physics and man

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Preface

What is physics? The answer to this question as provided by a textbook may seem formal and remote from human concerns, since physical models and theories are abstractions from experience. In this small volume of selected readings I have tried to give a different kind of answer, an answer that reveals some of the personal, social, and humanistic elements in physics. Accordingly, the articles stress interdisciplinary matters and do not expound physical principles or physical phenomena in technical terms.

The theme of the collection is established by Alan Holden's article "Artistic Invitations to the Study of Physics." Holden's ideas may surprise you, for his message is that you should not take physics too seriously or too purely. And that is very good advice to physics students and to physics teachers!

The selections are grouped into seven chapters, each introduced by a brief statement identifying the common significance of the items; yet, the articles are complete in themselves. You may therefore look for selections that supplement current material in your textbook; references to my textbook *Introductory Physics, A Model Approach* (W. A. Benjamin, New York, 1969) are included in several chapter introductions. You may instead prefer to read the book systematically from the beginning, or you may browse to follow your mood or interest of the moment. Only in the chapter on nuclear energy have I made an effort to follow the historical developments of the past thirty years.

I hope you will make an effort to become acquainted with the forty-nine individuals represented in this collection. About half of them are natural scientists who have added an outside interest to their professional work and describe this interest rather than their specialty. The remainder are non-scientists whose lives are touched by physics and who can therefore illuminate the interaction of physics with other human concerns.

Finding and selecting the articles for this book gave me a great deal of personal pleasure. First of all, I was compelled to read much interesting material I would otherwise have never encountered. Second, I discovered unsuspected interests and talents among my friends, many of whom have written about interdisciplinary problems in addition to the work with which I was familiar. Third, I corresponded and became acquainted with some of the contributors I had not known before. And, fourth, I became aware of a growing group of individuals, deeply concerned about the role of science in our world, with whom I felt a community of interest. I am indebted to all the contributors and their publishers for allowing their work to be used.

ROBERT KARPLUS

Berkeley, California
February, 1970

About the Contributor

ALAN N. HOLDEN (1904-) has served on the technical staff of the Bell Telephone Laboratories for more than thirty years. His life-long study of crystal growth and a recent interest in physics teaching led him to write a book for laymen (Crystals and Crystal Growing, with coauthor Phylis Singer, Anchor Books of Doubleday and Co., Inc., Garden City, New York, 1960) and to produce an educational film on the structure of matter with the Physical Sciences Study Committee.

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Artistic Invitations to the Study of Physics

ALAN HOLDEN
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The Robert A. Millikan Lecture Award is made annually to a physicist chosen by a special committee of the American Association of Physics Teachers because of his creative and imaginative contributions to the teaching of physics. The lecturer selected is one whom the Association wishes to honor at the Summer Meeting in the same way that it honors the Oersted Medalist at the time of the Annual Meeting. The award is made possible through the annual support of Prentice-Hall, Inc.; the first award was made in 1964.

The recipient of this award for 1968 is Alan Holden, Member of the Technical Staff, Bell Telephone Laboratories.

In 1791 when he was a boy of seventeen years, studying at Christ's Hospital, Samuel Taylor Coleridge wrote to his brother, "I have often been surprised that Mathematics, the quintessence of Truth, should have found admirers so few and so languid. Frequent consideration and minute scrutiny have at length unravelled the cause; *viz.* that though Reason is luxuriating in its proper Paradise, Imagination is wearily traveling on a dreary desert. To assist Reason by the stimulus of Imagination is the design of the following production."

The production was a problem of Euclid put in verse. But we can guess that the talented and charming beatnik was exposed later to a course in physics. Dreaming of himself as the Wedding Guest, he wrote, "He went like one that hath been stunned/ And is of sense forlorn./ A sadder and a wiser man/ He rose the morrow morn." Succeeding years have seen that wisdom spread: Don't study physics unless you're a physicist. Today physics acquires many practitioners, but aside from them its admirers are few and languid.

I once thought there was danger in this state of affairs—the danger of constructing a modern counterpart of the medieval priesthood, believed and not understood—but a composer of music divested me of that arrogance. Said he, "Don't kid yourself; people look upon a physicist as they

look upon a garage mechanic. If you want a job of physics done, you go to a physicist and pay him, and the little chap does it for you."

In fact, a healthy musical composer looks at his own trade in that way: He is a craftsman for hire. For several years J. S. Bach knocked off a new church cantata almost every week and trained his choir to put it on at the Thomaskirche next Sunday. No shenanigans like opus numbers: About 200 have come to light; an estimated 100 are lost.

Nowadays we, like the imperial Romans, discern barbarians at ever-increasing distances; we hire physicists to thwart them. Would you go to the moon? Given a little time and lots of money, the physicists can get you there. "Science bust mars Lisa opening" read a newspaper headline when the elevators conked out at the unveiling of the celebrated painting in Washington.

The composer's music may give pleasure to many or to few. There is a host of Gershwin lovers, a handful of Schönberg lovers. In any case the composer accepts without complaint[1] that his music will not give pleasure to everybody. But he believes that, if people will only listen, some of them will enjoy his music. And the physicist correspondingly believes that, if people will pay attention, he can shed for some of them a little light on what happens in the world—a physicist's kind of light—indeed his personal kind of light. Which prepares the ground for:

PROPOSITION 1—PHYSICS IS NOT A SINGLE THING

By a robust definition current in earlier times, an axiom is a self-evident truth. The proceedings of the Carleton Conference of 1956 make clear that my first proposition is not self-evident. That was a good conference. It promulgated the idea, among others, that ". . . these seven principles and concepts outline the minimum content which *any* introductory course must encompass . . . ." I attended, and subscribed to that notion, and have since come to question it.[2]

[1] To be sure Bach once wrote, "My masters are a poor folk, with little music in them," but we all have our low moments.

There is a physics that is a single thing. It is the flesh-and-bloodless body of understanding, visualized by most young students, which descends like manna from heaven and comes to rest in a textbook. But physics, like music, is made by people; and physicists, like composers, come in all kinds; and therefore their physics comes in all kinds, too. Look about you at the practicing physicists in your acquaintance and you know this.

It is hard to believe that physics was the same thing to James Joule and his contemporary, Rudolf Clausius. Professor Andrade tells that, when Willy Wien said to Ernest Rutherford, "But no Anglo-Saxon can understand relativity," Rutherford replied, "No, they have too much sense." J. J. Thomson wrote an Adams Prize essay examining the mathematical properties of toroidal vortices. R. W. Wood, so I have heard, projected such vortices toward his audience and knocked the hats off the ladies. Can physics have been the same to both? When Wolfgang Pauli visited Bell Telephone Laboratories, he examined the ongoing physical researches of which the institution was proudest. Asked what he thought of them he replied, I am told, "Ach, das ist alles triviale": they were irrelevant to the problems that interested him.

If physics is not a single thing, trying to teach it as if it were is mistaken. And if physicists come in all kinds, so (in spades) do physics students. At least we hope they do. Or, better, we *say* we hope they do. Our teaching practices may in fact be limiting them to *one* kind, the kind that we are relatively comfortable teaching.

There is a central core of physics that every physicist must learn, of course.[3] Must Coleridge

[2] A good conference tackles large questions, works hard, and has the courage to come up with responsible answers. If a few of the answers turn out to be questionable, that shouldn't discredit the conference. The report of this one can be read in Am. J. Phys. **25**, 417 (1957).

[3] Of course? Well, maybe; but maybe not by taking the courses that teach it. Count Rumford? Michael Faraday? Ludwig von Helmholtz? Perhaps it is crippling not to have passed through these courses; then much of the central core of physics has been constructed by cripples.

learn it too in order to get the hang of the thing? If so, must he learn it in the same way? Answering these two questions is impossible; but examining them is important nevertheless, and some of the examination must be conducted in the light of:

PROPOSITION 2—TEACHING PHYSICS IS A BLACK ART

Says my composer's garage mechanic, "Sure I'll fix your heap; but wouldn't you like to have me tell you about it?" Like as not, the answer is *no*. There is a Principle of Least Knowledge under which we all operate. Greek epigraphy, cryptogamic botany, Provençal philology—if we began learning about them, we might get interested, and that would be fatal. A microcosm of the menace is in the child's book review, "This book told me more about penguins than I want to know." God may not have intended us to be a learned folk: We learn what we need to learn in order to live (which God knows is quite a lot), and we resist the rest.

We resist our resistance, too, however, and try to learn and to teach. It is not clear which effort is the harder. But if you are ever assaulted with the abominable teacher-blasting aphorism, you might fling back the paraphrase, "Those who can, teach; those who can't, learn."

Perhaps my second proposition *is* a self-evident truth: I have found nobody who does not agree that teaching—teaching physics or anything else—is an art.[4] "Black" simply describes the species of art to which teaching belongs. Unfortunately the axiom, once stated, is commonly allowed to sit unused for any deductive purpose.

The "black arts" are the arts of presenting those other arts that live only in performance—drama, ballet, music, and the like. The words of a script, the notes of a score, are directions (necessarily quite incomplete) for performance. The playwright depends on directors and actors, the composer on conductors and instrumentalists, to bring his work to life. Between performances the

[4] Learning is an art also, as anybody who has tried to examine and improve his own learning processes will attest.

work sleeps, and each performance is a little different.

Insofar as physics is a body of diverse materials to be taught, the physicists who made it are analogous to the composers, and a physics teacher to a conductor. The performance is the whole coordinated bit—texts, lectures, laboratory, classroom work, office hours, exercises, and tests. Or perhaps computer programs, film loops, teaching machines, and closed circuit TV shows. And the art gives life by performance before one student, or a dozen, or a thousand.

A conductor makes a program of music—of pieces written usually by different composers—and good program making is one facet of his art. At his best he knows the music so well, even if it is new, that he can conduct it without score and so pay better attention to the performance. A physics teacher makes a course out of bits of physics constructed by different physicists, and good course making is . . . pursue the resemblance yourself.

Conductors sometimes arrange pieces of music for performance on other instruments than the composers intended. The results are often shocking—Debussy's "Reflets dans l'Eau" blasted from a pipe organ. I think I would feel a similar shock if somebody tried to teach wave mechanics by experiments with subharmonic oscillators. Here we come upon tastes, the things for which there is no accounting, and mine are Apollonian, not Dionysian. I prefer Bach to Handel, Matisse to van Gogh, David Garnett to Thomas Wolfe, and Robert Lowell to Dylan Thomas. The student cry to which the Apollonian spirit is responsive is "Teacher, tell it like it is," even when the cry comes from Dionysian lips.

Surely Adolf Hitler was one of the most able Dionysian teachers of recent times, and the blackness of his art was sinister. But all the performing arts are "black arts" because they depend on establishing an empathy, a resonance. The role of their practitioners is first to bemuse, then to engage, and finally to enlist their audiences.

"The Wedding Guest sat on a stone:/ He cannot choose but hear." That is magic; and not all magic is sinister, even though all of it is black. The

best magicians have always obtained their results by means of which they are more or less aware but which they cannot teach to others. There are courses in acting, conducting, teaching—but Merlin offers none in witchcraft, and the Sorcerer's Apprentice came a cropper.

To place teaching among the black arts is merely to classify it. It, like its fellows, is an art in its own right. Whether or not it employs lectures, it is not the art of acting. But making its membership in the arts explicit focuses attention on some worthy habits that all the arts share.

In particular, the arts are aware of one another; they look at one another out of the corners of their eyes. One pleasant, if somewhat trivial, result of this mutual inspection is their habit of making graceful references to one another. There are many paintings of musicians performing music, and the tables are turned in Moussorgski's "Pictures at an Exhibition." "L'Apres-midi d'un faune" we know better as Debussy's music than as Mallarmé's earlier poem.[5]

Much more important is the sharing of discovery. Just as the sciences, the arts make discoveries, and a discovery in one art can sometimes be transmuted to serve a purpose in another. Surrealism, popularly regarded as a painting movement, was invented by the poet André Breton, who directed its literary manifestations. In the English pre-Raphaelite movement of the last century, and in the French Dada movement of this century, the interaction between poets and painters was so close that it would be hard to say which were the prime discoverers.

It may be that teaching—even physics teaching—has already made artistic discoveries that are usable in the other arts. I have been told of an eminent European physicist who made a practice of teaching the introductory physics course in his university. As he lectured, scores of little things were successively happening at the hands of gremlins directed from a console on his lectern—a fusillade of tiny events relating to his remarks.

Only now have visual artists rediscovered that such goings on make an art form. Only now is

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[5] And better than as Varèse's later parody, "L'Apres-midi d'un Ford," octet for piccolos with solo Klaxon.

McLuhan erecting the assault upon all senses at once into an artistic communications theory. For teaching has not yet been noticed as an art by other artists, and their sidelong glances go elsewhere. And the glances of teachers, in their professional capacity, seldom stray to the other arts. Only painfully, belatedly, and in loneliness do they rediscover some of the artists' oldest discoveries.

To dispel this isolation, perhaps a small entering wedge would be participation in graceful reference. For example, I suspect that Hieronimus Bosch's paintings of Hell are full of elementary physics—levers, pulleys, and what not. His is a Hell, as an artist has remarked, to which nobody can imagine himself going: The analysis would be undistracted by strong emotion.

Consider, for another example, the opening musical phrase of the familiar French folksong, "Il était une bergère." When you take the words and the beat away, the bare succession of notes has time-reversal symmetry. Rhythm and meaning contribute "time's arrow": What is happening to the entropy of the situation then?

But interartistic reference degenerates into gimmickry if it is not graceful. Finding resemblances between "modern art" and the pictures taken by an electron microscope is amusing, but so is the old pastime of finding rabbits in cloud formations. He who adheres to "tell it like it is" has an allergy to the spurious. He who signs up for a course in "physics for poets" wants a course in physics, not poetry.

Again, much more important than these peripheral references is the sharing of discovery. Examine two large and ancient discoveries in the arts, with abiding application to all of them, including teaching. The first is the uses of *scale*, a discovery of the visual arts. The second is the uses of *repetition*, a discovery of the auditory arts.[6]

Turning to the visual arts and their lesson of

[6] Here for simplicity, I class literature as an auditory art. It is much more than that, of course. But Reuben Brower, deploring the ascendency of the "rapid reading" movement, reminds us that good writing, even if it is only expository, "sounds." Gibbon paced the floor as he wrote *The Decline and Fall of the Roman Empire*, reciting its sentences to be sure that they sounded.

scale, begin with the Roman portrait busts, carved through several centuries after Rome became an empire. Here was a remarkably perfected art form. Mounted at eye level in a museum, those people meet us as we enter the room . . . and they are the people that we see every day. We know them well—thoughtful, worried, responsible, arrogant. Added to superb craftsmanship, there is one controlling reason for the immediacy of these heads: They are almost life-size.

Heroic sculpture, no matter in what style, can never have such a uncanny immediacy. And it isn't intended to. These people, on horseback or wherever, are heroes. In legend they are larger than life; so must they be in effigy. The people carved on the side of Mt. Rushmore under the direction of Gutzon Borglum must be very important indeed.

Conversely the small plaster busts of famous men trivialize them, and carry neither dignity nor conviction. In point of fact, none of us little chaps could live day by day in equality with the familiar bust of Beethoven: It would shame us. The row of busts on the mantlepiece serves (say it softly) only to advertise to ourselves and our guests that we are cultured folk. Reduced to the size of jewelry, effigies acquire new interest, but purely one in craftsmanship.

There is a widely distributed little piece of moralistic sculpture showing three monkeys with their paws over their ears, their eyes, and their mouth. Hear no evil, see no evil, speak no evil. But the piece is always too small to carry conviction, and so its owner continues to hear, see, and speak evil anyway.

In short, the size of man is unity on the number-line of the visual arts. "Man is the measure of all things," said Plato. Notice the difference in the emotional impact, so to speak, of the two polyhedra in Fig. 1, one larger and one smaller than the head of a man.

You may protest, "These polyhedra are geometrically similar, and therefore identical for my purpose." But you are teaching Coleridge, whose sensitivities are sharper than yours in some areas, albeit less sharp in others. If you would teach him your way of abstraction—and probably you

would, for it is at the heart of physics—do it slowly and explicitly.

I have heard of a game invented to teach very young children the beginnings of the idea of a number base. It employed white, red, and gray counters: Three white counters were worth one red counter, and three red were worth one gray. The game was a failure. On looking into why, it

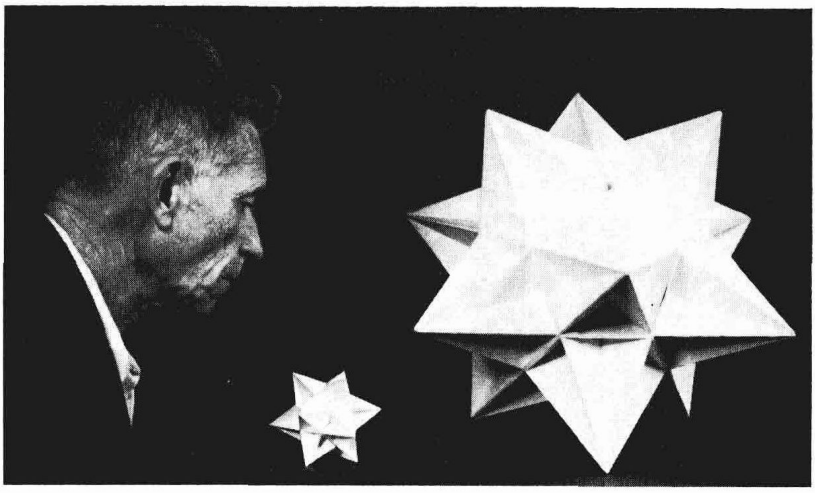

FIG. 1. Scaled up by a factor of 4, Louis Poinsot's *great icosahedron* becomes 16 times as important to the eye, and 64 times as important to the kinesthetic imagination.

emerged that all right-thinking people know a red thing is worth more than a gray thing. After the color assignments were interchanged, the game went well.

I made a polyhedron consisting of three interpenetrating cubes, and I colored the exposed parts of the cubes red, white, and blue. To you and me the colors are alpha, beta, and gamma. I'm afraid some of my nonmathematical friends think I am suggesting that the inhabitants of the United States of America are all squares.

A little pendulum is very cute, ticking off the seconds. A big one, a really long one, is majestic and at first rather mysterious. After traveling in one direction for awhile, it stops and turns around, even though you don't do anything to it. Perhaps Newton's first law is "important"? Then level the longest lecture table you have, cut a big brick of dry ice, and start it moving slowly. "Hey, the guy's right! It *does* go on forever."

As for *repetition*, any teacher already knows one rudimentary and relevant fact about it. He seldom learned anything himself the first time he heard it and, remembering that, he doesn't expect his students to do so either. But, at the same time, repetition is a bore, to him and to them. So how does he go about the job of repeating the things to be learned? And does he do it in the same way for the big things and the little things? For light and guidance and style, I suggest that he examine some musical and poetical structures. The way to examine them is to listen.[7]

Music has *passacaglias*, in which a tune is slowly repeated, over and over, to form a ground bass for a harmonic and contrapuntal superstructure. It has *canons*—simple nursery rounds such as "Frère Jacques," more elaborate canons such as Bach's—in which one voice presents a tune and others take it up in overlapping repetition. It has *fugues*, where a tune, after successive presentation by several voices in two related keys, is treated more freely and may even appear upside down or twice as fast. It has "Variations on a Theme by So-and-So" in which, after a simple statement, a tune is elaborated and ornamented in ways that delight by their increasing ingenuity.

Poetry has rhyme and meter—simple kinds of repetition—and assonance, which is subtler. It has repetitious structures such a ballade, rondeau, and triolet. It has refrain and envoy. It may induce surprise or shock by the sudden reappearance of an utterance. Examine Conrad Aiken's "Priapus and the Pool" for the many ways in which that poem presses antiphony and repetition into service.

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[7] To the interviewer who asked her what she thought of modern art, Gertrude Stein replied, "I like to look at it."

As you listen to poetry, sharpen your ear. For a silly example, take the limericks of Edward Lear. Aficionados of the limerick often find regrettable the bathos in his habit of repeating his first line for his last. But note the little twist in: There was an old person of Wick/ Who said "tick-a-tick, tick-a-tick,/ Chick-a-bee, chick-a-baw,"/ And he said nothing more,/ That laconic old person of Wick.[8]

I have heard of a course of lectures, delivered to graduate students at Harvard by a German refugee professor, in which for several weeks he started each lecture in the same way. "Last time we were talking about the Michelson–Morley experiment. Which is this!" And he turned to the blackboard and put up the same diagram. But then he sank his teeth in the experiment from one angle, and next time he grabbed and shook it from another. It was a style that epitomized the way physics itself is actually done. One, at least, of his auditors has never forgotten it.

There are larger auditory art forms. Music has symphonies, whose themes are repeated and varied for larger purposes. The last movement of Beethoven's Third Symphony takes a free theme-and-variations form, in which the musical possibilities in a simple succession of four notes are developed through humor, to triumph, to sadness. In a cyclical form such as that of César Franck's only symphony, the themes of earlier movements all reappear in the last. And there is Richard Wagner's opera, "Die Meistersinger," which is about a fine tune: The tune appears in fragments and in travesties, and only near the end does it receive full, final, authentic statement.

And correspondingly there are larger matters of physical concern. Newton's third law is pretty big stuff. It is a theme whose implications and uses do not emerge on a first statement. Its development for a student surely demands a symphonic or operatic scope: Perhaps Beethoven, Franck, or Wagner can help to suggest style.

And so, teacher, if you would teach physics to Coleridge or to anybody else, remember that you are an artist, and behave as artists do. Paint your

[8] Remember that "laconic" doesn't mean "taciturn." It means saying a great deal in very few words. In this example, so does Lear.