General Advice to Students

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"WHO AM I"

THE STUDENT

Russell H. Graham

The following selection, which is taken from *Vital Speeches of the Day*, Vol. XXXV, No. 3 (November 15, 1968), is an address to the students delivered by Dr. Russell H. Graham, President, Coffeyville Community Junior College, Coffeyville, Kansas, September 13, 1968, at the fall convocation. The title here is inclosed within quotation marks because it is treated as a quoted question an incoming freshman may have in his mind. The question is by no means a formal one and is, therefore, not ended by a question mark.

Welcome to Coffeyville Community Junior College—if you are here for the first time, we are indeed happy to have you with us—if you are returning, we are glad you are back. You are the fabric[1] of this institution, and for each of you there is a place here. Nevertheless, in your own minds you are perhaps asking yourselves, "Why am I here?" "Who am I?" You have a right to ask these questions and to realize and understand every facet[2] of the answers to them.

First, you are a college student. With that title come many responsibilities. Classes must be attended, lessons prepared, texts and reference books read, papers written, and for some, athletic achievements made.[3] These call for a discipline of

1. fabric—framework or structure; something put together.
2. facet—phase; aspect.
3. Note that each of the co-ordinate independent clauses following the first one is elliptical, with *must be* understood.

time and mind. So you are, therefore, an organizer—one who will arrange a work load and plan a schedule to suit the needs of the requirements. You are also a recipient—a vessel into which facts and figures will be poured, mixed, and hopefully retained. You are a recipient of the achievements and experiences of those whose works you pursue. You will be an analyst, able to study objectives, to reason, to separate, to criticize, and to recommend. In time, you will be able to discern the accurate from the inane[4]—to discriminate between validity and delusion. You are a responder, one who will be called upon to answer, to refute, to provide and participate. You are a seeker—an acquirer of the imaginations and expressions of men to whose minds and thoughts you will be exposed. You are an explorer, you will deal with the abstract, the theoretical, the explicit. You will be expected to do research and seek into areas new to you. It is hoped you will be an observer—attentive, perceptive, and a good listener. You are not a statistic[5] but a very important individual for whom new programs and new processes are innovated[6] to keep abreast of[7] the changing world.

When you ask, "Who am I," remember you are the leaders of tomorrow. You are tomorrow's teachers, tomorrow's businessmen, homemakers, bankers, accountants, journalists, doctors, and lawyers. You are the decision makers of the future. The outcome and reliability of those decisions depend on what you

4. inane—empty; void; senseless.
5. statistic—any value, item, etc., used in statistics. 意謂充數之一員。
6. innovate—introduce (something new) for or as if for the first time.
7. keep abreast of—level with, not behind.

learn today. You will help design and build the future—your future. We are here to help you prepare for that architectural assignment. Yours is an exciting existence—for there is much to learn. These years cannot be relived. The record you attain here, now, is permanent and lasting. Make every class, every course, an exciting adventure into the unknown. Discouragement may be a battle you will have to fight. Yet, no one will expect more of you than you are capable of giving. Most of you will succeed, will graduate, and continue with your education. Some of you will fail. But the decision is, in the long run,[8] your own choice. The teachers cannot learn for you. You do your own learning. The advantages, individually, remain the same for all. Help is always available—through advisers, counselors, instructors, mechanical aids and tools, a well-equipped library, and the administration. Take advantage of that help. Familiarize yourself with every aid and tool. Reconcile[9] yourself to the fact that you are here to study, to learn, to grow and you will have no fear of failure. Expose yourselves to the great minds of the past, have an awareness of the world and learn to appreciate nature and the values as set forth[10] by our standards and heritage. In the final analysis, college is primarily an intellectual experience. Training is involved; vocation is not negligible; social participation must be lively and interesting; physical activity must be vigorous. Nevertheless, the central objective of college is the cultivation of the life of the mind and we must make that our foremost

8. in the long run—in the end; ultimately.
9. reconcile—bring into harmony or agreement. 安心於。
10. set forth—utter or express as a declaration. 顯示。

aim.

Who are you? You are a student, a young man or woman for whom a whole college, a whole program of learning exists, and we, the administrators, the faculty, and the Board of Trustees[11] of Coffeyville Community Junior College, extend a warm welcome to each of you as you seek to find yourselves. We want sincerely to help you. We will endeavor to lead you on the way to becoming an educated man or woman able to accept his or her responsibility in the society of a complex and ever changing world.

ADDRESS TO FRESHMEN IN HARVARD COLLEGE[1]

James Bryant Conant

(1893-)

James Bryant Conant—American chemist and educator. A graduate (B.A., 1913; Ph.D., 1916) of Harvard, he became a member of the chemistry department there in 1916, served in World War I as a major in the Chemical Warfare Service, and returned to Harvard to become professor of chemistry (1927). In 1933 he succeeded Dr. Lowell as president of Harvard and continued in office until 1953, when he was appointed U.S. high commissioner for Germany. His administration at Harvard has reaffirmed his firm opposition to too narrow specialization. Notably among the experiments he inaugurated in the first six years of his administration are the extracurricular study

1. **Harvard University**—the oldest institution of higher learning in the United States. The Puritan migration to Massachusetts, constituting a proportion of educated men unique in the annals of colonization, included over a hundred graduates of Oxford and Cambridge. These men were determined that their sons should have the same education that they enjoyed. On October 23, 1636, the General Court of Massachusetts voted to give "£400 toward a school or college." In 1633 John Harvard, an immigrant Puritan minister to America, also a bachelor and master of arts of Cambridge, bequeathed £780 (half his estate) and 260 books, and the college, until then unorganised, was named Harvard College (1639) in his honor. By continual augmentation Harvard became, especially after 1869, under the direction of President Charles W. Eliot, in the highest sense a university, but the "college" proper (Harvard College), whose end is the liberal culture of undergraduates, continues to be the center of university life, as it is the embodiment of university traditions. The freshmen are usually housed in the older college dormitories centered about the historic Yard while the remainder of the undergraduates are for the most part members of one of seven residential houses, each of which is an independent student living center comprising dormitories, dining halls, common rooms, tutorial offices, libraries, and athletic facilities.

of American history and the national scholarships, which provide higher education for carefully selected students of unusual ability and promise from distant parts of the United States. His chief works include *Our Fighting Faith* (1942), *Gencral Education in a Free Society* (1245), and *Science and Common Sense* (1951).

This is an unimpaired version of the speech delivered by Dr. Conant in September 1953, with only the last three paragraphs of the original text deleted for brevity's sake.

It is my privilege as president of the university to welcome you to Harvard: I welcome you most cordially, both personally and on behalf of the faculty and the student body. We are glad you have come to us and hope you will find this college a place where you may spend four satisfactory years. These will be years of self-development—self-development along intellectual lines and as human beings. They will be full of excitement and, I hope, of enjoyment. I am sure that most of us who have been in your place wish we might have once again the unique experience of entering college. Harvard has much to offer you: the intellectual resources of an ancient college now part of a large university, the opportunity to study in many fields, the privilege of living in a community of fellow students and, above all, a great tradition of freedom—freedom coupled with a sense of earnest responsibility.

The very fact of your coming to us indicates that you share our faith in the importance of knowledge, our belief in the significance of man's power of understanding. You clearly think it worthwhile to continue this process of education four

years longer. You do not expect to obtain here a professional training—that is a matter for the graduate school—but something else, an experience which will equip you better to live a rich life in this highly complicated modern world. And this experience is much more than the acquiring of specific knowledge, necessary and valuable as that may be.

To my mind, one of the most important aspects of a college education is that it provides a vigorous stimulus to independent thinking. The tremendous range of human knowledge covered by the curriculum, the diverse opinions expressed by the professors, the interminable arguments with your friends—all these contribute to feed the intellectual curiosity of all but the most complacent student. A desire to know more about the different sides of a question, [and] a craving to understand something of the opinions of other peoples and other times make the educated man. Education should not put the mind in a strait-jacket of conventional formulas but should provide it with the nourishment on which it may inceasingly expand and grow. Think for yourselves! Absorb knowledge wherever possible and listen to the opinions of those more experienced than yourself, but don't let anyone do your thinking for you.

Bernard Shaw[2] in "Fanny's First Play,"[3] which you may recall is a play within a play, in the final scene places a

2. Bernard Shaw—Irish dramatist and critic (1856-1950); received Nobel Prize in Literautre, 1925.
3. Fanny's First Play—A drama by Bernard Show (1911), which by the device of a "play within a play" satirizes several contemporary critics.

number of dramatic critics on the stage to discuss the play, by an anonymous author, which had just been performed. The first critic whose opinion was asked complained: "You don't expect me to know what to say about a play when I don't know who the author is, do you?…If it's by a good author, it's a good play, naturally. That stands to reason." With this point of view we can all sympathize at times. This sort of intellectual crime we all commit in our lazy moods. We tend to form our judgments on the basis of labels. These labels may be the fashion of the moment, the verdict of the multitude or the cherished opinion of a little group that "really knows." It does not matter what the source, if you accept labels at their face value you have abdicated your functions as an individual. In art, in literature, in all matters where judgments of value are concerned, an education, particularly a college education, should provide the background from which each person can develop his own standards and ideas.

When we turn to politics and the economic problems which face the world—and who doesn't turn to them today!—the same considerations clearly hold. Somehow or other, out of the complexities of the past and present, each person has to shape his own philosophy as best he can. If you are willing to borrow somebody else's you are not of the stuff that makes a free and vigorous nation. It is admittedly difficult—swimming against the stream of ready-made opinions and the masses of propaganda which descend from all sides—but this is one of the hard tasks of your generation. Even during your college career you will find groups of propagandists ready to use you

for their own purposes; you will find them to right and to left. I heard the other day a story of a student who was discussing with an older man a proposed demonstration of some sort or other. "I admit it doesn't make much sense," he said, "but that is what they tell us we should do." The value of joining any group of enthusiasts who presume to dictate what one should do is extremely dubious. Have the courage of your convictions but be sure they are your own convictions arrived at patiently by hard thinking. There are plenty of people who are willing and anxious to shout, to march and to wave flags and banners. I do not feel that this type needs reinforcement from the student body. What we do need are citizens who will examine seriously and discuss vigorously the many difficult problems with which the times present us. On all sides we hear it said that what the world needs is leaders; it does, as always, of the right sort. But it needs above all an independent group of hard-headed, clear-thinking people who face the future courageously without taking refuge behind worn-out formulas and who can tell a statesman from a demagogue. The world does not need more followers, it has too many already. Don't acquire the habit young!

The university and all the other institutions of higher learning in this country are the result of a long, slow growth. Like individuals they have a lineage and have inherited many traits and accepted many traditions from their ancestors. Harvard is descended from Paris through Oxford and Cambridge. Colleges are not machines for training youth, hurriedly constructed according to blue-print designs. They represent rather the accumulation of the wisdom of generations of devoted teachers and learned scholars. They have been made possible by the efforts of those who loved learning and believed in its value for civilization. Laboratories, museums, libraries are at the command of the college youth to-day to assist him in his work—incalculable riches from the standpoint of even fifty years ago. All this is supplied by institutions in this country, privately endowed or publicly supported, because those who have preceded us were convinced that a steady stream of highly educated young men was essential for the welfare of the country. Will the events of the next fifty years justify this expectation?

Gentlemen, you and the other of your age who are entering the colleges and universities of this country are a selected group, in a sense a privileged group on whom heavy responsibilities will shortly fall. Only about one of twelve of the young men and women of this country receives a college education; some are not interested, some are incapable of benefiting, but many who could profit from it are for one reason or another deprived of the opportunity. Whether a smaller or a larger number should pass through our colleges is a large question and one I shall not touch on tonight but pass on to you as an educational problem worthy of many a night's argument with your room-mate. At all events, if civilization is to continue to prosper in these United States, in your hands and those of your contemporaries in other colleges lies the future.

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PULLING BACK FROM PERMISSIVENESS[1]

Outside, rain spattered the windows of University Hall, the high-ceilinged, portrait-lined[2] administrative heart of Harvard. Inside, there was not a vacant chair in the hall's steamy[3] conference room as some 200 members of the faculty of arts and sciences convened for a highly charged[4] debate. The topic: a complete overhaul[5] of the undergraduate general education curriculum[6], which for the past 30 years has served as a model for higher education.

At issue[7] is Harvard's revered tradition of welcoming graduating seniors into "the company of educated men and women." The late Harvard president, James Bryant Conant,

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1. The curriculum reform reported in this story was subsequently approved by the Harvard faculty senate on April 11, 1978, though the measure will not be fully instituted until 1983. President Charles William Eliot (1869-1909) of Harvard first introduced the elective system in the belief collegemen were old enough to know what was good for them. President Conant (1893-1978) was the first to see it was not so. The new direction in American higher education shows that educators believe young people still need guidance in what they are to learn.
   pull back—to retreat; to stop short.
   permissiveness—leniency toward things that used to be not allowed.
2. portrait-lined—lined (hung in a line) with the likenesses (of famous former Harvard people).
3. steamy—giving off vapors, i.e., of perspiration.
4. charged—emotion-filled; emotional.
5. overhaul—making needed repairs, adjustments, etc., to restore (a machine, etc.) to good working order.
6. general education curriculum—courses not intended to train in special competence.
7. at issue—what is to be debated on.

in a 1945 report entitled "General Education in a Free Scciety," maintained that an educated graduate must complete courses in three broad categories—the natural sciences, the social sciences and the humanities[8]. But with the loosening of requirements[9], the growth of specialized courses and the permissiveness of the 1960s, the general education idea all but disappeared. Easy courses that could be used to satisfy the requirements, such as "History 1380: European Oceanic Discovery, Trade and Settlement, 1680-1815" (dubbed[10] "Boats" by irreverent students), mushroomed[11]. Says David Riesman, Harvard professor of social sciences: "There was a feeling on the part of the faculty that too much had been given away."[12]

As part of a growing nationwide movement toward curriculum reform, Dean Henry Rosovsky started in 1947 a major review of Harvard's undergraduate course of study. The result was a 36-page proposal for a "core curriculum" that is now being debated by the faculty. Scrapping[13] the amorphous[14] general education categories, the proposal outlines specific course requirements in five precisely defined core areas. As it stands

8. humanities—philosophy, literature, classical studies, etc.
9. requirement—all that are called for graduation.
10. dub—to name.
11. mushroom—to grow or spread rapidly like mushrooms (or bamboo shoots with us) after a rain.
12. too much……away—too much concession has been made (to the students) to make it easy for them to graduate.
13. scrap—to abolish; to nullify.
14. amorphous—formless; ill-defined.

now, the proposal would require each graduate, whatever his major,[15] to have completed:

▲ One course in literature, one in music or fine arts and one dealing with the "contexts of culture"—like a study of Medicean[16] Florence or Neoclassicism[17]—in a "literature and the arts" core area.

▲ Two history courses, one contemporary and one on an older epoch like the French or Russian Revolution.

▲ A social science course such as a psychology course on personality and one on moral or political philosophy.

▲ One course in physical science[18] or mathematics and another in biological or behavioral science.[19]

▲ A course within a "foreign languages and cultures" category.

The proposal emphasizes that courses would be interdisciplinary,[20] with an eye toward[21] a "basic literacy in major forms

15. major—chief area of field of study.
16. Medician—of the Medici family, which ruled Florence, Italy, from the fifteenth century until the eighteenth. The "c" in Medici is pronounced "ch."
17. Neoclassicism—literary doctrines prevailing in 17th- and 18th-century Europe.
18. physical science—physics, chemistry, geology, etc.
19. behavioral science—psychology, anthropology and the like that study human behavior.
20. interdisciplinary—having to do with several disciplines, i.e. branches of learning.
21. with an eye toward—considering; aimed at.

of intellectual discourse"[22] for all students. Students would be required to take an expository writing course and to demonstrate competence in a foreign language, as they are now; they would also have to take a math review course if they failed an exam at the beginning of the freshman year.

A number of schools, including the University of Chicago, already have some version of a core curriculum, while St. John's in Annapolis, Md.,[23] has developed its own "great books curriculum."Other colleges, notably Brown,[24] are standing by[25] their liberalized[26] curriculums, in which students have few set academic requirements.

Champions of the core plan, including Harvard President Derek Bok, contend that students need more guidance in what they study. Says Government Professor Michael Walzer: "We can't function[27] as a nutritionist who tells his patients that they are very intelligent and that there's a supermarket around the corner." Proponents also argue that even though the new requirements are more rigid than existing ones, they would still fill only a quarter of an undergraduate's schedule, the same as in the present system. That would leave the equivalent of

22. intellectual discourse—communication of a learned or sophisticated nature.
23. Md. —Maryland.
24. Brown—university located in Providence, Rhode Island. Founded in 1764 (Harvard, 1636), it belongs to the Ivy League.
25. Stand by—to hold on to.
26. liberalize—to make liberal, i. e. to be more permissive.
27. function—to operate, to perform (certain duty).

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two years for a major area of study and one year for electives.[28]

Foes of the reform attack it as reactionary.[29] Says Sociology Professor Orlando Patterson: "Arriving at some fixed notion of what constitutes an educated person—in this day and age, it just won't wash.[30] it moves away from a view that learning to think for oneself is the key to a modern education." Meanwhile the Harvard *Crimson*, one student newspaper, has counseled that "the core will not solve one of Havard's fundamental problems, the dearth[31] of close association between students and faculty members."

Harvard's scientists in particular are massed[32] against the proposal, arguing that it slights technologically oriented[33] science courses and will discourage the "better students" in those areas from applying to[34] Harvard. But, counters one proponent of the system, "the kind of science student who'd turn this place down[35] because of the core is the kind who'd end up[36] at M.I.T.[37] anyway."

28. electives—optional courses which students may choose freely; opposed to prescribed or compulsory courses.
29. reactionary—going against the times.
30. wash— (British colloquialism) to withstand a test or examination.
31. dearth—lack.
32. massed—to gather or assemble in a mass.
33. technologically oriented—directed or tended toward technology.
34. apply to—to make request to…(for admission, help, etc.).
35. turn down—to reject; to refuse.
36. end up—to finish; to be finally.
37. M.I.T. —Massachusetts Institute of Technology, is located about one mile east of Harvard University in Cambridge, Mass.

If passed, the plan would be phased in[38] during the fall of 1979. But it would not be easy to put into effect. Many faculty members traditionally have preferred scholarship to teaching, and specialized graduate courses to basic undergraduate ones. "The real question," says Riesman, "is whether faculty members can be persuaded that they can teach these courses while keeping their peer respect."[39] Furthermore, says Physics Professor Robert Pound, "The likelihood that these enormous courses will cause any excitement is fairly small."

Despite the problems, it is expected that some version of the core will pass at a faculty vote on April 11—especially since Rosovsky, who turned down the presidency of Yale partly to push the reform, has personally lobbied[40] 150 to 200 of the 733 faculty members. Said one professor: "The dean has really hitched his wagon to this."[41]

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38. phase in—to carry out in stages by adding little by little.
39. peer respect—respect by peers, i.e. people of the same rank, age, group, social status, etc.
40. lobby—to persuade legislators to act in a favorable way to the persuader's cause.
41. hitch one's wagon to—to set one's goal on.

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Commencement address, St. John's College, Santa Fe, May 18, 1986

N. David Mermin
Cornell University

I have to say that the only other time I was asked to talk at a commencement was 1952, when I graduated from high school. So while I suppose I should have spent the last month thinking hard about the great challenges lying ahead for all of you, I was actually more preoccupied with the great challenge lying ahead for me. What can a middle aged theoretical physicist have to say to the graduating class of this unique college?

The answer came to me a few weeks ago, when I read in a pamphlet about St. John's College that the principal goal of a liberal education is to acquire the skills of *rational thought*, *careful analysis*, *logical choice*, *imaginative experimentation*, and *clear communication*. Having always regarded these as the primary tools of the physicist, I realized that I could do no better than to call to your attention a few examples of the application of these skills in public affairs, in private life, and on the frontiers of science.

Let's begin with *clear communication* in public affairs. Several years ago I was half listening to an early speech by a new President who was acquiring a reputation as a clear communicator. Talking about a trillion dollar national debt, he was saying: "A trillion dollars is so much money that it's hard to grasp the idea, so I want to tell you how to make it a little more real."

Instantly, the President had my full attention. I spend a lot of time trying to get students to think meaningfully about quantitative information, and I hate the mindlessness with which

people publicly discuss numerical facts without any attention to scale. Here, I thought was a new moment in public discourse. This President – this Clear Communicator – was probably going to explain that there were a quarter of a billion people in the country, so a trillion dollars was $4000 per person, or $16 000 per family of four. He would then go on to compare this public debt with the personal debt of such a family – maybe $40 000 on a home mortgage and $8000 on an automobile, and he would then discuss whether this 1 to 3 ratio of public to personal debt was or was not reasonable. A new era of *rational thought* was about to dawn.

That's what I expected. What he actually said was something like this: "If you took a trillion dollars in one dollar bills and stacked them on top of each other, the pile would reach halfway to the moon."

I had two reactions to this, and I maintain that the liberally educated person should have both. First, and most importantly, in the matter of *clear communication*, disappointment and dismay at this triumphant substitution of one meaningless number for another. Second, an annoying but irresistible urge – the unbreakable habit of one trained in *careful analysis* – to check this particular piece of foolishness. Was the President right?

Well, a dollar is a pretty sturdy piece of paper. A book of well made pages like that would probably be an inch thick if it had 400 pages. Don't forget that 400 pages are only 200 pieces of paper, so an inch is $200. A foot (10 inches) is $2000. A mile (5000 feet) is $10 million, a hundred miles is $1 billion, and a hundred thousand miles – half way to the moon – is $1 trillion. Right on! God protect us from such misuses of the noble art of arithmetic, but if you've got to do it, at least do it right.

Life will continually present you with such technically correct but wacky and wildly wrongheaded appeals to the fruits of arithmetic. Watch out for them.

Equally abundant are similar invocations of science. Last March I was at a meeting of the American Physical Society, which, improbably, took place in Las Vegas – the real Las Vegas – among the slot machines and blackjack tables of a huge establishment called the MGM Grand Hotel. After two days in this genuinely lunatic environment I couldn't stand it anymore. I got a rental car, and drove out to Hoover dam, which I'd always wanted to see. The contrast was powerful and dramatic between the dignity of this immense and overwhelmingly purposeful piece of architecture, and the vast monuments to bad taste and pointless frenzied activity that I had just escaped from, but what particularly intrigued me was a great plaza on the Nevada side of the dam built to commemorate the formal dedication by President Roosevelt.

Set in gleaming brass in an enormous marble pavement flanked at either end by two fierce, lean, gigantic white angels, was – what do you think? Surely a map of the Colorado river and the surrounding lands that this wonderful structure would fertilize and protect? No – not at all. Imbedded in that vast stretch of marble were a great many circular brass disks. They represented the positions of the planets with respect to the fixed stars on that day, September 30, 1935 that President Roosevelt dedicated the dam.

The attention to detail was impressive – the disks came in half a dozen sizes, representing stars of different magnitudes. Most remarkably, embedded in the pavement, in brass letters almost an inch high, was a giant astronomy lesson. To read it, you had to walk back and forth along each line of text, squinting in the blinding sunlight. But if you worked hard, walking back and forth, you could learn about red giants, white dwarves, cepheid variables, red shifts, and the expanding universe.

What did any of this have to do with Hoover dam? Absolutely nothing. It was an expression of exuberance: "We've conquered the Colorado river, and we've frozen the planets in place against the stars to help any visitors from outer space figure out when we did it. And please note that we know one hell of a lot about those stars."

Is Hoover dam a contribution to science? Certainly not. It is a contribution to human welfare, a spectacular achievement of engineering, and a great work of art. Somehow that wasn't

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enough, and it had to be additionally recorded in brass and marble that the achievement resembled the discovery of the expanding universe.

The world will continually present you with opportunities like these, to misinterpret big numbers and confuse with science things that are not. Often critical questions of *logical choice* depend on making the right interpretation or avoiding the confusion.

Fifty years after the construction of Hoover dam, the great public works projects of our time are done not by the Army Corps of Engineers, but by the National Aeronautics and Space Administration. A new space shuttle will cost a couple of billion dollars to build. How does one find the measure of such a sum? Not in a stack of ones stretching from Albuquerque to Los Alamos. Nor as the yearly income of 30 000 commencement speakers, nor even as a tenth of one percent of the national debt.

No. A couple of billion dollars is somewhat larger than the annual budget of the entire National Science Foundation, the nation's most important source of support for pure research in all the sciences. Why do we need another space shuttle? For the science. What science? Well, maybe it will be possible to make more perfect ball bearings in a weightless environment, or grow more perfect crystals, or improve the manufacture of pharmaceuticals. Ah, then it must be being done as part of the crash national program in crystal growing, pharmaceutical, and ball bearing betterment. No. It's being done for many complex reasons, but few of them have anything to do with science.

The space shuttle teaches us that *careful analysis* and *rational thought* have suffered a decline since 1935. In 1935 we needed a dam, built it, and then, in a ceremonial moment, tried to lend it an absurdly inappropriate cosmic significance. Today we build on that grand scale out of some inarticulated sense of cosmic significance, and then search around frantically for a purpose.

Watch out also for heroic efforts, launched on behalf of an articulated but manifestly preposterous goal. Recently, scientists have been called upon to render nuclear weapons "impotent and obsolete." This is a new level of confusion – the confusion of science with magic. The level of expenditure is also new: twenty-five billion dollars over five years just for research and development.

Scientists and engineers are almost unanimous in agreeing that the protection of people and cities that this program ostensibly aims at is impossible. Powerful demonstrations of its absurdity can be found in the pages of *Scientific American* or even the *New York Times*. Over half the faculty of the top twenty physics departments in the nation have signed a pledge not to participate in such folly. Even the organization established to carry out this parody of a research program acknowledges, when pressed, that the announced goal is impossible to achieve. Yet it looks as if spending at the rate of five billion dollars a year will be approved for a fantasy that will, inevitably, drain the resources for real scientific investigation, which pays some attention to where we are and where we can get to from there, as well as where we might like to be.

So much for rational thought in public affairs. President Delattre told me that a good commencement address should illustrate how intelligence and the liberal arts can affect a life, so I also tried to think on a very small scale, of characteristic incidents in my own life. I offer you two:

The first I flatter myself comes under the category of *imaginative experimentation*. I've lived for several years in England, a country where people drive on the wrong side of the road. I discovered that in England I could not correctly use the words right and left when I was in a car. Something deep within me knows ineradicably that "right" means "easy turn" and "left" means "hard turn"; and I invariably produced the wrong term when I tried to give directions.

More recently I was in Japan where they also drive on the wrong side, and I had to learn enough Japanese to give directions to cab drivers. Double trouble. Getting straight the difference between right and left is hard enough in a language where each is represented by an entirely meaningless sound. Now added to that difficulty, was the further problem of interchanging them while driving along the wrong side of the road.

The solution came to me in a great flash, and the same sense of pride and joy that accompanies a discovery in physics: don't learn the terms as "left" and "right" – learn them as "easy turn" and "hard turn." "*Hidari e magatte kudasai*" – "Please make the easy turn." It worked perfectly, and I see no flaw in my solution, until the improbable day I find myself giving instructions in Japanese in a country where they drive on the right.

Here's a second example of how *careful analysis* and *imaginative experimentation* can be put to work in your own lives. Suppose you add up the results of many measurements. Each has a certain error. How big is the error in the total? Well, you might think if you were adding up N items, the error in the total would just be N times the error in each. But it's not that bad. Some of the measurements will be too big, some too little, and when you add them up the errors start to cancel each other. In fact it's a famous theorem (which is very easy to prove) (and I hope you learned it in your four years here) that the error in the total is not bigger than the individual error by N, the number of measurements, but only by the square root of N, a much smaller number. If you're adding 100 items, the error in the total will not be a hundred, but only ten times the individual error.

You can put this principle to good use relieving tedium at the supermarket and checking the accuracy of the clerk. As you put items or groups of small items on the counter it's very easy to keep a running total of the price in your head if you estimate each item only to the nearest dollar – hardly more difficult than just counting what you put down. The size of the typical error in each estimate is 25 cents. If you have 35 items, then the square root of 35 is about 6 and so the typical error in your total will be 6×25 cents or about a dollar and a half. With a little practice you can begin to develop a sense of whether you've been rounding up more than you've been rounding down, and make the occasional adjustment to improve your total. I'm at the point where I often get to within a dollar of the right answer. My children are enormously impressed (or embarrassed) when I announce the total ("looks like about $43") just before the clerk rings up $42.38.

What is the point of all these examples? What have they to do with the life of a scientist, or the attitudes of the liberally educated? They share a few principles of almost banal simplicity: one should take nothing for granted; one should try to understand everything; one should constantly look for new ways to deal with old ideas, new ways to apply knowledge. One should take delight in surprises – in turning things upside down. In discovering that one was entirely wrong about something obvious.

One of the classic examples of this in the 20th century is the theory of relativity. You remember Newton's wonderful statement at the beginning of the *Principia*: "Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external...." Lovely as this is, as a description of nature one might think it was trivially self evident, or one might think it was devoid of content. Neither view is correct: as you know, it is simply wrong.

There is no absolute, true, and mathematical time. One man's now is another man's then is a third man's yet to be. Time is something we impose on nature, as we impose lines of latitude and longitude on the world. Minkowski's poem isn't as magnificent as Newton's, but it has the advantage of truth: "Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."

This is a good thing to know. If this astonishing discovery had not been made we would not today have anything remotely comparable to our present understanding of matter or the universe. But, just as importantly, in making this discovery or learning about it, we discover something very important about ourselves: that everything, no matter how evident or obvious, should be doubted, questioned, viewed with suspicion; that unexamined truths are likely to be falsehoods; and that there is much to be gained from the discovery that one has been deeply, persistently, and utterly wrong.

Here is a final example from my own work as a physicist in the last year and a half. Matter likes to solidify into crystals. The

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characteristic feature of crystals is that their atoms are arranged in regular periodic patterns, that repeat themselves like the design on a tile floor. Such patterns are often quite symmetric: if you take a crystal and rotate it appropriately it ends up looking exactly the same as before. It's very easy to prove that not any rotation is consistent with the periodicity of the crystal. Crystals can be symmetric under rotations that are a half, a third, a quarter, or a sixth of a complete revolution, but nothing else. (This is another nice theorem – if I had two hours and a blackboard I could teach you a lot of nice things.) In particular they cannot be symmetric under five-fold rotations, that are one-fifth of a complete revolution.

This means that of the Platonic solids only the tetrahedron, octahedron, and cube can have the same rotational symmetries as a crystal. The icosahedron and dodecahedron have five-fold rotational symmetries, and these are impossible.

This has been known for as long as the atomic theory of matter has been accepted, and has been one of the pillars of crystallographic science. It therefore caused a general sensation, when about a year and a half ago an alloy was produced whose electron diffraction pattern had certain characteristic features that occur only in crystalline matter, but with a rotational symmetry precisely that of the icosahedron (or dodecahedron). To get a sense of how revolutionary this is, you should know that Landau and Lifshitz, probably the most authoritative series of physics texts in the world, baldly states that icosahedral symmetry is "of no physical interest," since it does not occur in Nature as a symmetry of inorganic matter.

This is the context in which it is the most fun to do physics. Everything has to be reexamined. We thought we knew all the ways atoms might arrange themselves into chunks of matter, but now we've found stuff that has some properties we were sure only crystals could have, and another property we know no crystals can have. All the old ideas have to be viewed with suspicion – all the obvious old definitions have to be reexamined. Any idea is worth trying out, and most of them will probably have to be rejected. Papers are flying back and forth – new experiments are being done all over the world – so many conferences are being organized that if you went to half of them you wouldn't have any time to think about the problem at all. Priority disputes have erupted. The crystallographers think the physicists have gone crazy. The physicists deplore the limited imagination of the crystallographers. It's science at its raucous best.

This is not how you go about building Hoover dam. This stuff was found by accident. We have no idea what it's good for or where it will lead us. The entire national effort in this field probably amounts to a few hundred thousand dollars – to be viewed not as a hundred foot stack of ones, but as the cost of supporting a few dozen graduate students, since most of the experiments are easily done with existing equipment. These icosahedral quasicrystals are providing us a most excellent occasion for exercising the skills of rational thought, careful analysis, logical choice, imaginative experimentation, and clear communication.

The best I can wish for you on this commencement day is that you too will continue to find many such occasions.

~請貴系所教師、職員、學生務必熟記~

院級單位	基本素養	核心能力
理學院	1. 品德涵養及在地關懷 2. 科學之專業素養 3. 國際觀 4. 人文藝術陶冶	1. 理論與實務並重 2. 外語能力 3. 發現及解決問題的能力 4. 跨領域整合的能力 5. 溝通表達能力
應用數學系所	1. 具數理邏輯與思考能力 2. 具應用數學(計算數學軟體、計算機概論、數值分析、微分方程、動態系統、機率論、統計學)的基本素養	1. 邏輯推理的能力 2. 基礎數學(微積分、線性代數)的能力 3. 計算數學軟體實作的能力 4. 計算機概念及程式設計的能力 5. 進階數學(高等微積分、代數)的能力 6. 微分方程(常微分方程、偏微分方程)的能力 7. 數值分析及其程式設計的能力 8. 矩陣處理的能力 9. 離散數學的能力 10. 機率及統計問題處理的能力 11. 群環體抽象代數結構處理的能力 12. 上台表達的能力 13. 獨立思考的能力

~請貴系所教師、職員、學生務必熟記~

國立交通大學學生應具備之基本素養與核心能力

本校學生應具備之基本素養：

(1) 資訊素養(如電腦及網路的使用能力、解決資訊問題、資訊倫理、篩選資訊的能力、媒體素養…等)

(2) 公民責任(如民主素養、對公共事務的參與與認知，對權利義務的認知與實踐…等)

(3) 品德涵養(如情緒管理、尊重他人、尊重生命、社會服務…等)

(4) 人文及在地關懷

(5) 人文藝術陶冶。

本校學生應具備之核心能力：

(1) 專業知能(校級與各學院課程應培養之領域特質與專業知識)

(2) 國際觀

(3) 外語能力

(4) 發現及解決問題的能力(如觀察力、邏輯分析、創意思考、資訊判別處理、批判思考、決策思考、時間管理…等)

(5) 跨界多元思考的能力(如創意思考、跨領域整合…等)

(6) 群己平衡的認知(如身心平衡、團隊合作、溝通表達能力、人際關係、自我認知…等)。

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李怡嚴 對 普物生的建議

學習的方式與態度 :

大部份選修這一組（03）的同學，是主修物理或相關科目（如材料科學）的，這門『普通物理』實為各位最重要打基礎的課，學習的成效可能會影響到各位日後是否能順利把握各科有關物理科學的後續課程，以在自己所選擇的專業中站穩腳步。希望各位同學儘快收拾起在假日或在成功嶺鬆散了的心情，迅速進入學習的情況。在此我根據以往教學的經驗，謹提幾點建議，供各位同學參考。

首先，在大學中學習的方式與在中學很不同；中學生多少扮演着被灌輸的角色，而在大學中求學，如果不能自動自發，僅憑考試以前倉促記憶去應付，很難真正會學有所得。對學問的追求，教師僅能幫忙指路，以及在關鍵處解答疑難；真正的探索工作，還得自己去做，教師無法越俎代庖。在物理科學的學習過程中，必須着重於觀念的透澈與條理的明晰，對瑣碎細節的把握，應建立在統合關聯的基礎上。當各位同學在中學時，也許已習慣於接受各種『摩擬試題』的標準答案，以之作為聯考的敲門磚，而不去計較『標準答案』何以為『標準』；久而久之，可能會養成『不求甚解』的習慣，這對日後學習會產生非常惡劣的影響。我寧願自己是在多慮，希望各位並沒有感染到這種壞習慣；可是如果您經過反省後覺得確有如

此之傾向，則必須趁着還年輕的時候趕快努力改掉。一般人學習習慣的養成，大約在二十歲以前，在大一的時候去改動舊習慣，已經需要加一把勁，可是還來得及；如果由於怕難而再拖過幾年，等到大三、大四，學習的習慣已經定型以後，再覺悟想改，可能就已經會太遲了。

建議各位同學在上課以前，把課本上將要講到的地方大略先看過一遍；不僅看算式，還要注意文字的說明。這種預習的好處，在於可以先有一個大致的概念，聽課時不致於茫無頭緒，學習上並可掌握主動。預習並不需要全部都看懂，重要的是先在腦海中建立一個概括的骨架，遇有看不懂的地方，不妨做上一個記號後先行跳過，在姑且承認此部分結論的前提下繼續閱讀後面的內容，千萬不要因遇阻而停滯不進。在上課的時候，可以集中精力去聽懂那些較難的部份，並可針對關鍵之處問清楚。各章之末有 QUESTIONS ，有一部分在預習時可作思索的資料。書中 QUESTIONS 數目相當多，有些並不那麼簡單，在預習時遇到有想不透的，不妨暫時放下，必要時將思索過程用簿子記下來，留到復習時再想。

為使預習能充份發揮其功效，必須持之以恆，在上課前經常有所準備，保持進度超前，而且千萬不要因一時的落後而放棄預習，以致落後得越來越多。在進度後面追趕是很累人的事，很容易找到理由去拖延，甚至會認為『反正怎麼追也追不上，樂得先輕鬆一下』，終於演變成臨到考試前再抱佛腳的惡性循環。如果由於某些因素（例如準備別科的考試而挪用了太多正規的時間）而致暫告落後，有效的補救方法是，馬上先預習下一堂要教的章節，跳過中間落後的部分，而姑且承認其結論；等到復習的時候再徐圖補回。能這樣，落後的部分才有機會越補越少；而且，教科書中有很多重覆以及前後照應的地方，往往後面的閱讀剛好就可以有助於解決前面的困惑；因此只要力求保持計劃的進度，不使落後的情形過於惡化，補回中間跳過的部分並不會如想像那樣困難。

書上的英文相當淺近。雖然初讀時可能會不習慣，而且坊間譯本充斥，容易被引誘去看；可是為了保持正確性，（譯本無論如何比不上原本。）也為了養成日後利用英文吸取科技原始資料的能力與習慣，我還是希望各位能夠克服初期的困難，盡量去讀英文的教科書。在中學對英文已下過工夫的，當然不會有問題；即使以前未有過閱讀整本英文書經驗的人，相信在經過兩個星期至一個月的適應期以後，一定會發現，英文的科學書籍其實並不那樣難讀；其中的語法與常用的字彙，來來去去就是那有限的一些，看多了自然就熟能生巧，很多生字的意義，憑上下文就猜得出來。漸漸可將閱讀速度增加到能與中文相比，這絕對不是幻想。

上課時務請跟上講課之思路線索，盡量去瞭解各項觀念的意義，以及其間的邏輯關係。如果有疑慮或跟不上的地方，務請馬上告訴我，使我有機會來立即加以澄清。在堂上隨時提出問題是非常正常的事，由此可以增進教學雙向的溝通，千萬不要因為『不好意思』，或是為怕打斷講課影響了進度而不敢發問；您所問的問題很可能也是很多別位同學想問的，您將問題提了出來，增加了討論的機會，也幫助了別人學習。而我也可以從各位的問題中了解各位學習的進度，以作調整教課方式與快慢的依據。在此我再一次強調，千萬要改掉中學時被動的學習習慣。

每個週末，最好趁聽課印象猶在的時候，找一些時間來將一週所學的內容復習一遍；復習時最好反覆問自己：是否對每一個觀念都感到踏實、每一個推導過程是否都得到滿意的交待、每一個例題的演算是否都很明朗等問題，並且力求妥貼；遇到有不妥貼的地方，應該趕緊在堂上或堂下問個明白。以前暫時放開或跳過的地方，趁此機會可以補回。教科書每章之後都有 REVIEW AND SUMMARY ，復習時可作引路之用。各章的 QUESTIONS 也再度可供利用以澄清許多觀念；以前想不透的地方，可以再拿出來想一想，試試看有沒有新的路道，也可藉以探討自己長進了多少。

做習題是學習的一部份，可以從嘗試中考驗自己有沒有建立起正確的觀念、有沒有把握到適當的技巧；務請各位不要掉以輕心，不要抄別人的作業或甚至抄坊間的題解來塞責，那只是在欺騙自己而已。在所繳的習題作業中，最好盡量寫出解題的方針以及運算的過程（而不僅寫出答案），以便助教在批改各位作業的時候可以判斷您的做法對不對，並可以對症下藥，告訴您缺陷在那裡。對發回來的作業，希望各位再詳細看一次批改過的地方，記取教訓，使以後不致再犯同樣的錯誤。上面所挑選的各章習題，大多數相當富啓發性，而且除少數外，都並不太難，按部就班做去，應該沒有大問題。EXERCISES 一般說來更簡單一些，可以先做，以建立自己的信心。漸漸可以嘗試去解決 PROBLEMS， 一個值得嘗試的入手途徑，是與性質類似的例題相比較，對相同的地方，可仿用其技巧，揣摩其各項步驟的動機，並回顧書中 HINTS 所突顯的觀念與教訓，用來作必要變化的根據。應特別強調的是，藉由做習題可以養成分析問題的能力。從習題中抽取出關鍵的部份，看看與所學到的觀念有那些相關，嘗試用這些觀念將習題中已知與未知部份連繫起來，以求得答案；這種構思的方法，運用多幾次以後，自然熟能生巧，到那時，即使遇到較難的題目，也可從思索解答的過程中獲致突破的成就感而不會覺得是一項負擔。做習題的時間可以緊接着復習的時間，當時就試驗一下復習的效果，漸漸將所需做的功課做掉，不必在繳交前夕再苦苦追趕；由需要繳的習題數目來估計，每星期平均化費在習題上的時間大約應為六小時左右（當然可以有一些起伏），各位不妨用這個標準來衡量自己學習物理的能力，以及進展的情形。

數學在物理中一向是很重要的工具，需要熟習其技巧，在學習時請多加注意。本學期所用到的數學，主要為解析幾何、線性代數、與微積分（包括簡單的微分方程），前二者在中學應該已經教過，可是通常多不太會注意到物理上最有用的三度空間問題；後者在中學多講得不夠，必須在大學的微積分課程中從頭學起。好在普通物理的教科書中，對初用到較深的數學多會由物理的觀點從頭加以介紹，希望各位多利用這個特點，盡量給數學以物理的內涵；不管在別的地方學了多少數學，用於物理時最好能與物理觀念融會貫通在一起，不去強分那些是數學，那些是物理。本來數學也是從實際的問題衍生出來的，祇不過獨立發展得較為完整而有系統罷了；在利用這些系統當作工具時，正好追本溯源以提升其效果。數學中主要的研討對象——數與形——本就很適合於描述自然現象；而數學中的推理與演算，本來就是一種演繹的過程，非常適宜於建立理論的架構，並獲致可資驗證的推論。例如：空間的觀念自然用上了幾何（尤其是配上坐標的解析幾何）更宜於描述位置、連續性的運動使微積分有用武之地、旋轉可以很自然地被表現為線性變換等等，這些都使數學的描述與物理的觀念密

切接合在一起；使大家在學習時覺悟到，數學與物理其實是會互相支援的。而在解題中所常用到的一些數學技巧，其推演過程也往往會顯示出重要的物理規律。（例如：線性組合之於干涉。）能了解到這一層道理，對數學的功能就會愈加欣賞，而不會有畏懼感。

物理是一門系統性的科學，在學習過程中最好能避免瑣碎，建立整體性的概念。希望各位同學每當學完幾章稍告一段落後，找一些時間把所學過的物理觀念前後貫串思索一下，尤其應該着意各觀念間的關聯；漸漸在腦海中建立起一個日益密緻網絡，連繫着各個自然現象，以及現象間表現出來的條理與規律。思索若有心得，為免遺忘，不妨找一本簿子記下來，積久必有可觀。如果不習慣於這種『抽象性的』思考，則借助於應用的實例作為聯貫的線索，也是一條有效途徑；這方面可參閱教科書中的 ESSAY 以及許多通俗性科學雜誌（例如 SCIENTIFIC AMERICAN）上面的有關文章。本來，『應用』就是一連串自然現象在特定安排之下的再現；把握了安排與結果間的關係，當然有助於了解科學的規律。上述這些類型的思考，在科學課程的學習中，可將被動接受的資料徹底消化成為自己認知的一部份；希望各位能夠運用純熟，養成習慣，則不止在這門『普通物理』上可以游刃有餘，而且對以後的課程，也無往不利。

除了上節所提及的通俗性科學雜誌以外，這裡也許應該談一談關於課外參考書籍的問題。一般說來，如果行有餘力，參閱一些其他著者同類型的書籍，來和教科書相印證，未嘗不是一件值得鼓勵的事。任何一本書往往會傾向於某一種講法，與讀者的思路未必相近，冒然鑽下去未必會獲致共鳴；這時有另一種講法的書在旁邊比對，當然會容易瞭解得多。然而在入門的『普通物理』課的場合，通常不會有此情況；普通物理的教科書固然汗牛充棟，一般有名的，經過無數次試教改訂，多已演變得四平八穩，容易看得懂，而且其講法大多已標準化，各本之間足以比對印證的地方並不太多。因此我的建議是：學期開始的時候為了要適應大學新的學習環境，還是將心力集中在教科書上比較好。如果過了一陣子，您覺得很能夠勝任愉快，則可嘗試去看一些介乎普通物理與物理專業課程之間的套頭書，以求學得更深入一些。例如：ALONSO & FINN ：FUNDAMENTAL UNIVERSITY PHYSICS （一共有三本的那一套）；BERKELEY PHYSICS COURSE （一共有五本，著者與書名分別為： KITTEL, KNIGHT & RUDERMAN : MECHANICS; PURCELL: ELECTRICITY AND MAGNETISM; CRAWFORD: WAVES; WICHMANN: QUANTUM PHYSICS; REIF: STATISTICAL PHYSICS），以及由 Richard P. FEYNMAN 演講記錄下的 THE FEYNMAN LECTURES ON PHYSICS（共有三本）等。尤其最後那一套，不太容易讀，可是如能進入情況，每讀一次就會有一次的獲益。程度較高的同學，可以從這些書中提早學到東西，其他同學也無須好高騖遠，讀好教科書打穩基礎後，一樣有機會可以再進一步。

上面所說，是根據我自己的一些教學經驗而寫的，提出來供各位參考，希望能對各位的學習有所幫助。『普通物理』固然祇是一科入門課，然而，『好的開始，是成功的一半』；只要方向走對，以各位的資質，在作了上述的努力以後，相信一定可以在物理的學習上紮下堅實的根基；並可養成良好的讀書習慣，使以後到高年級再遇到物理課程的時候，也能夠應付裕如。預祝各位成功。

IF I WERE A FRESHMAN AGAIN

Thomas Arkie Clark

(1862–1932)

Thomas Arkle Clark—American educator. He was born at Minok, Illinois, and educated at Illinois, Chicago, and Harvard. He published a number of books and articles on the problems of undergraduate life. This essay is reprinted from *The Fraternity and the College* (1916).

It is the habit of age[1] to give sage[2] advice to youth. One of the pastimes in which everyone periodically indulges is the pleasant hallucination[3] that if he were given the opportunity to live his youth over again he would do it differently and more successfully. We are all of us, even though we have no more than reached middle age, given to[4] regretting our neglected opportunities and our lost youth. It gives one a virtuous feeling in imagination to dodge[5] all error, but it is extremely doubtful if many of us, even if we had a second chance, would avoid many of the pitfalls[6] into which we stumbled, or follow a straighter path than that by which we

1. age—old persons collectively, in contrast to *youth*.
2. sage—characterized by wisdom; showing judgment and discernment, as: sage advice, sage comment.
3. hallucination—fancied perception of something which has no real existence; illusion.
4. be given to—have the habit of.
5. dodge—avoid by some trick.
6. pitfall—a trap for animals to fall into; hence, figuratively, an error or danger into which it is easy for one to fall.

have so far[7] come. If it is merely pleasant for us to conjecture[8] what we should do if we had a second try at it; it may be profitable for those who are younger to listen. If only foresight could be as accurate as the backward view![9]

If I were a freshman again I should not work so many hours as I did. I put in[10] enough hours with my books in my hands, but I did not accomplish much. I had little concentration. Many students whom I know, and I was one of this sort, spend a great deal of time in getting ready to work. With a book in hand they look out of the window at the clouds or at the pretty girls passing along the street, and all the time they deceive themselves with the idea that they are working.

Many an evening, when the work was heavy, I would determine to begin early and get it over with;[11] but I could spend half an hour in arranging my books and getting myself seated in a comfortable chair. All this time I imagined I was working. I spent as much time in goading myself on to duties[12]

7. so far—up to now.
8. conjecture—guess.
9. If only foresight could be as accurate as the backward view! Here Clark states his wish that those who are young should first lay a plan and then carry it through. (1) *If* (often with *only*) may be used to introduce an exclamation indicating a wish, as: If only Dad could see me now! (2) *foresight*, the act or ability of foreseeing. (3) backward view, *hindsight*, i.e., ability to see, after the event, what should have been done: opposed to *foresight*. There is an English saying, "Hindsight is always better than foresight." 意謂「但願後學以此爲鑑。」
10. put in—spend.
11. get it over with—get through with it; have done with it.
12. goad oneself on to duties—incite or urge oneself to do work that one dislike doing.

that I should have liked to shirk or in getting ready to work as I did in actual labor. If I were a freshman I should plan my work, I should try to develop concentration—I should work harder but not so long.

I should learn to work with people about me. As it was, I lived a somewhat isolated life. I did my reading and my studying alone, and though there were some advantages in this method, there were serious objections. Now I must often work under different conditions from those by which I was surrounded in college; there is work to be done where there is no quiet, and I do it with difficulty. As I tried on a crowded ocean steamer to put these wandering thoughts on paper I was constantly annoyed by the confusion about me and by the spasmodic[13] attempts at conversation made by a well-intentioned but misguided young man at my side. If I had learned to work under different conditions I might have turned the conversation aside as a steep roof sheds the rain. I believe it is a great advantage for a young man to do his work himself, but he should not subject himself to the slavery of doing it alone.

I should take, as a freshman, if I had my work to do over again, more work that I have no especial fondness for or that I find difficult. I like an easy time as well as any one, and I do not wish to give the impression that I think it an error for a student to follow the profession he enjoys or to do the work he likes. In point of fact[14] I believe that a student

13. spasmodic—occurring very irregularly.
14. in point of fact—as a matter of fact.

should choose those lines of work along which his tastes lead him. I think it very likely that those things we do most easily we shall do best; but I have found that training comes through struggle, and that people are developed most who resist most, or who struggle against difficulty and opposition and overcome. I have known a good many geniuses, but they generally had the most commonplace[15] careers because they never learned to do difficult or disagreeable things.

Students come into my office every day who want to get out of work[16] or to drop a subject,[17] or to cut a class exercise[18] for no better reason than that they find the duty difficult or the instructor or the subject dull. Much of the work of life is not pleasant. Half the things I am forced to do during the busy days of the college year are unpleasant things and things I dislike doing. I have been forced to learn to give these things my best attention whether I like them or not. I wish I had learned in my freshman year to do more such things.

Just yesterday as I was sitting at the breakfast table talking to a young freshman, in whom I have a rather vital interest, as to next year's course, I suggested a subject which I thought good for him to take. "Is it easy?" was his first question, and when I answered in the negative his interest waned. In the world in which we must in time work there

15. commonplace—ordinary; neither new nor interesting.
16. get out of work—avoid, escape from work.
17. drop a subject—give up a subject which one has taken; cease to pursue a subject.
18. cut a class exercise—(Colloq.) be absent from a class exercise without being excused.

are few easy roads, few snap[19] courses. We shall be forced to do a great many hard things. If I were a freshman I should learn to do such things early.

Like a great many people, I suppose I am not now doing the work that as a college student I planned to do. I am in no sense[20] a fatalist, but I am convinced that men have their work chosen for them quite as often as they themselves choose it. If I had supposed that I should be called upon[21] to speak on the most unforeseen occasions and upon the most unfamiliar topics, I should have given myself while in college the practice which I believe is the method everyone must employ if he is to become a ready speaker. I have learned that, sooner or later, every intelligent man is called upon publicly to express his ideas, and no matter how abundant these thoughts may be, he will suffer much pain and have little success unless he has had pretty regular and persistent practice.

I ran across[22] an old classmate last spring, an engineer of no little repute,[23] whom I had not met since the day of our graduation. "How would you change your course," I said to him, expecting that he would long for more mathematics, "if you had it all to do over again?"

"I should learn to write and I should learn to speak," he

19. snap—(Slang) simple, easy; as, a snap assignment.
20. in no sense—absolutely not.
21. call on or upon—request or order (someone) to do something; require.
22. run across—meet by chance.
23. of no little repute—quite famous (repute, reputation; public esteem).

answered, "and I should begin as a freshman. As it was, I avoided every opportunity to do either, with the idea that only ministers and lawyers have need of such practice, and I suffer for it every day. My boy is to be an engineer, but I am going to see that he does not make the mistake that I made."

When I am called upon unexpectedly to speak and my knees shake and my voice falters,[24] and the word that I long for comes with difficulty, or fails to come at all, I agree with my classmate, and I feel sure that if I were a freshman again I should learn to speak correctly and without notes.

I wish that as a freshman I had learned to play well some athletic games. It is not entirely for the pleasure that I should have derived or should be able to derive from such games that I feel as I do, though that would mean much. If a man succeeds, as all hope to do, he gets into a business which is likely to be cruelly exacting,[25] and he demands some relaxation in which he finds pleasure. For me there is no pleasure in hitting a bag that simply bounds back to be struck again, or in pulling up a weight that drops stupidly and inertly[26] down to be raised the second time. I would rather hoe in the garden, saw wood, or beat a carpet hanging on a clothes' line in the back yard. I find no virtue in any of the machinery or in any of the "systems" devised by shrewd inventors for keeping the human system[27] in ideal working

24. falter—speak in hesitating way, or with broken voice.
25. exacting—demanding great care, patience, etc.
26. inertly—slowly; lifelessly.
27. the human system—the human body.

condition. If I am to have pleasure in exercise, and I will not take it from a sense of duty only, it must be in a physical contest where something definite can be accomplished, where I have a goal to attain or an opponent to beat. I would rather play a good game of tennis than agitate[28] all the exercisers[29] in Christendom.[30] I think there are few things that help more to keep men young and ready for the daily battles than good physical health; and the athletic game aids materially in bringing about that condition. One may learn, of course, late in his college career or even after he is out of college; but pride and awkwardness, and the manifold duties of the day come in and prevent one's doing so. If one does not develop some skill while a freshman he is very unlikely to do so later.

If I were a freshman I should determine to do some one line of work well. As I remember, I was principally concerned in[31] "getting through." I was not quite so modest in my scholastic ambitions as the young fellow who told me not long ago that a "pass" was as good as one hundred per cent to him, but at least I was not so much concerned about[32] doing my best in some one line of work as I wish now I had

28. agitate—rouse to action; move or force into violent, irregular action.
29. exerciser—(a) a person who exercises, (b) a mechanical apparatus for exercising the muscles.
30. Christendom—those parts of the world where most of the inhabitants profess the Christian faith.
The whole sentence means, I would rather play a good game of tennis than work on any apparatus or instrument for physical exercise the "civilized" world devised. 我寧願好好地打一場網球，而不願玩任何文明的機械運動。
31. be concerned in—be interested in.
32. be concerned about—be anxious about.

been. Practically every college man, freshman included, is rushed[33] with his work. He takes more "hours" than he should, or he neglects to prepare the assignments at the proper time, so that when his work is done it is done hastily. Nine out of ten freshmen are behind with assigned work. I have known fellows even to go as far as to argue that it is an excellent practice to get behind, for if one is to catch up he must then force himself to do a large amount of work in a short time. I grant that this may be a good thing, but work done under such conditions usually shows all the earmarks of slovenliness and superficiality.[34] There are many subjects in which I think it would be sufficient to merely[35] do good work, but at least in one subject I wish I had made it a point to take time to give the matter careful thought, and to do it as well as it was possible for me to do. One has to rush through work far too often later in life; it would be a comfort to remember that at one time at least I had deliberately taken time enough to do an assigned task well.

I should make more of an effort than I did to get acquainted with my instructors. The conception of the average freshman is that the college instructor is a somewhat abnormal mortal full of knowledge—sometimes—but without much understanding of the individual or sympathy for him. Some are; and some of this sort expended their time on me

33. rush—forced into hasty action, without time for reflection.
34. earmarks of slovenliness and superficiality—signs or characteristics of carelessness and shallowness.
35. to merely do—(This is a split infinitive. The splitting is justifiable if it avoid awkwardness or makes the meaning clear.)

when I was a freshman. I thought as a freshman that the less I bothered my instructor the better, and if by some good fortune he was ill or out of town I put it down at the end of the day as one of the blessings for which to return thanks. I came in the end to see that my instructors—even those who at first had seemed most impossible—were pretty human creatures, with a wide knowledge and a generous willingness to help. The trouble was with me quite as much as with them. I count it the greatest pleasure and benefit of my college life that I came to know one instructor well, that from this acquaintance there came to me a friendship and an inspiration that was worth more to me than all the rest of my college course. How much more it might have meant had I come more closely into contact with the real lives of the other men and women with whom I worked!

If I were a freshman I should not lose an opportunity to see and to hear the prominent men and women in public life who for one reason or another come to every college town. I was often hard up or "broke,"[36] and I could easily find an excuse for not going to lectures, or the concert, or the theater. Now I regret that I missed opportunities which never came again. I had always wanted to hear Henry Ward Beecher,[37] but when he came to town the dollar that was required to get into the lecture hall seemed big to me, and I decided to wait until the next time. But the next time never came, for Beecher died soon after, and, it is one of the regrets

36. hard up or "broke"—penniless or "bankrupt."
37. Henry Ward Beecher (1813—1887)—American preacher and writer, an advocate of the abolition of slavery.

(8)

THE METHOD OF SCIENTIFIC INVESTIGATION

Thomas Henry Huxley

(1825-1895)

Thomas Henry Huxley (huks'li)—an eminent English scientist, the author of a number of works. He was an ardent evolutionist and the chief expositor of Darwin's theory of evolution. His essays and addresses are very recommendable, "partly because they are excellent expressions of the spirit and methods of science, and partly because Huxley as a writer is perhaps the clearest and the most readable of the scientists."

The following speech was first delivered in 1866 to an audience of unread workmen in England. Since Huxley, a great popularizer, here was at his best, the speech, when published as an essay, won wide and lasting fame as a model explanation.

The method of scientific investigation is nothing but the expression of the necessary mode[1] of working of the human mind. It is simply the mode at which all phenomena are reasoned about, rendered precise and exact. There is no more difference, but there is just the same kind of difference, between the mental operations[2] of a man of science and those of an ordinary person, as there is between the operations and methods of a baker or of a butcher weighing out his goods in common scales,[3] and the operations of a chemist in performing

1. mode—way, manner, in which something is done. 行事之方法，狀態。
2. mental operation—the way in which one's mind works. 心智之運用。
3. scale—simple instrument for weighing.

a difficult and complex analysis by means of his balance and finely graduated[4] scales. It is not that the action of the scales in the one case, and the balance in the other, differ in the principles of their construction or manner of working; but the beam[5] of one is set on an infinitely finer axis than the other, and of course turns by the addition of a much smaller weight.

You will understand this better, perhaps, if I give you some familiar example. You have all heard it repeated, I dare say, that men of science work by means of induction,[6] and deduction,[7] and that by the help of these operations, they, in a sort of sense,[8] wring[9] from Nature certain other things, which are called natural laws, and causes, and that out of these, by some cunning skill of their own, they build up hypotheses[10] and theories. And it is imagined by many, that the operations of the common mind can be by no means compared with these processes, and that they have to be acquired by a sort of special apprenticeship to the craft.[11] To hear all these large words, you would think that the mind of a man of science must be constituted differently from that of his fellow men; but if you will not be frightened by terms, you will discover that you are quite wrong, and that

4. graduated—marked out in degrees. 刻度的。
5. beam—crossbar of a balance. 天平之秤桿。
6. induction—reasoning from particular facts or individual cases to a general conclusion. 歸納法。
7. deduction—reasoning from a known principle to an unknown, from the general to the specific, or from a premise to a logical conclusion. 演繹法。
8. in a sort of sense—to a certain extent; to some degree.
9. wring—obtain by force, effort, persuasion, pressure, etc. 取得。
10. hypothesis—supposition made as basis for reasoning. 假設。
11. craft—some special skill, art, or dexterity.

all these terrible apparatuses[12] are being used by yourselves every day and every hour of your lives.

There is a well-known incident in one of Moliere's[13] plays, where the author makes the hero[14] express unbounded delight on being told that he had been talking prose during the whole of his life. In the same way, I trust that you will take comfort, and be delighted with yourselves, on the discovery that you have been acting on the principles of inductive and deductive philosophy[15] during the same period. Probably there is not one here who has not in the course of the day had occasion to set in motion a complex train of reasoning, of the very same kind, though differing of course in degree, as[16] that which a scientific man goes through in tracing the causes of natural phenomena.

A very trivial circumstance will serve to exemplify this. Suppose you go into a fruiterer's shop, wanting an apple,—you take up one, and, on biting it, you find it is sour; you look at it, and see that it is hard and green. You take up another one, and that, too, is hard, green, and sour. The shopman offers you a third; but, before biting it you examine it, and find that it is hard and green, and you immediately say that you

12. apparatus—the instruments, materials, tools, etc. needed for a specific use, experiment, etc.
13. one of Moliere's plays—Moliere (1622-1673), a celebrated French writer of comedies. The play refers to *Le Bourgeois Gentilhomme*.
14. the hero—M. Jourdain.
15. philosophy—logic.
16. differ...as (*Archaic*). *Differ* is followed by *from* when it means to be unlike or different.

will not have it, as it must be sour, like those that you have already tried.

Nothing can be more simple than that, you think; but if you will take the trouble to analyse and trace out[17] into its logical elements what has been done by the mind, you will be greatly surprised. In the first place, you have performed the operation of induction. You found that, in two experiences, hardness and greenness in apples, went together with sourness. It was so in the first case, and it was confirmed by the second. True, it is a very small basis, but still it is enough to make an inducton from; you generalize the facts, and you expect to find sourness in apples where you get hardness and greenness. You found upon that a general law, that all hard and green apples are sour; and that, so far as it goes, is a perfect induction. Well, having got your natural law in this way, when you are offered another apple which you find is hard and green, you say, "All hard and green apples are sour, this apple is hard and green, therefore this apple is sour." That train of reasoning is what logicians call a syllogism,[18] and has all its various parts and terms,—its major premise, its minor premise, and its conclusion. And, by the help of further reasoning, which, if drawn out,[19] would have to be exhibited in two or three other syllogisms, you arrive at your final

17. trace out—discover by searching or researching evidence. 探尋。
18. syllogism—a form of reasoning in which two statements or premises are made and a logical conclusion is drawn from them. Example:
    All men are mortal (major premise). (三段論法即大前提，小前題，與結論)
    Socrates is a man (minor premise).
    Therefore, Socrates is mortal (conclusion).
19. draw out—extend. 延伸。

determination, "I will not have that apple." So that, you see, you have, in the first place, established a law by induction and upon that you have founded a deduction, and reasoned out the special conclusion of the particular case. Well now, suppose, having got your law, that at some time afterwards, you are discussing the qualities of apples with a friend: you will say to him, "It is a very curious thing,—but I find that all hard and green apples are sour!" Your friend says to you, "But how do you know that?" You at once reply, "Oh, because I have tried them over and over again, and have always found them to be so." Well, if we were talking science instead of common sense, we should call that an experimental verification.[20] And, if still opposed, you go further, and say, "I have heard from the people in Somersetshire and Devonshire,[21] where a large number of apples are grown, that they have observed the same thing. It is also found to be the case in Normandy,[22] and in North America. In short, I find it to be the universal experience of mankind wherever attention has been directed to the subject." Whereupon, your friend, unless he is a very unreasonable man, agrees with you, and is convinced that you are quite right in the conclusion you have drawn. He believes, although perhaps he does not know he believes it, that the more extensive verifications are,—that the more frequently experiments have been made, and results

20. experimental verification—the establishment or confirmation of the truth of a fact, theory, etc.by experiences. (verify—v.show the truth of.) 經實驗而得的證實。
21. Somersetshire and Devonshire—counties in southwestern England.
22. Normandy—a former province of France, on the English Channel.

of the same kind arrived at,—that the more varied the conditions under which the same results are obtained, the more certain is the ultimate conclusion, and he disputes the question no further. He sees that the experiment has been tried under all sorts of conditions, as to time, place, and people, with the same result; and he says with you, therefore, that the law you have laid down must be a good one, and he must believe it.

In science we do the same thing;—the philosopher[23] exercises precisely the same faculties, though in a much more delicate manner. In scientific inquiry it becomes a matter of duty to expose a supposed law to every possible kind of verification, and to take care, moreover, that this is done intentionally, and not left to a mere accident, as in the case of the apples. And in science, as in common life, our confidence in a law is in exact proportion to the absence of variation[24] in the result of our experimental verifications. For instance, if you let go your grasp of an article you may have in your hand, it will immediately fall to the ground. That is a very common verification of one of the best established laws of nature—that of gravitation. The method by which men of science establish the existence of that law is exactly the same as that by which we have established the trivial proposition about the sourness of hard and green apples. But we believe it in such an extensive, thorough, and unhesitating manner because the universal experience of mankind verifies it, and we

23. philosopher—scientist ("man of science," "scientific man").
24. variation—departure from a former or normal condition.

can verify it ourselves at any time; and that is the strongest possible foundation on which any natural law can rest.

So much, then, by way of proof that the method of establishing laws in science is exactly the same as that pursued in common life. Let us now turn to another matter (though really it is but another phase of the same question), and that is, the method by which, from the relations of certain phenomena, we prove that some phenomena stand in the position of causes towards the others.

I want to put the case clearly before you, and will therefore show you what I mean by another familiar example. I will suppose that one of you, on coming down in the morning to the parlor of your house, finds that a teapot and some spoons which had been left in the room on the previous evening are gone,—the window is open, and you observe the mark of a dirty hand on the window frame, and perhaps, in addition to that, you notice the impress[25] of a hobnailed shoe[26] on the gravel[27] outside. All these phenomena have struck your attention instantly, and before two seconds have passed you say, "Oh, somebody has broken open the window, entered the room, and run off with the spoons and the teapot!" That speech is out of your mouth in a moment. And you will probably add, "I know there has,[28] I am quite sure of it!" You mean to

25. impress—mark or print. 印跡。
26. hobnailed shoe—a shoe with heavy-headed nails set on sole. 跟上釘了粗頭釘子的鞋。
27. gravel—a loose mixture of pebbles and rock fragments coarser than sand, often mixed with clay, etc., much used for roads and walks. 砂礫；碎石。
28. there has—*There has* is in this case an ellipsis, meaning "There has been somebody, etc."

say exactly what you know; but in reality you are giving expression to what is, in all essential particulars, an hypothesis. You do not *know* it at all; it is nothing but an hypothesis rapidly framed in your own mind. And it is an hypothesis founded on a long train of inductions and deductions.

What are those inductions and deductious, and how have you got at this hypothesis? You have observed, in the first place, that the window is open; but by a train of reasoning involving many inductions and deductions, you have probably arrived long before at the general law—and a very good one it is—that windows do not open of themselves; and you therefore conclude that something has opened the window. A second general law that you have arrived[29] at in the same way is, that teapots and spoons do n t go out of a window spontaneously, and you are satisfied that, as they are not now where you left them, they have been removed. In the third place, you look at the marks on the window sill, and the shoe marks outside, and you say that in all previous experience the former kind of mark has never been produced by anything else but the hand of a human being; and the same experience shows that no other animal but man at present wears shoes with hobnails in them such as would produce the marks in the gravel. I do not know, even if we could discover any of those "missing links"[30] that are talked about, that they would

29. arrive at—gain.
30. "missing link"—intermediate forms undiscovered but assumed (or hypothesized) to have existed in the evolutionary process (or chain) between man and the anthropoid apes. 失去的聯鎖（介乎人與猿之間的，假定的，進化過程中人與猿的共同祖先）。

help us to any other conclusion! At any rate the law which states our present experience is strong enough for my present purpose. You next reach the conclusion that, as these kinds of marks have not been left by any other animal than man, nor are liable to be formed in any other way than by a man's hand and shoe, the marks in question have been formed by a man in that way. You have, further, a general law, founded on observation and experience, and that, too, is, I am sorry to say, a very universal and unimpeachable[32] one,—that some men are thieves; and assume at once from all these premises—and that is what constitutes your hypothesis—that the man who made the marks outside and on the window sill, opened the window, got into the room, and stole your teapot and spoons. You have now arrived at a *vera causa*,[33]—you have assumed a cause which, it is plain, is competent to produce all the phenomena you have observed. You can explain all these phenomena only by the hypothesis of a thief. But that is a hypothetical conclusion, of the justice of which you have no absolute proof at all; it is only rendered highly probable by a series of inductive and deductive reasonings.

I suppose your first action, assuming that you are a man of ordinary common sense, and that you have established this hypothesis to your own satisfaction, will very likely be to go off for the police, and set them on the track of[34] the burglar, with the view to the recovery of your property. But just as

31. liable—have a tendency to; be likely to.
32. unimpeachable—indisputable. 無疑義的。
33. *vera causa*—real cause. （拉丁語）眞正的原因•
34. on the track of—in pursuit of. 追踪•

you are starting with this object, some person comes in, and on learning what you are about, says, "My good friend, you are going on a great deal too fast. How do you know that the man who really made the marks took the spoons? It might have been a monkey that took them, and the man may have merely looked in afterwards." You would probably reply, "Well, that is all very well, but you see it is contrary to all experience of the way teapots and spoons are abstracted,[35] so that, at any rate, your hypothesis is less probable than mine." While you are talking the thing over in this way, another friend arrives, one of the good kind of people that I was talking of a little while ago. And he might say, "Oh, my dear sir, you are certainly going on a great deal too fast. You are most presumptuous,[36] You admit that all these occurrences took place when you were fast asleep, at a time when you could not possibly have knovn anything about what was taking place. How do you know that the laws of nature are not suspended during the night? It may be that there has been some kind of supernatural interference in this case." In point of fact,[37] he declares that your hypothesis is one of which you cannot at all demonstrate the truth, and that you are by no means sure that the laws of natur are the same when you are asleep as when you are awake.

Well, now, you cannot at the moment answer that kind of reasoning. You feel that your worthy friend has you somewhat at a disadvantage. You will feel perfectly convinced

35. abstract—take away; steal.
36. presumptuous—(of behavior, etc.) too bold or self-confident. 冒昧的。
37. in point of fact—in fact; in reality.

in your own mind, however, that you are quite right, and you say to him, "My good friend, I can only be guided by the natural probabilities of the case, and if you will be kind enough to stand aside and permit me to pass, I will go and fetch the police." Well, we will suppose that your journey is successful, and that by good luck you meet with a policeman; that eventually the burglar is found with your property on his person, and the marks correspond to his hand and to his boots. Probably any jury would consider those facts a very good experimental verification of your hypothesis, touching[38] the cause of the abnormal phenomena observed in your parlor, and would act accordingly.

Now, in this supposititious case, I have taken phenomena of a very common kind, in order that you might see what are the different steps in an ordinary process of reasoning, if you will only take the trouble to analyse it carefully. All the operations I have described, you will see, are involved in the mind of any man of sense in leading him to a conclusion as to the course he should take in order to make good[39] a robbery and punish the offender. I say that you are led, in that case, to your conclusion by exactly the same train of reasoning as that which a man of science pursues when he is endeavoring to discover the origin and laws of the most occult[40] phenomena. The process is, and always must be, the same; and precisely the same mode of reasoning was employed by Newton[41] and

38. touch—have to do with; concern.
39. make good—restore.
40. occult—mysterious; hidden; concealed. 玄妙的；隱藏的。
41. Newton—Sir Isaac Newton (1642-1727), English physicist and mathematician.

Laplace[42] in their endeavors to discover and define the causes of the movements of the heavenly bodies, as you, with your own common sense, would employ to detect a burglar. The only difference is, that the nature of the inquiry being more abstruse,[43] every step has to be most carefully watched, so that there may not be a single crack[44] or flaw[45] in your hypothesis. A flaw or crack in many of the hypotheses of daily life may be of little or no moment[46] as affecting the general correctness of the conclusions at which we may arrive; but, in a scientific inquiry, a fallacy,[47] great or small, is always of importance, and is sure to be in the long run constantly productive of mischievous,[48] if not fatal, results.

Do not allow yourselves to be misled by the common notion that an hypothesis is untrustworthy simply because it is an hypothesis. It is often urged, in respect to some scientific conclusion, that, after all, it is only an hypothesis. But what more have we to guide us in nine tenths of the most important affairs of daily life than hypotheses, and often very ill-based[49] ones? So that in science, where the evidence of an hypothesis is subjected to the most rigid examination, we may rightly pursue the same course. You may have hypotheses and hypotheses. A man may say, if he likes, that the moon is

42. Laplace—Marquis Pierre Simon de Laplace (1749-1827), French astronomer mathematician.
43. abstruse—profound; deep; hard to understand. 深奧的。
44. crack—partial breakage. 破綻。
45. flaw—a defective place.
46. moment—importance.
47. fallacy—error; false reasoning; a false or mistaken idea, opinion, etc.
48. mischievous—harmful or injurious.
49. ill-based—with very weak ground. 理由不健全的。

made of green cheese: that is an hypothesis. But another man, who has devoted a great deal of time and attention to the subject, and availed himself of the most powerful telescopes and the results of the observations of others, declares that in his opinion it is probably composed of materials very similar to those of which our own earth is made up: and that is also only an hypothesis. But I need not tell you that there is an enormous difference in the value of the two hypotheses. That one which is based on sound scientific knowledge is sure to have a corresponding value; and that which is mere hasty random[50] guess is likely to have but little value. Every great step in our progress in discovering causes has been made in exactly the same way as that which I have detailed to you. A person observing the occurrence of certain facts and phenomena asks, naturally enough, what process, what kind of operation known to occur in Nature, applied to the particular case, will unravel[51] and explain the mystery? Hence you have the scientific hypothesis; and its value will be proportionate to the care and completeness with which its basis has been tested and verified. It is in these matters as in the commonest affairs of practical life; the guess of the fool will be folly, while the guess of the wise man will contain wisdom. In all cases, you see that the value of the result depends on the patience and faithfulness with which the investigator applies to his hypothesis every possible kind of verification.

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50. random—lacking aim or method; purposeless; haphazard. 胡亂的；隨便的。
51. unravel—solve; make clear. 解開。

HOW to BECOME a *GOOD* THEORETICAL PHYSICIST

(9)

by Gerard 't Hooft

This is a web site (still under construction) **for young students - and anyone else - who are (like me) thrilled by the challenges posed by real science, and who are - like me - determined to use their brains to discover new things about the physical world that we are living in. In short, it is for all those who decided to study *theoretical physics*, in their own time.**

It so often happens that I receive mail - well-intended but totally useless - by amateur physicists who believe to have solved the world. They believe this, only because they understand totally nothing about the real way problems are solved in Modern Physics. If you really want to contribute to our theoretical understanding of physical laws - and it is an exciting experience if you succeed! - there are many things you need to know. First of all, be serious about it. All necessary science courses are taught at Universities, so, naturally, the first thing you should do is have yourself admitted at a University and absorb everything you can. But what if you are still young, at School, and before being admitted at a University, you have to endure the childish anecdotes that they call science there? What if you are older, and you are not at all looking forward to join those noisy crowds of young students ?

It should be possible, these days, to collect all knowledge you need from the internet. Problem then is, there is so much junk on the internet. Is it possible to weed out those very rare pages that may really be of use? I know exactly what should be taught to the beginning student. The names and topics of the absolutely necessary lecture courses are easy to list, and this is what I have done below. It is my intention to search on the web where the really useful papers and books are, preferably downloadable as well. This way, the costs of becoming a theoretical physicist should not exceed much the price of a computer with internet connection, a printer, and lots of paper and pens. Unfortunately, I still have to recommend to buy text books as well, but it is harder to advise you here; perhaps in a future site. Let's first limit ourselves to the absolute minimum. The subjects listed below must be studied. Any omission will be punished: failure. Do get me right: you don't have to believe anything you read on faith - check it. Try alternative approaches, as many as you can. You will discover, time and again, that really what those guys did indeed was the smartest thing possible. Amazing. the best of the texts come with exercises. Do them. find out that you can understand everything. Try to reach the stage that you discover the numerous misprints, tiny mistakes as well as more important errors, and imagine how you would write those texts in a smarter way.

I can tell you of my own experiences. I had the extreme luck of having excellent teachers around me. That helps one from running astray. It helped me all the way to earn a Nobel Prize. But I didn't have internet. I am going to try to be your teacher. It is a formidable task. I am asking students, colleagues, teachers to help me improve this site. It is presently set up only for those who wish to become theoretical physicists, not just ordinary ones, but the very best, those who are fully determined to earn their own Nobel Prize. If you are more modest than that, well, finish those lousy schools first and follow the regular routes provided by educators and specialized -gogues who are so damn carefully chewing all those tiny portions before feeding them to you. This is a site for ambitious people. I am sure that anyone can do this, if one is gifted with a certain amount of intelligence, interest and determination.

Theoretical Physics is like a sky scraper. It has solid foundations in elementary mathematics and notions of classical (pre-20th century) physics. Don't think that pre-20th century physics is "irrelevant" since now we have so much more. In those days, the solid foundations were laid of the knowledge that we enjoy now. Don't try to construct your sky scraper without first reconstructing these foundations yourself. The first few floors of our skyscraper consist of advanced mathematical formalisms that turn the Classical Physics theories into beauties of their own. They are needed if you want to go higher than that. So, next come many of the other subjects listed below. Finally, if you are mad enough that you want to solve those tremendously perplexing problems of reconciling gravitational physics with the quantum world, you end up studying general relativity, superstring theory, *M*-theory, Calabi-Yau compactification and so on. That's presently the top of the sky scraper. There are other peaks such as Bose-Einstein condensation, fractional Hall effect, and more. Also good for Nobel Prizes, as the past years have shown. A warning is called for: even if you are extremely smart, you are still likely to get stuck somewhere. Surf the net yourself. Find more. Tell me about what you found. If this site has been of any help to someone while preparing for a University study, if this has motivated someone, helped someone along the way, and smoothened his or her path towards science, then I call this site successful. Please let me know. Here is the list.

Note that this site NOT meant to be very pedagogical. I avoid texts with lots of colorful but distracting pictures from authors who try hard to be funny. Also, the subjects included are somewhat focused towards my own interests.

LIST OF SUBJECTS, IN LOGICAL ORDER (not everything has to be done in this order, but this approximately indicates the logical coherence of the various subjects. Some notes are at a higher level than others).

- Languages
- Primary Mathematics
- Classical Mechanics
- Optics
- Statistical Mechanics and Thermodynamics
- Electronics
- Electromagnetism
- Quantum Mechanics
- Atoms and Molecules
- Solid State Physics
- Nuclear Physics
- Plasma Physics
- Advanced Mathematics
- Special Relativity
- Advanced Quantum Mechanics
- Phenomenology
- General Relativity
- Quantum Field Theory
- Superstring Theory

More resources

The .ps files are PostScript files �.

(In this initial phase this page is still incomplete!)

Languages:
English is a prerequisite. If you haven't mastered it yet, learn it. You must be able to read, write, speak and understand English, but you don't have to be perfect here. The lousy English used in this text is mine. That's enough. All publications are in English. Note the importance of being able to write in English. Sooner or later you will wish to publish your results. People must be able to read and understand your stuff.

Free English courses and resources.

BBC world service learning English.

French, German, Spanish and Italian may be useful too, but they are not at all necessary. They are nowhere near the foundations of our sky-scraper, so don't worry. You do need the Greek alphabet. Greek letters are used a lot. Learn their names, otherwise you make a fool of yourself when giving an oral presentation. Now, here begins the serious stuff. Don't complain that it looks like being a lot. You won't get your Nobel Prize for free, and remember, all of this together takes our students at least 5 years of intense study (at least one reader was surprised at this statement, saying that (s)he would never master this in 5 years; indeed, I am addressing people who plan to spend most of their time to this study). More than rudimentary intelligence is assumed to be present, because ordinary students can master this material only when assisted by patient teachers. It is necessary to do exercises. Some of the texts come with exercises. Do them, or better, invent your own exercises. Try to outsmart the authors, but please refrain from mailing to me your alternative theories until you have studied the entire lot; if you do this well you will discover that many of these authors were not so stupid after all.

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Now, first things first :

Primary Mathematics:
Are you comfortable with numbers, adding, subtracting, square roots, etc.?

- Natural numbers: 1, 2, 3, ...
- Integers: ..., -3, -2, -1, 0, 1, 2, ...

Beginning Algebra (West Texas A&M)
Intermediate Algebra (West Texas A&M)

- Rational numbers (fractions): ¼, ½, ¾, $^{23791}/773$, ...
- Real numbers: Sqrt(2) = 1.4142135... , π = 3.14159265... , *e* = 2.7182818..., ...
- Complex numbers: 2+3*i*, e^{ia}= cos(*a*) + *i* sin(*a*), ... they are very important!

Set theory: open sets, compact spaces. Topology.You may be surprised to learn that they do play a role indeed in physics!

Dave E. Joyce's trigonometry course

This is a must:
Prof. James Binney's course on complex numbers(PDF)

(nearly) complete overview of primary mathematics(K.Kubota, Kentucky)

See also Chris Pope's lecture notes:
Methods1-ch1
Methods1-ch2

The complex plane. Cauchy theorems and contour integration (G. Cain, Atlanta)

Algebraic equations. Approximation techniques. Series expansions: the Taylor series. Solving equations with complex numbers. Trigonometry: sin(2*x*)=2sin *x* cos *x*, etc.

Infinitesimals. Differentiation. Differentiate basic functions (sin, cos, exp). Integration. Integrate basic functions, when possible. Differential equations. Linear equations.
The Fourier transformation. The use of complex numbers.

Convergence of series.

The complex plane. Cauchy theorems and contour integration (now this is fun).
The Gamma function (enjoy studying its properties).
Gaussian integrals. Probability theory.

Partial differential equations. Dirichlet and Neumann boundary conditions.

This is for starters. Some of these topics actually come as entire lecture courses. Much of those are essential ingredients of theories in Physics. You don't have to finish it all before beginning with what follows next, but remember to return to those subjects skipped during the first round.

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Classical Mechanics:

An intermediate level course on Analytical Classical Dynamics by R. Fitzpatrick, Univ. of Texas, Austin.

A good set of Lecture notes from Harvard.

A short course on Classical Mechanics by Prof. J. J. Binney

- Static mechanics (forces, tension); hydrostatics. Newton's Laws.
- The elliptical orbits of planets. The many-body system.
- The action principle. Hamilton's equations. The Lagrangean. (Don't skip - extremely important!)
- The harmonic oscillator. The pendulum.
- Poisson's brackets.
- Wave equations. Liquids and gases. The Navier-Stokes equations. Viscosity and friction.

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Optics:

A.A. Louro's lecture Notes on Optics

R. V. Jones lecture notes on Classical and Quantum Optics

- fraction and reflection.
- lenses and mirrors.
- The telescope and the microscope.
- Introduction to wave propagation.
- Doppler effect.
- Huijgens' principle of wave superposition.
- Wave fronts.
- Caustics.

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Statistical Mechanics and Thermodynamics:

The course "Statistical Mechanics" by Alfred Huan

Prof. Kelly's lecture notes on Statistical Physics

Gould/Tobochnik lecture notes

Intermediate level course on Statistical Mechanics by R. Fitzpatrick

- The first, second and third laws of thermodynamics.
- The Boltzmann distribution.
- The Carnot cycle. Entropy. Heat engines.

- Phase transitions. Thermodynamical models.
- The Ising Model (postpone techniques to solve the 2-dimensional Ising Model to later).
- Planck's radiation law (as a prelude to Quantum Mechanics)

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Electronics:
(Only some very basic things about electronic circuits)

Lessons In Electric Circuits by T. R. Kuphaldt

- Ohm's law, capacitors, inductors, using complex numbers to calculate their effects.
- Transistors, diodes (how these actually work comes later).

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Electromagnetism: Maxwell's Theory for electromagnetism

W.J.Spence, Electromagnetism

Notes on Classical Electromagnetism by R. Fritzpatrick.

Bo Thide's EM Field theory text(advanced)

Worked out exercises from Jackson's book,
set 1 / set 2

- homogeneous and

inhomogeneous

Maxwell's laws in a medium. Boundaries. Solving the equations in:

- vacumm and homogeneous medium (electromagnetic waves)
- in a box (wave guides)
- at boundaries (fraction and reflection)

The vector potential and gauge invariance (extremely important)
emission and absorption on EM waves (antenna)
light scattering against objects.

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Computational Physics :

Even the pure sang theorist may be interested in some aspects of **Computational physics.**

Mathematica for Students of Science by James Kelly

Angus MacKinnon, Computational Physics

Prof. Mathews' projects on Numerical Analysis

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Quantum Mechanics (Non-relativistic):

Introduction to QM and special relativity: Michael Fowler

Niels Walet lecture course on QM (Manchester)

Lecture Notes on QM from MIT

lecture notes

James Branson, Quantum Physics (UCSD)

- Bohr's atom.
- DeBroglie's relations (Energy-frequency, momentum-wave number)
- Schr�dinger's equation (with electric potential and magnetic field).
- Ehrenfest's theorem.
- A particle in a box.
- The hydrogen atom, solved systematically. The Zeeman effect.Stark effect.
- The quantum harmonic oscillator.
- Operators: energy, momentum, angular momentum, creation and annihilation operators.
- Their commutation rules.
- Introduction to quantum mechanical scattering. The *S*-matrix. Radio-active decay.

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Atoms and Molecules:

Notes on General Quantum Chemistry from Georgiatech

Lecture notes on Physical Chemistry by Darin J. Ulness

- Chemical binding
- Orbitals
- Atomic and molecular spectra

- Emission and absorption of light.
- Quantum selection rules
- Magnetic moments.

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Solid State Physics:

An introduction to Solid State Physics by Yuri M. Galperin

A course in Solid State Physics by Mark Jarrell

Solid State Physics: notes by Chetan Nayak (UCLA)

- Crystal groups
- Bragg reflection
- Dielectric and diamagnetic constants
- Bloch spectra
- Fermi level
- Conductors, semiconductors and insulators
- Specific heat
- Electrons and holes
- The transistor
- Supraconductivity
- Hall effect.

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Nuclear Physics

Five lectures on Nuclear Theory by D. B. Kaplan

A A primer in nuclear theory by J. Dobaczewski

- Isotopes
- Radio-activity
- Fission and fusion
- Droplet model

- Nuclear quantum numbers
- Magic nuclei
- Isospin
- Yukawa theory

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Plasma physics:

- magneto-hydrodynamics
- Alfv�n waves

Introduction to plasma physics by R. Fritzpatrick

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Advanced Mathematics:

See John Heinbockel, Virginia.
See Chr. Pope: Methods2�

Mathematics textbooks list

.'t Hooft: Lie groups in Physics, (now also in English) + exercises

For Lie Groups, see also the last section of Chr. Pope's lectures (under "General Relativity")

The special functions and polynomials(PDF) (just understand the principles)

- Group theory, and the linear representations of groups
- Lie group theory
- Vectors and tensors
- More techniques to solve (partial) differential and integral equations

- Extremum principle and approximation techniques based on that
- Difference equations
- Generating functions
- Hilbert space
- Introduction to the functional integral

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Special Relativity

Peter Dunsby's lecture course on tensors and special relativity

Prof. Firk's book on Special Relativity

- The Lorentz transformation
- Lorentz contraction, time dilatation
- $E = mc^2$
- 4-vectors and 4-tensors
- Transformation rules for the Maxwell field
- Relativistic Doppler effect

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Advanced Quantum Mechanics:

Prof. Stringari's course on Ultracold Fluids

Introduction to the Quantum Hall effect by A.H. MacDonald

Introduction to Coherent States and Quantum Information Theory by K. Fujii

Tutorial on Quantum information by

- Hilbert space
- Atomic transitions
- Emission and absorption of light
- Stimulated emission
- Density matrix
- Interpretation

of QM

- The Bell inequalities
- Towards relativistic QM: The Dirac equation, finestructure
- Electrons and positrons
- BCS theory for supraconductivity
- Quantum Hall effect
- Advanced scattering theory
- Dispersion relations
- Perturbation expansion
- WKB approximation, Extremum principle
- Bose-Einstein condensation
- Superliquid helium

Peter Zoller

Intoduction to Quantum Computation by A. Chatterjee

Advanced QM by Freeman J. Dyson

K. Schulten's notes on advanced QM

Hans Paar, Advanced Quantum Theory

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Phenomenology:

subatomic particles (mesons, baryons, photons, leptons, quarks) and cosmic rays; property of materials and chemistry; nuclear isotopes; phase transitions; astrophysics (planetary system, stars, galaxies, red shifts, supernovae); cosmology (cosmological models, inflationary universe theories, microwave background radiation); detection techniques.

Lecture notes on phenomenology by R. Casalbuoni

Paolo Franzini's notes on elementary particles

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General Relativity:

- The metric tensor
- Space-time curvature
- Einstein's gravity equation
- The Schwarzschild black hole
- Reissner-Nordstr�m black hole
- Periastron shift
- Gravitational lensing
- Cosmological models
- Gravitational radiation

Introduction + exercises by G. 't Hooft

Alternative: Sean M. Carrol's lecture notes on GR

Chr. Pope, Geometry and Group Theory, PS, PDF

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Quantum Field Theory:

Classical fields: Scalar, Dirac-spinor, Yang-Mills vector fields.

Interactions, perturbation expansion. Spontaneous symmetry breaking, Goldstone mode, Higgs mechanism.

Pierre van Baal's notes on QFT

The Conceptual Basis of Quantum Field Theory by G. 't Hooft
a chapter in Handbook of the Philosophy of Science

Magnetic monopoles and instantons

Particles and fields: Fock space. Antiparticles. Feynman rules.
The Gell-Mann L�vy sigma model for pions and nuclei. Lean

The Gell-Mann-L�vy sigma model for pions and nuclei. Loop diagrams. Unitarity, Causality and dispersion relations. Renormalization (Pauli-Villars; dimensional ren.) Quantum gauge theory: Gauge fixing, Faddeev-Popov determinant, Slavnov identities, BRST symmetry. The renormalization group. Asymptotic freedom.

Solitons, Skyrmions. Magnetic monopoles and instantons. Permanent quark confinement mechanism. The $1/N$ expansion. Operator product expansion. Bethe-Salpeter equation. Construction of the Standard Model. *P* and *CP* violation. The *CPT* theorem. Spin and statistics connection. Supersymmetry.

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Superstring Theory:

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Introduction + exercises

E. Kiritsis' Introduction to Superstring Theory

A more general site for superstrings

There are many more lecture notes to be found on the web.

There are numerous good books on all sorts of topics in Theoretical Physics.

Just to name a few:

Classical Mechanics:

- Classical Mechanics - 3rd ed. - Goldstein, Poole & Safko
- Classical dynamics: a contemporary approach - Jorge V. Jos�, Eugene J. Saletan

- Classical Mechanics - Systems of Particles and Hamiltonian Dynamics - W. Greiner
- Mathematical Methods of Classical Mechanics, 2nd ed. - V.I. Arnold
- Mechanics 3rd ed. - L. Landau, E. Lifshitz

Statistical Mechanics:

- L. E. Reichl: A Modern Course in Statistical Physics, 2nd ed.
- R. K. Pathria: Statistical Mechanics
- M. Plischke & B. Bergesen: Equilibrium Statistical Physics
- L. D. Landau & E. M. Lifshitz: Statistical Physics, Part 1
- S.-K. Ma, Statistical Mechanics, World Scientific

Quantum Mechanics:

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- Principles of Optics - M.Born, E. Wolf
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- Thermodynamics and an Introduction to Thermostatistics 2ed - H. Callen
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- R. Baker, Linear Algebra, Rinton Press

Find lists of other useful textbooks here: Mathematics, Physics

Find lists of other useful textbooks here: Mathematics, Physics
(most of these are rather for amusement than being essential for understanding the World),
or a little bit more seriously: Physics.

There already is some response. I thank: Rob van Linden, Robert Tough, Thuy Nguyen, Tina Witham, Jerry Blair, Jonathan Martin, David Cuthbertson, Trent Strong, and many others.

Mr. Hisham Kotry came with an important question:

"...You sketch the path for potential students through the forest of college level physics... Two years ago I decided to self-study theoretical physics by following the syllabus of a renown university and the advice from your page and now I'm half-way through the journey but I was wondering about what happens next? Quoting you from the former page "In short, it is for all those who decided to study theoretical physics, in their own time.", Do you know of anyone who got tenure at a physics department or any research institute based on studies he did in his own time without holding a university degree?"

This is not so easy to answer, unfortunately. What I can say, is:
Eventually, whether you like it or not, you will have to obtain some University degree, if you wish a self-supporting career in theoretical Physics. One possibility is to follow a Master course such as the one offered by our University. I don't know about your qualifications, but I suspect that, with enough determination, you may be able to comply.

This is not a burocratic argument but a very practical one. It is also advisable not to wait until you think your self-study is completed. You must allow your abilities to be tested, so that you get the recognition that you may well deserve. Also, I frequently meet people who get stuck at some point. Only by intense interactions with teachers and peers one can help oneself across such barriers. I have not yet met anyone who could do the entire study all by him/herself without any could do the entire study all by him/herself without any guidance. If you really think you have reached a professional level in your studies, you can try to get admitted to schools, conferences and workshops in topics of your interest.

3/04/06: Message received from John Glasscock, Bloomington, IN:
The only one I know of currently is John Moffatt at U Toronto, who was a student of Abdus Salam at Imperial College, London. He started life as a painter in Paris, had no undergraduate degree, taught himself, corresponded with Einstein, and was admitted, based on his demonstrated original work, at IC. (Source: Jo�o Magueijo, _Faster than the Speed of Light_. Perseus Publishing, Cambridge, MA. 2003.)

Suggestions for further lecture notes from Alvaro V�liz:

1. The archimedeans webpage: It has a lot of lecture notes in Physics and Mathematics from Part I and II from Cambridge.
2. David Tong's (DAMTP) lectures in classical mechanics I found these lectures fascinating.
3. Bo Thide's (Uppsala) lectures in electromagnetic theory.
4. Angel Uranga's lectures in String Theory._
5. I found also extremely helpful MIT's OpenCourseWare: Lewin's lectures in basic Physics are terrific (in video).
6. Michael Fowler's (Virginia) lectures in Quantum Mechanics (not checked, G. 't H.)

I thank Aldemar Torres Valderrama for his assistance in updating and renewing numerous links on this page.

§ Note that .ps files are PostScript files, so defend yourself against Microsoft PaintShop, that often wants to appropriate .ps files. PostScript files are read using GhostView (gsview)

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Last revised: 2009

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成為理論物理學家之條件

Perspective 眼光
Power 能力
Perseverance 毅力

楊振寧

成為實驗物理學家之條件

Passion 熱情
Precision 精準
Patience 耐心

丁肇中

我的学习与研究经历

杨振宁[1,2]

(1 清华大学 北京 100084)

(2 香港中文大学 香港)

1933年到1937年我在北平崇德中学念了四年书，从中一到中四．崇德中学当时有差不多三百个学生，有一间很小的图书馆，我常去里面翻阅各种杂志和书籍．我第一次接触到二十世纪的物理学就是在那间图书馆内看到了Jeans的《神秘的宇宙》中译本(见图1)．Jeans把1905年的狭义相对论、1915年的广义相对论和1925年的量子力学用通俗的语言描述，使得我发生了浓厚的兴趣．

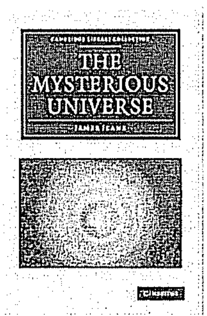

图1 神秘的宇宙

1937年抗日战争爆发，我随父母经过了漫长与困苦的旅程，于1938年春到了昆明．那时流离失所的中学生非常多，所以重庆的教育部准许中学未毕业的学生以同等学力的资格参加大学入学考试(见图2)，我就是这样于那年秋天成为了西南联合大学(以下简称联大)第一届新生．

图2 大学入学考试准考证

我没有念过高中物理学，为了参加那次入学考试，借了一本高中物理教科书，闭门自修了几个星期，发现原来物理是很适合我研读的学科，所以在联大我就选择了物理系．记得非常清楚的是，那次我在教科书中读到，圆周运动加速的方向是向心的，而不是沿着切线方向的．最初我觉得这与我的直觉感受不同，仔细考虑了一两天以后才了解，原来速度是一个向量，它不仅有大小而且是有方向的．

这个故事给了我很大的启发：每个人在每个时刻都有一些直觉，这些直觉多半是正确的，可是也有一些需要修正，需要加入一些新的观念，变成新的较正确的直觉．我从而了解到：**一方面直觉非常重要，可是另一方面又要能及时吸取新的观念修正自己的直觉．**

1942年春天，为了准备写一篇当时联大要求的学士毕业论文，我去找吴大猷教授(见图3)，请他做我的导师．四十多年以后，我这样描述吴先生怎样给我出了一个题目[1]：

(他)给了我一本 *Reviews of Modern Physics*(《现代物理评论》)，叫我去研究其中一篇文章，看看有什么心得．这篇文章讨论的是分子光谱学和群论的关系．我把这篇文章拿回家给父亲看．他虽不是念物理的，却很了解群论．他给了我狄克逊(Dickson)所写的一本小书，叫做 *Modern Algebraic Theories*(《近代代数理论》)．狄克逊是我父亲在芝加哥大学的老师．这本书写得非常合我的口味．因为它很精简，没有废话，在二十页之间就把群论中"表示理论"非常美妙地完全讲清楚了．我学到了群论的美妙和它在物理中应用的深入，对我后来的工作有决定性的影响．这个领域叫做对称原理．我对对称原理发生兴趣实起源于那年吴先生的引导．

对称原理是我一生主要的研究领域，占了我研究工作的三分之二．

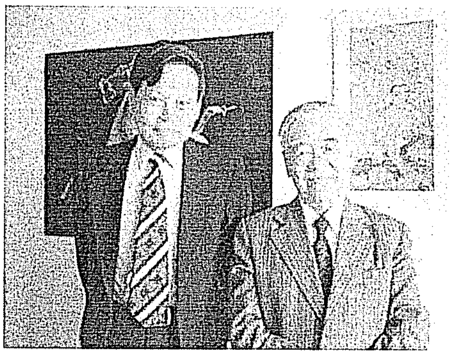

图 3 吴大猷先生(1907—2000)和我(1982 年摄于纽约石溪)

1942 年秋天我考进了清华大学研究院的物理系做博士生.(那时考入联大的本科生都是联大的学生,可是研究生各自算为北京大学、清华大学、南开大学三个学校的学生,虽然所有课程学习和考试仍然是在一起进行的.)我的导师是清华大学的王竹溪教授(见图 4),他的专长是统计力学,是他把我引导进了统计力学的研究领域.今天估计起来我一生的研究工作有差不多三分之一是在统计力学里面.

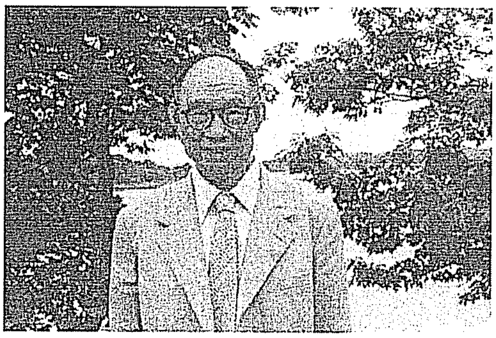

图 4 王竹溪先生(1911—1983)(1980 年聂华桐摄)

关于我在联大做研究生的经历,很多年后我作过这样的描述[2]:

1941 年到 1942 年,我是昆明西南联合大学物理系四年级的学生.这个系比较小,共有约 10 位教员、10 位助教、几位研究生和一些本科生.本科生每班不到 20 人.1941 年秋天开学的时候,一个新的面孔出现了,那就是黄昆.当时,他已经从北京燕京大学获得了物理学士学位,到联大来做助教.开学不久,我们就熟识起来,开始了我们半个世纪的友谊.

我们所读的课程里,两个是吴大猷教授教的经典力学和量子力学.量子力学是一个革命性的新发展.在 1925 年到 1927 年间起源于德国、瑞士、英国和丹麦.吴教授是中国的物理学家中,在 20 世纪 30 年代到 40 年代训练了最多量子力学学生的教授.我记得当时许多关于量子力学的讨论都是在吴教授的演讲之后进行的.通过这些讨论,我开始认识了黄昆的为人和他学物理的态度.

一年后,在 1942 年的夏天,黄昆和我都注册为联大的研究生.黄昆跟着吴大猷教授做有关天体物理学里原子和分子问题的论文,我跟王竹溪教授做有关统计力学的论文.当时研究生的补助金是不够的,所以我们都在找教学职位来增加我们的收入.我父亲的朋友徐继祖先生,是昆华中学的校长,他安排黄昆、我和张守廉(另一位物理学研究生)(见图 5),到昆华中学教书.三个人分了一个教师的位置,而学校安排了一座新建筑角落里的一间房间给我们三人住.

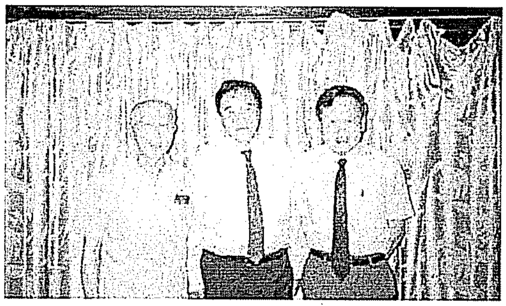

图 5 黄昆、张守廉和我(1992 年 6 月 1 日摄于北京大学为周培源先生举行的生日会上)

那所中学距离联大差不多三公里.我们三人白天经常在大学校园里上课、吃饭、上图书馆,晚上才回到我们的房间睡觉.因为大学校园内没有供应食水的设施,所以我们养成了一个习惯:每天晚饭后,回到中学以前,花一个或两个小时在茶馆里喝茶.那些茶馆集中于大学附近的三条街上.通过那些喝茶的时间,我们真正认识了彼此.我们讨论和争辩天下一切的一切:从古代的历史到当代的政治,从大型宏观的文化模式到最近看的电影里的细节.从那些辩论当中,我认识黄昆是一位公平的辩论者,他没有坑陷他的对手的习惯.我还记得他有一个趋向,那就是往往把他的见解推向极端.很多年后,回想起那时的情景,我发现他的这种趋向在他的物理研究中似乎完全不存在.

茶馆的客人们包括种种人物,有不少学生.可是大多数的茶客是镇民、马车夫和由远处来的商人们.大家都高谈阔论,而我们通常是声音最大的.有时候,正当我们激烈地辩论时,会突然意识到我们的声音太大,大家都在看着我们(这种意识并不一定使我们停止辩论).可是一般来说,学生们和其他茶客之间并没有不和的气氛.

在茶馆中,我们曾经目睹一些永远不能忘记的情景和事件:好几次坐在凤翥街的茶馆里,我们看见一队一队的士兵押着一些犯人向北方走去,走向昆

明西北郊的小丘陵地带，那里满布着散乱的野坟.每一个犯人都背着一块白色的板子，上面写着他们的名字和罪行.大多数的罪犯都静静地跟着士兵走，有少数却喊着一些口号，像："二十年后，又是一条好汉！"每一次当这种队伍走过时，茶馆的喧闹声就会突然止息.然后，远处预期的枪声响了，我们都静静地坐着，等待着士兵们走回来，向南方回到城里去.

衬着这种背景，我们无休止地辩论着物理里面的种种题目.记得有一次，我们争论的题目是关于量子力学中"测量"的准确意义.这是哥本哈根(Copenhagen)学派的一个重大而微妙的贡献.那天，从开始喝茶辩论到晚上回到昆华中学；关了电灯，上了床以后，辩论仍然没有停止.

我现在已经不记得那天晚上争论的确切细节了.也不记得谁持什么观点.但我清楚地记得我们三人最后都从床上爬起来，点亮了蜡烛，翻看海森堡(Heisenberg)的《量子理论的物理原理》来调解我们的辩论.

我们的生活是十分简单的，喝茶时加一盘花生米已经是一种奢侈的享受.可是我们并不觉得苦楚：我们没有更多物质上的追求和欲望.我们也不觉得颓丧：我们有着获得知识的满足和快慰.这种十分简单的生活却影响了我们对物理的认识，形成了我们对物理工作的爱憎，从而给我们以后的研究历程奠定了基础，这是我们当时所没有认识到的.

与黄昆和张守廉的辩论，以及我自己做教授以后的多年经验，都告诉我：**和同学讨论是极好的真正学习的机会.**

张守廉后来改念电机与控制论，在美国得到博士学位，现在还健在，是纽约州立大学石溪分校退休教授.黄昆后来在英国得到博士学位，在固体物理方面有重要贡献.于1950年代初回国，引进半导体物理学到国内，开启了中国的半导体研究.他于2001年获中国最高科技奖，于2005年去世.

1945年抗战结束后，我乘很小的DC3飞机飞到加尔各答.等了几个月的船位，于那年10月乘船经过红海、苏伊士运河和地中海，于11月24日到达纽约.1946年初我注册成为芝加哥大学物理系的博士生，去芝加哥的主要原因是我想跟恩里科·费米(Enrico Fermi，1901—1954，见图6)写一篇实验方面的博士论文.

2001年是费米诞生100周年，在芝加哥和罗马都举办纪念他的学术会议.我在会议上宣读的文章里有这样一段[3]：

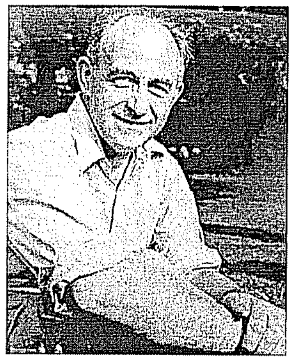

图6　恩里科·费米(摄于1940年代)

恩里科·费米是二十世纪所有伟大的物理学家中最受尊敬和崇拜者之一.他之所以受尊敬和崇拜，是因为他在理论物理和实验物理两方面的贡献，是因为在他领导下的工作为人类发现了强大的新能源，而更重要的是因为他的个性：他永远可靠和可信任；他永远脚踏实地.他的能力极强，却不滥用影响，也不哗众取宠，或巧语贬人.我一直认为他是一个标准的儒家君子.

当时芝加哥大学的物理系是全世界数一数二的.除费米以外，另外一位重要的理论物理教授是特勒(Edward Teller，1908—2003，见图7)，在物理与化学领域做过重要的工作，是天才型的物理学家.后来在1950年代，他发现了制造氢弹的方法，一跃而成世界名人.

图7　爱德华·特勒与我(摄于1982年)

我本来想跟费米做实验物理学的研究，可是那个时候他的实验室在阿贡(Argonne)，当时是保密的，我不能进入.所以费米推荐我先跟特勒做理论工作.

1946年上半年，我是特勒的研究生.记得他给我的第一个研究题目是关于Be与BeO的K-电子湮没的几率问题.他建议我用Thomas－Fermi－Dirac与Wigner－Seitz的近似方法做计算.几个星

期以后，我给他看我的计算结果，他很高兴地安排我做一个报告，那是我在美国第一次做学术报告. 记得那天在座十几个人中有好几位重量级人物，如费米、特勒、尤里（Harold Clayton Urey）和迈耶夫妇（Mayer）等. 报告以后大家的反应都非常好，特勒要我把此计算写成一篇文章. 于是我花了一星期来做此工作，可是写来写去始终觉得不能完全掌握我的计算的可靠性，因为其中用了好几种不同的近似方法，所以写不下去了. 特勒倒也不在意，给了我另外一个关于核物理的题目.

特勒当时有六七个研究生，我们每周一次或两次聚在一起和他讨论，也常常和他共进午餐. 特勒的新见解非常之多，对于当时的核物理学、凝聚态物理学、宇宙射线问题等等都非常有兴趣. 可是我渐渐发现，他的研究方法与我所喜欢的研究方法不一样. 所以我虽然继续参加他的讨论会，可是开始自己找理论题目.

1946 年秋天，费米介绍我去做艾里逊（Allison）教授的研究生，他是核试验物理学家，当时正在建造一台 400 千伏的 Cockroft—Walton 加速器. 他的实验室里有五六个研究生，我就成为其中一员，虽然我仍然继续参加特勒的讨论会.

当时我在芝加哥大学的物理系是非常有名的研究生，因为我在联大所学到的基本理论物理已达到了当时最前沿的标准，可是我的动手能力非常蹩脚. 同学们很佩服我的理论知识，常常要我帮他们解决理论习题，可是大家一致笑我在实验室里笨手笨脚. “Where there is Bang, there is Yang!”

1947 年对我是一个不快活的一年. 那时黄昆在英国做研究生，我给他的信中就曾用“Disillusioned”（幻想破灭）来描述我当时的心情. 为什么呢？因为一方面我虽然努力，可是没有做实验的天分，而理论方面呢，几个自己找的题目都没有成果.

博士生为找题目感到沮丧是极普遍的现象.

回想起来，那一年我自己找的理论题目包括下面四项：(1)1944 年 Onsager 的关于 Ising Model 的文章；(2)1931 年 Bethe 的关于 Spin Wave 的文章；(3)1941 年 Pauli 的关于场论的综合报告；(4)1943 年以后，许多关于角分布的文章. 这四个题目中前两个是统计力学里面的问题，我对它们感兴趣是受了王竹溪先生的影响. 后两个题目与对称性密切相关，我对它们发生兴趣是受了吴大猷先生的影响.

在这四个题目中，前三个当时芝加哥大学没有别人感兴趣，我自己一个人在图书馆中研读，求了解，求发展. 每一项都花了几个星期的努力，都以无成果而告终. 只有第四项是特勒极感兴趣的研究. 当时这方面的理论论文很多，可是都不够严谨. 我花了几个星期用群论分析“物理规律旋转不变”（Invariance of Physical Laws under Space Rotation）的意义，得出了几个漂亮的定理，写成一篇短文. 特勒很喜欢这篇文稿. 恰巧在 1948 年春天，全系师生都知道杨振宁在艾里逊实验室的工作不成功. 于是特勒主动来找我[4]：

有一天，特勒来找我. 他问，你做的实验是不是不大成功？我说，对了. 他说：“你不必坚持一定写出一篇实验论文. 你已写了理论论文，那么就用一篇理论论文来作毕业论文吧. 我可以做你的导师.”我听了这话很失望，因为我确实是一心一意想写一篇实验论文的. 我说需要想一想. 想了两天，决定接受他的建议. 作了这个决定以后，我如释重负. 这是我今天不是一个实验物理学家的道理. 有的朋友说这恐怕是实验物理学的幸运.

那么我的一年多的实验经历是否白费了呢？不是，绝不是：我从中了解到，实验工作者的价值观与理论工作者不同，这一点影响了我以后的许多工作，最显著的是 1956 年的宇称可能不守恒的文章与 1964 年的 CP 不守恒的唯像分析[5]（phenomenological analysis).

我的博士论文是我进入对称与不变性（Invariance）领域的第一篇文章. 紧接着又发表了我在此领域中第二篇文章，是关于 π^0 的自旋的工作，其中仔细分析了场论中不变性的群论表示. 这两篇文章使我一跃而成为用群论与场论分析对称的专家. 那时此领域才刚刚开始，能在那时进入此领域是极幸运的.

最好在领域开始时进入一个新领域.

1948 年夏得到博士学位以后，芝加哥大学留我做教员（Instructor). 我那时想学习重整化理论，而当时在芝加哥，费米、特勒和文策（Wentzel）三位教授都不研究此理论，所以一年以后我就申请去普林斯顿的 IAS(Institute for Advanced Study). 费米说去 IAS 很好，但那里的工作太理论化，像中古的修道院，要我只去 IAS 一年，即回到芝加哥. 我当然很同意他的劝告，可是[6]后来因为找女朋友的压力，我没有回芝加哥，结果在 IAS 共呆了十七年，1949—1966.

在这十七年间，我在芝加哥自己找的四个题目都开花结果了. 其中第一项，Ising Model，我是在偶然的机会找到了突破口[7]：

1949 年 11 月初的一天，在往返于普林斯顿大学对面的巴尔麦广场与研究所之间的街车（2011 年注：

应为面包车）上，Luttinger（路丁格）偶尔和我谈及Ising模型．Luttinger说，Bruria Kaufman（考夫曼）已经把昂萨格的方法简化，因而他的解可以通过$2n$个一系列反对易厄米矩阵而搞清楚．我对这种表象了解得很多，因而很容易就掌握了昂萨格—考夫曼方法的要点．一回到研究所，我就推导出昂—考解法的基本步骤，并为终于理解了昂萨格的解法而高兴．

……

我感到，利用隐藏在昂—考方法中的其他信息，便能把这个矩阵元计算出来．

……

经过大约6个月断断续续的努力，终于，所有的片断突然融合在一起，产生了奇迹般的各项相消的情形．

我眼睁睁地盯着出奇的简单的最后结果．

为什么我能够“很容易就掌握了昂萨格—考夫曼方法的要点”呢？回答：一方面我对“反对易厄米矩阵的表象”在昆明研读Dirac方程时就有了透彻的了解，而更重要的是我在芝加哥大学曾花了数星期去研究昂萨格的1944年的文章，虽然当时没有出成果，但是对其中的主要难懂的地方为什么难懂有了深入的认识，所以听到Luttinger的几句话就很容易地完全了解昂萨格解的真正精神．

这个经过可以浓缩为：王竹溪先生使我对统计力学发生兴趣．芝加哥时候的努力不成功，可是做了必要的准备工作．最后吸收了新方法，就开花结果了．这个过程：**兴趣→准备工作→突破口**，我认为是多半研究工作必经的三部（步）曲．

在上述这个过程中，最后的突破口，是由新的外来的启示引导出来的（Luttinger的几句话）．可是在多半的情形下，启示是自己“顿悟”出来的：在准备工作后，脑子里面下意识仍在寻找新的观念组合，最后突然找到了正确的组合，就顿悟了．Poincaré[8]曾把此顿悟叫做Sudden Inspiration，他说是unconscious work的结果．

我在芝加哥找的第三个题目是关于Pauli的有名的综合报告中关于电磁学之规范不变性（Gauge Invariance）．这是外尔（Weyl，见图8）于1918—1929年间发现的．我对此很妙的不变性非常感兴趣，想把它推广．（为什么当时我的同时代的研究生们没有也这么想呢？我猜是因为我对群论与不变性特别有兴趣，而他们多半对此没有什么兴趣．）

我把电磁学中的重要公式

$$F_{\mu\nu}=A_{\mu,\nu}-A_{\nu,\mu}\quad, \tag{1}$$

图8 外尔（Hermann Weyl，1885—1955）

推广为

$$F_{\mu\nu}=B_{\mu,\nu}-B_{\nu,\mu}\quad, \tag{2}$$

其中B_μ是一个2×2的矩阵，不像A_μ只是一个简单的1×1的矩阵．这个很自然的推广，却引导出越来越复杂的计算，所以最后只好放弃，那是1947年．那时我的目的是想把当时新发现的许多粒子，Λ，K等等用推广了的规范不变性来创建它们之间的相互作用．那时的几页杂记V5到V6a现在复印于图9．

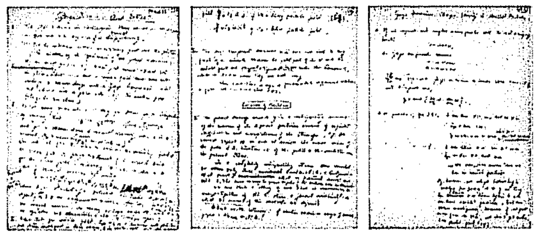

图9 1947年的几页杂记

以后的几年新发现的粒子越来越多，所以我数次回到这项尝试，每次都因同一原因：越算公式越复杂，“越丑陋”，而作罢．1953—1954年，我到BNL（Brookhaven National Laboratory）去访问一年，同办公室有两位年轻人，一位叫米尔斯（Robert Mills，1927—1999，见图10），是Norman Kroll（1922—2004）的学生，那时即将得博士学位．另外一位是实验物理研究生Burton Richter（1931— ），后来于1976年与丁肇中同时获得诺贝尔奖．

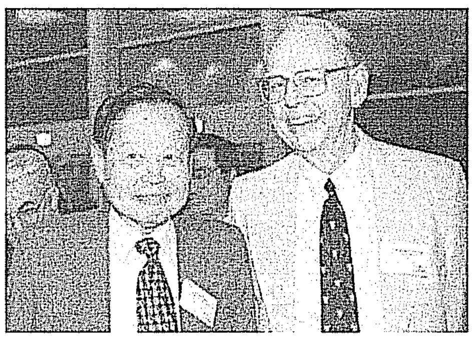

图10 米尔斯和我（1999年5月22日摄于石溪）

我很自然地就和米尔斯谈到了关于推广规范不变性的不成功的尝试。有一天，我们说(2)式虽然很自然，但是也许应修改为

$$F_{\mu\nu}=B_{\mu,\nu}-B_{\nu,\mu}+(B_\mu \text{ 与 } B_\nu \text{ 的多项式}) . \tag{3}$$

当时决定先尝试二次的多项式，如果不行，就尝试三次的，等等。幸运地，很快我们就发现如果把(2)式加上极简单的二次多项式，即

$$F_{\mu\nu}=B_{\mu,\nu}-B_{\nu,\mu}+B_\mu B_\nu-B_\nu B_\mu \quad , \tag{4}$$

以后的计算就越算越简单。我们知道我们挖到宝贝了!!!

有了这项突破，我们循着麦克斯韦(Maxwell，1831—1879)理论的发展方法，很快就写下了很漂亮的规范场方程式。可是新问题出现了：这些方程式似乎显示要有带电荷而质量为零的粒子，这是没有见过的粒子，也是理论上讲不通的。这个问题给我们带来了大半年的复杂而未能解决问题的计算，中间还有一段 Pauli 为难我的故事[9]。最后我们决定虽然此问题没有解决，但整个想法太漂亮，应该发表，于1954年6月写了一篇文章寄给 *Physical Review*，幸而立刻被接受了，于10月初发表。

这篇文章是我一生最重要的工作。虽然未竟全功，但是决定当时发表是极正确的。我从而认识到：**物理中的难题，往往不能求一举完全解决。**

关于质量为零的粒子问题，后来于1970年前后引进了对称破缺的观念而发展成极成功的标准模型。我当时不喜欢在基础物理理论中引进对称破缺[10]，所以失去了在这方面做贡献的机会。

关于米尔斯和我的合作，五十多年以后，CCTV的王志先生于2005年1月26日在电视访问中曾问过我，为什么我的很多工作都是跟人合作的。我的回答[11]：

合作有很多的好处，因为你知道你在讨论一个问题，有时候走不通了，你的想法都走不通了，那个时候假如另外有一个人跟你讨论讨论，问你几个问题，或者想出来一个新的方向，于是你就又起劲了，这是很重要的一个研究的途径。

所以我认为：**和别人讨论往往是十分有用的研究方法。**

1954—1956年间，新实验发现了更多新粒子，而奇怪的是其中两个粒子，θ 与 τ 的性质：它们衰变成不同数目的 π：

$$\theta \rightarrow \pi+\pi \quad ,$$

$$\tau \rightarrow \pi-\pi+\pi \quad .$$

越来越多与越来越准确的实验，都显示二者其实是一个粒子，只是有两种不同的衰变。这本来没有什么稀奇，可是物理学中有一项“宇称守恒”定律，是金科玉律。根据此定律，两个 π 的“宇称”是+1，而三个 π 的“宇称”是−1。如果 θ 与 τ 是同一粒子，那么它既能衰变成+1的宇称，又能衰变成−1的宇称，宇称就不守恒了，这是绝对不可能的！

这个问题当时叫 $\theta-\tau$ 谜，是1954—1956年间基本物理学中最困扰人们的问题。后来在1957年的一篇文章中[12]我说：

那时物理学家们的处境曾被描述为一个被关在黑屋子中的人。他知道在某一个方向一定有一个门可以走出去，但是这个门在哪个方向呢？

1956年夏天，李政道和我(见图11)为了找这个门，在**仔细检验**过去五类所谓证明弱相互作用中宇称守恒的试验后，发现原来它们都**并没有证明**宇称守恒：它们都不够复杂。我们也从而指出几类够复杂的试验可以检测**宇称在弱相互作用中**[13]**究竟是否守恒**。

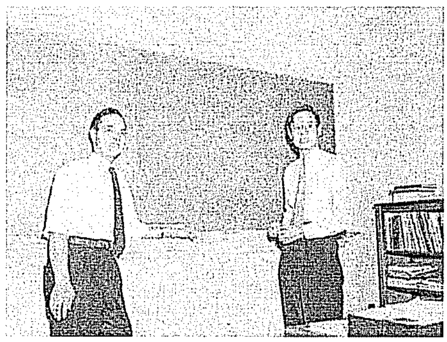

图11 李政道和我(1957年摄于普林斯顿高等研究所)

那年6月我们把这些结果写成预印本，寄去 *Physical Review*，也寄了很多份给同行们。很快就收到，与听到，一致的回应：**宇称绝对不会不守恒**，杨李所建议的实验都是浪费时间与资源！只有吴健雄(1912—1997，见图12)独具慧眼，她虽然受了 Pauli 的影响也不相信宇称会不守恒，可是她认为既然过去在β-衰变中并没有证明宇称是否守恒，那么现在就应该用实验去测试这个基本定律。

经过六个月的努力，她于1957年初宣布：在弱相互作用中**宇称并不守恒**，而且是极度不守恒。这项结果影响了物理学里面的多个领域：粒子物理、核物理、原子与分子物理，所以**震惊了整个物理学界**。至于为什么物理世界既有极准确的左右对称(宇称守恒)，又有微小的左右不对称(宇称不守恒)，至今仍是一个未解之谜。

图 12　吴健雄(1912—1997)

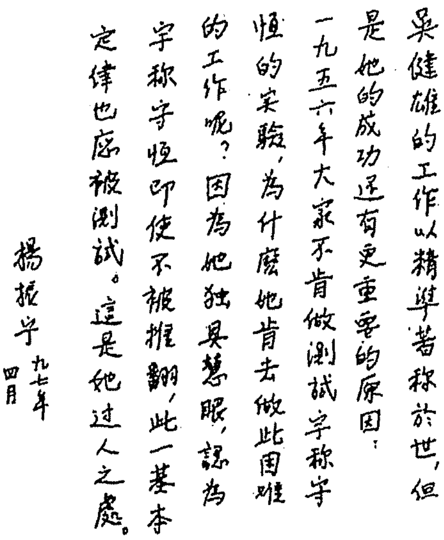

图 13　吴健雄去世后我写的一段话

吴健雄的巨大成功给她的启示是[14]：

永远不要把所谓"不验自明"的定律视为是必然的.

宇称不守恒给了物理学界，尤其是 Heisenberg (1901—1976)与 Pauli(1900—1958)那一代人，极大的震撼. 他们似乎觉得整个物理学基础都动摇了. 1957 年 1 月 15 日哥伦比亚大学召开记者会，宣布吴健雄的结果. 次日《纽约时报》头版登载此消息，说 Rabi(1898—1988)在会上说：

"可以说一个完整的理论体系从基础上被打碎了，我们不知道如何把碎片重新拼起来".

受了宇称不守恒的震撼，Heisenberg 和 Pauli 重新合作，于 1957—1958 年间尝试解决当时物理学中几个极基本的问题，如精细结构常数 $\alpha \sim 1/137$ 等. 这段不成功的合作的奇怪历史我曾在[15] 1986 年一个演讲中作过描述. 显然他们二位认为基本物理原理又动摇了，又回到了 1924—1925 年前后的极端紊乱状态，又需要大胆的新的理论框架，又需要大胆的新的猜测. 他们二人这一年多的合作研究的态度与方法，和我这一代物理学家所熟悉的完全不同. 我认为科学史家从他们这次合作细节中，也许能够窥测到 1924—1925 年间，他们创建 Exclusion Principle(不相容原理)，与创建矩阵力学时的心理状态. 这项研究历史细节的工作我以为极值得做，但是至今还没有人做过.

1961 年夏天，我到斯坦福大学访问，恰巧 Fairbank 和 Deaver 在做超导圈中磁通量量子化的实验. 这个实验把我引入超导领域，后来从而发展出 ODLRO 观念. 1963 年开始，为了寻找确有 ODLRO 的数学模型，我和吴大峻、杨振平做了许多计算，又回到我在芝加哥时研究过的第二个题目：Bethe 的 1931 年文章. 可是这一次我们是从扩大了的角度研究 Bethe 的问题，所以自然地引入了延拓(Continuation)的观念. 用此观念，Bethe 的复杂的方程式就受到控制了，就可以向许多方向发展了. 1966—1969 年间，杨振平和我利用此观念，写了好几篇颇有份量的文章. 事后分析一下，这次经过仍然是上文所提到的

兴趣→准备工作→突破口

模式，可是"准备工作"与"发展"之间有了外来的新因素：从扩大了的角度研究 Bethe 的方程式. 所以，**把问题扩大往往会引导出好的新发展方向.**

事实上，1954 年米尔斯和我所做的工作，把电磁学的规范不变观念扩大到非阿贝尔规范不变，就是扩大问题的另一个实例.

1966 年我离开普林斯顿，接受纽约州立大学(SUNY)新创建的石溪(Stony Brook)分校的聘任. 在石溪我开始与研究生接触. 我自己很少收研究生，一生只毕业过大约十个博士生. 不过我影响了好几位不是我自己的石溪博士生. 他们本来都想搞理论高能物理，我告诉他们理论高能物理在 50 年代到 70 年代虽有辉煌的成就，但是到了 70 年代末一个年轻人就很难搞进去. 而且进入 80 年代，因为大加速器太昂贵，识者认为前途堪忧. 但是年青人不了解这一点，以致全世界聪明的研究生进入这一行的特多，造成粥少僧多的现象.

受了我的影响好几位石溪博士生与博士后改入了别的领域，例如加速器原理和生物物理，今天十分成功，他们都很感激我早年给他们的劝告. 这个经验所给的启发是：

一个研究生最好不要进入粥少僧多的领域.

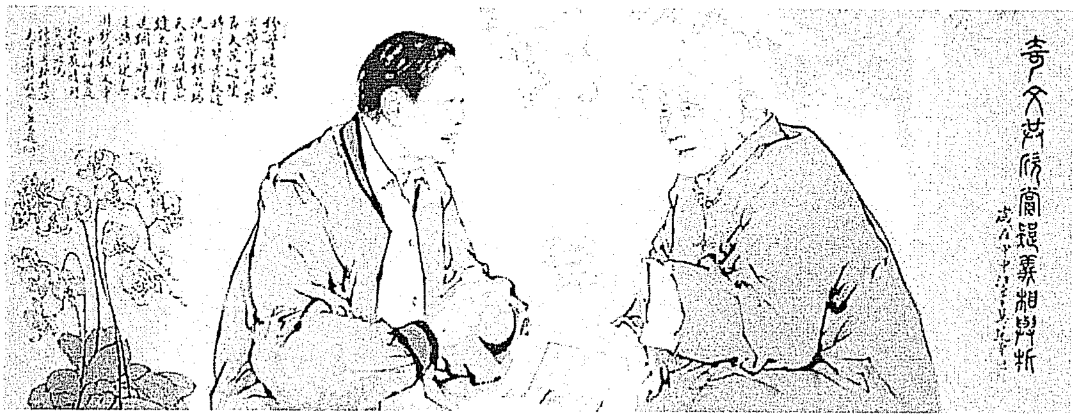

图 14　范曾于 2004 年所作大画

上面讲到了好多项我个人多年来得到的启发与感受：

(1)一方面直觉非常重要，可是另一方面又要及时吸取新的观念修正自己的直觉.

(2)和同学讨论是极好的真正学习的机会.

(3)博士生为找题目感到沮丧是极普遍的现象.

(4)最好在领域开始时进入一个新领域.

(5)兴趣→准备工作→突破口

(6)物理中的难题，往往不能求一举完全解决.

(7)和别人讨论往往是十分有用的研究方法.

(8)永远不要把所谓"不验自明"的定律视为是必然的.

(9)把问题扩大往往会引导出好的新发展方向.

(10)一个研究生最好不要进入粥少僧多的领域.

其中我觉得特别值得注意的是：兴趣→准备工作→突破口. 下面我对此项从兴趣到准备工作到突破口的三步曲做两点补充：

(1)我父亲是研究数学的，我小时候他很自然地给我讲了一些"鸡兔同笼"、"韩信点兵"等四则问题. 我学得很快，他很高兴. 很多年以后在美国，我有三个孩子，他们小时候我也介绍给他们"鸡兔同笼"、"韩信点兵"等问题，他们也都学得很快，我也很高兴. 可是我与他们有一个区别：我父亲介绍给我四则问题之后，过了一年他再问我，我都记得很清楚；我的孩子们，我一年后再问他们，他们就把四则问题完全忘得精光. 结论：外来的信息如果能够融入个人脑子里面的软件之中，就可能会"情有独钟"，有继续发展的可能，像是一粒小种子，如再有好土壤、有阳光、有水，就可能发展成一种偏好(taste)，可以使这个人喜欢去钻研某类问题，喜欢向哪些方向去做"准备工作"，如果再幸运的话，也就可能发展出一个突破口，而最后开花结果.

(2)诗人、画家范曾于 2004 年作了一张大画(见图 14)送给南开大学陈省身数学研究所. 画上他题了一首诗，其最后七个字是锤炼出来的美丽诗句：真情妙悟铸文章. 范曾从来没有和陈先生、也没有和我，谈起科学创作的过程. 他的诗句似乎表明艺术家的创作过程也和科学家一样遵循同样的三步曲吧.

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課本

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有一本原本及分成上,下的影本

顧問

邵錦昌

馮明光

助教

李融宗

郭彥廷

黃世宵

助理

陳奕宏

國立清華大學100學年度行事曆

教育部100年3月21日臺高(一)字第1000042313號函同意備查

年	週次	日	一	二	三	四	五	六	月	日	星期	辦理事項
100年			1	2	3	4	5	6	8月	1	一	(1)100學年度第1學期開始
		7	8	9	10	11	12	13				(2)暑期班二階段退選開始(至8日止)
		14	15	16	17	18	19	20		15	一	新生申請100學年度第1學期學雜費減免(至19日止)
		21	22	23	24	25	26	27		22	一	100學年度入學各級新生、轉學生選課(至29日止)
		28	29	30	31					28	日	祖父母節
										30	二	暑期班期末考試(至31日止)
										31	三	暑期班結束
						1	2	3	9月	1	四	外國學生(含交換生)春季班申請開始(至11月1日止)
		4	5	6	7	8	9	10		2	五	100學年度第1學期第3次選課開始(至6日止)
	1	11	12	13	14	15	16	17		5	一	學士班新生入學報到與講習(至7日止)
	2	18	19	20	21	22	23	24		7	三	學士班新生、轉學生註冊
	3	25	26	27	28	29	30			8	四	研究生新生註冊
										9	五	(1)研究生新生學分抵免申請(至16日止)
												(2)100學年度第1學期加退選開始，加簽及校際選課受理收件(至26日止)
										12	一	中秋節
										13	二	(1)全校各級學生上課開始、註冊日
												(2)受理就學貸款申請(9、13日兩天)、校內獎學金申請(至10月31日止)、受理軍公教遺族就學減免申請(至23日止)
												(3)導師輔導選課(至29日止)
												(4)100學年度第1學期碩士生論文口試開始
										16	五	更改99學年度第2學期學生成績截止
										28	三	教師節(停課一天)
								1	10月	3	一	弱勢助學金申請(至14日止)
	4	2	3	4	5	6	7	8		10	一	國慶日
	5	9	10	11	12	13	14	15		11	二	100學年度第1次行政會議
	6	16	17	18	19	20	21	22		17	一	期中教學意見反映週(至28日止)
	7	23	24	25	26	27	28	29		19	三	繳交100學年度第1學期學分費截止
	8	30	31							24	一	休退學及畢業生退2/3學雜費(學分費) 截止
										31	一	(1)100學年度第1學期二階段退選開始(至11月28日止)
												(2)期中成績預警開始(至12月16日)
				1	2	3	4	5	11月	1	二	(1)100學年度第1次校務會議
	9	6	7	8	9	10	11	12				(2)外國學生(含交換生)春季班申請截止
	10	13	14	15	16	17	18	19		16	三	全校運動大會(停課一天)
	11	20	21	22	23	24	25	26		30	三	教師進修及休假研究申請案送人事室截止
	12	27	28	29	30							
						1	2	3	12月	1	四	申請100學年度第2學期學雜費減免開始(至16日止)
	13	4	5	6	7	8	9	10		5	一	休退學及畢業生退1/3學雜費(學分費)截止
	14	11	12	13	14	15	16	17		13	二	100學年度第2次行政會議
	15	18	19	20	21	22	23	24		19	一	教學意見調查開始(至101年1月8日止)
	16	25	26	27	28	29	30	31		30	五	(1)100學年度第2學期第1次選課開始(至101年1月3日止)
												(2)導師輔導選課(至101年3月5日止)
101年	17	1	2	3	4	5	6	7	1月	1	日	(1)開國紀念日
	18	8	9	10	11	12	13	14				(2)外國學生(含交換生)秋季班申請開始(至3月15日止)
		15	16	17	18	19	20	21		3	二	100學年度第2次校務會議
		22	23	24	25	26	27	28		6	五	100學年度第2學期第2次選課開始(至10日止)
		29	30	31						9	一	(1)期末考試開始(至13日止)(2)100學年度第1學期休學申請截止
										16	一	寒假開始
										22	日	除夕
										23	一	春節
										31	二	(1)教師送繳100學年度第1學期成績截止
												(2)100學年度第1學期結束
												(3)100學年度第1學期研究生論文口試結束

					1	2	3	4		1	三	100學年度第2學期開始
		5	6	7	8	9	10	11		10	五	100學年度第2學期第3次選課開始(至14日止)
		12	13	14	15	16	17	18		17	五	100學年度第2學期加退選開始，加簽及校際選課受理收件(至3月5日止)
	1	19	20	21	22	23	24	25		20	一	(1)全校各級學生上課開始、註冊日
	2	26	27	28	29				2月			(2)100學年度第2學期入學新生註冊
												(3)導師輔導選課(至3月5日止)
												(4)受理就學貸款申請(17、20日兩天)、校內獎學金申請(至3月30日止)、受理軍公教遺族就學減免申請(至2月29日止)
												(5)100學年度第2學期碩士生論文口試開始
										24	五	教師提出更改100學年度第1學期學生成績截止
										28	二	和平紀念日
						1	2	3		2	五	梅竹賽(至4日止，2日下午停課)
	3	4	5	6	7	8	9	10		5	一	100學年度第2學期加退選、加簽及校際選課截止
	4	11	12	13	14	15	16	17	3月	6	二	100學年度第3次行政會議
	5	18	19	20	21	22	23	24		15	四	外國學生(含交換生)秋季班申請截止
	6	25	26	27	28	29	30	31		23	五	繳交100學年度第2學期學分費截止
										26	一	期中教學意見反映週(至4月6日止)
										30	五	休退學及畢業生退2/3學雜費(學分費)截止
	7	1	2	3	4	5	6	7		2	一	校際活動週(停課至3日止，2、3日兩天課程由教師自行擇期補課)
	8	8	9	10	11	12	13	14		4	三	民族掃墓節、兒童節
	9	15	16	17	18	19	20	21		9	一	(1)100學年度第2學期二階段退選開始(至5月7日止)
	10	22	23	24	25	26	27	28	4月			(2)期中成績預警開始(至5月25日止)
	11	29	30							10	二	100學年度第3次校務會議
										15	日	各系級單位完成專任教師評量初審
										28	六	校慶環校路跑
101年										29	日	校慶日
				1	2	3	4	5		7	一	100學年度第2學期二階段退選截止
	12	6	7	8	9	10	11	12	5月	8	二	100學年度第4次行政會議
	13	13	14	15	16	17	18	19		11	五	休退學及畢業生退1/3學雜費(學分費)截止
	14	20	21	22	23	24	25	26		16	三	全校游泳賽
	15	27	28	29	30	31				28	一	(1)轉系、轉所申請(至6月25日止)
												(2)教學意見調查開始(至6月17日止)
										31	四	(1)教師升等資料、教師進修及休假研究申請案送人事室截止
												(2)各院級單位完成專任教師評量複審
							1	2		1	五	申請101學年度第1學期學雜費減免開始(至15日止)
	16	3	4	5	6	7	8	9		5	二	100學年度第4次校務會議
	17	10	11	12	13	14	15	16		8	五	(1)101學年度第1學期第1次選課開始(至12日止)
	18	17	18	19	20	21	22	23				(2)導師輔導選課(至101學年度第1學期加退選截止)
		24	25	26	27	28	29	30	6月	9	六	畢業典禮
										15	五	101學年度第1學期第2次選課開始(至19日止)
										18	一	(1)期末考試開始(至22日止)、(2)100學年度第2學期休學申請截止
										20	三	教師送繳應屆畢業生100學年度第2學期成績截止
										23	六	端午節
										25	一	暑假開始
										27	三	暑期班選課及繳費開始(至7月5日止)
		1	2	3	4	5	6	7		2	一	暑期班上課開始
		8	9	10	11	12	13	14		6	五	(1)暑期班選課及繳費截止
		15	16	17	18	19	20	21	7月			(2)教師送繳非應屆畢業生100學年度第2學期成績截止
		22	23	24	25	26	27	28		31	二	(1)100學年度第2學期結束
		29	30	31								(2)100學年度第2學期研究生論文口試結束
												(3)碩士班研究生申請逕行修讀博士學位截止

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