

14 Composing Scientific English

We are such stuff
As dreams are made on, and our little life
Is rounded with a sleep . . .

William Shakespeare

For humans are of the type of material that constitutes dreams, and their relatively brief existences terminate, as well as taking their inception, in a state of unconsciousness.

R. F. Gombrich (1989)

By translating Shakespeare's famous lines from the *Tempest* into stilted academic prose for readers' amusement, the British scholar Richard Gombrich exhibits his dissatisfaction with such prose. The same dissatisfaction has motivated many commentators to criticize scientific writing as having degenerated into a "molasses of jargon and academic code." We would guess many scientists would agree with that opinion, except as it might apply to their own prose. But we believe it is a facile generalization and not much help to anyone wanting to improve his or her scientific prose. Here is why.

Current scientific English as exemplified in the best journals differs markedly from the somewhat more reader-friendly prose that characterized scientific communication at the beginning of the scientific revolution in England. To illustrate this point, let's examine a seventeenth-century passage from Sir Robert Boyle's *Experiments and Considerations of Colours* (1666). We apologize for the length of this passage, but only at such length is the character of Boyle's style fairly exhibited:

I know not whether I may not on this occasion add, that Colour is so far from being an Inherent quality of the object in the sense that is wont to be declar'd by the Schools, or even in the sense of some Modern Atomists,

that, if we consider the matter more attentively, we shall see cause to suspect, if not to conclude, that though Light do more immediately affect the organ of sight, than do the bodies that send it thither, yet Light it self produces the sensation of a Colour, but as it produces such a determinate kind of local motion in some part of the brain; which, though it happen most commonly from the motion whereinto the slender strings of the *Retina* are put, by the appulse of Light, yet if the like motion happen to be produc'd by any other cause, wherein the Light concurs not at all, a man shall think he sees the same Colour. For proof of this, I might put you in mind, that 'tis usual for dreaming men to think they see the Images that appear to them in their sleep, adorn'd some with this, and some with that lively Colour, whilst yet, both the curtains of their bed, and those of their eyes are close drawn. And I might add the confidence with which distracted persons do oftentimes, when they are awake, think, they see black fiends in places, where there is no black object in sight without them. But I will rather observe, that not only when a man receives a great stroak upon his eye, or a very great one upon some other part of his head, he is wont to see, as it were, flashes of lightning, and little vivid, but vanishing flames, though perhaps his eyes be shut: But the like apparitions may happen, when the motion proceeds not from something without, but from something within the body, provided the unwonted fumes that wander up and down in the head, or the propagated concussion of any internal part in the body, do cause about the inward extremities of the Optick Nerve, such a motion as is wont to be there produc'd, when the stroak of the Light upon the *Retina* makes us conclude, that we see either Light, or such and such a Colour.

Let us ignore small differences in spelling and punctuation and the ornate sentence structure and phrasing common to the period; they are not material to the point we want to make. Even discounting these, we can see that Boyle's prose lacks the characteristics we associate with current scientific English.

In the first place, Boyle does not use specialized technical terms except perhaps "Optick Nerve" and "Retina." A vast lexicon of scientific and technical terms did not yet exist. Second, Boyle does not favor verbs in the passive voice: for example, rather than the modern "if the matter *is considered* more attentively," Boyle writes "if we consider the matter more attentively." Moreover, Boyle exhibits no qualms about using first-person pronouns (*I* and *we*) repeatedly.

Third, nominalization practices differ greatly. (Nominalization is the grammatical alteration of verbs into nouns—the alteration, for example, of *evolve* into *evolution*.) Its systematic use is another characteristic of current scientific English. In Boyle's prose, however, nominalizations are few and

far between: his commonplace choices, for example, “sensation” and “motion,” pass without notice. Fourth, complex noun phrases, so characteristic of current scientific English, are scarce in Boyle. His average noun phrase is short—it is a noun and its accompanying article, adorned occasionally by an adjective and a prepositional phrase: for example, “the slender strings of the *Retina*.” Indeed, Boyle’s short noun phrases are so numerous that the lengthiest of them—“the Inherent quality of the object in the sense that it is wont to be declar’d by the Schools”—passes almost without notice. Also entirely absent are noun strings, that is, a central noun preceded by multiple modifiers, as in “planar graphite fused six-membered ring structure” (Kroto et al. 1985), used to designate a new form of carbon. Finally, Boyle’s prose differs in its use of verbs. A characteristic of current scientific English, a corollary of the omnipresent long, complex noun phrase, is the use of weak verbs and of the same few verbs repeatedly: for example, the predicates *to be*, *to have*, *to show*, *to find*, *to use*. In contrast, Boyle “considers,” “concludes,” “observes,” “endeavors”; his men “see,” “think,” and “receive”; his light “produces,” “concur,” “causes.”

Clearly, over the centuries a sea change has occurred. Scientific English has evolved, just as standard written English has. In this chapter, we describe the general characteristics of the current state of this evolution: a fondness for verbs in the passive voice; the systematic use of nominalization, long noun phrases, and noun strings (and their concomitant weak verbs); and, finally, the proliferation of technical terms. We believe in the middle path to good scientific prose: that is, not avoiding these characteristics if at all possible, nor blindly using them at every turn of phrase, but mastering them.

A Strong Reliance on the Passive Voice

Typical verbs express an action—what he, she, or it did: “The boy hit the ball.” The verb is in the active voice. But English also allows you to express the same thought differently: “The ball was hit by the boy.” The verb is now in the passive voice. The agent of the action, the boy, appears after the verb, while the object of the action, the ball, appears before it. In the passive voice you can also omit the agent if you wish. You can write: “The ball was hit.” The passive voice is a way that English allows writers to remove explicit mention of the human agent from a sentence. An object, process, or concept appears in the subject position.

Those dispensing how-to-write advice routinely advocate shunning the passive voice and embracing the active. Some writing teachers go so far as to see any use of the passive voice as a sign of weak writing. So construed,

passive equals bad, *active* equals good. That formula is even reinforced by the choice of names for the two verb voices. In marked contrast, some scientists seem to believe that good scientist-writers ought never use the first-person pronoun *we* or *I*. Suppressing the first-person pronoun thus forces them to use passive voice verbs in abundance.

In reality, scientists have freely used both passive verbs and first-person pronouns from the beginning of modern science. Our own research has shown that the passive voice appeared on average about once per hundred words in the seventeenth century. That rate steadily increased over time until it had doubled by the early twentieth century. Thereafter, it has remained relatively flat. Still, with more than two uses per hundred words, modern scientists clearly do not practice the advice preached by many writing teachers. And given another twentieth-century norm, one first-person pronoun per hundred words, they do not forgo this modest “personal” touch either.

Particularly in methods sections, you will likely find English scientific prose heavily laden with verbs in the passive voice. To exemplify this practice, let us turn to a passive passage from David Baltimore’s “Viral RNA-Dependent DNA Polymerase” (1970), a classic paper on understanding viruses and designing drugs to combat them:

A preparation of R-MLV containing 150 μ l. *was layered* over a linear 5.2 ml. gradient of 15–50 per cent sucrose in PBS-EDTA. After centrifugation for 2 h at 60,000 r.p.m. in the Spinco “SW65” rotor, 0.27 ml. fractions of the gradient *were collected* and 0.1 ml. portions of each fraction *were incubated* for 60 min in a standard reaction mixture. The acid-precipitable radioactivity *was then collected and counted*. The density of each fraction *was determined* from its refractive index. (emphasis ours)

Now let’s change the original passive verbs into active:

We layered a preparation of R-MLV containing 150 μ l. over a linear 5.2 ml. gradient of 15–50 per cent sucrose in PBS-EDTA. After centrifuging this mixture for 2 h at 60,000 r.p.m. in the Spinco “SW65” rotor, *we collected* 0.27 ml. fractions of the gradient and incubated 0.1 ml. portions of each fraction for 60 min in a standard reaction mixture. *We then collected and counted* acid-precipitable radioactivity. *We determined* the density of each fraction from its refractive index.

Is one passage better than the other? Not really. They are just different. In the first, the performers of the different actions in the lab are hidden from view. In the second, the human agents take center stage. It comes down to a matter of emphasis. What is the central story here: what the authors did in

the lab or what was done by them in the lab? Baltimore decided on the latter. Most scientists would agree with his choice.

Here is the important point about the selection of voice. When good writers want to stress or make unequivocal what they or some other person did, they begin sentences with the pronoun *we* (for a paper with multiple authors) or *I* (for a single author) or a person's name (Harmon, Gross, etc.). When they want to emphasize the objects of the world, the products of scientific methods and the laboratory, or other inanimate constructs, they frequently must use the passive voice. In general, current scientific English relies heavily on the passive voice because science is about objects and events, not people.

A Network of Nominalizations, Complex Noun Phrases, and Noun Strings

Current scientific English is characterized by nominalizations: nouns converted into verbs. Nominalizations often end with either “-tion” or “-ment,” as in *development*, but sometimes they undergo no change in form:

They pursued *research* on how amphibians evolved from fish.

They *research* how amphibians evolved from fish.

You can find an abundance of nominalizations in almost every sentence of current scientific English. Take the following from an article by Wilmut and collaborators (1997) on the first mammal to be cloned from an adult cell (Lamb 6LL3, better known as Dolly). In it, the nominalizations we italicize form a network that conveys a significant part of the meaning of the passage, the importance of process:

Development of embryos produced by nuclear *transfer* depends upon the *maintenance* of normal ploidy and creating the conditions for developmental *regulation* of gene *expression*. These *responses* are both influenced by the cell-cycle stage of donor and recipient cells and the *interaction* between them (reviewed in ref. 9). A *comparison* of *development* of mouse and cattle embryos produced by nuclear *transfer* to oocytes or enucleated zygotes suggests that a greater *proportion* develop if the recipient is an oocyte. This may be because factors that bring about *reprogramming* of gene *expression* in a transferred nucleus are required for early *development* and are taken up by the pronuclei during *development* of the zygote.

This passage exhibits another defining characteristic of current scientific English: its nominalizations are often embedded in long and complex noun phrases, such as “development of embryos produced by nuclear transfer”

and “a comparison of development of mouse and cattle embryos produced by nuclear transfer to oocytes or enucleated zygotes.”

The typical complex noun phrase in scientific English consists of a head noun (*development* and *comparison* in the above examples) with multiple modifiers to the right or left, sometimes in both positions. One of the main grammatical differences in sentences in modern scientific English compared to its precursor is the frequent use of such noun phrases as the subject. Handling them adroitly is essential to good scientific writing.

We now turn to the thought process behind how an author might construct a typical sentence in scientific English—that is, two complex noun phrases connected by a fairly common main verb (*to determine*). For that purpose, we borrow the first sentence in an article by Fred Sanger and his colleagues (1977) reporting the first ever sequencing of an entire genome—the bacteriophage called ΦX_{174} , a virus that infects bacteria. The article begins with an abstract distilling the essence of the discovery. Its first sentence is as follows:

A DNA sequence for the genome of bacteriophage ΦX_{174} of approximately 5,375 nucleotides [*noun phrase*] has been determined [*verb*] using the rapid and simple “plus and minus” method [*noun phrase*].

How was such a sentence constructed? Let’s pretend the author has not yet written a word. We are looking over his shoulder at the computer terminal and spurring him on by asking questions about his research as he attempts to translate it into written words.

Our first question is “Given that this is the first sentence in the entire paper, could you choose a single word that describes either the content of the paragraph it heads or even the whole paper?” The answer he gives us is the nominalization “sequence” (not coincidentally, the nucleus noun in the article’s title).

“A sequence of what?” we ask. His answer is “A DNA sequence.”

That raises another question. “There are an infinite number of DNA sequences. Could you be more specific?” He amplifies, “A DNA sequence for the genome of bacteriophage ΦX_{174} .”

We could ask about the definitions of the technical terms here, but we will assume our readership of molecular biochemists knows these terms already. However, even experts in the field might not know anything much about ΦX_{174} other than that it is a bacteriophage. “Could you be a little more specific?” we wonder. His answer is to elaborate with further technical detail: “A DNA sequence for the genome of bacteriophage ΦX_{174} of approximately 5,375 nucleotides.” (This long and complex noun phrase, the subject of the sentence, is also, not coincidentally, the subject of the article as a whole.)

Our next question is “What’s the significance of ‘5,375 nucleotides’”? He answers, “My readership understands that this quantity signifies a simple genome, one well suited to the task at hand.”

We take him at his word but then ask, “What’s the task at hand?” His response is “To determine all the 5,375 nucleotides in this genome; this would be the first time anyone has sequenced a complete genome.”

“So,” we wonder, “how did you determine the sequence?” He responds, “I used the plus and minus method.”

“Why that method?”

“Because it is rapid and simple.”

“What is this method?”

“I will provide further details later in the paper.”

We have run out of questions, so we can now piece together the author’s answers :

A DNA sequence for the genome of bacteriophage ΦX_{174} of approximately 5,375 nucleotides has been determined using the rapid and simple “plus and minus” method.

The words in italics constitute the complex noun phrases in the sentence. The two key questions all readers want answered at the beginning of a scientific article are these: What is your major claim? How did you arrive at that claim? This typical example of scientific English answers both those questions succinctly.

Another defining feature of current scientific English is a variant of the complex noun phrase, the noun string. In standard as opposed to scientific English, writers normally qualify and expand on the meaning of a single head noun by means of modifying words added to the right. Let’s start with the word “experiment.” In standard English, an author might add a qualifying phrase after that noun, linked to that noun by means of prepositions and conjunctions:

experiment *at high temperature and high pressure*

In this noun phrase, the modifier to the right of the head noun has no verb. A dependent clause can also be added to this construction:

experiment at high temperature and high pressure *that produced NO₂*

In current scientific English, as distinguished from standard English, writers routinely transfer phrases and clauses from the right to the left of the head noun. You find

high-temperature high-pressure experiment that produced NO₂

Or

high-temperature, high-pressure, NO₂-producing experiment

Before the twentieth century, scientists rarely used such noun strings—nominal constructions in which prepositions, conjunctions, and pronouns disappear. On average, scientific prose has about three such constructions per hundred words.

The preference in current scientific English for nominalizations, long and complex noun phrases, and noun strings leads to the concomitant of this tendency: a preference for commonplace verbs in main clauses. Here is an example from a classic theoretical article on superconductivity by Bardeen, Cooper, and Schrieffer (1957), with the main verbs in italics:

A theory of superconductivity *is presented*, based on the fact that the interaction between electrons resulting from virtual exchange of phonons *is* attractive when the energy difference between the electrons states involved *is* less than the phonon energy, $\hbar\omega$. It *is* favorable to *form* a superconducting phase when this attractive interaction *dominates* the repulsive screened Coulomb interaction. The normal phase *is described* by the Bloch individual-particle model. The ground state of a superconductor, *formed* from a linear combination of normal state configurations in which electrons *are* virtually *excited* in pairs of opposite spin and momentum, *is* lower in energy than the normal state by amount proportional to an average $(\hbar\omega)^2$, consistent with the isotope effect. A mutually orthogonal set of excited states in one-to-one correspondence with those of the normal phase *is obtained* by *specifying* occupation of certain Bloch states and by *using* the rest to form a linear combination of virtual pair configurations. The theory *yields* a second-order phase transition and a Meissner effect in the form *suggested* by Pippard. Calculated values of specific heats and penetration depths and their temperature variation *are* in good agreement with experiment. There *is* an energy gap for individual-particle excitations which *decreases* from about $3.5kT_c$ at $T=0^\circ\text{K}$ to zero at T_c . Tables of matrix elements of single-particle operators between the excited-state superconducting wave functions, useful for perturbation expansions and calculations of transition probabilities, *are given*.

The most common verb of all, *to be*, appears repeatedly. Most of the other verbs appear frequently in all scientific articles: *present, describe, form, yield, suggest, decrease, give*.

In addition to its high-frequency verbs, the passage is typical in that it is rife with complex noun phrases and noun strings, culminating with a complex noun phrase dense even by the standards of the physics literature:

“tables of matrix elements of single-particle operators between the excited-state superconducting wave functions, useful for perturbation expansions and calculations of transition probabilities.”

Heavy Reliance on Technical Terms

We come now to the most visible characteristic of current scientific English, its employment of a vast array of technical terms. Without question technical terms constitute the crucial element in defining the difficulty most of us experience in reading this prose, a difficulty experienced not only by the general public but by scientists outside the special field with which a particular article deals. Here is a highly technical passage by Chien Liu and colleagues (2001) on the halting of light for the purpose of information storage:

During the storage time, information about the amplitude of the probe field is contained in the population amplitudes defining the atomic dark states. Information about the mode vector of the probe field is contained in the relative phase between different atoms in the macroscopic sample. The use of cold atoms minimizes thermal motion and the associated smearing of the relative phase during the storage time. (We obtain storage times that are up to 50 times larger than the time it takes an atom to travel one laser wavelength. As seen from equation (1), the difference between the wavevectors of the two laser fields determines the wavelength of the periodic phase pattern imprinted on the medium, which is 10^5 times larger than the individual laser wavelengths).

The technical terms in this passage—“probe field,” “population amplitudes,” “mode vector,” “relative phase,” “laser wavelength,” “wavevector,” and “periodic phase pattern”—cannot be clarified merely by resorting to a dictionary. This is also true about many of its “ordinary” expressions, really technical terms in disguise: “storage time,” “information,” “dark state,” “cold atoms,” “smearing.” And we have not yet reached equation 1! The passage yields its meaning only to those with an intimate acquaintance with applied quantum physics. But that is all right. The passage is meant only for those with an intimate acquaintance with quantum physics.

Conclusion and Checklist

The writing in even the best scientific periodicals routinely violates the writing guidelines routinely expounded by respected authorities. Within the typical longish sentences of scientific writing, one typically find verbs in the passive voice, nominalizations, complex noun phrases, weak verbs, noun strings,

and a host of technical terms. We believe that is not because scientist-writers are needlessly obscure or incompetent communicators. Rather, the content drives the writing style.

Still, all these features do get routinely overused and abused in scientific English, making an already complex message more complex than need be. Most scientific prose does benefit from judicious trimming of these elements. Our advice is not to avoid or even minimize them at all costs but to learn how to use them effectively. As you begin to revise, then, we recommend that you weigh the following:

1. For each main verb in the passive voice, ask what verb voice works best—should the grammatical subject name the actor or the material being acted upon? Do not hesitate to use the passive voice (agentless) or name the agent—*I* or *we* or *Smith et al.*—as the situation demands. An important competing consideration involves controlling the flow of information for the purpose of closely linking one sentence with the previous—a topic we save for the next chapter.
2. For each nominalization such as *development*, *observation*, and *evaluation*, ask whether you ought to covert it into a verb. That revision can shorten the sentence and replace a weak verb: compare “A typical *requirement* of image *formation* is . . .” with “Image formation typically requires . . .” or “Forming an image typically requires . . .” But remember that the abstract nature of scientific writing dictates a higher density of such words than everyday writing.
3. For each complex noun phrase in a given paragraph, ask whether they are linked in a way that makes your main point clearly and concisely. If not, look to simplify the information load carried by the noun phrases. Take the earlier example of “*Tables of matrix elements of single-particle operators between the excited-state superconducting wave functions, useful for perturbation expansions and calculations of transition probabilities, are given.*” Might not that make for easier reading as “We provide tables listing matrix elements of single-particle operators between the excited-state superconducting wave functions. These matrix elements are useful for perturbation expansions and calculations of transition probabilities”?
4. For each noun string, ask whether it will cause your readers any hesitation in grasping the various interrelationships. If so, revise by unpacking and making the connections more explicit. For example, “planar graphite fused six-membered ring structure” might be clearer as “the planar graphite structure consisting of a fused six-member ring,” even though it is not as concise.

5. For each technical word or phrase, ask whether your intended audience really will understand its meaning. You may need to define it at first mention or choose a different wording. To theoretical physicists, the following expression is plain as day: “matrix elements of single-particle operators between the excited-state superconducting wave functions.” For chemists with an interest in developing new superconducting materials, it might not be. For the rest of us, it is a foreign language.

EXERCISE

The following technical passage concerns the development of a strain of laboratory mice able to resist cancer cells:

Despite many decades of intense research, the mechanism behind the spontaneous regression of cancer in humans and animals has remained a mystery. Zheng Cui and colleagues have bred a colony of lethal-cancer-cell-resistant BALB/c mice that exhibits spontaneous regression of advanced cancer. Mediation of this capability was found to occur by a massive infiltration of host leukocytes, but the discovery of the gene that results in the concurrence of the anticancer innate immunity has not yet been made. Remarkably, the mice-based anticancer immune system cells were injected into untreated mice, which then showed complete resistance to lethal cancer cells.

What sentences have verbs in the passive voice? What nouns are nominalizations? What words or terms would you consider “technical”? Are there complex noun phrases? Any noun strings? See if you can improve this passage by revising in accord with the above checklist.

15 Improving Scientific English

In an article titled “The Science of Scientific Writing,” George Gopen and Judith Swan (1990) wrote that “complexity of thought need not lead to impenetrability of expression.” We could not agree more. Yet as Gopen and Swan also no doubt recognize, the key question for scientific writing is “Impenetrable to whom?” There is no escaping the fact that current scientific English exhibits a high level of what linguists call “cognitive complexity”—that such English, while adhering to the conventions of English grammar and usage, deviates from what most nonscientists regard as standard formal English. Indeed, it deviates from what many *scientists* regard as standard formal English. Nonetheless, even with the stylistic constraints and complexities that have evolved over time, as discussed in chapter 14, contemporary scientific prose is capable of transparency to its intended audience.

We find seven basic guidelines helpful for achieving that end; accompanying each we provide a question or two to test whether the guideline has been followed. We do not claim that these are the only guidelines or questions with which to improve scientific English. We claim only that they are easily comprehended and, after a little practice, easily applied.

1. Add context. Have you provided sufficient background to enable readers to understand any new technical terms or concepts?
2. Explain the significance of your measurements and observations. For any results presented, have you provided the reader with a firm basis for evaluating their significance?
3. Be precise. Have you avoided vague generalizations such as “The temperature increased”? The critical reader will want to know by how much.
4. Specify the agent of actions if not evident from the context. Is it clear who or what performed the action?
5. Trim back excessive nominalizations and eliminate the superfluous. Can some of your nominalizations be usefully turned back into their verbs? Have you stripped away excess verbiage, including details that do not advance the paper’s overall argument? Is any statement self-evident and

therefore a candidate for excision (“Curing breast cancer would relieve the suffering of millions”)?

6. Weed out the ambiguous or unnecessarily complex. Have you simplified any expressions that the intended reader might find confusing? Have you used ordinary words whenever possible, instead of technical terminology?
7. Use clear transitions. Have you used appropriate words or phrases to indicate shifts in thought? Is the content of each sentence clearly linked to an earlier sentence?

To demonstrate the use of these guidelines, we will apply them to two passages: one from a first draft, another from a published article. Both passages summarize a discovery: one in the field of high-temperature superconductivity, the other in the halting and storage of light. For each passage, we give a little background information, the passage itself, and our analysis of the text. In each passage we have inserted frequent superscripts consisting of numbers and letters. In your first reading, we recommend that you ignore these. Then review the passage again in conjunction with the subsequent analysis, keyed to the superscript numbers and letters. Each number corresponds to one of our seven guidelines, each letter to a specific comment. Superscript “2c” is an example: “2” signifies the second guideline and “c” our third comment on it. After studying our analysis, read our revision and compare it with the original. (We borrowed this method of presentation from a classic writing handbook, *The Reader over Your Shoulder*, by Robert Graves and Alan Hodge.)

Draft Passage on Superconductivity

THE ORIGINAL PASSAGE

The draft text below relies heavily upon abbreviations, measurements, complex technical terms, passive verbs, and hyphenated noun phrases. The first-person pronoun *we* appears two times, but overall the writing is highly impersonal. It is also highly compressed. This passage will probably be incomprehensible to you, unless you are an expert on superconductivity. If you are such an expert, you might consider the passage readable at first glance. The sentences are short. No sentence has multiple clauses. One sentence follows logically from the next, more or less. The complexities arise for the most part because the author has assumed an intimate knowledge of his subject. Still, one might ask, could the message be made clearer? Could the author have made it more easily digested by a fellow expert, maybe even by your average materials scientist or engineer curious about the subject? That is the task before us.

We start with some background information for readers unfamiliar with high-temperature superconductivity. In the mid-1980s, scientists discovered that certain ceramic materials might be able to transport electricity without any resistance at or above 77 degrees kelvin (that is, minus 321 degrees Fahrenheit). This is called “high-temperature” superconductivity because the previous record was much lower, under 25 degrees kelvin. One of the most promising materials used in these superconductivity experiments was the compound $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$, commonly referred to as YBCO. The discovery of this ceramic caused a major stir in the scientific community. It meant that superconducting materials might be able to function with a coolant of liquid nitrogen, a relatively inexpensive refrigerant that forms at 77 kelvin and is commonly used in research labs around the world. The commercial possibilities for the electric power sector seemed very promising indeed.

After the initial elation died down, many serious technical obstacles emerged. One was how to make an electricity-carrying wire out of a ceramic that was so weak and brittle. A possible solution was to coat a metal wire with a very thin film (less than 1 micrometer) of the YBCO. But that presented another problem. This ceramic did not bond strongly to the metal. New coating methods had to be invented. In that effort, researchers found that they achieved good bonding when they inserted a specially textured (“biaxial”) layer of a third material (“buffer”) between the metal wire (“substrate”) and the YBCO film. We now present the original draft with superscripts keyed to the analysis that follows:

Inclined substrate deposition (ISD) offers the potential for rapid production of high-quality biaxially textured template layers suitable for YBCO-coated conductors.^{1a} We have grown biaxially textured magnesium oxide (MgO) films^{5a} on Hastelloy substrates by ISD^{7a} at deposition rates of 20–100 Å/sec.^{2a} Microscopy of the ISD-MgO films showed columnar grain structures with a roof-tile-shaped surface.^{2b} A small phi-scan full-width at half maximum (FWHM)^{5b} of approximately 10° ^{6a} was observed on MgO films.^{2b} YBCO films were grown^{7b} on ISD-MgO buffered substrates by pulsed layer deposition. We obtained a critical current density of $>5 \times 10^5$ A/cm² at 77 K on a 0.5-μm-thick YBCO film.^{2c} Recently, a one-meter-long ISD-MgO metallic substrate^{6b} was fabricated.^{2d}

PASSAGE ANALYSIS

1. INSUFFICIENT CONTEXT

- a. Inclined substrate deposition (ISD) offers the potential for rapid production of high-quality biaxially textured template layers suitable for YBCO-coated conductors.

Is it safe to assume that readers of a specialized journal on materials science have sufficient previous knowledge to comprehend this first sentence? What is “inclined substrate deposition”? Why is “biaxial texturing” important? What is YBCO? Why should we even care about the subject? In our judgment, all readers, whatever their experience, would welcome at least a few introductory sentences to set the stage for appreciating the authors’ achievement:

Revision

The superconducting material $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ (YBCO) shows promise for use in electric power wires operating at temperatures that exceed that of liquid nitrogen (77 K). For that promise to be realized, a method is being sought to deposit biaxially textured template layers of MgO on a metal substrate suitable for later YBCO deposition. Previous researchers [1–4] have found that biaxial texturing of the MgO film strengthens the bonding of the superconducting layer.

With the new introductory sentences in place, we can now go to a slightly revised version of the original first sentence:

Revision

Smith et al. [5] report that inclined substrate deposition (ISD) offers the best route to rapid production of high-quality template layers.

Any reader uncertain about the particulars behind “inclined substrate deposition” can consult the reference indicated by the bracketed 5.

2. SIGNIFICANCE UNCLEAR

a. . . . deposition rates of 20–100 Å/sec . . .

How are we to assess the achievement that “20–100 Å/sec” signifies? The numbers by themselves mean nothing unless we add the explanatory phrase “acceptably rapid” before “deposition rates.” The word *rapid* echoes the use of that word in the first sentence of the original.

b. Microscopy of the ISD-MgO films showed columnar grain structures with a roof-tile-shaped surface. A small phi-scan full-width at half maximum (FWHM) of approximately 10° was observed on MgO films.

Of these sentences we would ask: do these physical characteristics (grain structure and FWHM) indicate that the MgO films will serve their intended purpose? We also wonder about the significance of the expression “small phi-scan full-width at half maximum of approximately 10° .” Is that clear?

Revision

Our analysis of these films revealed near ideal surface features for YBCO deposition: microscopy showed columnar grain structures with a roof-tile-shaped surface, and a small phi-scan yielded a full-width at half maximum of approximately 10° , confirming good biaxial texture.

- c. . . . a critical current density of $>5 \times 10^5$ A/cm² at 77 K on a 0.5- μ m-thick YBCO film.

We might assume that passing more than 500,000 amperes of current through a square centimeter is obviously impressive. But we can easily add explanatory text to make that point more clearly:

Revision

Measurements on a thin (0.5- μ m) YBCO film met our goal of $>5 \times 10^5$ A/cm² for the critical current density at 77 K.

- d. . . . a one-meter-long ISD-MgO metallic substrate was fabricated.

What is the significance of fabricating a piece “one meter long”? Does a meter length have some commercial use? Again, adding an explanatory phrase, in accord with our second guideline, helps to clarify:

Revision

As evidence of the commercial potential for ISD, we recently fabricated a wire sample of ISD-MgO metallic substrate that is one meter long.

5. SUPERFLUOUSNESS

- a. . . . magnesium oxide (MgO) films . . .

We would remove the words “magnesium oxide” on the grounds that the abbreviation MgO is perfectly understandable by our technically literate audience.

- b. . . . full-width at half maximum (FWHM) . . .

We would drop the abbreviation FWHM from the original as superfluous information since it does not appear again in the passage. Of course, if FWHM were to appear in a subsequent paragraph, it should remain as is. Abbreviations like this are definitely useful in scientific writing. However, when used to excess or indiscriminately, they can impede understanding by demanding too much of the readers’ memory.

6. AMBIGUITY

- a. . . . a small phi-scan full-width at half maximum (FWHM) of approximately 10° . . .

This expression took us awhile to unravel. Is it a small phi-scan or small full-width at half maximum? We would revise the phrase to “a small phi-scan yielded a full-width at half maximum of approximately 10° .” We do assume that a knowledgeable reader knows the meaning of “phi-scan” and “full-width at half maximum.”

b. . . . a one-meter-long ISD-MgO metallic substrate . . .

We can express this long noun string more clearly as “a wire sample of ISD-MgO metallic substrate that is one meter long.” In this case, we would opt for clarity over conciseness.

7. POOR TRANSITIONS

a. We have grown biaxially textured MgO films on Hastelloy substrates by ISD . . .

We do not learn the connection to inclined substrate deposition, the subject of the first sentence, until near the end of the second sentence. We can fix that problem with an introductory phrase tying the two sentences together: “Using this technique, we have grown . . .”

b. YBCO films were grown . . .

This sentence introduces a new topic without any word or phrase warning us. What about “Next, we grew YBCO films on . . .”?

REVISION OF ORIGINAL

(1) The superconducting material $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ (YBCO) shows promise for use in electric power wires operating at temperatures that exceed that of liquid nitrogen (77 K). (2) For that promise to be realized, a method is being sought to deposit biaxially textured template layers of MgO on a metal substrate suitable for later YBCO deposition. (3) Previous researchers [1–4] have found that biaxial texturing of the MgO film strengthens the bonding of the superconducting layer. (4) Smith et al. [5] report that inclined substrate deposition (ISD) offers the best route to rapid production of high-quality template layers. (5) Using this technique, we have grown biaxially textured MgO films on Hastelloy substrates at acceptably rapid deposition rates, 20–100 Å/sec. (6) Our analysis of these films revealed near ideal surface features for YBCO deposition: microscopy showed columnar grain structures with a roof-tile-shaped surface, and a small phi-scan yielded a full-width at half maximum of approximately 10° , confirming good biaxial texture. (7) Next, we grew YBCO films on ISD-MgO buffered substrates by pulsed layer deposition. (8) Measurements on a thin (0.5- μm) YBCO film met our target of $>5 \times 10^5 \text{ A/cm}^2$ for the critical current density at 77 K.

(9) As evidence of the commercial potential for ISD, we recently fabricated a wire sample of ISD-MgO metallic substrate that is one meter long.

Our revision reveals the logical structure of the original: logic and grammar are now in synch. In our revision, sentence 2 specifies what was needed to realize the “promise” defined in sentence 1. Sentence 3 clarifies sentence 2. Sentence 4 presents a specific method for realizing the promise mentioned in sentences 1 and 2. Sentences 5 and 6 explain what the authors accomplished by applying the fabrication method in sentence 2. Sentence 7 describes the logical next step after the success summarized in sentences 5 and 6. Sentence 8 reports a key performance measurement of the material mentioned in sentence 6. Sentence 9 mentions yet another milestone on the road to developing a commercial product. A coherent story emerges as the paragraph unfolds. It gives us a progress report on the development of a superconducting material.

Our revision is considerably longer than the original because we added context-setting information and amplified some expressions for the sake of readability. In the process of revision, we also made a few guesses about what scientist-authors and readers would be thinking. But we believe our revision achieves our goal of making the original more easily digested by those who might be interested in a progress report on the subject matter. The draft is now ready for publication. We hope you agree.

Published Passage on the Halting and Storage of Light Pulses

THE ORIGINAL PASSAGE

Now we will apply our guidelines to the first paragraph in an article that appeared in *Nature* concerning the stopping of light (Liu et al. 2001). The text itself has much to admire: not only the science but the composition as well. The passage follows the standard template of scientific introductions, the subject of chapter 1:

Electromagnetically induced transparency [1–3] is a quantum interference effect that permits the propagation of light^{5a} through an otherwise opaque atomic medium; a “coupling” laser is used to create the interference necessary to allow the transmission of resonant pulses^{5b} from a “probe” laser.^{1a} This technique has been used [4–6] to slow and spatially compress light pulses by seven orders of magnitude, resulting in their complete localization and containment^{5c} within an atomic cloud. Here we use electromagnetically induced transparency^{7a} to bring laser pulses to a complete stop in a magnetically trapped, cold cloud³ of sodium atoms^{1b} [4]. Within

the spatially localized pulse region, the atoms are in a superposition state determined by the amplitudes and phases of the coupling and probe laser fields. Upon sudden turn-off of the coupling laser, the compressed probe pulse is effectively stopped;^{5d/6a} coherent information initially contained in the laser fields is “frozen” in the atomic medium for up to 1 ms. The coupling laser is turned back on at a later time^{6b} and the probe pulse is regenerated;^{5e} the stored coherence is read out and transferred back into the radiation field. We present a theoretical model that^{7b} reveals that the system is self-adjusting^{6c} to minimize dissipative loss during the “read” and “write” operations. We anticipate applications^{7c} of this phenomenon for quantum information processing.^{6d}

Before beginning our analysis, which will inevitably point to violations of our guidelines, we would like emphasize that this passage is well-organized throughout and is, in general, well-written. Take the second sentence as an instance of exemplary scientific prose:

This technique has been used [4-6] to slow and spatially compress light pulses *by seven orders of magnitude*, resulting in their complete localization and containment within an atomic cloud. (our emphasis)

The phrase “to slow and spatially compress light pulses by seven orders of magnitude” is a good example of adherence to guideline 3: be precise. If the authors had written only “to slow and spatially compress light pulses,” we might have legitimately wondered by how much. Consider also the phrase “This technique has been used [4-6] to slow.” We might be tempted to criticize its use of the passive voice, to ask, “Who used it, the present writers or others?” But the bracketed numbers point to references with those names: because context has provided clarification, guideline 4 has not been violated. Moreover, “this technique,” placed in the subject position, forms a better link to the previous sentence than would the names of the scientists who used it (guideline 7). We would consider it ill advised to change from the passive to active voice.

When reading our passage analysis, we ask that you bear in mind three points. First, very little published prose is beyond criticism. There always seems to be a clearer, more succinct wording. Second, there are limits to the amount of time that even the most conscientious scientists can devote to fiddling with their English in an illusory quest for perfection. Third, we are not specialists in the field of quantum physics or laser technology, and our revisions may unintentionally distort the authors’ intended meaning. Nevertheless, we are confident we have identified some communicative areas where there is room for improvement in the interest of clarity.

PASSAGE ANALYSIS

INSUFFICIENT CONTEXT

- a. Electromagnetically induced transparency [1–3] is a quantum interference effect that permits the propagation of light through an otherwise opaque atomic medium; a “coupling” laser is used to create the interference necessary to allow the transmission of resonant pulses from a “probe” laser.

This first sentence defines the technical term “electromagnetically induced transparency.” But readers do not yet have any means of telling why this term is being defined. Addition of some context-setting text might help ease us into this highly technical first sentence:

Revision

Light pulses are the fastest and most robust carriers of information, but they are difficult to localize and store. The present letter reports the demonstration of a technique that traps, stores, and releases excitations carried by light pulses. This light storage technique is based on a recently demonstrated phenomenon of ultraslow light velocity, which is made possible by electromagnetically induced transparency [1–3].

It can be argued, of course, that for an audience of applied quantum physicists—the intended audience—the original first sentence is an appropriate beginning; more is not necessary. We would merely point out that our new beginning is adapted from the introduction to an article in *Physical Review Letters* concerning a light-stopping technique employed by another group of Harvard researchers (Phillips et al. 2001).

- b. a magnetically trapped, cold cloud of sodium atoms . . .

What is a “cold cloud of sodium atoms”? Why “sodium atoms”? We derived an expansion of this phrase from an article in *Scientific American* by Lene Vestegaard Hau (2001), the lead researcher of the team that produced the article.

Revision

. . . a magnetically trapped cloud of sodium atoms cooled to 500 billionths of a degree above absolute zero [4], a temperature at which a Bose-Einstein condensate forms, one in which all of the atoms behave synchronously.

3. IMPRECISION

- . . . cold cloud . . .

How cold is “cold”? See comment 1b for the answer.

5. SUPERFLUOUSNESS AND EXCESSIVE NOMINALIZATION

- a. that permits the propagation of light . . .

Here we have a nominalization (“propagation”) that we can convert to a verb for conciseness: “that permits light to propagate . . .” See chapter 14.

- b. to allow the transmission of resonant pulses . . .

Another nominalization from the same sentence can go: “to transmit resonant pulses . . .”

- c. their complete localization and containment . . .

We can delete “and containment” as superfluous because “complete localization” implies “containment,” though perhaps there is a subtle point we are missing.

- d. Upon sudden turn-off of the coupling laser, the compressed probe pulse is effectively stopped . . .

Wouldn’t it be simpler to say: “Turning off the laser halts the compressed light”? Does that alter the intended meaning?

- e. The coupling laser is turned back on at a later time and the probe pulse is regenerated . . .

To maintain parallelism in sentence structure to our suggested revision in comment 5d above, we would change to “Turning the coupling laser back on . . .”

6. AMBIGUITY AND VAGUENESS

- a. probe pulse is effectively stopped . . .

We would eliminate the word *effectively* because it means both “in an effective manner” and “for all practical purposes,” that is, *not* completely.

- b. on at a later time . . .

We would question what a “later time” means. Does it mean during or after the 1 millisecond of capture mentioned in the previous sentence? We decided on the former, though our choice could easily be mistaken.

- c. the system is self-adjusting . . .

What “system”? We would recommend the more specific “experimental system.”

- d. . . . this phenomenon for quantum information processing.

What “phenomenon”? Is it the “self-adjusting” of the previous sentence or all the phenomena of the stopping and storing of light just described? We suspect the latter.

7. POOR TRANSITIONS

- a. Here we use electromagnetically induced transparency . . .

A smoother transition would be “With this technique, we have brought . . .”

- b. We present a theoretical model that reveals that . . .

The subject has changed from the authors’ experimental work to a theoretical model, but what’s important here, we suspect, is not the theoretical model per se but the finding that the system self-adjusts. A better transition might be “According to our theoretical model, the experimental system self-adjusts . . .”

- c. We anticipate applications . . .

The subject has again changed, this time to applications of the research. We could better signal that change by beginning this sentence “Our research findings . . .”

REVISION OF ORIGINAL

(1) Light pulses are the fastest and most robust carriers of information, but they are difficult to localize and store. (2) The present letter reports the demonstration of a technique that traps, stores, and releases excitations carried by light pulses. (3) This light storage technique is based on a recently demonstrated phenomenon of ultraslow light velocity, which is made possible by electromagnetically induced transparency [1–3]. (4) Electromagnetically induced transparency is a quantum interference effect that permits light to propagate through an otherwise opaque atomic medium: a “coupling” laser is used to create the interference necessary to transmit resonant pulses from a “probe” laser. (5) This technique has been used [4–6] to slow and spatially compress light pulses by seven orders of magnitude, resulting in their complete localization within an atomic cloud. (6) By using this technique, we have brought laser pulses to a complete stop in a magnetically trapped cloud of sodium atoms cooled to 500 billionths of a degree above absolute zero [4], a temperature at which a Bose-Einstein condensate forms, a medium in which all of the atoms behave synchronously. (7) Within the spatially localized pulse region, the atoms are in a superposition state determined by the amplitudes and phases of the coupling and probe laser fields. (8) Turning off the coupling laser halts the compressed probe pulse; coherent information initially contained in

the laser fields is “frozen” in the atomic medium for up to 1 ms. (9) Turning the coupling laser back on within this time regenerates the probe pulse; the stored coherence is read out and transferred back into the radiation field. (10) According to our theoretical model, the experimental system self-adjusts to minimize dissipative loss during the “read” and “write” operations. (11) Our research findings have important potential applications in quantum information processing.

Our revision reveals the logical structure of the original. Sentence 1 establishes a physics problem. Sentence 2 states in brief the authors’ solution to the problem in sentence 1. Sentence 3 defines the “light storage technique” behind the solution. Sentence 4 defines the technical term introduced at the end of sentence 3. Sentence 5 presents what earlier researchers achieved with the technique in sentence 4. Sentence 6 presents what the authors did that topped the earlier research in sentence 5. Sentences 7–10 elaborate on sentence 6 by explaining what the authors achieved in the lab and by theoretical analysis. Sentence 11 alludes to the benefit to society of the achievement defined in sentences 6–10.

As with our superconductivity example, our revision is longer than the original. In both cases, their authors could argue, plausibly, that we should have left well enough alone. Further, we were not constrained, as the authors of the halting-of-light article were, by the parsimonious word count dictated by *Nature* for article length or by the time pressure to establish priority speedily for an important discovery. Our purpose here is not to second-guess but to provide an example of how applying our guidelines to a passage can reduce the mental processing required by the reader and widen the article’s audience.

Conclusion

The goal of scientific English is to achieve clarity. To do so is not to fight against the agreed-upon constraints of current scientific English: its heavy reliance on technical terms and its systematic employment of the passive voice, nominalization, complex noun phrases, noun strings, and weak verbs. Rather, the task is to achieve clarity within these constraints. In this chapter we offer guidelines for achieving clarity when so constrained. We do so to demonstrate that this achievement is within everyone’s reach. We are not asserting that ours is more than a beginning; we believe that even greater clarity is within everyone’s reach, though not without considerable effort. But for that another book of instruction is necessary. Fortunately, in our need we can turn to that masterpiece of pedagogy, Joseph Williams’s *Style*.

EXERCISE

Here is a concocted superconductivity paragraph with each sentence numbered for easy reference and discussion.

(1) In the mid-1980s, novel ceramic materials that transport electricity without loss (“superconducting”) at a much higher temperature than ever achieved before were discovered. (2) Liquid nitrogen forms at 77 kelvin. (3) $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$, commonly referred to as YBCO, is a superconducting material. (4) Since then, scientists have created YBCO compositions with even higher superconducting temperatures. (5) They suggest that superconducting materials could function with a coolant of liquid nitrogen, a relatively inexpensive refrigerant. (6) A major stir in the scientific community arose because of these discoveries.

Are you able to easily follow the flow of information? Are the transitions from one idea to the next clear? They should not be, because we purposely wrote the paragraph to confuse. Go through it and check the logical connections between each sentence and its preceding sentence.

Answer

Here is our analysis of the missed connections:

- Sentence 2. What does liquid nitrogen have to do with the superconducting materials in sentence 1?
- Sentence 3. What is connection between YBCO and 77 kelvin in sentence 2?
- Sentence 4. How is “then” connected to YBCO in sentence 3, if at all? Temperatures “higher” than what?
- Sentence 5. Does “they” refer to scientists in sentence 4? If so, it makes no sense.
- Sentence 6. What “discoveries”? Only one “discovery” stated in sentence 5?

CHECKLIST

Now, with our checklist below in mind, see if you can revise the sentences to improve the continuity of thought.

- Add context to provide sufficient background so that your readers will understand any new technical terms or concepts.
- Explain the significance of data reported.
- Quantify how much or how many for comparative expressions (*hot, cold, high, low, increase, decrease*, etc).
- Specify the agent of actions if not evident from the context.

- Trim back excessive nominalizations and eliminate the superfluous.
- Revise to root out the ambiguous or unnecessarily complex.
- Check for logical connections within and between sentences.

A Final Thought

In closing, we wish to return briefly to the question with which this book began: Why bother? We offer one more reason: there is a tradition to uphold. Henry Oldenburg, first editor of the first scientific periodical in English, commented on the importance of communication to science as long ago as 1665: “[T]here is nothing more necessary for promoting the improvement of Philosophical [Scientific] Matters, than the communicating to such, as apply their Studies and Endeavours that way.” Within the enormous body of literature created by Oldenburg and countless others, you can find the name of every researcher of importance: Isaac Newton, Robert Boyle, Antoine Lavoisier, Charles Darwin, Louis Pasteur, Marie Curie, Albert Einstein, Werner Heisenberg, Linus Pauling, Rosalind Franklin, Richard Feynman, and Francis Crick, to name an illustrious dozen. You may never scale the same heights scientifically. Few ever do. But you can seek to approach them in terms of clarity and forcefulness of argument. Our hope is that this book helps you do that.

ACKNOWLEDGMENTS

We both have benefited greatly from the books on writing by the late Joseph M. Williams (notably *Style* and *The Craft of Research*). We have also had the pleasure of his company on several occasions. Moreover, Alan Gross participated in an NEH Summer Seminar with Prof. Williams, for him a career-altering experience. What struck us the most about Williams's personality was his insatiable curiosity and uncanny capacity to see below the surface of things. His genius, we believe, lay in his ability to question conventional wisdom on communicative practices. We hope a little of that critical intelligence rubbed off on us.

Both authors wish to thank the several dozen scientists who graciously shared their PowerPoint presentations and research proposals with us. We learned something from all of them, although we could not use them all. Especially helpful in their response to our queries were Allan I. Basbaum, University of California, San Francisco; Adrian Bejan, Duke University; Terrence J. Collins, Carnegie-Mellon University; Daniel Dzurisin, U.S. Geological Survey; Fred Gould, North Carolina State University; Kip Hodges, Arizona State University; Roald Hoffmann, Cornell University; Terry L. Hunt, University of Hawai'i-Manoa; Richard M. Iverson, U.S. Geological Survey; David Jewitt, Institute for Astronomy, University of Hawaii; Abraham Loeb, Harvard University; Shane Ross, Virginia Tech; Thomas D. Seeley, Cornell University; Solomon H. Snyder, Johns Hopkins University; and Michael Wolfe, Harvard University.

One prominent scientist who did not send us a proposal did offer an intriguing comment via e-mail: "I think . . . you will have a hard time finding anyone who can successfully write a proposal that is likely to be funded. It has become a random process." We can understand his deep skepticism: nowadays highly worthwhile proposals get routinely rejected. Nonetheless, we are still naive enough to believe that success is more likely for those able to construct a credible and clearly written argument, one capable of persuading others that the funding of their research will benefit science and society.

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