Reviews of Modern Physics Style Guide

APPENDIX A: WRITING A BETTER SCIENTIFIC ARTICLE

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Using examples drawn from the pages of *RMP*, the author presents specific writing techniques that can enhance the sense of immediacy between writer and reader and improve the clarity, economy, and polish of scientific writing. The first half of the article is devoted to elements of good style applicable by anyone, while the second half treats problems often encountered by non-native writers of English.

What sets a first-rate scientific article apart from the thousands of forgettable publications that appear in the literature every year? For a very few, content alone ensures that the paper will be widely cited. But for most, it is the way the article is written. A good article puts us in touch with a good mind (or team of good minds) at work, whose quality is revealed by clarity, economy, order, and perhaps wit. These rather abstract qualities are warmed by the author's effort to share his or her interest in the subject as if speaking with a colleague, presenting the work not as a series of cut and dried results, but as an ongoing process by which understanding is sought. The reader whose interest is thus engaged can then share the author's satisfaction as a solution begins to emerge.

A number of specific writing techniques can enhance the sense of immediacy between you and your reader. In addition, avoidance of some common pitfalls will reduce dullness, wordiness, and pomposity, which – contrary to popular belief – are not desirable attributes in a scientific article, but represent negative values of the clarity, economy, and wit mentioned above. In this guide, I describe practical measures that you, the author, can take to give your writing greater impact, with examples drawn from the work of *RMP*'s contributors. The guide is divided into two sections, one of more general application, for anyone interested in writing better, and the other aimed specifically at the author whose first language is not English.

A. Elements of good style for everyone

1. Active and passive voices

You have heard this before, but it bears repeating: active sentences are more vigorous than passive ones. When you want to put more muscle into your prose style, replace "Science is done by people" with "People do science."

Writers of scientific papers often favor the passive because it relieves them of naming themselves as the ones who conducted an experiment or proposed a theory. Saying that "it was thought that the magnetoresistance could provide an answer" shields the person who thought so from the critical gaze of his audience and is vague enough to spread credit or blame, implying that the writer was not alone in having this idea. The passive voice also provides a way out for those who feel reticent about naming names and pointing fingers when discussing others' work. Keeping names to a minimum, such a writer introduces, say, the work of Erikson *et al.*, and then follows with a three-page description in which "the bubble formation was simulated," "a constant of $a = 1.5$ was assumed," and "agreement with the model of McCray was found to within 3%." There are three problems with this approach. First, it sounds stuffy. Second, it may lead to confusion, especially if other people's models and parameters were adopted by Erikson *et al.* and need to be discussed as well. After a while the reader will no longer be sure whose work is being described. And third, any effort to dissociate science from its practitioners by describing it passively is doomed to failure, since readers not only know that scientists do science, they are very interested in which scientists – it could well be one of their friends or competitors. Changing to the active voice and stating who did what – "we simulated the bubble formation," "McCray assumed a constant of $a = 1.5$," "they found" – will tell readers what they want to know and set the work in the context of human endeavor.

The active voice also encourages economy. Compare the following pairs of sentences:

A review of the main problems in this field was given by Luo *et al.*

Luo *et al.* reviewed the main problems in this field.

A discussion of intrinsic pinning is offered in Sec. VIII.

In Sec. VIII we discuss intrinsic pinning.

In each pair above, the active version uses fewer words. Most readers will perceive this brevity as the mark of a direct and vigorous mind.

There are, of course, occasions when the passive voice is useful. Sometimes you will want to put emphasis on the thing being acted upon, by naming it at the beginning of a sentence.

This problem has been the subject of intensive study ever since 1934.

And, for simple variety, a modest number of passive constructions can lend grace to a piece of writing, especially when no particular agent is being obscured by them:

All perturbations can be naturally divided into two classes.

Abstracts are another place where the passive voice is appropriate. Abstracts appear separately from the articles they describe, in on-line listings and reference works like Physics Abstracts. Use of the first person in such an impersonal setting sounds a bit odd. (However, consider the active alternative, "This article surveys...," "The authors find that...")

2. Economy

A clean, direct style shows respect for your reader's time. While it is possible to be so direct as to be blunt and graceless, most scientific writing suffers from the opposite tendancy, wordiness. One exercise that helps to curb wordiness in your writing is to see how many verb-noun phrases you can replace by simple verbs. For example,

make a decision	decide
experience failure	fail
place under consideration	consider
perform an experiment	experiment
give indications of	indicate
present a discussion of	discuss
conduct an investigation	investigate
make an attempt	try
introduce a replacement	replace

The expressions in the left-hand column need not be banished from your writing. They can be useful for creating parallels, introducing variety, or smoothing a transition. If you find, however, that you are using a great many, be aware that you may be regarded as windy and your papers as needlessly long.

A few other wordy expressions deserve mention here. One is "the fact that." It can always be replaced by a more economical construction:

the fact that Clark succeeded	Clark's success
owing to the fact that	because
despite the fact that	although
he was unaware of the fact that	he was unaware

Another is "the reason... is that" and variants of this pattern. Generally, rearranging a sentence so as to start with a subject and verb produces a more vital sounding statement:

The reason for solving the Cauchy problem first is that...

We solve the Cauchy problem first because...

The main theme of this section is to tell why we have chosen to generalize...

This section presents our rationale for generalizing...

My purpose has been to provide a description of thermodynamic phase transitions.

I have tried to describe thermodynamic phase transitions.

Then there is "the case." Personally, I am rather fond of "In the first case" and "in the second case," but have to grant that "cases" can be totally useless appendages, better amputated:

for the case of	for
in many cases	often
it has rarely been the case that we	we rarely
in the case when	when

If the writer is tempted to use "in the case where," he or she should see the section on grammar below.

3. Forward momentum

Here is an actual sentence from a contributor to *Reviews of Modern Physics*:

> That the wavelength of any oscillator employed must necessarily be very small follows from the circumstance that the length of an accelerator of given energy – i.e., the lengths of the individual drift tubes in an accelerator with a given number of drift tubes (and hence acceleration gaps) – to which a given voltage is applied, and through which a given species of ion is accelerated – is proportional to the period, hence the wavelength, of the oscillation.

Before publication, this sentence was edited to about two-thirds of its present length. Its problem, however, is not length per se. It suffers from the author's attempt to cover everything. The cumulative effect of multiple asides, parenthetical remarks, i.e.'s, and "hences" is to leave the reader feeling like a passenger in a car whose driver starts up, then stops, then starts again, then stops, etc. Moreover, by the time the reader gets to the verb "is proportional," he or she is likely to have forgotten the subject, the length of an accelerator.

Asides and parenthetical remarks can enhance a text. They reflect the way people talk and thus give a conversational tone to any piece of writing. When overused as above, however, they will kill the momentum of the

article. To keep the reader moving forward, one should use them judiciously and not place more than one between a subject and its verb, where they become merely distractions.

Here are some examples of sentences that use parenthetical remarks to good effect. The asides serve a variety of functions: (a) helping to organize the material; (b) offering a tidy place in which to stow ramifications of the main statement; (c) drawing the reader's attention forward to a subject that will be discussed further on; (d) enhancing author-reader immediacy by offering opinions – "crude," "pathological," etc. – and simply giving a more personal style to the presentation. Note that only two of the asides below are interposed between a subject and its verb, thus ensuring minimum loss of momentum.

> Finally, we note that the derivation, crude as it is, reveals one very important point: the precise details of the collision rules (aside from certain pathological choices to be discussed later) do not affect the form of the constitutive hydrodynamic equations.
>
> It is easy to solve this equation (since we have dropped the inconvenient, higher-order terms).
>
> Hydrodynamic flows can be obtained (albeit at considerable computational expense) from large molecular systems.
>
> The exciting lattice-gas simulations of hydrodynamics have exploited one of the strengths of the method: fluctuations (to excite bifurcations), complex geometries (to exploit the ease of coding boundary conditions), or phase transitions.
>
> Either an inhibitory substance h is produced by the activator (which slows down the activator production) or a substate s is consumed during autocatalysis (whose depletion slows down the self-enhancing reaction).

Some of these are long sentences, but they are perfectly clear and easy to follow.

Generally, short sentences quicken the pace and long ones slow it down. The same can be said of paragraph lengths. A paragraph break allows the reader to take a breath and refocus. Provide enough of them to keep the members of your audience fresh, as this too will help keep them moving through the article.

4. Inviting the reader in

Bringing the rhythms of everyday speech into an article by the use of a few asides is one way to invite the reader into your world – or, at least, into the world of the topic you are writing about. Addressing the reader directly is another. That mind-to-mind contact that characterizes the best scientific articles comes about only when the writer is friendly towards the reader. This does not mean that you need to pretend a familiarity that you do not feel. It does mean that you should take pains to speak to your reader as if he or she were in the same room with you – and not the recipient of an anonymous prerecorded message. To see how well you are accomplishing this, scan your manuscript first for questions and then for other remarks addressed to the reader.

If you have not up until now included questions in your writing, consider what they offer. A rhetorical question can be a wonderful device. It states the problem without your needing to say "In this section I shall be considering the problem of..." It creates the illusion that you are thinking the problem through at the very moment you are speaking. And it engages the reader's participation in finding an answer. If you are very daring, you can even put the question in your reader's mouth by saying, "The reader may well ask..." This allows you to disarm potential critics and capture attention for your answer.

One should not underestimate, either, the power of a gracious remark to one's reader. The following well-worn phrases may seem so obvious as to be unnecessary, but they perform vital work in welcoming the reader to your intellectual world, where you will engage him or her in friendly discourse or serve as a guide over unfamiliar terrain.

> Let us suppose
> Consider
> Contrast this with
> Before we turn to
> Up to this point we have not
> Let us take a closer look at
> Let us now attempt
> Indeed, we shall see
> Clearly, what is happening here is that
> Seeing this, we should not be surprised to find
> Remember that
> It is sometimes helpful to think of t as
> Going beyond this approximation brings us up against
> We now return to
> The reader is warned
> A cautionary remark

Many of these phrases make particularly graceful openings for paragraphs and for subsections. Your subject matter will suggest other ways of combining cordiality with critical exposition.

5. Hedging

There seem to be many writers who take it as an operating principle never to commit themselves firmly to any point of view. They will hedge even simple statements of historical fact, and their "conclusions" sections are full of

"may"s and "might"s and "it would seem"s. In a review paper, this will not do. Part of the job of the reviewer is to describe the field as he or she sees it. We want the reviewer to be fair, but not irresolute.

A classic sign of commitment avoidance is misuse of the auxiliary verbs "may" and "could":

> Schrödinger may be counted as one of the first to propose the concept of what are now called "coherent states."
>
> This term could be regarded as combining nonlinear and spatial dispersion.

Actually, it would be perfectly accurate to say

> Schrödinger first proposed the concept of what are now called "coherent states."
>
> This term combines nonlinear and spatial dispersion.

When you are confident of your facts, speak with authority. Save "could," "would," "may," "might," and other expressions of uncertainty for situations that truly warrant them.

Another frequently used hedging expression is "associated with," as in

> Under suitable circumstances, pairs of fermions are associated with bosonlike behavior.
>
> The differences between Chakravarty's and Schwinger's calculations are associated with differences in the value of the constant prefactor C.

Under scrutiny, statements like these appear not only imprecise, but weaselly. How much better to say, with precision and conviction,

> Under suitable conditions, pairs of fermions exhibit bosonlike behavior.
>
> The differences between Chakravarty's and Schwinger's calculations are due to different values of the constant prefactor C.

6. Dropping names: abbreviations and acronyms

There is no rule at *Reviews of Modern Physics* that says you must replace all frequently used terms with groups of letters. On the contrary, our copy editors have been instructed to disallow excessive abbreviations, so that no article looks like alphabet soup. Readers who do not share your familiarity with the subject, but would like to learn, should not be forced to translate the jargon of your subfield, which to them will seem li ke a private code. Limit yourself to a handful of the most widely used abbreviations and define these where they are introduced.

Even justifiable and widely known abbreviations should not be used as the subject of a sentence. Thus, while you might refer to "the BCS approach," change "BCS found that…" to "Bardeen, Cooper, and Schrieffer found that…"

7. Time travel: the mixed-tenses syndrome

Consider the following discussion.

> Andrews noted that the absence of Bragg peak splitting at $x = 0.016$ is due to the small magnitude of the spontaneous deformation, which at $x = 0.016$ should be 25 times smaller than at $x = 0.05$. At the same time, experiments on diffuse scattering of x-rays (Varma *et al.,* 1991) indicate that homogeneous deformation regions with an average size of at least 1000 Å exist in the crystal even at $x = 0.016$. This conclusion was supported by subsequent experiments.

If you find yourself a bit at sea after reading this passage, you are probably experiencing disorientation from time shifts. Either the past or the present tense may correctly be used in such a discussion, but not both. Stick to one tense per topic. For example, when discussing a paper by Smith, you can say "Smith finds a heavy concentration of H, which indicates…" or "Smith found a heavy concentration of H, which indicated," but you should stay with the same tense until the end of the paragraph.

8. Contrast and variety

The English language is a rich medium, offering the writer a choice of short Anglo-Saxon words and longer latinate words, as well as borrowings from French, German, and other sources. Not surprisingly, to an American ear, a judicious mix sounds most pleasing. This is how people talk and it is also easiest to read.

One of the dangers of writing about physical principles and other abstractions is that one finds latinate words so useful one favors them over all others. Consider this pair of examples:

> An initial outline of the most feasible candidate states and of their experimental identification will be followed by discussion of…
>
> I first outline the most feasible candidate states and how one might go about distinguishing them experimentally. Next I discuss…

The second example does use latinate words, but they are mixed with shorter, Anglo-Saxon ones. Its effect is

direct and accessible, qualities strengthened by the active voice. In contrast, the heavily latinate (and passive) first sentence seems dense and pedantic. If you suspect that others might find your writing a bit dry, check it for its Latin density. Do you say

first	or initial?
place	or location?
is	or consists of?
find	or detect, determine, establish?
use	or utilize?
takes place	or occurs?
takes the form	or is represented by?
looks like	or appears similar to?
is needed	or is required, is necessary?

The point is not that shorter words are better, only that a balance of long and short will be more pleasing.

In the same way, a variety of sentence lengths is also pleasing. An article made up entirely of short, choppy sentences is no more to be preferred than one of long, rambling ones. When you find that you have been favoring either short or long for awhile, slip in a bit of contrast. Here is an example of a sentence that I believe combines long and short in a refreshing fashion (note the rhetorical question):

> Since it is almost certain (and will henceforth be assumed) that corrections to the theory are of the order of 25% even for Z as large as 64, the pragmatic reader might well ask: "What can the theory do for me?"

9. Grammar

This guide is not intended to be a treatise on English grammar, but here is a very brief list of errors to be avoided in polished scientific writing.

(1) "We will" and "we shall." The correct form is "shall" for the first person and "will" for the second and third. Reversing them is supposed to provide unusual emphasis – e.g., "We cannot review the vast literature here, but we will give a brief overview of recent work in the field." The exchange of "we will" for "we shall" is widely accepted in spoken English, but this is one instance in which you should not write as you speak.

(2) Contractions (can't, don't, they'll, etc.). These should not be used in scientific articles or in any other professional writing.

(3) Dangling participles. When an "-ing" word is used in a phrase like "leaping to the obvious conclusion" or "inserting the higher number," the phrase should be immediately followed by the agent who is doing the leaping or the inserting. The following examples fail to provide an agent and are thus incorrect:

> Leaping to the obvious conclusion, the equation...
>
> Inserting the higher number, the answer can be found.
>
> Comparing the energy density and the lifetime, only a chemical storage mode makes sense.

They can be repaired (a) by providing an agent:

> Leaping to the obvious conclusion, we decide that the equation . . .

(b) by rearranging the order:

> The answer can be found by inserting the higher number.

or (c) by expanding the "-ing" phrase to an independent clause:

> When the energy density and the lifetime are compared, only a chemical storage mode makes sense.

(4) Possessives before "-ing" words. A possessive pronoun (e.g., our, its, their) or a possessive form of a noun (Brown's, the equation's) should precede "-ing" words, as in the following examples:

Right: There is no danger of the rule's being broken.

Wrong: There is no danger of the rule being broken.

Right: This led to his locating all unstable periodic orbits up to ninth order.

Wrong: This led to him locating all unstable periodic orbits up to ninth order.

Right: We denote this by N' to prevent its being confused with N.

Wrong: We denote this by N' to prevent it being confused with N.

Right: A direct consequence of momentum's being conserved...

Wrong: A direct consequence of momentum being conserved...

(5) Introducing conditions. The subjunctive mood provides a neat, simple way of stating conditions:

> This model requires that the system remain near equilibrium.
>
> We impose the constraint that the eigenmodes satisfy the boson commutation relation.
>
> It is important that theory be compared with experimental results.

Those unfamiliar with this construction may try to strengthen it by inserting "should" or "must" before the verb. Such insertions are superfluous.

Wrong: Heinz required that L must be less than 8 mm.

Right: Heinz required that L be less than 8 mm.

Wrong: Observations of deuterium abundance demand that the density of baryons in the universe should be rather low.

Right: Observations of deuterium abundance demand that the density of baryons in the universe be rather low.

(6) "That" and "which." These two relative pronouns are not interchangeable. "That" is the right choice for restrictive clauses: "An approach that is based on perturbation theory offers several advantages" (only an approach based on perturbation theory is under consideration – "that is based" limits or restricts the kind of approach we are talking about).

"Which" is the right choice for nonrestrictive clauses: "This approach, which is based on perturbation theory, has generated a good deal of controversy" (the nonrestrictive "which" clause simply gives additional information – the sentence would still make sense without it).

Authors who choose incorrectly tend to overuse "which." For a discussion of when each is appropriate, and why, I refer the reader to Wilson Follett's *Modern American Usage* (**?**), in the lexicon under "That, which, relative." Two easy-to-remember models, however, are

> The house that Jack built.
>
> The umbra is surrounded by a penumbra, which is not as dark.

Note that "which" is usually preceded by a comma. And keep in mind a third option, no "which" or "that" at all:

> "An approach based on perturbation theory. . . ,"
>
> "This approach, based on perturbation theory, has generated. . . "

(7) "Where." This word is correctly used to refer to a place or a region. Common usage in the scientific literature allows it also to be used to refer to an equation. However, it should not be used for nonlocalized abstractions. Change

a case where	to	a case in which
a situation where	to	a situation in which
a form where	to	a form in which

Change "in the case in which" simply to "when."

(8) Starting a sentence with "also." It is generally bad form to begin a sentence with "also," not because there is a rule against this, specifically, but because the adverb "also" is then likely to be separated from the verb it modifies. Sentences like these:

> Also we can adjust the parameters.
>
> Also it is desirable to apply the highest feasible voltage.
>
> Also the concept of the classical limit will be discussed.

can be improved by moving "also" in to follow the verb or auxiliary verb:

> We can also adjust the parameters.
>
> It is also desirable to apply . . .
>
> The concept of the classical limit will also be discussed.

(9) Starting a sentence with "This." Pronouns like "this" or "these" spare us from having to repeat cumbersome phrases and provide a smooth link with what has gone before. They can, however, contribute to vagueness and lack of focus if the thing to which they refer – the antecedent – is not clear. To banish any doubt, provide a reminder: "this approach," "this procedure," "this substitution," "these terms."

10. Frequently misused words and expressions

(a) Data. This is a plural noun and requires a plural verb – e.g., "The neutron scattering data are not helpful." The singular is datum.

(b) Cite and quote. To refer to an article is to cite it: "Details can be found in the two papers cited above." To reprint a sentence or passage from it is to quote it.

(c) Three Latin abbreviations:

- Cf. Latin *confer* = English *compare*. Authors wishing to refer their readers to a figur e, equation, or article sometimes write "cf. Fig. 32," "cf. Eq. (2.3)," or "cf. Orsini, 1995." They should be certain, in doing this, that they mean "compare." When no comparison is being made, they should write "see." The two are not interchangeable.
- E.g. Latin *exempli gratia* = English *for the sake of example*. This abbreviation is use d between two nouns, the first describing a class of things, the second describing a specific instance:

> . . . discussed by many authors, e.g., Brownell, 1988.
>
> . . . in several review articles (e.g., Brownell, 1988).
>
> . . . the larger mammals, e.g., elephants.

In a sentence like the following, e.g. should be replaced with "see, for example," because the referenc e is not an example of the preceding noun:

> The oscillations were generally interpreted as waves induced by penetrating convection (e.g., Bahng and Schwarzchild, 1953).

When there is no general noun as in:

> "See, e.g., Brownell, 1988"

the use of e.g. is unidiomatic in English. Instead, say

> See, for example, Brownell, 1988.

- Et al. Latin *et alii* or *aliae* or *alia*, depending on gender = English *and others*. Use this abbreviation to refer to two or more unnamed co-authors ("others"), but not to a single co-author. Note that et is a whole word, not an abbreviation, and therefore should not be followed by a period.

11. Being concrete

Your readers would rather hear about a bear than a mammal, a sandwich than nutrition, and a car wreck than an accident. Translating this principle into an article about lattice-gas models or gauge invariance, however, is a challenge. To meet it you need to be ready to link the everyday world with the scientific. One of the easiest places in which to do this is your introduction. This is your stepping-off point into the world of the abstract. Rather than plunging right in, you are allowed to take two or three sentences to lead your reader to the diving board. A certain irreverence helps. Consider, for example, these openings from two of *RMP*'s more lively authors:

> "Even scientists who have spent the last few years under large rocks cannot help having heard of Supernova 1987A in the Large Magellanic Cloud (the associated neutrino burst having readily penetrated the very largest rocks)" [Virginia Trimble, Rev. Mod. Phys. **60**, 859 (1988)].

> "It is a fundamental quantum doctrine that a measurement does not, in general, reveal a preexisting value of the measured property. . . Setting aside the metaphysics that emerged from urgent debates and long walks in Copenhagen parks, can one point to anything in the modern quantum theory that forces on us such an act of intellectual renunciation? Or is it merely reverence for the Patriarchs that leads us to deny that a measurement reveals a value that was already there, prior to the measurement?" [David Mermin, Rev. Mod. Phys. **65**, 803 (1993)].

Supposing that your style is more conservative than that of the two writers above, you can still refer to the concrete, everyday world with great benefit to your text. And you will be in good company. Schrödinger's cat, the small dark cloud on the blue sky of physics referred to by Planck, Feynman's story of the woman with the turtle-based cosmology – all have captured the imaginations of countless readers.

Clever gimmicks are not necessary. You might, for example, say something about the external appearance or the setting of an experiment, especially if it is a historic one. This is quite different from showing in a diagram the placement of gates, counters, relays, amplifiers, etc. I once attended a public lecture on the birth of high-temperature superconductivity, delivered by a leading theorist. Unfortunately, it was pitched over the heads of most people in the audience, myself included. At the end of the lecture, as we were filing out of the hall, a neighbor voiced my own complaint. "Yes," she said, "but what did these experiments look like? What would I have seen if I just walked into the laboratory?"

Of course, many of your readers will already know this, but it does no harm to describe the experiment in a way that the initiated will enjoy and the uninitiated learn from. I loved it when my elementary astronomy textbook described the neutrino telescope in Homestake Gold Mine as "a 400,000-liter tank of cleaning fluid."

The charm of contrast between the abstruse and the mundane need not be limited to the opening of a paper. Here are a few more examples:

> "The difference between the two types of variables can be elucidated by describing two ways of watching fish. In the Eulerian picture one stays at a point and watches whatever fish happen by; in the Lagrangian picture one picks out a particular fish and keeps track of where it goes" [P. J. Morrison, Rev. Mod. Phys. **70**, 467 (1998)].

> "One can imagine an ensemble of 10^9 - $10^{10} M_\odot$ black holes that have descended from dead galaxies and are now roaming freely and hoovering up an occasional remaining star in the volume R^3" [F.C. Adams and G. Laughlin, Rev. Mod. Phys. **69**, 347 (1997)].

> "It should be clear to anyone who has ever wrapped a rubber band around a cylinder that any mapping with winding number n can be deformed into any other mapping with winding number n, but that two mappings with distinct winding numbers cannot be deformed into one another" [David Mermin, Rev. Mod. Phys. **51**, 597 (1979)].

> "As late as the spring of 1946, neither the fact of Sloan's (1941) patent application nor the concept it embodied of electrons surfing in a disc-loaded waveguide was known even by those most intimately involved" [Paul Forman, Rev. Mod. Phys. **67**, 417 (1995)].

> "Radiative fluxes from 1987A are still changing on time scales short compared to journal publication time scales" [Virginia Trimble, Rev. Mod Phys. **60**, 859 (1988)].

> "I have observed that the Hamiltonian philosophy is like avocado: you either like it or you don't" [P.J. Morrison, Rev. Mod. Phys. **70**, 467 (1998)].

The important thing to remember is that science is indeed done by people – people who live in a world of cats, blue skies, rubber bands, and journal publication as well as in the intellectual world of concepts and relationships. These people are like your audience and in many cases they *are* your audience. Speak to them.

12. Choosing a title

In the years I have worked at *Reviews of Modern Physics*, I have noticed an inverse correlation between length of an article's title and age of its author. Younger physicists, eager to make a splash in the literature, like titles that could serve as abstracts, spelling out the particulars of the work and sometimes running on so long that they require a reduced font to fit onto the page. Perhaps these authors imagine their readers as a very large dissertation committee or think that, to be taken seriously, they must present their work with as much aplomb as they can muster.

Their elders already know a large portion of their readership personally and are not intimidated by them. From the security of tenured positions, they are more likely to try a catchy or witty title, use language calculated to attract a wider audience, and save the details for the paper itself.

There are, of course, exceptions to complicate this generalization, but whether it is a mark of my age or of my youth, I favor the simpler and shorter titles, as do *RMP*'s Editor and Associate Editors. We often ask our authors to replace particularly cumbersome titles. Table X contains a selection of article titles in their Before and After versions. The Afters have all been published in *Reviews of Modern Physics*, whereas some of the Befores are fictitious, having been created for the sole purpose of offering a bad example. I apologize to authors who submitted perfectly good titles yet are represented in this list as providers of bad ones. And I promise never to reveal which Befores are genuine.

B. Elements of style for non-native writers of English

To write about physics in a language other than your native tongue must be a daunting undertaking, and I am continually impressed by how well *RMP*'s contributors manage it. Nonetheless, certain problems seem to be more daunting than others, judging from the frequency with which they come up. Here are a few areas in which the non-native writer of English needs to be especially careful.

1. Past tense and present perfect

Non-native speakers of English often select a two-word past tense, thinking this to be analogous to the French *passé composé*, for action that is completed and thoroughly in the past. Unfortunately, English is just the reverse of French in this regard. The two-word past or present perfect (e.g., has surveyed, have shown) describes action that is recent and perhaps ongoing, whereas the simple, one-word past tense (surveyed, showed) is more appropriate for history. The sentences below show typical misuse of the present perfect, with corrections indicated:

> At the same time it $\overset{was}{\wedge}$ ~~has been~~ shown by these authors in 1985 that...

> These studies ~~have~~ acquired new impetus after York discovered that...

> The way out of this difficulty $\overset{was}{\wedge}$ ~~has been~~ indicated a long time ago by Adams (1957)...

Conversely, actions in the very recent past are better descibed by the two-word present perfec t:

> In this section we $\overset{have}{\wedge}$ tried to draw attention...

> Recent research $\overset{has}{\wedge}$ focused on...

2. Plurals in singular dress

One of the ways in which English is not logical is its use of the singular for things that we know to be plural. Consider the following:

TABLE X Examples of simplified titles.

Before	After
The diabolical nature of conical intersections of potential-energy surfaces of the same symmetry	Diabolical conical intersections
Nuclear magnetic resonance techniques as a probe of C_{60} and C_{60} superconductors: structural, electronic structural, and superconducting-state	Nuclear magnetic resonance of C_{60} fulleride sup erconductors
Technology for improving the resolution of large ground-based astronomical telescopes	Improving the resolution of ground-based telesc opes
Reparametrization invariance and physical processes in stochastic growth equations	Stochastic growth equations and reparametrization invariance
Chaos in the class generated by perturbing periodic orbits	Strange attractors and the origin of chaos
The search for and discovery of the top quark	The discovery of the top quark

a six-decade inertial range
a two-meter radius
the many-body problem
gamma-ray bursts
nearest-neighbor sites
a multipulse observation

Where units of measure are involved, it is conventional to give them only in singular form. P erhaps the other examples are an extension of this rule. Whatever the origins of this convention, take m y word for it, one does not say "a six-decades inertial range" or "the many-bodies problem." There is , however, one exception. The plural is correct in "a first-principles calculation."

3. Placing the verb early in the sentence

English-speaking readers grow impatient when forced to wait too long for a verb. The following sentences are marked to position the verb closer to the beginning of the sentence:

> If $\overset{we\ neglect}{\wedge}$ the processes of entropy generation such as plasma heating owing to decay or the annihilation of massive particles when they depart from thermal equilibrium ~~are neglected~~, then N_γ coincides with the photon concentration...

> At low temperatures the interaction $\overset{is\ substantial}{\wedge}$, not only between particles in clus ters, but also between different clusters, ~~is substantial~~.

> In Table IV $\overset{are\ listed}{\wedge}$ the expected numbers above 10^{20} eV, if the true rate is ta ken from the integration of Eq. (43) given in Sec. V ~~are listed~~.

4. Placement of adverbs

In English, adverbs are more often placed before the verb than after it. While placement after the verb is not incorrect, it usually has an awkward and foreign sound to a native English speaker. Two cases deserve special care. First, an adverb should not be placed between a verb and its object:

Wrong: Impurities affect also the elastic properties.
Right: Impurities also affect the elastic properties.
Wrong: If we extend further the analogy...
Right: If we further extend the analogy...

Second, when an auxiliary verb is used, place the adverb between the auxiliary and the verb, as in the following examples:

will rapidly converge
has long been known
could severely limit
may also be incomplete
would then follow
might incorrectly assume
can no longer be seen
had not yet received

An exception is the adverb "differently," which always goes after the verb:

are handled differently
must evolve differently
could behave differently

Adverbs placed at the beginning of a sentence are understood to apply to the whole statement rather than to a single verb. Common examples:

Unfortunately
Consequently
Hence
Analogously
Moreover

5. Nouns as modifiers

Like German, English sometimes uses nouns as modifiers:

the *CP* conjugation operator
the interaction potential
the order parameter

More often, however, it prefers to introduce them after the thing modified, using "of" or another preposition:

the expansion of the universe
(not the universe expansion)

the reorientational dynamics of Li
(not the Li reorientational dynamics)

the wavelength of light
(not the light wavelength)

the concept of the coherent state
(not the coherent state concept)

a rise in temperature
(not a temperature rise)

an upper bound for the density of matter
(not a matter density upper bound)

the decay of the X meson
(not the X-meson decay)

I can offer no hard and fast rule, as idiom is not consistent, but when in doubt you are more likely to be right placing noun modifiers after the thing modified. Long strings of modifiers are almost always better positioned later in the sentence. For example, the following phrases are grammatically correct, but awkward:

kinetic-ballooning-mode-induced losses

few- and infinite-degree-of-freedom fluid-mechanical systems

Rearranging these makes for a smoother sentence and eliminates the need for multiple hyphens:

losses induced by the kinetic ballooning mode

fluid-mechanical systems with few or infinite degrees of freedom

6. Articles

People whose first language has no articles (e.g., Chinese, Japanese) tend to omit articles from their English writing. In the following pairs of sentences, corrections are shown in italics.

Wrong: Study of x-ray absorption spectra has a long history, beginning with discovery of x-ray by Roentgen.
Right: *The* study of x-ray absorption spectra has a long history, beginning with *the* discovery of *the* x-ray by Roentgen.
Wrong: Coherent states defined by Eq. (3.10) are nonorthogonal.
Right: *The* coherent states defined by Eq. (3.10) are nonorthogonal.
Wrong: S^2 is usually called Bloch sphere.
Right: S^2 is usually called *a* Bloch sphere.
Wrong: As early as 1980s...
Right: As early as *the* 1980s...

People whose native language uses more articles than English (e.g., German) often allow extra articles to creep over into the English version. The following sentences are marked to delete unnecessary articles.

It follows from ~~the expression~~ $\overset{Eq.}{\wedge}$ (5.3)...

They include ~~the~~ corrections due to ~~the~~ general relativity.

The use of ~~the~~ "effective Hamiltonians" is not limited to ~~the~~ solid state physics.

The number of unit cells of ~~the~~ volume v_o...

Even a small change in the delta values would suffice for ~~the~~ ferroelectric ordering to occur.

The importance of ~~the~~ many-body effects in x-ray spectra...

Finally, definite articles (the) and indefinite articles (a, an) are sometimes confused. "A" and "an" should be used for general statements, "the" for particular and specific things. The following incorrect sentences have been marked to show the proper article:

This case demonstrates ~~an~~ $\overset{the}{\wedge}$ opposite behavior.

~~The~~ $\overset{A}{\wedge}$ degeneracy of this type usually leads to...

For ~~the~~ $\overset{a}{\wedge}$ conduction band with uniform level spacing, one may calculate...

7. Describing figures

When describing the curves in a diagram, choose the idiomatic English terms,

solid line	rather than	full line
dashed line	rather than	broken line
heavy line	rather than	thick line

For economy, use data-point symbols ($\bullet, \circ, \Box, \triangle$) whenever possible, rather than words. This also eliminates the problem of how to describe the symbols in English. Finally, for greatest clarity, name the curve or give the data point first and then give the description:

> $\Box$, Smith *et al.*, 2005. $\circ$, predication of Azarian, 2000.

> Solid curves, nonlinear evolution as described by Eq. (4.9); dashed curves, linear evolution in accordance with Eq. (4.21) for the fastest-growing mode.

8. Participles and infinitives

Where other languages combine a noun with an infinitive, English often favors a noun-participle combination:

Wrong: The probability to find a given type...

Right: The probability of finding a given type...

Wrong: A convenient method to generate sum rules...

Right: A convenient method for generating sum rules...

Wrong: The idea to look for a power series...

Right: The idea of looking for a power series...

There are, however, important exceptions. "Ability," unlike "probability," should be followed by an infinitive:

> "A Penning trap has the ability to hold a single particle indefinitely."

Other exceptions: "Right," as in "the right to remain silent," "need," as in "the need to be careful" – see "necessity" below, under Frequently Misused Words and Expressions.

9. Covering two possibilities

The following very efficient construction is a Europeanism rarely encountered in articles by native English speakers:

> With an increase (decrease) in interaction strength, the limit on the number of massless particles grows more (less) restrictive.

Many editors would let this stand, figuring that the reader is probably intelligent enough to sort it out, but this construction certainly violates the rule of thumb that good prose can be understood when read aloud. A native English-speaker would treat the two possibilities separately:

> With an increase in interaction strength, the limit on the number of massless particles grows more restrictive, whereas with a decrease it becomes less so.

10. Omitting "it"

In the following examples, non-native speakers are tempted to insert "it" where idiomatic usage leaves it out:

> When these terms are independent of each other, as ~~it~~ is the case for $N = 3$, the criterion of Iac obson and Amit is satisfied.

> The existence of a stable fixed point is less conclusive that ~~it~~ was originally supposed.

11. Frequently misused words and expressions

(1) Evidently, apparently. In English these words do not carry the weight that you might think. They are not simply another way of saying "It is evident that..." or "It is apparent that..." but introduce an overtone of doubt. A native English speaker would interpret them as "The evidence to date supports it (but I am reserving judgment)" or "It appears to be so (but the final word is not yet in)." For a more forceful statement, choose "clearly" or "obviously," or "plainly," or spell out "It is evident that..."

(2) As seen, as is seen, it is seen. These constructions have the effect of telling the reader what he or she sees. Try to involve the reader in a shared vision by using "As can be seen" or "As we have seen..."

(3) Contrary, conversely, in contrast, unlike. The expression "on the contrary" is used to contradict a positive statement. It has an argumentative tone.

When you wish only to compare different things, use "in contrast" or, for opposites, "conversely."

Be careful with "unlike," which requires two comparable nouns – two people, two atoms, two Hamiltonians. A common error is to try to compare, say, scientists with models or a theory with a variable:

Wrong: Unlike the work of Adams, Cohen uses...
Right: The work of Adams, unlike that of Cohen, uses... or
Right: Unlike Adams, Cohen uses...
Wrong: Unlike the case of covalent crystals, here the neighboring atoms...
Right: Here the neighboring atoms, unlike those in covalent crystals,...

When the comparison does not involve two specific nouns, replace "unlike" with "in contrast."

Wrong: Unlike in neurophysiology...
Right: In contrast to neurophysiology...

(4) Firstly. This word has fallen into disrepute and is not permitted in APS publications. Its sisters, "secondly" and "thirdly," are quite acceptable. One can say "first, secondly, thirdly." For parallelism, I propose "first, second, third."

(5) Estimation. This word is a false friend. It is used subjectively in English for esteem, regard, or a high or low opinion of something, e.g., "In my estimation, the contract is worthless." For objective or scientific attempts to predict a result, use "an estimate" or the participle "estimating":

Wrong: Estimations based on Eq. (3.37)
Right: Estimates based on Eq. (3.37)
Wrong: This result will prove useful for the estimation of L.
Right: This result will prove useful for estimating L.

(6) Evidence. When experiments produce data supporting a theory, the data (plural) are referred to collectively as evidence (singular). There is no plural "evidences." Moreover, there is no such verb as "to evidence." Other verbs should be used, according to the circumstances: to reveal, to indicate, to suggest, to bear out, to confirm, to argue for, to support, to bear witness to, to signal.

(7) Of . . . of. Sentences that employ two or more "of"s in close succession are ungainly. An English-speaking writer would instinctively try to rearrange them:

Poor: The probability of formation of strongly coupled clusters...
Better: The probability that strongly coupled clusters will form...
Poor: Studies of the features of turbulence in accretion disks...
Better: Studies of turbulence in accretion disks...
Poor: Calibration of the estimates of the energy of the primary particles.
Better: Calibration of the energy estimates for the primary particle.

(8) Compared to. The two most common ways of stating a comparison in a scientific paper are demonstrated by the following models:

Model A: The size of the halo is small compared with the separation between galaxies.
Model B: This cross section is significantly smaller than those predicted by Eq. (23).

In Model A, a noncomparative form of the adjective – small, high, broad, weak, etc. – is used with "compared to." In Model B, a comparative form – smaller, higher, broader, weaker, etc. – is used with "than."

The error to be avoided here is to mix elements from the two models and to produce a sentence that has both a comparative adjective and "compared to":

Wrong: Power corrections are greater for the delta as compared to the nucleon.
Model A: Power corrections for the delta are great compared to those for the nucleon.
Model B: Power corrections are greater for the delta than for the nucleon.

(9) Favor. An event can be energetically favored or not energetically favored. It is never energetically favorable or unfavorable.

(10) Monotony. Be careful not to confuse "monotonic" (the mathematical sequence) with "monotonous" (boring).

Wrong: The energy per atom decreases monotonously.
Right: The energy per atom decreases monotonically.

(11) Singular. The word "singular" has two meanings in English. The first is the opposite of "plural." The second is "rare" or "deviating from the norm." To avoid ambiguity, use "single" when referring to number.

Ambiguous: singular crystal surface (unusual crystal surface?)

Clearer: single-crystal surface (surface of one crystal)

(12) Enable, allow, permit. Verbs of empowerment take an object – generally the person or persons being empowered:

Wrong: The experiment does not allow to distinguish between $T/1nt$ and $T^{3/2}$.
Right: The experiment does not allow one to distinguish between $T/1nt$ and $T^{3/2}$.
Wrong: This device enabled probes of new areas.
Right: This device enabled Kelly to probe new areas.
Right: This device made possible probes of new areas.

"Enable" must have a person or pronoun as object, followed by an infinitive. "Allow" and "permit" may be used like "Enable" (followed by person-plus-infinitive) or they may take simple objects.

. . . so as to allow deeper penetration.

. . . which permits a lively exchange of ideas.

Note that an infinitive, standing alone, is not a suitable object for any of these verbs.

Wrong: which permits to use the Hamiltonian.
Right: which permits use of the Hamiltonian.
Right: which permits us to use the Hamiltonian.

(13) Necessity. English favors the noun "need" over "necessity," probably because it lends itself to a simpler sentence construction. "Need" can be followed by an infinitive:

The need to use low temperatures. . .

The need to take into account. . .

whereas "necessity," in a similar position, must be followed by "of" and an "-ing" form:

The necessity of using low temperatures. . .

The necessity of taking into account. . .

Plainly the second construction is more cumbersome. It is thus seldom used, though not incorrect.

(14) Absence. A person or an element can be absent, but an event cannot. When something does not happen, scientifically speaking, English prefers "no" to "is absent."

Wrong: The frequency dispersion of B is absent.
Right: There is no frequency dispersion of B.
Wrong: The depolarization is absent.
Right: There is no depolarization.
Right: No depolarization takes place.
Right: Depolarization does not occur.

However, "absence" as a noun is okay: "From the above analysis we infer the absence of long-range order."

(15) The question. When English refers to "the question," it leaps right in to state it, using only a comma, a colon, or the preposition "of." This probably sounds abrupt to a European ear. Nonetheless, inserting other words and phrases is unnecessary and usually wrong:

Wrong: . . . will answer the question concerning its origin.
Right: . . . will answer the question of its origin.
Wrong: . . . will answer the question as to whether. . .
Right: . . . will answer the question of whether. . .
Wrong: . . . will answer the question about which model. . .
Right: . . . will answer the question, which model. . .
Wrong: The question can be raised as to what happens when. . .
Right: The question can be raised: What happens when. . .

(16) Replace, substitute. The verb "to substitute" is always accompanied by "for." The verb "to replace" can stand alone:

Active: Y replaces X.
Active: We substitute Y for X.
Passive: X is replaced by Y.
Passive: Y is substituted for X.

(17) Aspects. This noun rarely appears alone in English, but is followed by "of" and an object. If you cannot provide the object, replace "aspects" with a different word.

Wrong: Two aspects deserve special mention.
Right: Two aspects of this problem deserve special mention.
Wrong: Section V treats off-equilibrium aspects.
Better: Section V treats off-equilibrium processes.
Wrong: Adiabatic processes are likely to be relevant in various aspects.
Better: Adiabatic processes are likely to be relevant in several ways.

C. Conclusion

I hope that the examples above have encouraged you to pay closer attention, in writing your next scientific article, to writing techniques that can make it more vital and engaging. A greater reliance on the active voice, reduction in wordiness, judicious use of asides and questions directed to the reader, concrete examples drawn from everyday life, and a little extra grammatical polish should go a long way towards giving your writing greater impact. The first step, however, is to abandon the idea that, to be respected, you must speak in a stuffy manner for a stuffy judgmental audience. If you think of your reader as a colleague or potential colleague, someone with whom you might one day hold an animated discussion over lunch, you will be better able to communicate the excitement that your work holds for you. Mind-to-mind contact between author and reader is the goal towards which you are working when you write a paper. The closer you come to achieving it, the more memorable your writing will be and the greater the rewards for you and for your readers.