

# **Basic Concepts of Neuronal Function**

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**A Multilevel,  
Self-Teaching  
Textbook**

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**BASIC CONCEPTS OF  
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A Multilevel  
Self-Teaching  
Textbook

LITTLE, BROWN AND COMPANY  
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SEM

This preface is addressed to teachers who may want to use this book in their classes. Students are welcome to read this portion, which outlines the goals and background for the writing of this book, or they can proceed directly to Chapter 1.

### PRINCIPLES IN A FOREST OF FACTS

It is our firm conviction that biology in general and neurophysiology in particular have reached milestones in their development. As any scientific field progresses from its initial descriptive phase to analytic maturity, typically a major change occurs in the teaching techniques required to introduce newcomers to the field. The descriptive phase requires a historical-anecdotal teaching method. The principles that underlie the field are not entirely clear, even to its teachers, and the historical approach exposes the excitement of the “chase,” of the logical sequence by which the major innovators have made their successive contributions. In contrast, when the analytic phase is reached, the introductory course is made up of the generally accepted underlying principles of the field. At this point, the historical sequence may be abandoned in favor of a sequence designed to introduce the field with maximal clarity, with minimal ambiguity, and in the shortest possible succession of logical steps.

This book attempts to teach basic principles of neurophysiology. Even if one recognizes the superiority of teaching the basic principles, how is this to be accomplished in practice? We have found that the teaching process (as a closed loop) can clarify the principles underlying neurophysiology. It is our experience that if motivated, intelligent students do not understand an explanation, there must be a basic flaw in the teaching, i.e., in the textbook lectures given to the students. The unsatisfactory replies that we formerly gave to students' questions led us to write this book.

### STUDENT LEARNING WITH A MULTILEVEL TEXTBOOK

Even with a logical sequence of principles, a textbook still must communicate well to many students in different curricula in a variety of fields in a multitude of schools. Usually this requirement is ignored, being generally directed to the students of the author, a solution that reflects only the limitations of the traditional textbook. Students are remarkably adaptable if given half a chance. With these factors in mind, we wrote this book in a multilevel format (see Chapter 1), to communicate to a variety of students (with different interests) within the confines of a single book. **Students interested in “just the basics” can stick to the “core” material (which is clearly labeled), venturing into more complex material only when available time and mood coincide. Those interested in greater depth will profit from reading and understanding the “didactic simplifications,”** especially if someday they will have to teach this material themselves! Thus, by clearly indicating the intended readership, paragraph by paragraph, we do neither student a disservice and may broaden the outlook of both.

Although we wrote this book in the context of medical school education, we are confident that it will also be useful in dental and pharmaceutical schools, and in graduate and undergraduate courses in physiology, zoology, physiological psychology, and bioengineering.

The relationship of this book to other scientific writings is shown in the accompanying diagram. The goal of this multilevel textbook is to cover the basic part of the conceptual continuum more simply than the standard textbook does, without trying to supply *all* the more complex descriptive and experimental detail usually presented in a standard textbook. However, **this book offers sufficient knowledge for students to be able to get from standard works (and more advanced texts) whatever additional information they may want.** This book is more detailed than the popular scientific writings for the layperson (e.g., *Scientific American*) because the minimal knowledge of neurophysiology needed in medicine or in other specialized courses is greater than the knowledge that can be culled from lay sources.

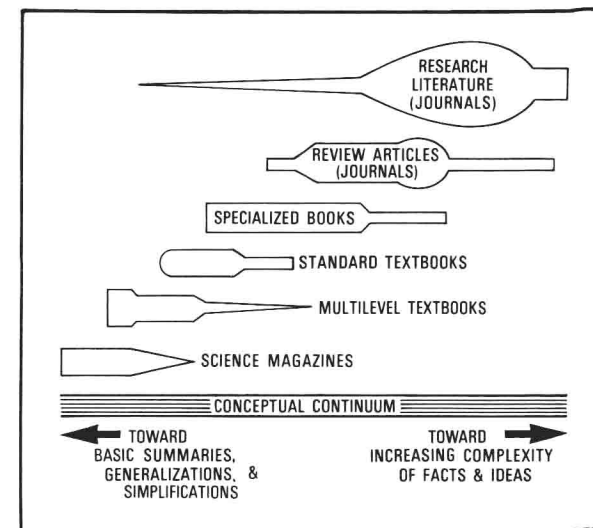
### TESTED TEXTBOOKS

The role of multilevel textbooks in the medical curriculum has been described elsewhere [25]. The basis of any successful teaching material must rest on the experimental method; that is, the teaching ability of the material must be user-tested. In practice, we elicited student feedback with sentence-by-sentence criticisms, made the appropriate corrections to the text, and then repeated the process. On the basis of user testing in medical and pharmaceutical schools, as well as in undergraduate classes in neurophysiology and bioengineering, and graduate classes in physiology, we believe that the apparently large audience for which this book is intended can actually be served well by it.

### EASE OF TEACHING

This book is written so as to ease the burden of teaching. We seek to serve a large range of teacher interests and backgrounds by making the book both adaptable to individual instructors' preferences and also as self-teaching as possible, thus freeing the teacher from the more mundane tasks of information transmission and (in our experience) raising the quality of questions posed by students. The first feature is provided in the following way: Each paragraph is numbered (with a small number to the left of the last line) sequentially from the top of the page. Thus, "page 305.2" refers to the second paragraph on page 305. In this way, the index can directly cite a given paragraph, and so can an instructor! Such numbering allows the instructor to modify the levels that we have assigned to the various parts of the book. It is a simple matter to give to students a list of the paragraphs that are to be included or excluded from a given level, keeping the basic definitions of level as described in Chapter 1. The instructor may say, "The following paragraphs are to be considered as second level: 305.2, 307.3. . . The following are to be considered third level: 305.4, 419.7. . ." *Of course, only changes in emphasis need to be so listed. In a few minutes students can mark their copies of the text to correspond to the individual instructor's judgment as to the importance of each paragraph.* One should not underestimate how much students value explicit delineation of what the instructor considers important!

One word of caution to those who modify the levels available in the text: We have ensured that no material in the first or second level is dependent on material in the third or fourth level. Thus, material can be moved to the left (made "more important") without concern for whether parts of the learning sequence will be disrupted. However, if material is moved to the right (made "less important"), teachers should be aware that they may have demoted a section on which a later idea depends. (The students will point out such discrepancies, should they occur!) To minimize such occurrences, we tried to limit the amount of material making up the intellectual core (the first and second levels).



## OTHER UNUSUAL FEATURES

The casual observer flipping through the book may notice a number of unusual gimmicks. We assure you that each and every gimmick has been tested and retained on the basis of student reactions rather than the authors' idiosyncrasies. These features are as follows: (1) The multilevel format, already described and discussed, is used. (2) Questions are interspersed throughout the text to encourage active student participation. (3) Either hints or answers to the questions are given in easy-to-find locations on nearby pages. (4) The book is printed the oblong way so that students can see more of the organization of the levels at one time. This format also means the line length is longer, there is space for illustrations and notes in the right-hand margin, and turning the pages to read the hints is easier. (5) The most important statements for review purposes are in boldface type. (6) At times a lighthearted approach is used (even at the expense of revealing the personalities of the authors) since students find such small diversions a welcome respite during long study hours. (7) Each paragraph is numbered, not only to allow flexibility to individual instructors, but also to permit the user of the index to find a specific reference quickly and accurately. (8) There are numerous illustrations, many of them original, to aid in visualizing concepts.

## FROM MICROSCOPIC TO MACROSCOPIC

As you can see from the preceding description, this book is written for students, in contrast to many textbooks that seem to have been written for the authors' peers and have little regard for the "teachability" of the result. For this reason we took an approach that we did not ourselves experience as students: to move always from the microscopic to the macroscopic and from principles to specifics. While some instructors may find that this approach is not to their taste, we are confident that their students will like it. We trust that after one more generation this problem will lessen, as neurophysiology makes the transition to a field based on principles that must, of necessity, involve subcellular (molecular) events.

## A WORD OF CAUTION

We ask that those who would like to evaluate this text do so by a thorough reading of the sections of interest. We doubt that a quick "flip-through" will allow a reader to appreciate the value of the text, given the number and types of innovations in both format and content. Even with a thorough reading of a section, those who are knowledgeable may think that "this feature is not necessary" because they cannot remember what it is like to encounter the material in ignorance! In other words, we are surer of the student's response than we are of the teacher's! But we take this to be a good sign, for a scientific field has not progressed unless students take a shorter time to learn the same material than their teachers did. The intellectual path in the newer material is shorter and, consequently, is foreign in some ways to readers who traversed the longer path some time ago.

We recommend strongly that those wishing to experience the full usefulness of our approach to membrane phenomena follow the "shorter version" described in the next section. The consistency of viewpoint, emphasizing the electrical-capacitative analogy, is best appreciated by seeing how readily it allows understanding of steady state and transient potentials and electrical, mechanical, and chemical transmission, as outlined.



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# Introduction to a Multilevel, Self-Teaching Method

## WHY THIS BOOK?

As knowledge in neurophysiology has advanced, the complexity and difficulty of the standard textbook have increased in like measure. We have reached the point at which many “beginning” textbooks are too advanced for the novice! Even more important, **almost all textbooks offer more information than any student can assimilate** or even use! Under these circumstances, the student has no way to distinguish what is most important (i.e., should be learned) from what is less important (i.e., should be ignored at first). As a result, many students resort to memorizing relatively trivial (but attractive) details while failing to master the major concepts of the field.

**The main purpose of this book is to make clear those ideas that are of fundamental importance in neurophysiology.** That often these ideas are not readily absorbed from standard textbooks seems to us not a failure on the part of the student, but a defect in the standard textbook format, which does not give adequate clues to the relative importance of different sections of the subject matter. Hence, we wrote this book in a multilevel format.

## MULTIPLE LEVELS

**To distinguish clearly the importance of the material presented in this book, the text is divided into four “levels” of significance.** These levels are marked by different amounts of indentation and different numbers of vertical lines. You should look **now** through the book to see the format.

||| The **first level**, indented 5 spaces from the left-hand margin and marked by **four** vertical lines, is used for the **most basic** and **most important generalizations**, which introduce or summarize the core material. These brief statements indicate what material immediately follows. On the first reading, you may not understand the vocabulary or concepts. However, **upon review, you will find that these summaries help you remember the main points.**

||| The **second level**, indented 10 spaces from the left-hand margin and marked by **three** vertical lines, is used for detailed exposition of the core material of neurophysiology, the material all students are expected to understand and master (and on which later material is based). Levels 1 and 2 together comprise about 50 percent of the book.

||| The **third level**, indented 15 spaces from the left-hand margin and marked by **two** vertical lines, contains material that only the more interested students need to learn. Here are found further ramifications of general principles, the 5 percent of exceptions to rules that are 95 percent correct, experimental verifications for some of the “facts” presented at the second level, and so on. This level makes up about 25 percent of the book.

| The **fourth level**, indented 20 spaces from the left-hand margin and marked by **one** vertical line, presents obscure points that the authors enjoy, references to mathematical derivations, more detailed descriptions of experimental methods

of interest to graduate students in physiology, and so on. The fourth level makes up about 25 percent of the book.

**How the multilevel arrangement will help you.** (1) You can read only what is most appropriate for you at the time, **without having to read everything**. (We know that as an eager student, often you read everything in the textbook—but you may not always have time for that!) (2) If you are interested in something, you can find additional information by going to a higher level in this book, rather than searching in some other book. (3) You can **easily review the main points** before an exam.

**An efficient way to use this book.** (1) When you start to read a chapter, you may find it helpful to get an overview of the material to be presented by flipping through the chapter, **reading just the headings**. (2) Study the chapter, concentrating on the first and second levels, that is, the core material. The first-level generalizations will be clear to you only when you have mastered the second-level material. (3) If you are interested and have already mastered the second level, feel free to read into higher levels, **but that material is not necessary for understanding what follows in the succeeding first and second levels**. (4) Before the exam, review at least the main points in the first and second levels. **The first level is especially valuable for such reviewing.** Follow any changes in level that your instructor has given you.

### BOLDFACE WORDS AND SENTENCES

A book can seem pretty dull if it contains only summarizing statements that you are supposed to memorize. Often it is hard for the reader to follow both the ideas and the language in such outlines. So this book contains **additional** comments, introductory statements, careful and detailed explanations, and so on, to make the book easier to read and follow. However, **the really crucial sentences are in boldface type** so that you will be sure to notice them on **first reading** and be able to **review** them easily later. You have probably underlined important parts of your previous books—feel free to underline the portions you want to emphasize—the boldface indicates what WE want to emphasize!

### WRITING SPACE

On the right-hand side of many pages, there is space for you to make notes, comments, reminders, and so on. The more you work with a book, the more useful it is to you, both now and in the future, so don't hesitate to use this space.

### FIGURES

Figures are located in the space on the right-hand side of the page. When a figure is repeated, the original figure number is shown after a slash mark; for example, Fig. 6-2/4-18 is a duplicate in Chap. 6 of the original Fig. 4-18. This numbering system also applies to equations. This system allows you to trace back in the text easily, should you wish to review the text that accompanied the original figure or equation.

## PARAGRAPH NUMBERING

To the left of the vertical lines are small numbers at the end of each paragraph. These numbers permit the index to direct you to a specific paragraph! A reference in the index to 302.3 indicates the third paragraph on page 302.

## REFERENCES

Students should remember that the “facts” presented in textbooks are merely conclusions based on experimental evidence, which may change when more accurate (or more complete) studies are made. Wherever facts are quoted that have not achieved widespread acceptance and hence are not yet in textbooks, we cite the source by a number enclosed in brackets, corresponding to the Bibliography at the end of the book. However, some of the references in this book are other textbooks. They are included to allow students the opportunity either to study an alternative explanation of a baffling fundamental concept or to obtain an introduction to the research literature through a standard textbook containing a more complete discussion of the experimental background material than we considered advisable here. These references are also given in brackets. Since not all the texts listed in the Bibliography will be readily available to the average student, we included multiple references for the most basic concepts. However, it would make difficult reading if every concept mentioned in every text were referenced in this book; while we tried to list the clearest alternative explanations, no slight of an uncited text is intended when referencing does not include it.

## QUESTIONS

Interspersed throughout the text at all levels (except the first) are **questions**. There are different classes of questions, **indicated by how they are labeled**.

**QUESTION:** This heading indicates questions that follow the material just presented, and it will help you understand the material. **You should try to answer these as you read.** If you can answer these questions, then you know the basic material of that level.

**Question:** This heading indicates questions that are more difficult, require other knowledge, or involve more complex reasoning. (Note that it is not set in all capitals.) Feel proud if you answer them correctly, but don't worry if you don't.

**EXAM QUESTION:** This heading indicates samples of questions that you should be able to answer in an exam. They are taken from old exams or are like those that might be asked. They are placed at the ends of some sections and chapters, just as exams come after you have covered a number of topics. Use these questions to get a feel for how well you are remembering the material.

**NOTE:** **Since the questions are segregated according to level, you need concern yourself with only those questions in the level that you are reading or that you have mastered.**

**NOTE ALSO:** If there is a sequence of questions, we put them in order of increasing difficulty.

NOTE FINALLY: The questions in most textbooks are at the ends of the chapters, where they are usually ignored. The fact that questions in **this** book are **in the text** indicates that we mean them to be of **help to you in your learning**. Thus, many of them are quite simple—if you have understood what you have read, often you will be reassured by answering such questions easily. However, the harder questions may give you some insight into how the thinking of the neurophysiologist differs from that of normal people!

## HINTS

What good are questions without answers? In this book we intend for you to learn most of the material without additional aid, so answers **are** provided—they are called hints because sometimes they do not give you the answer directly, but give an additional hint, so that you can work it out yourself. **It is very important that you try to get the answer yourself before looking at the hint.** Write down the answer **before looking**. Of course, you can cheat and peek at the answer before thinking about it; no one will know, but you won't really have had to chance to use your available knowledge, especially when it is less than you would like it to be! **Pulling together information into a usable form** is a most important part of your training. Let's put it another way: Neither scientific problems nor patients come with hints attached! There is a skill involved in actively using your own brains. It takes practice to learn to reason things out. If you miss the question, who will ever know? And you get to read the hint whether you're right or wrong!

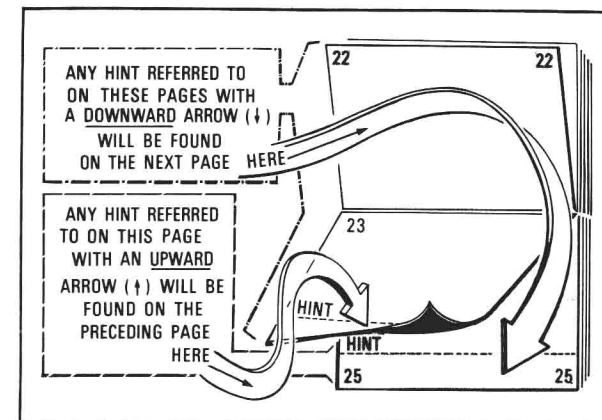
**Where to find hints.** At the end of each question, there is a hint number with an arrow [e.g., "(Hint 5↓)"]. If the arrow points **down**, then the hint is at the bottom of the **next** two-page spread (see diagram). If a page number is also given, the hint is on the bottom of that page. Hint numbers with the arrow pointing **up** are at the bottom of the **preceding** two-page spread.

**DON'T FORGET: Try working on the answer before you lift the page to look at the hint!**

## THE END OF THE BEGINNING

Soon you will be able to determine firsthand whether these gimmicks are as helpful to you as they have been to our previous students.

As teachers, we are pleased that by means of this book our efforts will reach many students; but we regret that by the nature of such long-distance, one-way communication, we do not have the advantages of direct interaction with our readers. Writing a book, like studying, can be a solitary occupation: authors, in the dark of night, endeavor to put their thoughts into clear phrases while students, in the dark of night, endeavor to grasp and retain what was written. We hope that you will let us know of both the failures and successes of our efforts, in the hope that the next edition will be improved, just as previous versions of this material have been improved by the students who took the time to tell us their reactions. We would be happy to hear from you by mail; or, if your path somehow crosses ours, please don't hesitate to meet us directly.





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## **Neuroanatomic Background of Neurophysiology**



## INTRODUCTION

Since students may come to study neurophysiology from a variety of backgrounds, this chapter provides essential terminology, particularly in neuroanatomy. (Those who are familiar with these ideas may still find it of some interest to skim this chapter; the approach used here is different from the usual viewpoint of neuroanatomy.)

Classically, anatomy is the study of form, while physiology is the study of function. Of course, such a distinction implies that form and function **can** be considered separately. Historically, a biological science begins with the study of form, progresses to the study of function, and finally realizes that the two are largely inseparable.

Hence quite detailed anatomic descriptions often must be included in the body of the text, at the point where the interrelationship between form and function will be understood best. This chapter merely provides a general background in the concepts and terminology common to many chapters of the book. Students should consult textbooks of histology and neuroanatomy to appreciate the full range of anatomic knowledge. Here we skim off from that body of knowledge only those points having direct application to the main goal of this book: a description of the principles on which the nervous system operates, as understood at present.

The general approach of this book is to go **from** an understanding of **the parts** of the nervous system **to the interworking** of those parts; we hope to show that in many cases the behavior of large groups of cells can be inferred from an understanding of the functioning of single cells.

Thus, **we move from the microscopic to the macroscopic**, from a single cell to groups of cells, and from simple principles to the more complex interactions of several variables. Let us take the same approach now—let us treat anatomy by going from the cell to the tissue, to the organ, to the organ system. Hence we start with cells.

## CELL THEORY

Our modern understanding of the nervous system rests on the idea that the nervous system consists of a complex organization of single cells.

**Each cell is the progeny of another cell, and each is delineated from others by a boundary: the cell membrane. The cell membrane separates the internal and external environments of the cell.** Outside the cell is the extracellular fluid, which, although it may still be inside the body, is a jumble of chemicals in dilute solution, in contrast to the intracellular fluid of the cytoplasm. Inside the cell are highly organized macromolecules that are concerned with the cell's replication, growth, and maintenance (the nucleus); with the cell's energy metabolism (the mitochondria); and with any special products that the cell may produce for extrusion or excretion (the endoplasmic reticulum and Golgi apparatus).

**Table 2-1.**

Dimensions Related to the Meter Standard		Dimensions in Common Neurophysiological Use	
1 mm (millimeter)	= $10^{-3}$ m (meter)	1 cm (centimeter)	= $10^{-2}$ m
1 $\mu$ m (micrometer, formerly called micron)	= $10^{-6}$ m		= $10^4 \mu$ m
			= $10^8 \text{ \AA}$
		1 mm (millimeter)	= $10^{-1}$ cm
			= $10^3 \mu$ m
			= $10^7 \text{ \AA}$
		1 $\mu$ m	= $10^{-4}$ cm
			= $10^{-3}$ mm
1 nm (nanometer)	= $10^{-9}$ m		= $10^4 \text{ \AA}$
		1 $\text{\AA}$ (angstrom)	= $10^{-10}$ m
			= $10^{-8}$ cm
			= $10^{-7}$ mm
			= $10^{-4} \mu$ m

**Table 2-2.** Units of Time in Common Neurophysiological Use

1 ms (millisecond) = $10^{-3}$ s (second)
1 $\mu$ s (microsecond) = $10^{-6}$ s
1 Hz (hertz) = 1 cycle/s

**Table 2-3.** Units of Volume in Common Neurophysiological Use

1 mL (milliliter) = $10^{-3}$ L (liter)
1 $\mu$ L (microliter) = $10^{-6}$ L
1 nL (nanoliter) = $10^{-9}$ L
(Note that often the milliliter is used as the standard of reference since 1 mL of H <sub>2</sub> O has a volume of 1 cm <sup>3</sup> .)