	5 19/20
6	24 7/8		4 7/8	4 27/26
7	25 4/8		4 2/8	4 1/4
8	26 0/8		3 6/8	3 21/32
9	26 1/8		3 5/8	3 11/36
10	26 6/8		3 0/8	2 39/40
12	27 1/8		2 5/8	2 13/48
14	27 4/8		2 2/8	2 1/8
16	27 6/8		2 0/8	1 55/64
18	27 7/8		1 7/8	1 47/72
20	28 0/8		1 6/8	1 9/80
24	28 2/8		1 4/8	1 23/96
28	28 3/8		1 3/8	1 1/16
32	28 4/8		1 2/8	0 119/128

Figure 2b. Boyle's table of lower pressures.

The 'Law' in Boyle's Law

The concept of scientific laws, such as Boyle's law, has a venerable tradition. Laws are empirically substantiated generalizations or regularities. For some, they are the basic units of scientific knowledge. Laws reflect a conception of nature as law-like or machine-like, as expressed in the mechanical philosophy, famously advocated by Boyle (Sargent 1995). Nature may thus be described by reducing phenomema to their parts and the laws that govern their interaction. Elucidating these laws is widely portrayed as the/a major goal of science. Familiar examples of laws might also include Snel's law of refraction, Galileo's law of the oscillating pendulum, Newton's laws of motion, Ohm's law of electrical resistance, and Mendel's Law of Independent Assortment. As typically presented and interpreted, scientific laws distinguish themselves as invariant and universal (Hempel 1966, 54, 58; Ziman 1978, 32; Kosso 1992, 52-60, 190; Woodward 2003, pp. 167, 236-238, 265-266). Indeed, it is their universality and invariance that typically accounts for their value and authority as generalizations.

From a gendered perspective, Boyle's law is distinctly 'yang' (masculine). Accordingly, one might profitably reflect on the yin (feminine) alternatives. What other views of nature and the aims of science are possible? A yin perspective will highlight, in particular, contexts and wholes, instead of internal parts. One is poised to consider reductionism versus holism, invariance versus contingency, and universality versus particularity and context-dependence, as well as conceptions of scientific knowledge without laws. Such analysis need not negate a conventional view of laws as "wrong." Rather, it brings into relief the relevant assumptions and their effects, or consequences. Still, by probing the "negative space," a gendered analysis may show how or where conceiving science in terms of laws is limited and thus misleading—while profiling the alternatives and how they offer a "corrective" balance.

Viewing Boyle's Law Contextually

Adopting a gendered yin perspective, then, let us consider the context of Boyle's law. In what sense is it universal? Does it hold in all cases? Well, no. It depends on context. *At high pressures*, the direct inverse relationship of pressure and volume breaks down (Figure 3). Henri Regnault (in 1852), Louis Cailletet and Emile Amagat (1883) noted this variation two centuries after Boyle's work. In modern terms, we would say that <there is a limit to the compression>. Under very high pressures, the gas begins to behave more like a liquid than a compressible gas. These findings restrict the scope of Boyle's law. They set conditions on when it applies. Boyle's law only holds in the limited domain of pressures up to approximately ten atmospheres. Never mind that these pressures are infrequently encountered in daily human life: the law is *not universal.*

Perhaps the behavior of gases at high pressures is a rare, minor exception. Suppose one stipulates explicitly, then, that only certain pressures apply:

$$\forall\, P \ngtr\ngtr 0 \Longrightarrow \Delta P \propto 1/\Delta V$$

For all pressures not too high (not substantially greater than zero), the change in pressure is inversely proportional to the change in volume.

Is Boyle's law universal now? No. *At low temperatures*, the relationship does not hold. The linear relationship breaks down under these circumstances, as well (Figure 4). Historically, this was noted by Thomas Andrews in the 1860s (Andrews 1869). Here another context qualifies scope. But this case also introduces something unexpected: a new variable. The equation or formula does not even refer to temperature as relevant. An experimenter, for example, would need to be aware of temperature, even if only to ensure that the system was not at low-temperatures. The simple expression of Boyle's law hides this variable entirely.

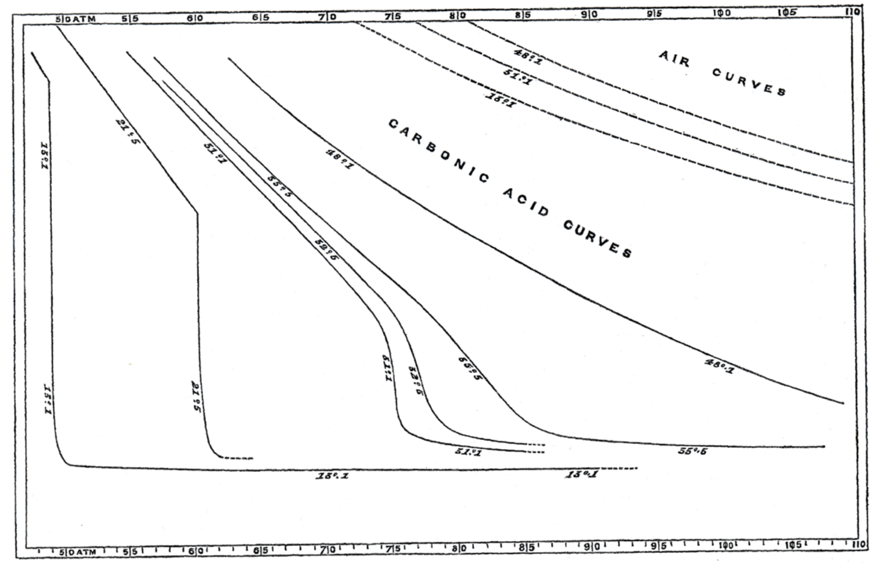


Figure 4. Effect of lower temperatures (successive curves to left) on pressure-volume relationship of carbon dioxide (Andrews 1869).

Well, then, let us add both these conditions, or provisos:

$$\forall\, T >> 0 \;\&\; \forall\, P \ngtr\ngtr 0 \Longrightarrow \Delta P \propto 1/\Delta V$$

For all temperatures well above zero,
and for all pressures not too high,
the change in pressure is inversely proportional to the change in volume.

Is Boyle's law "fixed" now? For example, having restricted the scope of the law, is the law now securely invariant? Well, no. Temperature is indeed important. —Not just the range of the temperature, but also its constancy. As Boyle himself (and others of his era) noted, the behavior of gases is sensitive to changes in temperature. This was formalized a few decades later, of course, by Jacques Charles (in 1787) and Joseph-Louis Gay Lussac (1802) in yet another law, which now bears (alternately) their names.

Hence, while the relationship between pressure and volume may be addressed independently of temperature, temperature is nonetheless relevant. Constant temperature is a *boundary condition* (a concept introduced by philosopher John Herschel). Sometimes it is expressed as a *ceteris paribus* clause: "all else the same." But not all other things need to be equal. The amount of illumination, the relative motion of the system, or gravity exerted on it, have no effect on gas behavior, so far as we know. No one need stipultate these as boundary conditions or imagine them in a *ceteris paribus* assumption. So specifying what must remain constant is important indeed if one expects the law to hold. The invariance of Boyle's law, ironically, depends on context.

Well, let us now add our additional boundary condition:

$$\forall\, T \gg 0 \;\&\; \forall\, P \not\gg 0 \;\&\; \forall\, \Delta T = 0 \Longrightarrow \Delta P \propto 1/\Delta V$$

For all temperatures well above zero,
and for all pressures not too high,
and at constant temperatures,
the change in pressure is inversely proportional to the change in volume.

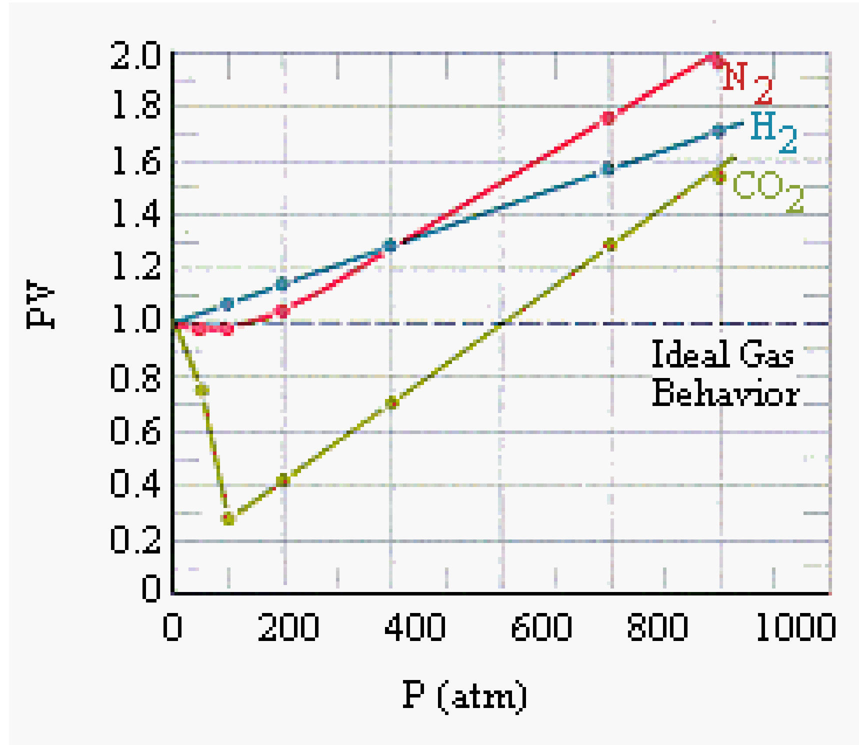


Figure 4½. Different pressure-volume relationships for different gases.

Is Boyle's law expressed fully now? No, still not yet. ("Oh, for goodness' sake! What is it now?") If the volume is very low (or the density very high), the volume of the gas molecules relative to the volume of the space between them becomes significant. Intermolecular interactions (London forces) become relevant. The behavior of the gas changes noticeably. Moreover, because the size of the gas molecule matters, the deviation will be specific for each gas. Here is another case limiting the scope of Boyle's law. —And even the limitations are not uniform. —And there are others. Any gas with strong polarities may also exhibit intermolecular forces, although of another sort. These gases, such as carbon dioxide, also deviate from the simplified "ideal" (Figure 4½). Ultimately, then, we must also take into account the nature or identity of the gas (or gases). Johannes van der Waals investigated these various dimensions of gas behavior in the 1870s and 80s and, coincidentally, the nature of some of the intermolecular forces. His work was recognized by a Nobel Prize in Physics in 1910. As van der Waals noted, one can "correct" for the subtleties of molecular size and interactions, but these corrections (known as van der Waals constants) differ for each gas (Figure 4.6). Thus, even his now well known generalized form of the gas law, his equation included variables specific for each gas:

$$\left(P + \frac{a}{V^2}\right)(V - b) = nRT$$

To be accurate, or realistic, Boyle's law must sacrifice universality.

Compound	a (L^2-*atm/mol*^{2})	b (*L/mol*)
He	0.03412	0.02370
Ne	0.2107	0.01709
H_2	0.2444	0.02661
Ar	1.345	0.03219
O_2	1.360	0.03803
N_2	1.390	0.03913
CO	1.485	0.03985
CH_4	2.253	0.04278
CO_2	3.592	0.04267
NH_3	4.170	0.03707

Figure 4.6 van der Waals contants for various gases.

One may well be tempted to imagine Boyle's law as an exception: that most scientific laws are indeed universal and invariant. Not so. Consider, for example, Galileo's "law" of the period of the pendulum:

$$t = 2\pi\sqrt{\frac{l}{g}}$$

(where *t*= the time of the period, *g*=9.8 m/sec^2; *l* is the length). This formula only works (and with limited precision, at that) for pendulums with small angles of swing (generally reported as less than 10°). The familiar equation is an approximation based on the broader characterization:

$$\frac{d^2x}{dt^2} + \frac{g}{l}\sin(x) = 0$$

(where *x* is the angle of swing). This may be universal, but it is rarely used. It cannot be solved analytically and requires iterative substitution even to approximate solutions. But even this expression assumes that the mass is concentrated on a single point and that no friction affects either the fulcrum or the interaction of the pendulum and its medium. These are not just boundary conditions, but unrealizable idealizations. Ohm's Law of electrical resistance, too, has numerous exceptions: for example, at high current densities. Many common materials "violate" Ohm's Law: temperature-sensitive resistors (such as filaments in incandescent light bulbs, or sensors in digital thermostats); air (whose threshold resistance results in bolts of lightning); diodes (common electronics components), light-sensitive resistors, piezoelectrics (used in touch-sensitive switches), weak electrolyte solutions, varistors and high-vacuum electron tubes, as well as other more technical variants. Newton's Laws of Motion do not apply at relativistic velocities (approaching the speed of light), and (like the pendulum law) exclude friction. Mendel's Law of Independent Assortment breaks down, as most students learn, for genes linked on the same chromosome. Snel's Law of Refraction does not apply for 'Icelandic spar', or calcite. In all these cases, laws seem very unlawlike. Scope circumscribes universality. Boundary conditions and exceptions limit invariance. That is, context is manifest.

Adopting a gendered perspective, one need not contend that these or other scientific laws are completely invalid. Nor need one discount their informativeness. The emphasis, instead, is on context. Few experts in science or philosophy of science deny (despite popular conceptions) that laws are ultimately contextual. Nor do they contend that knowledge of the context or limits is peripheral. For example, Toulmin (1960, pp. 31, 63, 78-79, 87) underscores that laws have particular scope of application or domains. He even suggests that articulating this scope is a major function of scientific research (also see Kuhn 1970). Still, Toulmin and others contend, the provisos are not part of the law. Of course, that is a philosophical sleight of hand. Only by erasing these conditions does a law acquire the illusion of universality. Laws, if not *false*, are illusory. They attain law-like status only by arbitrary specification of background conditions—a control which may be locally informative, but not universally valid. Boyle's law, like so many others, is only "lawlike" when qualified:

$$\forall \text{ elastically compressible gases}, \forall\, T{>>}0\ \&\ \forall\, P \not> \not> 0$$
$$\&\ \forall\, V{>>}0\ \&\ \Delta T{=}0 \implies \Delta P \propto 1/\Delta V$$

For all elastically compressible gases,
for all temperatures well above zero,
and for all pressures not too high,
and for all volumes well above zero,
and at constant temperatures,
the change in pressure is inversely proportional to the change in volume.

A yin-gendered view of laws exposes and highlights this double irony: universality comes at the cost of limited scope; invariance, only with conditions. The lawlike world of "for all..." is inseparably coupled with a set of contingent "if-and-only-if"s.

Viewing Boyle's Law Holistically

The yin-yang contrast also underscores parts versus wholes, reductionism versus holism. To generate a gendered alternative, one inverts the conventional (yang) gestalt. Extending awareness of the context(s) just elucidated, one asks: why are laws central, and the exceptions "exceptions"? What privileges "laws" as primary? What if cases now framed as "outside the scope" or "not within the boundary conditions" were framed as "inside" the system instead? One could well relegate Boyle's law to the background, while foregrounding the contingent behavior of gases. Boyle's law would thus no longer serve as a model, or ideal. Rather, it would be a special case. One would not deem Boyle's law the norm, from which other observations and conditions *deviated*. Instead, Boyle's law would demarcate a patch of local regularity, extra-ordinary perhaps for its mere regularity. A contextual view embraces the whole, Boyle's law only a part. What is commonly known as the ideal gas law is ultimately an *idealized* gas law. It does not describe or embrace the spectrum of all *real* cases. An unrepentantly staunch realist might thus regard Boyle's law as peripheral, or secondary. In a yin perspective, *laws* are the exception, not the rule. Complexity and particularity of causal events become standard. As reflected in the analysis above, regularities such as Boyle's law are local, not universal. Generalities are contingent, not invariant.

Displacing laws from a foundational position gives way to a corresponding alternative conception of causation. Laws result from reducing the world into component parts and causes. A system boundary is drawn to differentiate "internal" variables, cast as relevant, from "external" variables. Laws simplify. They guide thinking about causality to individual causal factors, even where a set of causal conditions may apply. One searches for *the* cause of an event. Accounting for complex events involves *compounding* individual (distinctly identifiable) causal laws, layering one cause upon another in discrete, independent layers. The laws function as basic units for interpreting causality. Laws also support thinking in terms of causal chains. Discrete causes trace to discrete effects, which may then cause further isolatable downstream effects. Laws reflect a fundamentally reductionistic approach to causality.

A yin view of causation, by contrast, is holistic. It highlights causal webs. It underscores multiple simultaneous causal factors. It considers the potential for multiple causal effects, especially under alternative causal scenarios. It resonates with a *state system* view of causality. That is, effects are not atributed to individual causes, or even to a composite of overlapping causes. Rather, effects are due to the entire state of the system. One identifies the multivariate whole as "the" cause, differentiating—but not privileging—individual elements. Pressure does not increase *merely* due to a decrease in volume, as suggested by Boyle's law. Rather, pressure increases due to the extant pressure, temperature, volume, type of gas, changes in volume (and not temperature) and the opportunities (or lack of opportunities) for other potential changes (such as a rise in temperature, perhaps, or the bulk movement of the gas in an unbounded system such as the atmosphere). Laws can be specified, but only as isolated patterns. One observes the patterns only when certain variables are held constant or their values stipulated: the *boundary* conditions and parameters defining *scope*. The behavior of gases is multivariate. In the yin, state-system approach, pressure, temperature, change in temperature, volume, and nature of the gas (at least) are relevant for *all* instances. Boyle's law is an explicit and contingent *reduction* from that complex picture. The yin scientist remains steadfastly holistic and contextual.

A yin view of causality may be illustrated with the playful devices of Rube Goldberg (Figure 5). He delighted viewers by imagining how a modest action, such as emptying an ice cube tray or cooling hot soup, resulted from an elaborate and improbable series of events. The humor arises largely from the convoluted causal pathway, underscoring the (otherwise humorless) expectation that simple effects have simple causes. Goldberg's elaborate mechanisms also highlight causal lineages, often labeled in an alphabetical sequence. Each event causes the next, in an extended but exact causal chain (a yang interpretation, as profiled above). At the same time, Goldberg's machines are funny by being

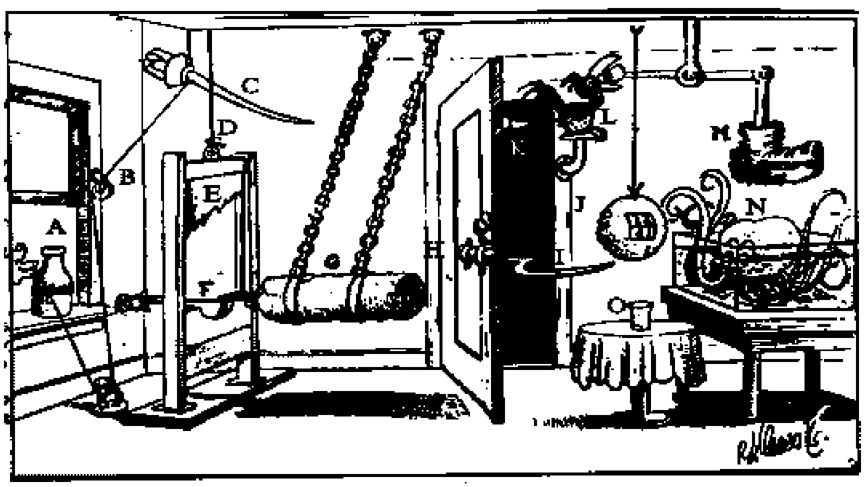


Figure 5. A Rube Goldberg device for making fresh orange juice.

incredibly contingent (yin). The causal scenario is exceptionally fragile. Each element must be appropriately placed and oriented. Should even one element be out of alignment, the causal cascade is interrupted. The design elicits a fun anticipation, echoed in successive steps, of "only if"s. The causal structure is remarkably contingent. In addition, many elements must be prepared. Rolling balls are preset, falling hammers lifted, springs prewound (all storing potential energy). The causal action is already primed, but "impeded." Each action often releases, or triggers, the next. The "cause" is quite indirect, relying very much on the set-up. Without being primed, the causal mechanism would just not work. Here, the state system view highlights the critical role of contextual variables—the scaffolding and set-up—in how each apparently individual causal link functions. The causal lineage is merely an artifact of the causal structure, by design exceptionally baroque and artificial. Goldberg's apparently silly devices, then, offer sophisticated commentary on reductionistic causal perspectives. Their whimsy helps celebrate a yin approach to causality. Accordingly, one may be impressed by an apparatus where Boyle's law appears. In an open system, such as the atmosphere, a gas under pressure moves (hence, wind!). A change in volume is observed only when the system is closed. Like the elaborate scaffolding in Goldberg's devices, the structure of the causal context may be easily overlooked.

One may further illustrate the complementary yin and yang views of casuality through an analogy: billiard balls. Conventional (yang) views of causation focus on billiard ball collisions. Each moving billiard ball expresses a mechanical vector: a cause. One ball hits another with an observable effect. The second ball may, in turn, hit another, and then perhaps another, leading to a causal cascade. Perhaps a cue ball hits a whole rack of fifteen balls, with scattering effects, all calcuable (in principle) from the cue ball's original vector. Coincidentally, this image parallels the kinetic theory of gases, the modern explanation for Boyle's law (Figure 6). In that interpretation, the gas molecules are

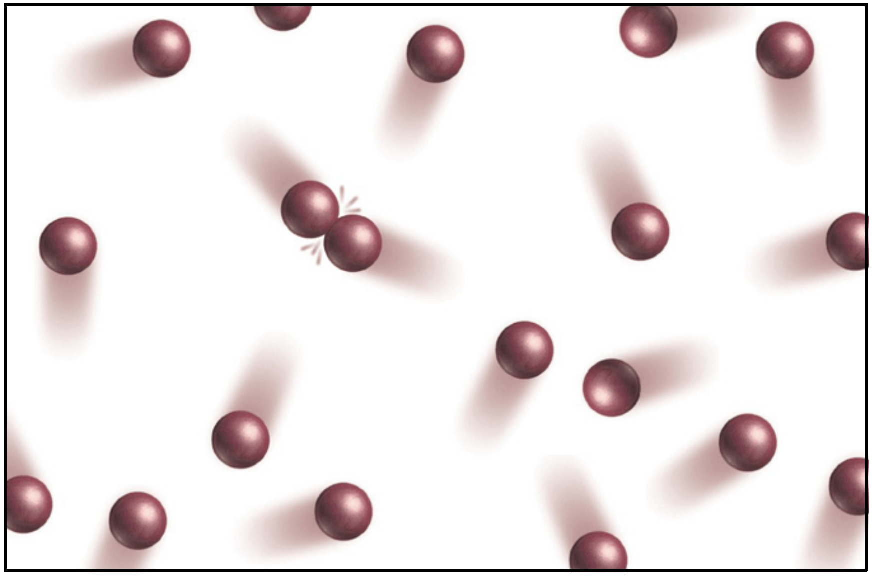


Figure 6. The kinetic theory of gases: molecules as metaphorical billiard balls.

like billiard balls colliding in three-dimensional space. The pressure (effect) is a collective summation of all the movements of the individual gas molecules, each with their own vector (discrete contributing cause). In the yin, state-system view, one considers the ecology of the billiard balls. That is, the status of the whole billiard table is important. Billiard balls are not assumed to be intially at rest: the system is already complex and active, not passive in response. Nor are the balls assumed to be of the same material. They need not react in uniform ways: identical vectors underdetermine a collision outcome (different gases?). The billiard table environment matters: it may not be level, or remain level (temperature of the gas?). A tilted table affects all the components at once, even when the balls are not colliding. Some causal factors may undulate the surface, generating different local conditions across the table, leading again to different responses for apparently similar collisions. Some balls may contain iron, so changes in the magnetic field (context) may matter more than the motions of individual balls (parts). With uniform balls on a level billiard table—which stays level—simple interactions may indeed be discernible. But that is a special case, however familiar. The yin view looks well beyond the billiard balls—or individual gas molecules—as component causes. It emphasizes the whole and the contexts of the parts.

Ultimately, then, a holistic alternative to Boyle's law might not look like a law at all. It would be framed in terms of the whole set of variables known to affect gas behavior (the context noted in the previous section). Boyle's law would be embedded in a state system documenting the causal structure. Reciprocal changes in pressure or volume would be an isolated thread observed just when other variables exhibited certain values: distinctively a subset of all gas behavior. The more familiar formula for Boyle's law would be an excerpt, noticeably incomplete without noting the special, narrow conditions integral to the whole causal picture.

Viewing Boyle's Law Ecologically

A gendered analysis of Boyle's law and causality may extend deeper still. Aware that apparently universal, invariant laws are contingent, and reductionism is not necessarily complete (or exclusively warranted), one may well consider further the context(s) in which such a yang perspective arose and functions. Why interpret causality in terms of laws? Why view the world as fundamentally law-like at all? Indeed, is there any alternative conception of natural order, besides merely capitulating to chaos and indeterminism? Here, one may fruitfully turn first to the history of the notion of laws of nature. Robert Boyle and his work on the spring of air, in fact, were significant in establishing the new philosophy and the worldview that supports our current views of causality.

The very phrase 'law of nature' may well strike the naive observer as odd. How did an ostensively legal term enter science? Moreover, laws are normative, or prescriptive, and oriented to humans in society. Science, by contrast, is descriptive, and applies to a non-intentional nature. What ultimately connected law and science occurred, equally oddly perhaps, through natural theology. The key shift occurred in the mid- to late seventeenth century in Western Europe. By then, general principles in astronomy and mathematics had long been denoted as laws. But their role was in purely formal systems, functioning to ground logical derivations and to justify explanations — much as in a legal context. With the rise in commerce, industry and technology in the 1500-1600s, emphasis shifted from abstract ideas to concrete demonstrations. Interpretations of nature became more oriented to experience, material investigation and craftsman-like experimentation. Modern science (as we know it) was emerging. Yet the perspective was still religious. Natural philosophers (the early counterparts of today's scientists) endeavored to interpret God not only through the Bible, but now also through 'the Book of Nature'. God's physical creation supplemented God's word as a source of understanding the divine. The formal laws were giving way to empirically generated claims, but still within a religious context.

It was in this natural theological framework, where scientific methods were dramatically transformed, that a second meaning of 'law' entered (Steinle 2002). Here, 'law' denoted divine authority. Earlier thinkers had appreciated nature's complex order. For example, they conceived the motion of the planets as a divine clockwork, animated by God. Now (with windmills and watermills as new images, for example), nature became self-perpetuating. Nature became ordered like a *machine*. God was still the authority, but now one step removed, as the artificer or designer (rather than motive power). In the new intepretation, God established the principles by which the machine operated. His omniscience was critical. By reading the 'Book of Nature' carefully, one could discover these basic causal principles empirically. René Descartes called them '*laws of nature*'. The term 'law' conspicuously indicated the divine source of nature's order. The order was *ordained*. Ordered nature itself was ordained. In England Robert Boyle and his contemporaries echoed Descartes' label (and Francis Bacon's programmatic vision), and presented their aim as articulating these laws. For Descartes, Boyle and others, causality in nature was properly reduced to motions and physical properties, by which all other qualities and phenomena would be understood—and understood as God intended them. Institutionalizing the machine metaphor, Boyle named it the *mechanical philosophy*. In particular, he presented his investigations on the 'spring of air' as a model. His studies, he claimed, substantiated that air had a mechanical property, akin to small springs, by which one could understand or explain its observed behavior. (On the gas law itself, however, see below.) Boyle's mechanical philosophy was an apt expression of the new interventionist spirit and experimental methods, well suited to interpreting an autonomous natural order instilled by God by probing causal systems as machines. By the end of the seventeenth century, then, the notion of laws of nature embodied ideas about causality, experimental method and natural order, all permeated, through the metaphor of a machine, with divine authority.

Western science, of course, has since mostly shed its early theological framework. Legal analogies hold no muster. Still, potent vestiges of these perspectives persist. For example, while faith in a natural order is no longer associated with an omnipotent creator, the faith in a natural order itself remains strong. Scientists generally function on a belief not only that they may periodically find patterns in nature, but that the world *is* fundamentally orderly and law-like. For example, simplicity is widely endorsed as a theoretical virtue, not just a pragmatic preference for working with fewer variables or more tractable formulae. Support for Occam's razor reflects a belief that nature *is* indeed simple. Yet as a methodological principle, it remains problematic: how can one justify it empirically? Laws such as Boyle's law, when touted as universal and invariant, reflect a view that nature is simple and orderly. Yet, as noted earlier, the pressure-volume relationship is more complex. The pervasive belief in a natural order expressible in simple laws is part of a worldview, distinctively yang in nature.

A Linguistic Divertissement

Likewise, vestiges of the legal metaphor remain, most notably in our language. Again, the denotative meanings are hardly theological or legal. No one construes breaking the law of gravity as criminal, and Bugs Bunny only gets a laugh when he stands upside-down—without falling—with an innocent aside, "Well, I never studied Law." Still, the normative dimension of laws of nature persists. The network of meanings embedded in discourse on scientific laws still portrays law-like behavior as a norm, or valued standard. The effect, while mediated by language, is unmistakable. The term 'LAW' fundamentally structures an invisible metaphor. Its implicit images and connotations strongly shape and guide our thinking about nature (Lakoff and Johnson 1981). Thus, while laws in science are deemed objective, *linguistically* they prescribe, like laws in society, "expected" behavior and how nature "should" act. Hence, one hears that a gas "BEHAVES ACCORDING TO" Boyle's Law. A system is "GOVERNED BY" Newton's Laws of Motion. A resistor "OBEYS" or "FOLLOWS" Ohm's Law (or does not). As Boyle himself stressed, air does not have free will, nor act intentionally. Still, the language conveys a standard of sanctioned behavior. Laws define order in nature, as civil laws do in society.

Laws thus implicitly sort natural phenomena into two categories with uneven status. The sorting is cryptically normative, not merely descriptive. Icelandic spar "VIOLATES" Snel's Law. A large angle pendulum, or one dampened by friction, "DEVIATES" from Galileo's Law. Mendel's Law "BREAKS DOWN" for linked genes. Diodes, air, light bulbs, etc., are "EXCEPTIONS" to Ohm's Law. At high pressures and low temperatures, carbon dioxide "FAILS TO ADHERE TO" Boyle's Law. (Even "DEFYING" the law of gravity conveys a subversive image.) Laws in science, following the implicit metaphor with laws in society, dictate norms of proper or expected behavior. They are an implicit basis for evaluation, like a Providential order. The modern gas law, while secular, still refers to "IDEAL" gases. The other gases are implicitly less than ideal. The language itself conveys and reinforces the norm of a mechanical (law-like) order.

The normative dimension of laws has puzzling consequences. For example, one hears experimenters claim that certain results "shouldn't" happen or that something has gone "wrong." In such cases, the language refers to the phenomenon or nature, not the law or the scientists who applies and interprets it. It is Icelandic spar, large-angle pendulums, linked genes and non-ideal gases that are cast as "deviations" or "exceptions." Paradoxically, *nature* contradicts laws of "nature." Deviations from a scientific law do not impugn the law, or the assumption of law-like behavior. Rather, the language frames the natural event as outside the proper "natural" order. Friction "interferes" with the "true" laws of motion. Hence, lab instructors create extraordinary conditions (minimizing friction) trying to to demonstrate "ordinary" motion. Friction is discounted. In pursuit of realism, the artificial displaces the real. Ideal gases supplant real gases. As a law, Boyle's law *defines* true nature. The persisting legal metaphor reinforces the yang view that laws are privileged descriptors of causality. How else can one arrive at the ironic (if not perverse) conclusion that nature persistentally violates the laws of nature?

Understanding how Boyle's mechanical philosophy took hold and shaped Western thinking, one is well prepared to appreciate a complementary, yin view of causality. First, one challenges the natural theological heritage as a culturally limited context. One denies laws privilege. Accordingly, the "un-law-like" earns parity. One dissolves the implicit hierarchy between "laws" and their "deviations." Nature cannot violate laws of nature if laws are not regarded as fundamental. This perspective may seem, to some, to profoundly upset assumptions of Western science or its worldview. So many laws of nature have been "found," that one may be tempted, by simple induction, to imagine that all of nature is therefore law-like. A gendered perspective reminds us that no such conclusion is warranted without systematically exploring the "negative space" of phenomena beyond laws. Law-like behavior certainly exists. For example, in Boyle's J-tube. But laws may describe only patches of regularity, as vividly suggested by the contingent scope and context-dependence of Boyle's law. Outside a J-tube, a local increase in air pressure rarely reduces volume. Rather, the air moves. Weather happens. The world at large seems more complex than laws, or the machine metaphor, allow. The simple mechanical order of laws gives way to complexity. As Nancy Cartwright (1999) cogently and eloquently posits, our world may well be "dappled."

With no divine authority (or its secular equivalent) guaranteeing a lawlike causal order, neither the machine metaphor nor mechanical philosophy seems appropriate. A proper framework or image embraces instead contingency, context and complexity. The yin alternative is *ecological*. [fn: compare and contrast w/ Merchant = 'organic'; Potter = 'hylozoic'] An 'ecological philosophy' for science is, of course, still 'logical'. But the focus shifts to the 'eco', or *oikos:* the environmental context and its complex interactions. Instead of viewing nature as a machine, one likens a pendulum or resistor or gas to an entangled bank, as portrayed so vividly by Darwin in the finale to the *Origin of Species*. In a yin view of causal order, one *expects* numerous variables. Context and contingency are the norm. Laws themselves (like Boyle's law) are treated as the odd special cases. A holistic view of system causality and a state-system approach to causal relationships become welcome expressions of — and tools in — that view. Particular causes (or particular constellations of causes) become as important as general causes expressed in laws.

Parity for non-law-like behavior highlights the significance of particularity. That is, runaway generality is held in check by a healthy nominalism. Epistemic values extend beyond universality and invariance, and include greater realism for individual cases. For example, "laws" of motion tend to eclipse or peripheralize the particulars of friction, which vary for each case. In yin science, an account of motion is incomplete without characterizing the frictional properties of the material involved. Electrical resistance is similarly material-specific. Ohm's Law may be easy for calculation, but the bulk of the work is determining empirically whether it describes the material at hand. Likewise, one needs to know the specific gases and their properties to characterize their behavior. As noted, to describe gas behavior fully, the van der Waals constants of each component gas are essential, beyond what is expressed in Boyle's law. The world viewed through the epistemic value of realism is less abstract, more contingent on particulars. It is also more finely resolved and, hence, more complex. Indeed, the unabridged mathematics of the oscillating pendulum are so complex that one cannot *solve* the equation determinately (even though the motion is deterministic). The kinetic theory of gases draws on statistical thermodynamics, but the calculations are too complex. The derivation relies critically on probabilistic assumptions. It cuts corners in several steps by excluding rare cases as inconsequential. Even if such heuristics are justified for most contexts, they show the limits of the mechanical approach. The machine metaphor is typically too unwieldy where the world is complex.

Tracing Boyle's law to a mechanical philosophy shows it deeply embedded in a particular view of nature. Boyle regarded air as a mechanical device: a spring. Boyle's law seems a simple expression of that view, reducing gas behavior to few variables with simple, regular interactions. The kinetic theory further reduces gases to an ensemble of molecules, assigning causality to the internal parts arranged in a machine-like order. The gendered alternative, by contrast, underscores the "ecology" of Boyle's law

— or, more particularly, the ecology of the behavior of air in his J-tube. Temperature, volume (or density), component gases, etc. are indispensable variables for interpreting air pressure causally. Sometimes it follows a strict pattern, other times not. Nature my be both patterned and ostensibly unpatterned. The "law" in Boyle's law may be, if not an illusion, a product of cultural context. A yin perspective yields a profoundly different interpreation of natural order.

Summary: Viewing Boyle's Law Lawlessly

The challenge posed by the gender of Boyle's law is ultimately not to reconceive the pressure-volume relationship, nor to provide an alternative formulation of the law (c.f., Potter 2001, pp. 151-154). It is, rather, to reconceive the whole framework of casual thinking at the very heart of framing laws. How does one (re)focus on the phenomenon and think causally *without* a law? (Is it even possible?!)

The mere image of forsaking laws of nature, of course, bristles with potentially disruptive images of anarchy. It reeks of chaos and disorder. But the effect, we have seen, is purely linguistic. By linking law and order in the civil realm, the *language* still tends to shape, even dominate, thinking about nature. A lawless nature may thereby seem to imply indeterminism. However, science without laws need not be any less deterministic. Yin science need not disavow determinism. What differs is how one characterizes, or expresses, causality. A state system approach, for example, is fully deterministic without relying on laws. The other chief difference may be in acknowledging limits in our ability (or interest) in characterizing the world deterministically. Complex systems do not necessarily exhibit machine-like regularity. Understanding or studying them scientifically may not involve reducing them to laws.

So: take away the law from Boyle's law and it may seem as if nothing remains. What remains, of course, is Boyle' apparatus and its behavior—and even Boyle's measurements: a concrete example of how air responds when external pressure is changed for a confined volume (where the boundaries of the container may move freely). What is missing is a generalization reduced to just a few relevant variables. One may still reason from the particulars. Here, the reasoning is primarily analogical, rather than deductive in structure. Analogy is based directly on similarities with the particulars of other cases, rather than on indirect appeal to general laws. A gendered, lawless alternative to Boyle's law draws on a different form of reasoning, while still focusing on causation.

Ironically, perhaps, the legal context may provide an instructive metaphor. In the practice of law, especially in juridicial contexts, one distinguishes fundamentally between statute (or code) law and common law. Statute law is based on rules, or codes: like the laws of nature. One assesses actions in reference to the generalities laid down in the law, as expressed in explicit statements. One reasons deductively. Common law, by contrast, is case-based. One assesses actions based on precedent, or similar cases encountered in the past. Interpretation emphasizes the basis for similarity. One reasons chiefly analogically. Of course, numerous variables, or bases for similarity, are usually possible. The effectiveness of an analogy may be highly contingent. Context plays a major role. Yet the multitude of benchmarks can be beneficial, especially in interpreting complex cases. Under statute law, statutes may sometimes overlap and provide conflicting interpretations. Case-based reasoning can often resolve this. Both frameworks provide viable systems of law and interpreting justice (notwithstanding conflicting preferences among legal scholars). Yang science resonates with statute law, yin science with common law.

The legal distinction has deeper overtones, as well. The perceptive reader may have noticed that my discussion so far has referred only to 'laws of nature', not 'natural laws'. The terms may seem interchangeable, and indeed are often conflated in practice. But the phrase 'natural law' has a specific and significant meaning in the legal context. The distinction has further overtones for science. Within statute law, statutes—that is, the laws—may be construed in two ways. In the 'positive' perspective, laws are humanly derived. In another, laws reflect principles embedded in the created world and discoverable by inquiry. Such laws are deemed *natural laws*. 'Natural laws' refer to ideal forms that transcend human interpretation, perspectives, cultures or history. Their justification comes, in a sense, *from* nature. Again, natural theology once promoted the idea of natural laws whose principles were endowed by a just God. Natural law is also inherently rule-based, statute law. Natural theology thus aligns comfortably with statute law. God's order becomes reflected both in laws of nature *and* statutes. In natural theology, natural law and laws of nature function in harmony, perhaps in concert. Referring to a 'natural law' in science (rather than a 'law of nature') thus tends to imply not only that nature is ordered in a certain way, but that the specific expression of the law itself comes from nature, or is ordained. It seems 'NATURAL', and therefore beyond doubt or criticism. Laws of nature, when cast as natural laws, tend to erase the dimension of human interpretation—and perhaps also their fallibility. Here, one may perceive how cultural context again tends to bias modern Western science towards particular views of laws and causal order and of causal reasoning, while masking the very role of the culture in those views. Discourse on 'natural laws' thus further promotes the legal metaphor, and deepens its perceived authority.

Not coincidentally, perhaps, debates in the legal context about natural law versus positive, or human-made, law were active when Boyle worked on the spring of air and framed his mechanical philosophy (Shapin and Schaffer 1985).

The legal context helps in further articulating the gendered alternatives in science. In the yin perspective, case-based reasoning displaces statute-like laws of nature, and analogy displaces deduction. In the lawless alternative, laws give way to exemplars and material models as primary (Kuhn 1970, Giere 1995, 1999). Hence, one might talk of Boyle's J-tube, rather than Boyle's law. One compares new cases to Boyle's original. To the extent that the variables are the same — including temperature, etc. — one expects to find similar behavior. Here, there is no need to detour through a general law, first by abstracting Boyle's J-tube inductively in the first instance, then by warranting a new case (in the second instance), through further induction, as an authentic instantiation of the general law. Reasoning from case to case does require, however, clear attention to specific variables and details of context. One quickly learns the limits of similarity, thereafter appropriately documented along with the exemplar.

A focus on models and particularity also underscores the importance of material culture and experimental systems in investigation (Rheinberger 1996). It is no surprise, perhaps, that subsequent revisions to Boyle's law followed Boyle's model in using mercury in glass tubes. For example, with the construction of the Eiffel Tower (Fig. 20), Louis-Paul Cailletet was able to build and support a column of mercury of unprecedented height. With it, he could study the same system, but now with pressures up to a hundred atmospheres. His revision of Boyle's law followed from his variation in a closely similar set-up. Boyle's J-tube is a local and contextual case of gas behavior. But it is no less valuable on that account. Indeed, its particularity helps keep reasoning through analogy in check.

Figure 20. Eiffel Tower in 1889, where Louis Cailletet built a tall, high-pressure manometer.

A gendered analysis of

Boyle's law does not develop an alternative relationship of pressure or volume (or the spring of air). Nor does it necessarily reject Boyle's apparatus or his findings. Rather, it invites a different way of conceiving causality and, with it, a complementary way of doing science. The gendered analysis of Boyle's law invites the question of whether a full fledged alternative, yin science is possible. What would it look like? How would it function? (Is yin science possible at all, or merely a conceptual phantasm?) Here, one must wander further afield from gas behavior. One prospective example, with a history spanning millenia, might be traditional Chinese medicine (Allchin 1996, Kaptchuk 2001). It resonates with a holistic, state system approach to health and disease. Disease is not necessarily framed as having one root cause, especially not as a single pathogen as in Western biomedicine (and the concept of linear causality). Diagnosis, accordingly, involves collecting a wide array of information. One does not sort through the information, searching for the telltale sign of one disease. All the information is relevant in assembling a syndrome. That syndrome is then compared with the physician's knowledge of and experience with other cases. Echoing a state system approach, the treratment is aimed at restoring the patient's system to health, not to fix one isolated "cause" of the disease. Returning to Western medicine, one may contrast an approach that conceives a germ as "the" ultimate cause of a disease. One might study the varation in susceptibility or recovery from pathogenic diseases. One would highlight instead the significance of "risk factors," such as nutrition, individual levels of hormones or protein types that shape physiology, or other medical conditions. These fragmentary images may provide a concrete basis for pursuing science "lawlessly."

Boyle and the "Law" in Boyle's Law

A great irony lurks in Boyle's law. That is, Boyle himself did not recognize it as a law. He certainly produced data commensurate with the law. And he surely understood the mathematics, used to assemble his list of figures of "what the pressure should be according to the hypothesis" (Boyle 1662; Figure 2). As noted earlier, Boyle also embraced the concept of laws and law-like causality in science by advocating the mechanical philosophy as well as the natural theological context of laws of nature (Boyle 1661). Yet Boyle did not regard his findings about the condensation and rarefaction of air as a universal law in the sense now accepted (and analyzed above). Rather, he referred to the spring of air more modestly: as a 'habit of nature' or 'custom of nature' (Boyle 16--/19--; Sargent 1995; Shapin 1996, pp. 328-330, 338-350). These he considered matters of local, perhaps contingent, experience, more akin to cases in common law than universal natural laws. Boyle never stated the gas law, nor wrote an equation for the relationship. Indeed, he was disinclined to characterize nature mathematically (Shapin 1996, pp. 333-338). At the same time, Boyle's research was also more holistic than one might imagine if one focused just on the J-tube data. He investigated, in particular, extremely low pressures (the 'Boylean vacuum') made possible with the new air pump. Quantifying the relationship between pressure and volume ultimately emerged only as a secondary exercise (more below). The law as currently expressed and interpreted are thus due to the tradition that followed. Boyle, for his part, focused more broadly (and 'ecologically') on exploring what variables were relevantly affected by the conditions in his new apparatus. He tested the effects widely on animals, plants, sound, magnetism and adhesion (Boyle 1660). He was also aware of (although he did not measure) the contextual effects of temperature and "atmospheric tides" on the Torricelli tube, today's mercury barometer (Boyle 166-). Boyle was not quite so reductionistic, or yang, as "his" law might seem to imply. Ironically, then, much of the gendered analysis of Boyle's law above does not apply to Boyle himself. Indeed, one might wonder if Boyle's law is aptly named and what Boyle's name has to do with the law at all—a second theme to which I now turn.

The 'Boyle' in Boyle's law

Boyle's law is named after, of course, Robert Boyle, whose data so elegantly fits the simple law-like formula, PV=k. It is remarkably widely known in popular culture. Students remember the Boyle of Boyle's law even decades after studying chemistry and forgetting the law itself. The name reflects a tradition in science of eponymous laws and theories (and even units of measurement): named after their discoverers, to honor their achievements. Oddly, perhaps, the label 'Boyle's law' does not refer at all to its content: to pressure or volume, compression or dilation, or even air or gases (ideal or otherwise). Instead, it draws attention to the human scientist and to scientific work, or labor, of discovery. Moreover, while science is popularly viewed as objective and value-free, eponymy is, ironically, all about expressing value. Naming the pressure-volume gas law implicitly honors Boyle and even the law as an occasion worthy enough for commemoration. The very eponymy of Boyle's law thus raises important questions about the practice of science, how scientists and their work are valued, as well as who is valued, and why. These topics, too, may exhibit gendered contexts—and thus also gendered alternatives.

Viewing Boyle's Law Communally

Laws are typically named for the discoverer. Hence, one would likely imagine that Boyle discovered Boyle's law. Indeed, the question, "Who discovered Boyle's law?", might seem posed only in jest, much as Groucho Marx asked the obvious, "Who is buried in Grant's tomb?" But here the question has a legitimate scholarly context—which does not necessarily yield the expected answer (Agassiz 1977). Boyle certainly published the data which we implicitly recognize (now) as indicating the pressure-volume law (Figure 2). The central question, rather, is how the data was generated and what was claimed on its behalf. For example, Boyle himself noted some indebtedness to Richard Towneley. Boyle focused initially only on increasing pressures, collecting data on how it condensed air confined in a J-tube. He envisioned air as composed of spring-like corpuscles, like minute bits of wool, that resisted compression. Boyle did not (at first) conceive elasticity in the dilation, or expansion, of air under lower pressures. Towneley, having seen Boyle's data on compression, suggested as much and compiled his own data. Boyle, in turn, echoed Towneley, in particular by borrowing the design of his experiment (connecting his J-tube to an air pump in order to decrease the pressure on the column of mercury). Boyle seems to have received a hand in developing his work. Others were also working on the same topic and, given other events, might have inspired — or even upstaged — Boyle: Henry Power and William Brouncker (each mentioned by Boyle himself), as well as Robert Hooke. Boyle's experiment thus seems less unique and less a product of his skills alone. Even the renowned table of results, especially the comparisons with mathematically derived expectations, was probably suggested by Robert Hooke (Shapin 1996, p. 326). Finally, Boyle did not express his discovery as a law-like equation. Nor did he see it as a law of nature. These features of his "discovery" belong to later interpreters. Deeper knowledge of historical context leads one to question who to properly credit.

Figure 21. Robert Hooke, Boyle's assistant who likely contributed to quantification of the spring of air, parallel to his own later law of springs (portrait attributed by Lisa Jardine).

One may be tempted to ask, "yes, so, who *really* discovered Boyle's law?" Indeed, historians have debated vigorously in trying to resolve the question (while contending further how to define 'discovery'). In a gendered analysis, the answer may not be nearly so important as the context of the question itself. Why expect a single "who"? Why assume discovery is a discrete event, as popularized in the image of a flash of genius? (Brannigan 1981). From a yin perspective, discoveries may well be distributed events, and hence collaborative. Consolidating discovery into a single person expresses a value. An eponymous law celebrates the individual, rather than the community. Boyle's case underscores the yin alternative by illustrating how the collective, or scientific community, may be significant. First, ideas are shared. Towneley learned from Boyle, and Boyle, in turn, from Towneley. Boyle used Hooke's mathematical recommendation. Later scientists refined or formalized Boyle's expressions. The work was ultimately collaborative. Second, communal organization can capitalize on variation. Discovery may depend in part on contingent events or opportunity (sometimes expressed as chance, accident, luck or good fortune). History "selects" certain lineages, which can hardly be predicted or planned in advance. The investigations of Power, Brouncker and Hooke functioned in this large scale view of process. If Boyle, because of personal events or perspective, had not reached his results or published them, others likely would have later (some did anyway: Power, 1664). Perhaps under modestly different historical circumstances, we would be discussing Power's law today and asking if Boyle's contributions were significant enough to earn partial credit. The collective may thus be an important unit for "natural selection" in science: capturing variation in ideas or approach, as well as the contingencies of beneficial "accidents" (Campbell 1974). Focusing on individuals, for example by naming a law after Boyle exclusively, eclipses the view of process at the level of the community. Just as laws tend to erase contingency and context in nature, so can eponymy mask the role of contingency and context in the human history of science. The name 'Boyle's law' tends to misrepresent the *process* of science.

Boyle's case also illustrates another yin property of communities in science: the role of criticism and subsequent research in deepening knowledge. Boyle's original account, *Touching the Spring of Air*, published in 1660, did not include the now famous tables illustrating the pressure-volume relationship (Figures 2a, 2b). Indeed, Boyle had not yet done any rigorous quantitative analysis. He designed his J-tube meaurements in response to criticism by Jesuit scholar Francis Line, known academically as Franciscus Linus. Linus believed that the column of mercury in a Torricelli tube was pulled upwards. The suction could be felt directly if, instead of using a closed tube, one placed one's finger over the end of an open tube and performed the same experiment. For Linus, no experiment yet showed that air had enough spring to push the mercury upwards. Linus found a gap in Boyle's experimental reasoning. Boyle had not excluded all alternative explanations. He needed to demonstrate the spring of air more thoroughly. He thus aimed to show that successively greater external pressure would be matched by corresponding compressions, or reductions in an enclosed volume of air. Very large compressions could be achieved, he imagined. He did not expect to see a strictly reciprocal relationship, but he clearly recognized it from his data. By formalizing the mathematical pattern he was then able also to calculate "what the pressure should be according to the hypothesis." Linus was ultimately wrong in underestimating the spring of air and supporting a cohesive force that prevented vacuums. In popular accounts, Linus becomes the hapless reactionary, bound by old-fashioned Aristotelian beliefs. In retrospect, it is easy to dismiss Linus's alternative proposals. One cannot so easily dismiss his historical role. In challenging Boyle, he motivating him and guided him to greater experimental depth (without which one could not judge Linus so harshly). Without Linus, Boyle may not have discovered the pressure-volume relationship. Here, naming the law after Boyle also reflects a value in the final product alone, in contrast to the process (including criticism). It also values the right answer rather than skilled reasoning (with its occasional misguesses or errors). The yang eponymy celebrates Boyle as a hero whose effort yielded a scientific discovery. A yin perspective of science highlights the process which generates and ultimately justifies a discovery: diverse interpretations, collaborations, as well as errors and disagreements, in a communal network of mutual guidance.

Linus's criticism also epitomizes another fundamental feature of science obscured by focusing on Boyle alone: the communal (social) system of checks and balances that identifies and resolves potential error. Not all published scientific claims are ultimately correct. Suppose Boyle had been mistaken? Linus's alternative interpretation would have been far more critical than it was in exposing deficits in Boyle's work. Evidence requires interpretation. Such interpretation begins at the personal level. Each individual brings unique cognitive resources to their scientific thinking—some perspectives may challenge entrenched beliefs, others may reflect unchallenged assumptions or beliefs; *all* derive necessarily from the individual's culture and biography, and none need be explicit. Interpretations of data may thus vary from individual to individual. Ideally, claims are "tested" against the community's alternative perspectives for robustness across and in relation to their interpretive contexts. Boyle's law notably passed muster among others. Reliability in science is fundamentally communal.

The role of the system of checks and balances is especially evident when it fails. Cultural prejudices may be shared across a community of researchers. Some individuals may have more authority than others for exerting their views. Such cultural sources may relate to (at least) gender, race, ethnicity, nationality, age, class, religion, affluence, political ideology, and political economy. Again, such variations may be beneficial *or* detrimental, depending on context. Nor are all visible to the participants. A diversity of perspectives in the scientific community is thus critical to its pursuit of objectivity (Longino 1990, Harding 1991, Solomon 2001). Ultimately, focusing on science as the work of individuals by celebrating lone discoverers tends to mask or hide the essential communal structure of reliability in science. Appealing to Boyle's law thus implicitly undervalues the social system whereby new ideas are introduced and validated, and error is discovered and rooted out.

Viewing Boyle's Law Equitably

Acknowledging the collective nature of Boyle's discovery does not automatically mean, of course, that Boyle might not deserve special honor. Indeed, Boyle expressed the values of communalism in advocating investigative communities—and working actively to form them. His deeds matched his rhetoric: Boyle was unusually generous among his contemporaries in acknowledging the contributions and work of others. Yet focusing on any individual still expresses other particular values, as well. The gendered analysis is sensitive to their context and consequences, especially relative to possible alternatives.

Boyle likely did not blow his own glass J-tube. Or mine his own mercury. Nor did he build the air-pump that rarefied the atmosphere. The air-pump was designed and built mostly by Robert Hooke, hired as a technical assistant (but who later gained fame on his own). Boyle and Hooke modified, in turn, earlier designs of air pumps by Otto Guericke (Fig. 22) and Caspar Schott. In addition, Ralph Greatorex (spelling varies), an instrument maker

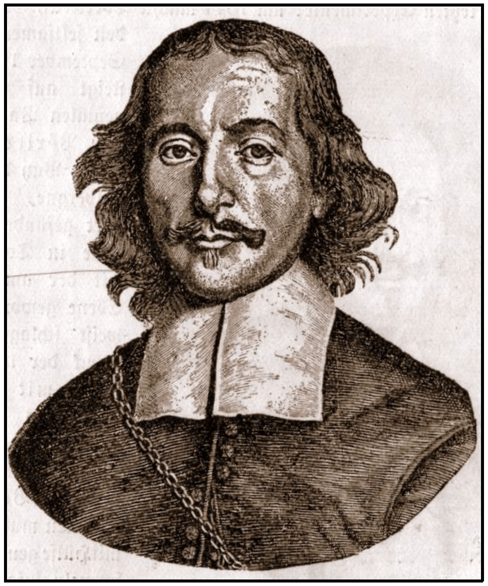


Figure 22. Otto von Guericke, designer of an air pump, on which Boyle's was modeled.

participated in designing and building the apparatus and perhaps in executing the experiments. All these people are typically invisible (Shapin 1989). Boyle was a "gentleman" investigator—he probably witnessed and participated in many experiments, but also left much of the work—in the sense of manual work, or labor—to others. He could afford to do so (literally, in a pecuniary sense). Boyle relied on numerous assistants, both skilled and unskilled (Shapin 1994). Boyle was more forthright than most in acknowledging his technical assistants. Yet he still carries the credit—not just the bulk of the credit, but full credit. Boyle presumably earns that credit as the intellectual authority. Of course, Boyle held the position of power. His intellectual status, especially among his "gentlemen" peers, was intimately tied to his status in a cultural and economic hierarchy (class). Regardless, without real data, Boyle's published table would be an abstract fiction not half so worthy of scientific merit. Thus, without the technicians and all the materiality of the experiment, there would have been no science (then as now). Crediting Boyle, rather than the glassblower, the miner, the air-pump designer, the air-pump maker or the air-pump operator, and even the technician who measured the mercury levels and recorded the critical data, reflects a value. Intellectual labor is valued over manual labor, even skilled craft labor. Likewise, conceptual achievements are valued over experimental ones, which rely on their own specialized skills. The material culture is discounted. Referring to "Boyle's law" not only subtly eclipses the role of others besides Boyle, but also privileges the intellectual component. In science, where the emphasis is typically on empirical demonstration, that bias is particularly ironic. A yin perspective might highlight instead something like "Boyle's Lab's Law" as more equitable, even if twisting the tongue a bit. Indeed, that might appropriately respect Boyle, who tended to generously acknowledge those who assisted him.

Even if one were to broadly recognize Towneley *and* Power *and* Brouncker *and* Linus *and* Hooke *and* Greatorex *and* all the unnamed technicians and laborants, along with Boyle, one would still find a notable exclusion. That omission might be more obvious in other characterizations of Boyle (now less frequent) as the "father" of modern chemistry (Pilkington 1959). (While such overtly sexist language has diminished, one still finds it widely in popular discourse, such as college chemistry class websites and online encyclopedias.) Here, the gendered value is easy to spot(!). Where are the women? (Namely, who were the "mothers" of chemistry and modern science?) Of course, women are not found for the same reason that the technicians were generally invisible: the power structure of the period peripheralized them. Historians have yet to identify a women in Boyle's laboratory or intellectual circle, regardless of whether they have been properly credited. And that poses a dilemma for someone whose yin sense of equity might readily extend to crediting both male and female participants in science. Indeed, the problem extends well beyond the case of Boyle. Nearly all eponymous laws (at least those commonly encountered) are named for men. The attributions may not be historically incorrect. Yet there is disparity nonetheless. Most basic laws were discovered during historical eras and in cultures where women were not afforded equal opportunity to achieve in science. The institutionalization of male-oriented eponymous laws "freezes" this cultural contingency of the past. The whole repertoire of eponymous laws (and theories and units) thus supports an image that, while men and women may be equally welcome in science, only men's scientific achievements are *noteworthy* or valued. The problem becomes especially acute in classrooms where prospective scientists are nurtured and sometimes inspired by role models—and where basic laws are the mainstay. No amount of equal opportunity for earning credit today can remedy the imbalanced image in the already established nomenclature. The name of Boyle's law is a nefarious sexist artifact. Perhaps the only alternative is to abandon existing eponymy altogether. Ostensibly objective and historically accurate, the 'Boyle' in Boyle's law is nonetheless deeply gendered.

Viewing Boyle's Law Non-Competitively

In France and throughout most of continental Europe (English speakers are often surprised to learn) "Boyle's" law is known as *Mariotte's* law. Edmé Mariotte, a member of the French Académie des Sciences, also investigated *The Nature of Air*, and in 1676 published findings on pressure and volume that paralleled Boyle's (Mariotte 1676/1923). Moreover, Mariotte explicitly called it a "rule of nature" ("règle de la nature") (p. 9), based in part on the "law or rule of nature" ("loi ou règle") that natural bodies are always contiguous (p. 43). Given the later date of Mariotte's publication (even after Boyle's revised, expanded editions), his references to the "spring" ("ressort") of air, his analogy with cotton (in lieu of wool) (p. 47), as well as his use of a J-tube in investigating the condensation and dilation of air, it is hard to imagine that Mariotte did not draw in part on Boyle's work (although he reports no such debt). Yet Mariotte also presented many other investigations: using a Torricelli tube (barometer) to assess changes in wind and weather (pp. 21-25); the dissolution of air in water and other fluids (pp. 27-38), including blood (pp. 56, 62-63); the expansive force of gunpowder (pp. 38-47); the shape of bubbles (pp. 26-27) and the bursting of thin glass vessels due to changes in external air pressure (pp. 16-21); and the roles of humidity, air pressure and altitude on boiling, clouds and rain (pp. 48-57); all replete with his own quantitative studies. Mariotte's achievements arguably deserve recognition—and one could freely elect to name a law after him. Still, some declare Mariotte a plagiarist (James 1928). For them, the name 'Mariotte's Law' seems inappropriate because Mariotte did not *discover* the law. It is *Boyle's* law, not Mariotte's. What is at stake, here? It is not about relative degrees of credit or contributions within a community, nor even nationalistic bias. Rather, it is about *priority*, and even *proprietorship*. To interpret the 'Boyle' in Boyle's law, then, one needs to understand fundamentally why priority is valued and why it is so closely associated with eponymy and a sense of ownership.

The value of priority is fundamental to the institutional structure of modern (Western) science. As exemplified in all the examples above, eponymy is a form of credit. It is not some external culture imposing its values. Eponymy occurs within science. It may appear to be a gesture of retrospective appreciation, an extra reward for "a job well done." But it is, by design, part of a system of motivation, originally envisioned by Francis Bacon (Fig. 23), further advocated by Boyle, and ultimately institutionalized into the fabric of scientific practice. Basically, recognition is offered in exchange for novel discoveries. Two features are essential for the prize. The first is novelty. Originality and innovation are valued. (Progress in science may not be inherently guaranteed; but it can be deliberately driven by such a system of motivation.) The second criterion is publication, or public presentation. This may seem less relevant. But it was critical, and perhaps central, when the system originated. Bacon envisioned knowledge as a public good, or value. Yet investigation at the time was largely private — supported by individuals for their own curiosity or entertainment or for personal profit. Bacon (1611) conceived public recognition as a device to motivate investigators to share their knowledge publically. Boyle (1661), too, wanted information shared—and also shared promptly, so that others could develop the findings further. Indeed,

Figure 23. Francis Bacon, who advocated a system of credit for novel discoveries.

Boyle developed the genre of short scientific essays for presenting such results, to replace comprehensive volumes, typically delayed and filled out with irrelevant material (Sargent 1995). Boyle was hoping to shape an investigative *community*. This framework for exchanging public knowledge with recognition was formally adopted by the Royal Society, ultimately setting an institutional precedent for the conduct of science. Modern science, *by design*, recognizes only the first to publish. Hence, the standard values Boyle's contributions, rather than Mariotte's.

Several centuries later, science remains structured around priority. Competition for credit is now explicit (Latour and Woolgar 1979). The competitive system has predictable consequences. For example, the motivational framework favors scientists who are interested in gaining credit and working intensively, rather than pursuing questions leisurely or thoroughly (Hull 1988). Institutionally, science rewards the ambitious. It also tends to motivate short-term studies of minimal quality, rather than high quality long-term studies. Ironically, the system also fosters fraud, enticing those who seek the rewards yet are indifferent to the knowledge it should reflect (Toumey 1997, Judson 2004). By default, researchers are implicitly encouraged to err on the side of premature publication, at the expense of quality. As the pace hastens, retractions proliferate. New information appears piece-meal, in fragments, at the cost of completeness. Ironically (one can imagine Boyle's prospective dismay), results are not always shared openly, but sequestered to protect priority—or the potential for future priority. While the competitive system of reward (epitomized by eponymy) seems to "domesticate" ambition in the service of developing knowledge, it also produces pathological side-effects, with corresponding challenges for regulating them.

Given the flourishing of science in a capitalist economy, the competitive structure of science may seem "natural"—and as invisible as technicians and women once were. A gendered perspective, however, highlights the competitive system as distinctly yang. One might anticipate, therefore, finding different behaviors in women and men in science, at least to the extent that women are enculturated with different personalities and values than men. Male/female differences may well indicate gendered responses to a gendered science. For instance, women and men seem equally capable in scientific education and their earning of advanced degrees, and women are often recruited into scientific fields on a par with men. Yet, the pipeline is "leaky" and many women abandon scientific careers: the competitive environment seems one important factor, although its full significance is yet to be studied fully. Documented cases of fraud and retracted papers seem to exhibit a similar bias towards males (in greater proportion than their representation in science). Males in our culture, gendered in its own way, seem more responsive to competitive incentives. By using the framework of eponymy, reference to 'Boyle's law' thus implicitly accepts, perpetuates and indirectly endorses the essential value of competitiveness that renders the institutional structure of science inherently gendered.

The system of recognition and rewards goes deeper than perhaps the social conventions of eponymy. Priority now also determines ownership. Discoveries, or ideas, become property. One may easily interpret Boyle's law as, literally, Boyle's: the possessive form in eponymous laws readily suggests ownership. Indeed, priority helps generate and identify intellectual property. Knowledge becomes commodified (Lewontin 1991). What Bacon and Boyle and early members of the Royal Soceity envisioned as a public good has, ironically, become privatized. Hence, priority disputes rage—not just as tests of egos, but now as contests for economic capital. Priority focuses even more strongly on individuals, whose ownership is easier to document and manage than when distributed among a collective. Priority will tend to compound to those who already wield power, amplifying already existing disparities. The value of priority, institutionalized in eponymy, ultimately transforms scientific inquiry into a competitive economy and the labor of discovery into economically negotiable intellectual property.

Summary: Viewing Boyle's Law Anonymously

The gender of the 'Boyle' in Boyle's law is not about *Boyle's* gender. That is a red herring. Rather, it is about the value system embodied in eponymy. The gender here is not primarily about the 'who', but the 'how' of science. Current Western science exhibits gender in its institutional structure: its basis in competitive motives, its framework for commodifying intellectual property, and the politicization of priority, and thus the inequitable and politically biased distribution of credit and power.

One yin-inspired alternative might be to "unname" Boyle's law. Call it, perhaps, 'The Law Formerly Known as Boyle's'. (The backwards-looking reference would at least underscore the problem of past assumptions or biases.) —Or one could name the gas law, like any gas law, a 'gas law'. For example, the more complete version, associated with the Nobel Prize-winning work of Johannes van der Waals, is called simply the 'ideal-gas law', not Van der Waals' Law. (Note, however, that van der Waals did not go uncredited: the constants for each particular gas needed to solve the more complex equation bear his name.) For the special cases relating just pressure and volume, the name 'PV law' would be short—and even more economical than 'Boyle's law'. At the same time, one need not succumb to a faceless, inhuman science: stories of science can well celebrate human achievement, including Boyle's along with everyone else's. Until such time as we can refer to Boyle's law descriptively, while not implicitly valuing Boyle exclusively, one might refrain from an implicitly gendered label.

At a deeper level, however, a yin alternative involves restructuring scientific practice. First, one abandons the practice of eponymy altogether. Distribute credit. Foster communalism. Acknowledge that all participants contribute fruitfully and that scientific work (like any work?) may flourish when everyone has a stake in the outcome. Encourage and reward extra labor, but through other means (such as compensation), not exclusive privilege or *political* power (or social capital). Support the process without using competition as an external, potentially counterproductive motivator. Develop incentives that foster the goals of inquiry: judicious criticism and quality work. Establish collaboration and sharing of data as norms, to be stiffly sanctioned when not respected. Design a system where witholding data earns no value. Establish forums for productive dialogue. Promote criticism without divisiveness and sharing without self-promotion. Value negative results and the deeper level of understanding based on unexpected error (Allchin 1999). Let the system do the work in guiding individual behavior thorough incentives, rewards and sanctions *directly* related to furthering the investigative process.

Framing a gendered alternative, of course, may be more challenging than profiling the gender itself. With centuries of experience, ways of thinking about science are easily habituated. Indeed, the yang spirit of reductionism characterizes science just as it does nature: reducing it to idealizations and casting them as foundational and universal, rather than as normative judgments. A yang view of science itself tends to erase the relevance of these institutional contexts. Nonetheless, one may search for prospective alternative models, especially on the local level. For example, one may consider various small research communities. Are insights to be found in public research institutes (CDC, NIH, USGS), private labs (Cold Spring Harbor, Scripps) or commercial research facilities (Bell Labs, 3M)? In such institutional settings, the collective goal may tend to dissolve individual competitiveness by design (even where individuals earn credit for their efforts). Competition for credit would be further de-emphasized if scientists were employed for their promise and skill as researchers, not for their publication record alone. What does it mean to expand the scope of such potential models?

What's NOT in Boyle's Law

As profiled above, 'Boyle's law' can misrespresent both the content and process of science. The appeal to a 'law' obscures relevant experimental variables and contingencies, while the appeal to 'Boyle' obscures alternatives to the political structure of science. Yet noting alternatives in these two dimensions does not exhaust a gendered analysis. In addition, one may highlight the context of the research projects themselves. Why do particular questions seem significant or why does an answer seem prospectively valuable, and thus worthy of investing investigative resources? What other questions might have been addressed instead, using the same resources? Here, a gendered analysis highlights the context of *problematics*. Research, and even curiosity, may address only certain types of questions, while leaving other, equally warranted questions unanswered. The resultant body of scientific knowledge is not necessarily fully objective, in the sense of balanced, or equally informative in all fields.

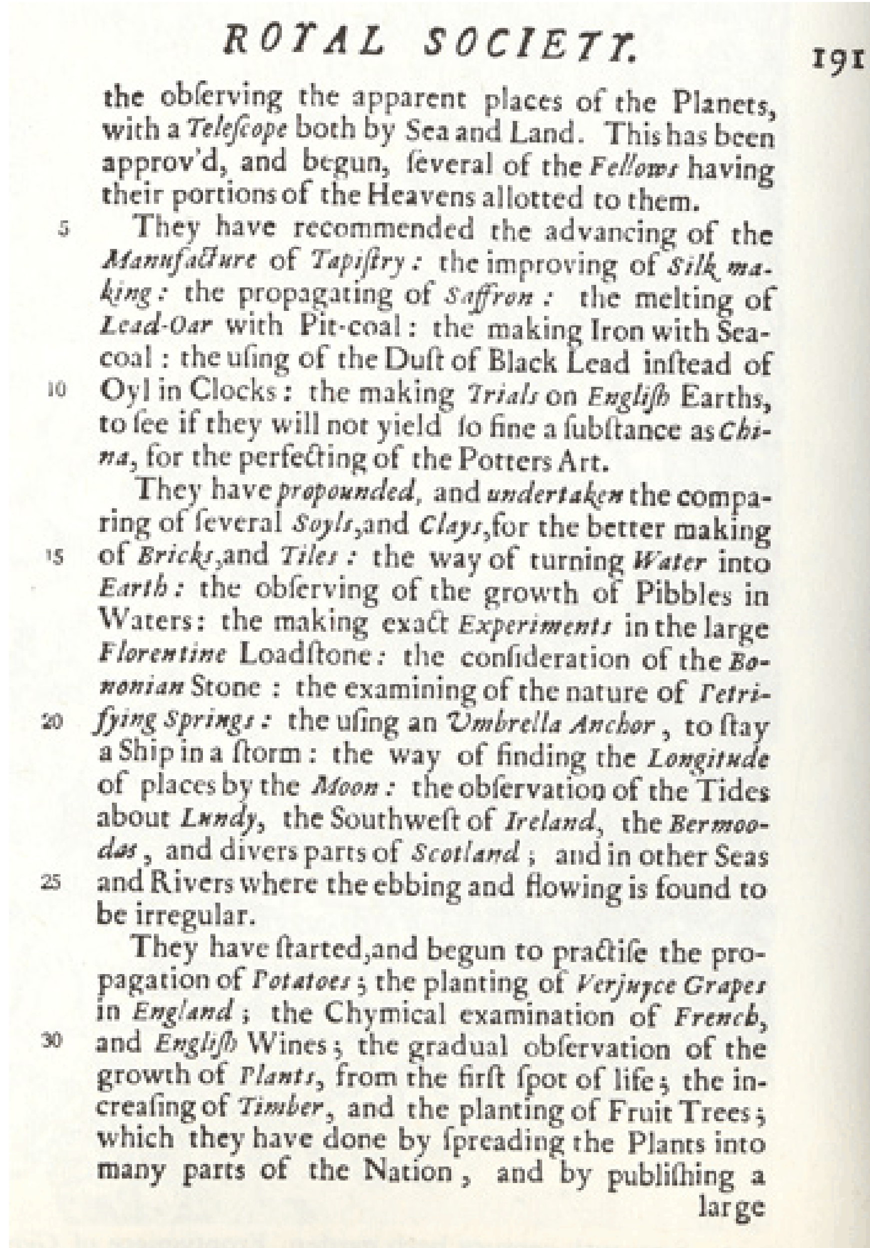
Boyle's law emerged, as noted earlier, from addressing criticism about Boyle's claims on 'the spring of air', or its elastic power. Boyle's original suite of experiments on pneumatics (1660) had many intellectual sources (Frank 1980). Beginning in 1644, the Torricelli tube (today's mercury barometer) had revived debates about the possibility of a vacuum, and opened discussion on the weight of air, as well as on the elasticity of air. For example, not long before Boyle initiated his studies, Christopher Wren had suggested to him investigating Descartes' notion that "atmospheric tides" (due to the moon), might account for daily fluctuations in the level of the Torricellian experiment (Boyle 1670, pp. 64-65). Boyle also belonged to a group of elite gentlemen discussing natural philosophy, and they had been talking about nitre (saltpeter) — well aware of the significance of gunpowder manufacture in the political context of England at the time. The group also regularly discussed Cartesian mechanical philosophy. Boyle, especially, had reflected on matter in terms of corpuscles, rather than traditional notions of elements (fire/earth/air/water or principles of sulphur/mercury/salt). Corpuscles, Boyle had mused, might explain the chemical reconstitution of nitre, as well as its expansive properties, and might also explain the 'spring' of air. When Otto Guericke in Germany developed an air pump, he demonstrated how one could generate an enclosed volume of rarefied (or condensed) air. Boyle saw the air pump as an opportunity to explore his corpuscularian philosophy experimentally and pursued it.

Boyle's orientation may seem without any significant context. The gendered perspective invites considering context further. First, what enabled Boyle (pragmatically) to pursue such investigations? Here, Boyle's economic status afforded him leisure time, as well as important financial resources — most notably, perhaps, for hiring Robert Hooke to design and build a modified air pump. Boyle himself acknowledged that the:

> opportunity to prosecute Experiments . . . to be perform'd as it ought to be, doth . . . require . . . oftentimes too more Cost, than most are willing, or than many are able, to bestow upon them. (Boyle 1682, "Defense", p. *xii*)

Wealth also had another significant, more intellectual role. It entitled Boyle to ask the questions. Second, then, what guided Boyle's scientific outlook and the questions he elected to pursue? We have already encountered Boyle's natural theology. Boyle barely escaped a strike of lightning as a young man, and he interpreted it as a sign from God to inquire into why. Boyle devoted himself to a life of investigating nature. Indeed, he considered working in his laboratory on Sunday a form of worship. Boyle's view of nature was not fully independent of his religious outlook. His conception of laws of nature (discussed above) resonated with a particular view of natural order. Boyle was looking for how God's world, long viewed culturally as a clockwork, was self-sustaining according to regular principles. Boyle was a mechanist. The corpuscularian philosophy he adopted was shaped by his religious perspective. Mechanical metaphors and reductionism not only guided the eventual expression of his findings about nature, but also the very problems he posed. Boyle, not coincidentally then, set out to discover exactly what he ultimately found: nature — even its chemical and biological dimensions — cast in terms of physical, mechanical principles. Anything Boyle studied, whether elements or nitre or air, would ultimately systematically exclude the non-mechanical.

Of course, an individual research project can hardly exhibit distributional balance. The question of balance emerges more at a social, or institutional level. In this case, Boyle's selectivity was echoed in the research of the early Royal Society [cite source here]. The majority of projects (59%) were oriented to economic and military problematics (Figure 24). While the Royal Society postured itself as a public institution, promoting natural investigation as a public good, it primarily supported discovery for private enterprise, or personal profit (reflecting the values of owners of capital in a capitalist economy). The list of primary research topics is telling. They involved (in decreasing order) mining, marine transport, military technology, general technology and husbandry, and the textile industry. Most tended to support an industrial economy, and most focused on physical science or technology. Where was public health and hygiene? —Worker safety? —Alternative small-scale technologies, such as worker's tools, say? —Natural history? —Sustaining soil or water quality? —Physiology, as it may have contributed to personal health? These seem public goods worthy of public investigation. One alternative project advocated by a founding member of the Royal Society, John Evelyn — and published the same year as Boyle's landmark response to Linus — drew attention to the preservation of forests. Evelyn's concern might have been environmental (by today's reckoning) had he not framed it in terms of the need for ship masts for trade and naval defense. His published appeal was coupled with research findings on how to prosper from apple trees through cider production, echoing the aim linking research and economic profit. The Royal Society's science, however reliable or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the obſerving the apparent places of the Planets, with a *Teleſcope* both by Sea and Land. This has been approv'd, and begun, ſeveral of the *Fellows* having their portions of the Heavens allotted to them.

They have recommended the advancing of the *Manufacture* of *Tapiſtry*: the improving of *Silk making*: the propagating of *Saffron*: the melting of *Lead-Oar* with Pit-coal: the making Iron with Sea-coal: the uſing of the Duſt of Black Lead inſtead of Oyl in Clocks: the making *Trials* on *Engliſh* Earths, to ſee if they will not yield ſo fine a ſubſtance as *China*, for the perfecting of the Potters Art.

They have *propounded*, and *undertaken* the comparing of ſeveral *Soyls*, and *Clays*, for the better making of *Bricks*, and *Tiles*: the way of turning *Water* into *Earth*: the obſerving of the growth of Pibbles in Waters: the making exact *Experiments* in the large *Florentine* Loadſtone: the conſideration of the *Bononian* Stone: the examining of the nature of *Petrifying Springs*: the uſing an *Umbrella Anchor*, to ſtay a Ship in a ſtorm: the way of finding the *Longitude* of places by the *Moon*: the obſervation of the Tides about *Lundy*, the Southweſt of *Ireland*, the *Bermoodas*, and divers parts of *Scotland*; and in other Seas and Rivers where the ebbing and flowing is found to be irregular.

They have ſtarted, and begun to practiſe the propagation of *Potatoes*; the planting of *Verjuyce Grapes* in *England*; the Chymical examination of *French*, and *Engliſh* Wines; the gradual obſervation of the growth of *Plants*, from the firſt ſpot of life; the increaſing of *Timber*, and the planting of Fruit Trees; which they have done by ſpreading the Plants into many parts of the Nation, and by publiſhing a large

Figure 24. Sample page from the Proceedings of the Royal Society, reviewing projects it promoted.

"objective" its findings, was not (despite its own rhetoric, perhaps) designed "objectively" to benefit everyone equally. Wealth, as in Boyle's case, entitled one to ask the questions and to differentially seek knowledge that could amplify private profit. The Royal Society, like Boyle (and often reflecting Boyle's vision), also exhibited gender in its research problematics. One can easily imagine an alternative body of science that would have been (even then) more humanist, less capitalist, and (broadly speaking) more ecological, less mechanical (Merchant 1980). That challenge remains with us today, of course, in terms of how resources are allocated towards researching alternative energies, non-proprietary pharmaceuticals, low-tech medicine, sustainable (often small-scale) technologies, organic farming, climate change, environmental preservation, etc.

[? prospective discussion of interventionist style of experiment, manipulating variables rather than perturbing complex systems or relying on comparative observation ?]

A similar question about the scope, focus and resolution of scientific knowledge is echoed not in the halls of research but in the halls of learning. What do teachers (or school systems) choose to teach in science and about science? How do they represent the world through science? How do they represent science itself? Even limited to facts, many alternative perspectives are possible through selection of topics, relative emphasis, and lessons about fundamental concepts. What is included in a science curriculum—and what is not—is fundamental to how nature and science are understood culturally. *Teaching* Boyle's law is potentially gendered, too. —And the ubiquity of Boyle's law in chemistry education (and the prevalence of chemistry as a standard science class) underscores its importance as an example in analyzing the gender of science in a cultural context.

Many, *many* people remember Boyle's law from school. And almost as many people probably never have occasion to use it. Why, then, is it taught so widely (so incredibly widely)? One might imagine, perhaps, that knowing about an inverse relationship of pressure and volume is fundamental to understanding the world around us. Yet one does not need Boyle's law to know, for example, that the more you compress a balloon (or an inflated pig's bladder?), the harder it is to compress it further. This is knowable through common experience—and was so even in the 17th century. Educationally, however, such a simple qualitative understanding does not reflect the quantitative relationship generally considered central to the law. It is thus the *mathematical expression of nature*, rather than the mathematical formula itself, that is important. The central lesson—deemed important even for those who will never need to calculate any values for pressure or volume—is about reducing nature to numerical order. Boyle's law is also an occasion for talking about Boyle's conception of matter (with or without Boyle as a foil). Students learn how the modern kinetic theory of gases explains the law, atomically, mechanically. All the gendered elements in laws of nature and their overtones for conceiving causality and nature are thus captured in standard lessons about Boyle's law. Students seldom learn more than what they are taught. Thus, teaching the simplified version of Boyle's law also teaches simplicity in nature. Omitting the complex reinforces a simple, or simplistic, worldview (Allchin 2001a). Ultimately, most students can pass a chemistry class without knowing much about acids and bases in their own household, and without understanding the chemistry of cooking or cleaning or batteries or gasoline combustion—despite being able to solve problems involving Boyle's law, oxidation-reduction or solubility reactions, the periodic table and mass equilibria. Much chemical education, I suspect, is more about (re)instantiating a mechanical worldview and certain images of science than it is about appreciating chemical principles in the world we experience. To the extent that Boyle's law is gendered, education that is modeled on Boyle's law, while not embracing other forms of chemical knowledge, is also gendered. Alternatives exist.

Appreciating the Yang in Boyle's Law

Some may see yin alternatives as purported *replacements* for Boyle's law or for (an alleged) yang science. For them, a gendered analysis may seem to imply that we must accept *either* Boyle's law *or* Boyle's J-tube. It may seem that *either* we adopt the PV gas *or* "anything goes"! However, the very either-or framework itself is also gendered. Indeed, it echoes the yang structure of either-or competition for scientific credit and the winner-take-all principle governing eponymy. In a yin approach, alternatives need not be mutually exclusive. They may be *complementary*. Indeed, the complementary concepts of yin and yang from Daoist philosophy function expressly here to show the limitations of the strict either-or dichotomies that tend to pervade Western philosophy.

Nor does a gendered analysis necessarily profile error. Denying eponymy to Boyle or declining to construe the PV relationship as a causal law does not mean that Boyle's law (in its canonical form) is utterly false or misguided. Even accepting yin alternatives, yang perspectives need not be *wrong*. Indeed, the whole right-or-wrong, truth-or-error dichotomy is yet another form of a limited yang, either-or view. Objective knowledge may be expressed in many ways. Many maps—each reliably benchmarked—may represent the same territory. Even maps that seem incommensurable may each be "objective" and true, when interpreted appropriately (Kuhn 1970). Complementarity does not entail error.

Error or misleading conclusions may arise, however. They emerge primarily when the context or limitations of the perspective are masked or disregarded. James Hutton expressed it eloquently when he criticized "anti-phlogistic" doctrine in the later 18th century:

> There may be no error in the explanation of phenomena, so far as regards their assumed principles; but the greatest when their principles should be considered as comprehending all the appearance. (Hutton, 1794, p. 207; see Allchin 1994)

Thus, casting Boyle's PV relationship as a universal law exhibits a sort of scientific hubris. Boyle's law does become incorrect *if* one neglects its empirical contexts and contingencies. Boyle's law does not properly recognize who discovered the law *if* one discounts the many co-contributors—or *if* one fails to acknowledge the political eclipse of potential contributors. Gendered alternatives thus serve a vital function in science. Like experimental controls, they help expose the relevance of otherwise hidden variables. They help bring into relief and clarify the assumptions or nature of other perspectives. They may reveal telltale omissions or deficits. A yin perspective thus helps keep the "bias" and any unwarranted pretensions of yang science healthily in check—and vice versa. Yin and yang complement one another. Even when they may seem at odds, the different perspectives function fruitfully and interactively as an "*ironic diptych*" (Haraway 1989, p. 161).

At the same time, in profiling assumptions the gendered alternatives to Boyle's law help circumscribe the appropriate (positive) context of its yang perspective. That is, articulating limits also helps underscore the relative merits and scope of using the canonical form of Boyle's law. One appreciates the yang in Boyle's law by discerning its proper context. Well aware of the alternatives, then, one can revisit Boyle's law and yang science.

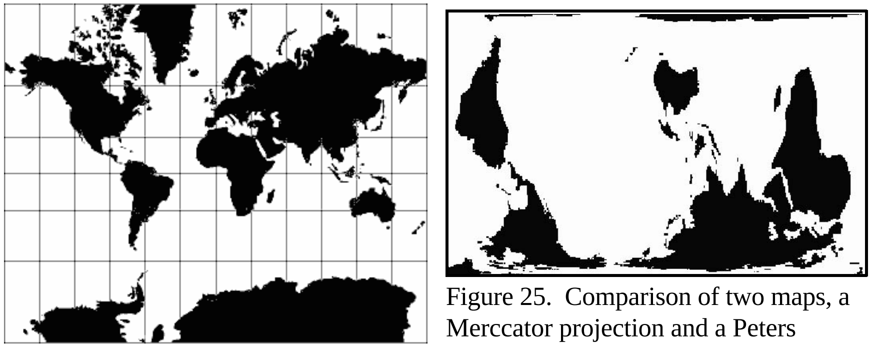

Figure 25. Comparison of two maps, a Merccator projection and a Peters projection, form an ironic diptych that shows how each map, while accurate, exhibits a particular perspecctive.

One may appreciate its virtues, while still acknowledging that such virtues do not exhaust a full understanding of the behavior of gases or of doing science.

At one level, the edifice of science founded on Boyle's law may speak to its fruitfulness. First, then, the lack of true universality for Boyle's law does not necessarily intrude upon its *usefulness*. Boyle's law allows calculations involving closed systems, much like Boyle's J-tube. Thus, one can trace a lineage from Boyle, first to Denis Papin, his technical assistant in the late 1670s, who reconceived the mercury in the glass tube as a moving piston in a metal cylinder, in designing a simple atmospheric engine. The lineage continues (ostensibly) with Newcomen and his variant engine, then the steam engine and later still the modern internal combustion engine. In each case, one can calculate important changes in the enclosed volume from changes in pressure, or vice versa. Similarly, Boyle's law is useful for assessing or designing boilers (that produce steam power), ventilation systems and automobile airbags. In open systems, of course—like the atmosphere—volume and pressure do not strictly vary inversely; rather, the air *moves*. Wind happens. Boyle's law describes just closed systems. [? footnote on pressure as a macroscopic, system-level measurement?] In addition, most engineers concerned with behavior of gases address temperatures and pressures near the human environment. They generally work with air or gases described by Boyle's formula. For them, assumptions about the empirical context are relatively secure. Indeed, the qualifications about high pressures, low temperatures or non-Boylean gases (so important to considering whether the law is truly universal) are *locally irrelevant*—and thus typically cast aside. For the *local* needs and *context* of most engineers, the canonical (truncated) Boyle's law is as "universal" as they will ever need.

Second, reductionism may have particular benefits. For example, modeling a system initially with just a few variables may provide a baseline for further research. Laws, as tentative simple assumptions, may facilitate probing causal complexity. Even models *known* to be false may support productive investigation (Wimsatt 1987). Indeed, the many qualifications to Boyle's original law were eventually discovered within a fundamentally reductionist research program (by Charles, Gay-Lussac, Regnault, Amagat, Andrews, van deer Waals, etc.). Laws may be effective *heuristics*, or problem-solving short cuts. Their approximations may be serviceable enough. At the same time, the instrumental use of law-like models limits their claims to realism. Ideal gas laws are selectively realistic, at best. Still, as witnessed in over three centuries of productive science using reductionistic frameworks, selective realism may be realistic enough for many cases.

Third, embracing law-like causality seems fruitful where law-like behavior can be documented. Engineers who use the yang form of Boyle's law work effectively within pockets of regularity. Causal laws may also bring generality and explanatory power, even at the cost of realism (Levins 1966). (Loss of realism for laws does not mean, of course, loss of realism for science: that is a paradox only for yang perspectives.) Laws may also provide a structure for quantitative precision where isolated patterns do exist. Laws become increasingly less fruitful, however, in complex and highly dynamic systems. Non-linear dynamics (so-called 'chaos') are not always best characterized by laws or law-like causality, even when viewed deterministically. Consider again the example of Chinese medicine as a prospective model for yang science. It helps circumscribe the authority of predominantly yang, Western biomedicine and, perhaps, also its causal structure. Viewing Chinese medicine and Western biomedicine as complementary, one may characterize how each functions effectively in particular contexts (Kaptchuk 2001, p. 31). Western biomedicine is highly effective for infectious disease and vaccinations (where germ theory maps causality) and for trauma and emergency care (acute care, where single variables tend to generate dramatic short-term effects). Chinese medicine, by contrast, excels in chronic conditions (for example, arthritis) or cases where etiology is less clear and presumably multi-variate. "Also, it seems that Chinese medicine is preferable for functional disorders, benign self-limiting problems, psychosomatic complaints, psychological stress, and intractable and catastrophic conditions that resist resolution with biomedicine. Chinese medicine is also valuable in helping people adopt and cope with incurable conditions and serious emotional conflict. It is often adopted for illness prevention and health maintenance" (ibid.). The contexts of yin and yang approaches in alternative medicines offer a model for interpeting causal frameworks more broadly. Ultimately, we may hope to differentiate more clearly the contexts where laws are effective scientific tools and where they are not.

Finally, one may consider the positive role of eponymy. Even to the extent that science is a collaborative enterprise on the large scale, the role of the individual is nonetheless important on another scale. It hardly seems inappropriate to celebrate the effort of specific persons or to show appreciation for individual contributions. Nor does it seem misplaced to highlight the human and historical dimensions of science, especially in a culture that so often views science as abstract and transcendental, and hence remote from humanistic concerns. Also, to the extent that humans come to science with ambitious or competitive motives, it does not seem ill conceived to try to tame them towards epistemic ends. An educational system that erased Boyle and history would fail to represent science well no less than a system that focused on Boyle exlcusively.

A gendered analysis, even emphasizing yin persectives, does not necessarily eclipse yang perspectives—although it does function to keep them in conceptual check. The aim is not to eliminate gender as some form of bias. Nor is it to transcend gender to reach some "higher" objectivity. Rather, the aim is balancing complementary perspectives, while discounting neither.

Conclusion: Appreciating the Yin Beyond Boyle's Law

Critics of gender in science sometimes contend that even if women (rather than men) had investigated gases and "crunched the numbers," they would still get Boyle's law(!). Such critics, one may now see, misinterpret the nature of gender, and thereby underappreciate the depth of its significance for science. It is not (strictly) about whether Boyle or other scientists were male or sexist (Potter 2001, pp. 3-12). Nor is the aim of a gendered analysis to articulate some alternative *law* (Potter 2001, pp. 151-154). Indeed, a yin scientist might refrain from speaking in terms of laws altogether. Rather, the gender concerns mostly what is absent. The yin alternatives are typically beyond Boyle's law, in blindspots and areas typically cast in shadow. They are about relevant variables omitted, underused structures of conceiving causality and motivation in scientists, and underexplored views of order in nature.

Why peripheralize Boyle's sex? Is it because sex is never relevant to science? No. Any part of a scientist's cognitive background or outlook is potentially relevant. That may include biographical experiences, ethnicity, religion, class, affluence, as well as personality or style. It also includes, notably in some cases, someone's political standpoint. For example, individuals from disempowered groups (including women in many cultures) may help sharpen focus on how power rests on conceptual disparities, unasked problematics or incomplete evidence in science. (Of course, what is significant in this last set of cases is power, not gender or even sex per se.) Science benefits from multiple standpoints, or particular cognitive resources. As noted earlier, any given variant perspective may prove an asset or a liability. The source of "creative genius" is simultaneously the source of "unhealthy bias." This is precisely why the communal nature of science is so important. The question in the case of Boyle's law is whether perspectives based on male/female outlook or male/female politics were relevant. Were men and women positioned to probe, conceive or endorse the relationship between pressure and volume differently? Narrowly, at least, the spring of air seems remote from the particularity of women's lives, then or now. In the case of condensation or dilation of gases, gender seems to be found elsewhere than in sex or the politics of male and female.

Gender is more fruitfully viewed culturally. Here, the Daoist complementaries yin and yang help conceive gender apart from male and female (whether viewed biologically or politically). Boyle's gender, as well as the gender of those who subsequently adopted his law, is a cultural artifact. As reflected in the analysis above, the gender reflects further contexts or resonances in natural theology and its secular worldview equivalents, legal concepts, capitalist ideology, and especially in class and economic power. Understanding these contexts opens deeper appreciation of a role for critical balance from alternative perspectives.

Some contend that gender enters science just where evidence is incomplete (e.g., Potter 2001, pp. xii-xiii, 175, 184; Longino 2001). (Philosophers know this as the "underdetermination of theory by data": data is always logically insufficient, inherently leaving "interpretive flexibility.") In this view, gender reflects a form of bias that may be eliminated or crowded out by collecting the appropriate data. In the analysis above, however, the quality or quantity of evidence was never at issue. More or less evidence is irrelevant. Deeper knowledge of variables in the behavior of gases, for example, only further highlights the gendered role of using the simple law. It does not eliminate the exclusion of context. Nor will more information alter a fundamental, reductionistic outlook or law-like worldview. Boyle was not credited with his law because no one knew about others who contributed. Indeed, one may imagine the honor was given despite such awareness. Gender in science is not a "problem" of poor evidence—to be "solved" by more exhaustive research or more rigorous statistical tests or more gender-free investigators. Nor is Boyle's law somehow exempt from gender by casting pneumatics as a so-called Exact Science. As I hope to have demonstrated, gender is not fundamentally about factual error at all, and it is not something that can be simply erased. Gender, whether yin or yang, is a question of perspective—and inescapable.

Regardless of the completeness of evidence, however, one may nonetheless find the completeness *of perspectives* wanting. Gendered analysis focuses on such perspectives, and by considering their context and alternatives, profiles their meaning. Alternatives reconfigure information, rather than primrily add to it. They shift gestalts, reverse foreground and background, invert central and peripheral. Rather than inquire whether all the relevant information is at hand, one may first ask what information is deemed relevant and why. Thus, in highlighting the experimental context of Boyle's law, a gendered perspective yields an alternative, more complete causal expression, an alternative framework for causality, and an alternative worldview of nature and natural "order." In underscoring the political and economic context of naming Boyle's law, it yields a more equitable alternative to eponymy, an alternative system of motivation and incentives, and an alternative view of valuing knowledge. In examining the context of what is not in Boyle's law at all, it yields an alternative, more humanist and ecological research agenda and educational curriculum. Context may therefore highlight a particular type of error (Allchin 2001b): errors of incompleteness based on limited perspective.

Ultimately, one may wonder why gendered analysis matters. Indeed, to the extent that Boyle's law is an esoteric scientific fact of practical use to relatively few, profiling its gendered nature may seem trivial or downright silly. At the same time (as noted earlier), Boyle's law is widely known. It does not function primarily as a formula for calculating gas pressures or volumes. Rather, Boyle's law is a cultural icon of science. It epitomizes science's aim as bringing law-like order to nature, its ideal form of expression in simple yet mathematically rigorous equations, and its system of value as privileging individual discovery through competition. These images, as pervasive as the teaching of Boyle's law, reflect how individuals are enculturated to science and thus how the culture tends to interpret the nature of science.

What is science, according to Boyle's law? When one teaches Boyle's law as unqualified, and embedded in a reductionistic view of causality and law-like natural order, one teaches that nature is simple and rule-bound. (By implication, to the degree that science is modeled as an ideal instituion, it teaches that society, too, is ideally simple and rule-bound, endorsing a legal conservatism.) Boyle's law also teaches, by example, that science is a simple meritocracy, resulting from the work of special individuals (geniuses, perhaps, like Newton or Einstein). (By implication, privileged status in society, too, reflects a history of merit, even if enjoyed by only a few, also tending to justify the status quo and dispel questions about unequal distribution of wealth and power). Political overtones aside, the images and concepts of simplicity inherent in the canonical Boyle's law shape public knowledge. Someone indoctrinated into simple science is unprepared to appreciate or interpret the complexity in science on occasions when it informs important public or private decision-making (say, in cases of climate change or nuclear waste). In addition, those schooled to expect simple science and mathematical-type certainty are easily betrayed when claims (at first advanced without context) prove false. Science suffers a disillusioned public, which then fails to respect scientific knowledge when it matters. All this amplifies the problem of gendered perspectives which are incomplete and misleading about science in all the ways noted above.

Ironically, gendered analyses are sometimes belittled as inherently anti-science (e.g., Koertge 1998). I trust that the analysis above shows how yin perspectives promote better science. If one's aim is *empirical adequacy*, one does not omit the empirical context of Boyle's law. If one aims for *complete and effective investigation*, especially for complex and dynamic systems, one does not rely exclusively on reductionism as a guide. If one wants only *scientifically warranted* claims, one does not assume the world is always law-like. If one aims for *reliable publication*, one does not rely on eponymy and a competitive system of credit. If one aims for *balanced and representative knowledge*, one does not ignore how economic considerations shape problematics. Yin perspectives on Boyle's law underscore the fruitful alternatives. Gendered analysis thereby opens the way for a deeper, fuller science.

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