

Invited Paper

Looking forward: Teaching optics in the 21st century

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ABSTRACT

The teaching of optics will become more difficult in the future because the amount of teaching material is increasing rapidly for two reasons: new facts about optics evolve at a rapid rate; understanding the adjacent disciplines becomes more important since optics will be engaged increasingly in interdisciplinary activities.

The capacity of the human brain will not increase.

The situation is not hopeless, however, for three reasons: the fundamentals of optics will not grow or change drastically, in my opinion; the advancing technologies of computing and communicating may be used more intensively in support of teaching; improvements are possible, if more teamwork is utilized in education. Learning as a team and also teaching by a team is more efficient than traditional procedures.

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1. INTRODUCTION

A warning: any statement about the next century is SUBJECTIVE. Not only the statements, but also the style and the drawings of this article are influenced by SUBJECTIVE preferences for reasons that are related to the core of this article: how would I myself teach optics in 10 to 20 years from now, if I had the opportunity to do so?

The topic as expressed by the title is extremely large for two reasons: the "student of optics" may be anybody between the ages of kindergarten and post-retirement. The "teacher of optics" may be a parent, the TV set, a friend, an ordinary teacher, a regular professor, a competitor, a book, a conference, a video tape or the host of an exchange visitor.

My remarks will be more or less appropriate for any student-teacher constellation. But the first year graduate student and his professor is the situation which is predominantly on my mind while writing these lines.

The overall plan of this article is shown on table 1.

So far we have treated the part "definition of the problem" of the INTRODUCTION. We now discuss the 5 postulates and 3 recommendations, as shown in table 2.

About postulate 1:

"Library explosion" is a term which describes aptly this postulate. Many new journals are created every year. Existing journals become fatter all the time.¹ Librarians would like to obtain budget increases at the rate of 20% per year. The size of the optics curriculum (number of teaching hours per week) would have to increase at a rate of more than 10% per year, if the students knowledge of optics should be always up to date.

About postulate 2:

Optical instruments are now less often "stand alone systems". Instead we find optical components as parts of an overall system with electronics and fine mechanics in it. The operational concepts of the total system may be from computer science, from signal processing, from medicine, from laser materials processing, from chemistry, from fluid dynamics, or from elsewhere. The ideal optics professional should understand all those disciplines in order to be able to design the appropriate optical sub system.

About postulate 3:

The size of the human brain has probably doubled during the past 10.000 or 100.000 years. It will not grow at a rate comparable to the "information explosion".

Postulates 1,2,3 together are rather pessimistic.

About postulate 4:

As in any other field, the growth of the fundamentals tends to appear in bursts. In optics the decades of 1870-1910 constituted such a burst, as indicated by names such as Maxwell, Hertz, Michelson, Planck, Einstein, von Laue. A more recent burst did occur, when it became possible to increase the phase domain density of photons well above unity. The increased phase domain density is the common cause of almost all exciting laser applications. My guess is: it will take at least another decade, before most benefits of laser light are harvested. If I am right, then the fundamentals of optics as of today will remain essentially unchanged during the coming decade. Hence, the teaching of the fundamentals will not explode, I suppose.

About postulate 5:

The traditional teaching aids are chalk plus blackboard for the professor, and paper plus pencil for the student. Slides, overhead transparencies and movies are newer additions. Most recent improvements are gifts from electronics, that is computer and communications hardware. The electronic teaching aids will be discussed in chapter II. These novel aids will be a blessing if utilized sensibly. But improper use might be harmful. More in II.

And now the RECOMMENDATIONS

(A) The FUNDAMENTALS should be taught thoroughly. How to do that will be discussed in chapter

III. Fundamentals without any facts or examples are like a naked skeleton. Hence, a few facts as illustrations should go with the fundamentals. But not more than just enough facts necessary for grasping the fundamentals.

(B) The knowledge of FACTS is indispensable in any professional activity. But those facts should not clutter the human brain. The facts should be stored IN DATA BANKS. How to use data banks is something that ought to be taught systematically, but not so much in class as by homework assignments.

The extreme case, a brain full with fundamentals but bare of facts, is a fiction. The accumulation of a reasonable amount of facts will occur automatically in the process of doing anything in - or with - optics. Everybody will collect his own stockpile of facts. Two colleagues with the same understanding of the fundamentals, but with different supplementing sets of memorized facts, may form the nucleus of a successful TEAM. One can teach teamwork of this variety in a graduate course attended simultaneously by physics and by electric engineering students. PH- and EE-students should form pairs who are expected to solve homework problems jointly.

Teamwork is also something the professors should do more often. Two profs with supplementing skills and specialities might teach a course jointly. Not only the students would benefit, also the professors themselves..

(C) Professors and their professional organisations should try to INFLUENCE the development of modern electronic TEACHING AIDS. Why? A warning example is the flood of new journals and of new textbooks, many of them not really good, but not really bad either. So these journals and books will be produced, paid for and read by students who ought to be confronted only by the very best teaching aids. It would be unfair to criticize only the profit-oriented publishers or profit-oriented societies. Society committees on teaching do behave too gentlemen - like in my opinion.

I dare to predict: unless the teachers take an active stand, the electronic teaching aids will be fancy, impressive, expensive, comfortable for professors and students, but of questionable educational value. Let me illustrate my point of view by a personal example: when I am very eager to understand a lecture as thoroughly as possible, I will take notes while I am listening. And I will try to draw the figures shown by the speaker. Afterwards I will throw away my notes without every looking at them. But I will try with paper and pencil to recapitulate the essence of the lecture. Why do I do that? Because understanding and effective memorizing are ACTIVE procedures. My approach is apparently uncomfortable. Commercialised approaches are likely to be designed for optimal comfort and profit. A course that is comfortable for the professor and comfortable for the students is a waste of time.

2. IMPACT OF COMPUTING AND COMMUNICATIONS TECHNOLOGY

2.1. On data banks

The need for data banks has been justified already in the context of recommendation B. Actually, there might better be TWO kinds of data banks, sponsored by two different entities. Data bank type 1 would contain the more permanent facts, like for example: "The Wollaston prism consists of ... It can perform the following basic operation ... It is used in the following categories of instruments ... Wollaston lived from ...

until .. in His invention was independently re-discovered by ... ". Another example: "The method of stationary phase is It is relevant for"

There exists already a book, called "ABC der Optik"², which presents facts in a style represented by the Wollaston example. The ABC book is 30 years old, yet still quite useful. For me it is the optics book I touch more frequently than any other professional book. It certainly needs updating and a translation from German to English. While doing so it should be computerized according to the rules of data banks. The existing cross-referencing notes could be somewhat amplified. The job of creating such an optical data bank type 1 is tremendous. It might be performed under the auspices of the International Commission for Optics ICO, and financed by UNESCO. That makes sense since ICO is a "subsidiary" of UNESCO (via ICSU and IUPAP). Furthermore, the job would fit into the Charter of UNESCO, since such a data bank would be helpful for developing nations which attempt to establish a reasonable amount of technologic independence.

The type-1 data bank would predominantly a READ-ONLY memory. The type-2 data bank would rely also heavily on ERASE. It would store for example the latest commercial data on laser diodes. Every manufacturer would be allowed to enter data about his products - and pay for it, similar as for entries in trade journals. A consortium of existing trade journals could manage this data bank. Another possible coordinator might be an organisation such as LIA, the laser industry association,. Its members are manufacturers of laser and electro-optical goods. Other sponsors might be the operators of the international e-mail networks. An international organisation of librarians might be another valuable partner, which could contribute the expertise on cross referencing.

2.2. On graphic tools

Moire is a good test case for checking the abilities of graphic tools. Moire is what one observes, if two overhead transparencies are put on top of each other and then projected. Usually the two masks are identical. When displaying Moire one encounters the difficulty of aligning the two masks properly. Computerised display technology could alleviate this problem. One would require commands such as SHIFT, ROTATE, MAGNIFY, ADD, MULTIPLY and ERASE. Three-color capability, with variable color shades, would add to the intuitive and esthetic appeal.

Moire is a valuable teaching tool. Two beam interferences, for example, can be visualised by superposing two sets of concentric equidistant rings. Moire has also been useful and inspiring at several R&D occasions, such as for the measurement of the optical transfer function OTF³, for the design of variable Fresnel zone plates⁴, which led to the invention of varifocal lenses⁵. In other Moire applications the two masks are not identical, for example in spatial pulse modulation⁶, in shadow logic "OPALS"⁷ and in picture display with variable grey scale⁸.

Besides computer-based flexibility and color capability the opportunity to display a figure DYNAMICALLY is desirable. For example, a figure describing an optical instrument is much easier to understand if it does not appear completely at once on display. Instead, one would first see the light source, usually on the left side. Next appears a collimator lens on the screen, then the object, etc. This sequence is pedagogically sensible

because it corresponds to the sequence of cause-effect conclusions. Once a total figure has evolved from left to right, it should be possible to erase temporarily the left half. That is what I would like to be able to do with table 3a and 3b in⁹, when explaining the phenomenon of coherence as a rather trivial case of spatial coordination.

Another situation where the feature "sequential display" is quite desirable, occurs, if one wants to show, how a rectangle can be synthesized from four corner pattern¹⁰. A "corner pattern" is unity in the north east quadrant and zero elsewhere. The value "unity" might be positive or negative, as shown in the top row of table 3. In the second row two shifted corners are added, both positive or both negative. In the third row one positive and one negative corner are shifted and added. The remaining non-zero areas are horizontal stripes, bounded on the left side. Finally in the fourth row the two patterns from the third row are superposed such that a rectangle remains as non-zero. If I had simply done this experiment step by step with 4 appropriate transparencies on an overhead projector, it would have been understandable immediately, without the need to say very much. As a consequence we may extrapolate the slogan "a picture is worth a thousand words" into: "a dynamic display is worth a million words".

The figure with the corners (table 3) is apparently drawn by hand, with crummy lines. A similar figure (Fig.7 in¹⁰), made by computer, may have more appeal for some viewers. However, to my taste, computerised figures often look quite sterile and appalling. To me a hand drawn figure such as Fig. 2 in Denisjuk's most recent article on holography¹¹ has charm. It creates a friendly atmosphere which is conducive for the learning process. It has a human touch, which is often missing in computerized images. The two cited figures are reproduced here as table 4.

And now another example of "sequential display", which simultaneously serves to express my belief, that it is possible to teach the art of inventing¹². The table 5 lists some categories of inventions. An example of "inventing by intrapolation" is shown in table 6, where the seven steps are shown above each other. It would be easy to let those 7 steps occur under computer control as a continuous sequence. The continuity would make it easier to digest the line of thoughts.

Two examples of "inventing by translation of concepts" made use of modulation schemes in communications theory, which enabled me to find new versions of holography^{13,14}. Similar in spirit but much more influential was the way E Leith invented the off-axis holography. The category of "inventions by translations" is most likely to happen in interdisciplinary activities. The curriculum should be designed accordingly. In my own case, a one-hour-per week course on the fundamentals of modulation (as part of elective courses in applied physics) turned out to be one of my most profitable learning experiences.

2.3. Centralized teaching?

Imagine "the best optics professor of the country" is video-taped while presenting his lectures. Copies of those tapes are distributed to every university in the country and presented there by a video technician at a classroom full with students. Or the lectures of "the best optics professor in the world" are taped and the text translated and "synchronized", as it is commonly done with Hollywood movies. Does it make sense?

In my opinion the answer is neither 100% YES nor 100% NO. Remote video teaching as a SUPPLEMENT to personal teaching in real time makes sense to me, but only as a supplement. One positive argument is that expensive and difficult experimental demonstrations cannot be duplicated everywhere. Another positive argument has to do with the language capability of a young aspiring scientist, who is about to attend his first international conference. He will get more out of it if he has practiced already listening to lectures in English. One more argument: as a young scientist I knew I was reasonably good according to the standards of my home town. But I had no idea if I would be able to follow the lines of thoughts as presented by a famous professor from Florence, from Paris, from London or from Boston. It would have been very valuable for my orientation, if I had had the opportunity to get acquainted with those big wheels by watching video tapes of their lectures before embarking on my first international conference trip.

2.4. Less mathematics, more numerical computing?

The teaching of mathematics to non-mathematicians is a famous controversial issue. On the one side there are the math professors, who insist on keeping the monopoly of teaching math. Many physics and engineering students leave the university in despair because of an unforgiving math professor. On the other side there are the applied practitioners, who believe it is good enough if one knows how to use computer programs such as in "MATHEMATICA". One does not need regular math lectures for using those programs, they believe.

My own recommendation is to learn mathematics three times. At first rigorously from a math professor. It is a valuable exercise in thinking precisely. The success of a student in such a math course should not be decisive for the survival as a student. More or less simultaneously with the course on abstract math should be a course offered on "practical math on the computer". This course should be taught by a computer scientist, who also explains how a computer works internally. The third encounter with mathematics should occur somewhat later, when a student listens to an optics professor, who teaches a course on something like "optical information processing". Such a course would contain a homogeneous mixture of fundamental optics with Fourier analysis, systems theory and probability theory. The intricate mixture of optics with parts of math will create an intuitive grasp of the mathematical tools.

3. EMPHASIS ON FUNDAMENTALS

3.1. How to select the fundamentals

A few examples may serve to illustrate how the fundamentals can be emphasized while teaching optics. By "fundamentals" I mean those concepts that remain true and useful even if the technology changes drastically.

As a professor one always faces the dilemma: too much material and not enough time. One faces the choice of either reducing the size of each chapter by the same factor. Or one keeps a few chapters at full length, while other chapters are reduced to a few definitions and to advice about suitable literature for voluntary self studies. I prefer the second approach. As examples I will now mention 6 answers to the question on "what is light?". (One could easily find more than 6 answers.). About holography I will mention 10 ways to explain it. These 10 explanations are still incomplete since they do not cover Denisjuk's thick holograms, for example.

Is it not a waste of time to explain holography ten times? I do not believe so. Every explanation has its own merit for understanding a certain aspect of holography. Furthermore, one needs more than one way of explaining holography, if different "neighbours" want to be introduced to holography. I would respond quite differently, if approached by a curious mathematician, or by a chemist, or by a communications engineer. I would try to formulate my answer such that it latches on to the prior knowledge of the questioner. I would try to use his (or her) own jargon. A little story may help to illustrate my point. Almost 40 years ago the director of a TV R&D laboratory came and asked: "how many dB does a typical photographic lens have?". My first answer was: "a lens does not have any dBs. It may have aberrations, and its performance will be limited ultimately by diffraction". The TV engineer knew as little about aberrations as I knew about dBs. Eventually, he convinced me that his question was quite sensible, which led me to re-invent the modulation transfer function. The lesson I learned was: when talking to a TV engineer about the quality of a lens, use the MTF language. But when interacting with a lens designer it is necessary to understand what aberrations are.

Back to the question: how to select the fundamentals? Not only fundamentals WITHIN optics, but also fundamentals FOR optics are to be selected. Parts of mathematics belong to those external fundamentals, as mentioned before. The atomic physics, which underlies the interactions of light and matter is also important. The statistical interpretation of entropy is useful for appreciating the universal significance of information theory. Computability and nonlinear dynamics are other topics of lasting importance.

3.2. What is light?

The table 7 contains 6 ways to answer that question and a philosophical CAVEAT, saying that "what is" questions belong into metaphysics, outside of science. Expressed in another way, a concept like a ray is certainly a convenient model for describing some portions of optics. Is a ray more than a model? Is any concept residing in our brain more than a model? That is a question of a type which I sometimes formulate while wiping the blackboard. Such questions are meant for contemplation in private. Some students really like such philosophical stimulations.

The third and the sixth answers ($x, \tan \alpha$; WIGNER stuff) need some explanatory comments. The top row of table 8 shows a single ray, a bunch of rays starting from a single point, and set of parallel rays. Those three cases are presented in the second row in the artificial $(x, \tan \alpha)$ domain. Why leaving the genuine (x, Z) domain in favor of the artificial $(x, \tan \alpha)$ domain? Because some basic physical processes have a very simple counterpart in that artificial domain, as can be seen in the lower half of table 8. It is quite easy to continue from here on to the fundamentals of radiometry. A few examples will convince the student that the light intensity $I(x, \tan \alpha)$ behaves like an incompressible fluid.

A curious student may ask if the behavior of light like an incompressible fluid is valid also if we use the wave model instead of the ray model. I would be happy about such a question because it would provide the motivation for introducing the Wigner distribution function $WDF^{15,16}$. I would define the WDF and then show that it behaves almost exactly like $I(x, \tan \alpha)$. I would conclude such a chapter, saying: it is quite feasible to start physical optics by proclaiming: "light is Wigner stuff". To support this proclamation I would deduce wave optics and also ray optics from WDF theory. By presenting the deduction of various models of

light in this unorthodox way I am able to instill some intellectual modesty: human knowledge is certainly useful, but not absolute, only relative and subjective.

3.3. Ten definitions of holography

The table 9 contains those ten definitions. The list is certainly not complete. Numbers 1 and 2 are probably the most popular explanations. One of the references to case (3) is¹⁷ and to case (4)¹⁸. The cases (5-9) are covered in^{19,20}. The case (7) is supported here by table 10, which refers to Fourier holography. The primary question of holography is: how is it possible to reconstruct amplitude AND phase of a wavefront inspite of the phase blindness of all optical detectors? Loosing the phase information is a 50 % loss. That is tolerable, if 50 % about the arriving complex wavefront is known anyway. But this 50 % prior knowledge must be allocated strategically. Two approaches are shown in table 10.

Again: why TEN explanations? Why in one single explanation not sufficient? The answer is: it is not difficult in principle to present a comprehensive theory of holography which is capable of answering every question. But that might be too cumbersome or too abstract or not well matched to the preparedness of whoever asks a specific question.

To be more specific I will now ask the reader a few questions, assuming that the reader understands holography thouroughly: "Why is one of the two twin images always pseudoscopic?" - "Why is the resolution of the holographic plate much finer than the resolution of the reconstructed image?" - "Is it possible to create a holographic image instantaneously?" - "Compare the performance of binary computer holograms with ordinary holograms, which consist of sinusoidal interference fringes!".

Probably none of the readers would use always the same explanation scheme for the four questions.

3.4. Complexity theory

Complexity theory is a new fashion with many old roots. Basically, it is the viewpoint opposite to the "reductionist world view". The reductionist divides matter into molecules, molecules into atoms, atoms into nuclei and electrons, etc. The whole world is understood in principle, if the interaction between elementary particles is understood. In a nut shell, the reductionist views at the world from "bottom up". The complexity fan is convinced that his view "top down" is more relevant and comprehensive. Obviously, there is a lively controversy between bottom-up and top-down advocates. The question: "is complexity physics? is it science? what is it?" has been addressed recently in a readable short article²¹.

It is natural and also productive if exponents of the two viewpoints interact. When teaching optics one should offer both approaches. So far there are only a few pieces in the literature which are labelled expressively as "complexity theory in optics". In retrospect however it began around the turn of the century when von Laue and others discussed such structural questions as "the degrees of freedom in a wavefield behind a finite aperture". Apparently the topic of "complexity in optics" is not yet mature and well organised. But that is not an argument against including it into a course on modern optics. On the contrary, in my opinion. It is quite encouraging for a student, if his professor admits that neither he nor any other professor

knows the answer to a particular question.

4. HOMEWORK ASSIGNMENTS

In our country a Masters degree in physics is largely based on a research project which takes typically one and a half years to complete. Many students told me, after they obtained the MSc degree: "during those 1 1/2 years I learnt more than I did earlier during 4 1/2 years. The reason is probably that I was involved as an MSc student in a PRODUCTIVE manner, while before, everything was RECEPTIVE. Maybe not quite, since solving homework problems did certainly require initiative. However, the problem sets seemed to me somewhat sterile and artificial, probably not like problems in a genuine professional situation. Maybe homework problems have to be that way. Otherwise the prof or his assistants could not judge accurately the quality."

Genuine problems are almost never well defined. Genuine problems are usually open ended. If homework problems are of that kind it is difficult to compare the achievements of students. But that price should be paid, at least with about 50 % of the homework assignments. A few examples are suggested in table 11. Recently an answer to the first problem did appear in the literature²². The second problem has been addressed in a delightful Season's Greetings present²³. It consisted of photographs of twelve diffraction pattern, caused by 1, 2.. or 12 pinholes, arranged on a circle. As a homework assignment one would have to simplify the project considerably, possibly replacing the laboratory experiment by a digital simulation.

5. FINAL REMARKS

Many of the points raised in this article need considerable refinements or modifications. But I hope I was able to show that the teaching of optics in the twentyfirst century can be even better than today, inspite of some severe difficulties ahead. Novel technical means will be available. To take advantage of novel opportunities is possible only if one is willing to sacrifice some traditional approaches in order to make room for additions to an already overcrowded curriculum.

About the tables and figures: I hope at least some of you like them, INSPITE - or even BECAUSE - of the lines drawn without a computer.

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LOOKING FORWARD :

TEACHING OPTICS IN THE 21st CENTURY

I. INTRODUCTION

THE PROBLEM, 5 POSTULATES, 3 RECOMMENDATIONS

II. IMPACT OF C + C (Computers + Communication)

DATA BANKS , GRAPHIC TOOLS ;

CENTRALIZED TEACHING ?

LESS MATH TEACHING ?

III. EMPHASIS ON FUNDAMENTALS

EXAMPLES :

6 x WHAT IS LIGHT ?

10 x EXPLANATION OF HOLOGRAPHY

COMPLEXITY THEORY : A TOP-DOWN VIEW

IV. HOMEWORK PROBLEMS : OPEN ENDED

V. FINAL REMARKS

Table 1

POSTULATES

- (1) KNOWLEDGE AND FACTS
WILL INCREASE DRAMATICALLY
- (2) OPTICS WILL BECOME
MORE INTERDISCIPLINARY
- (3) THE CAPACITY OF AN INDIVIDUAL BRAIN
WILL NOT INCREASE
- (4) THE FUNDAMENTALS OF OPTICS
WILL NOT INCREASE DRAMATICALLY
- (5) TEACHING AIDS
WILL ADVANCE CONSIDERABLY

RECOMMENDATIONS FOR PROFESSORS

- (A) CONCENTRATE ON THE FUNDAMENTALS
- (B) TEACH HOW TO USE DATA BANKS
AND TEACH TEAM WORK
- (C) INFLUENCE THE DEVELOPMENT OF
TEACHING AIDS

Table 2

SYNTHESIS OF A RECTANGLE
FROM 4 CORNER ELEMENTS

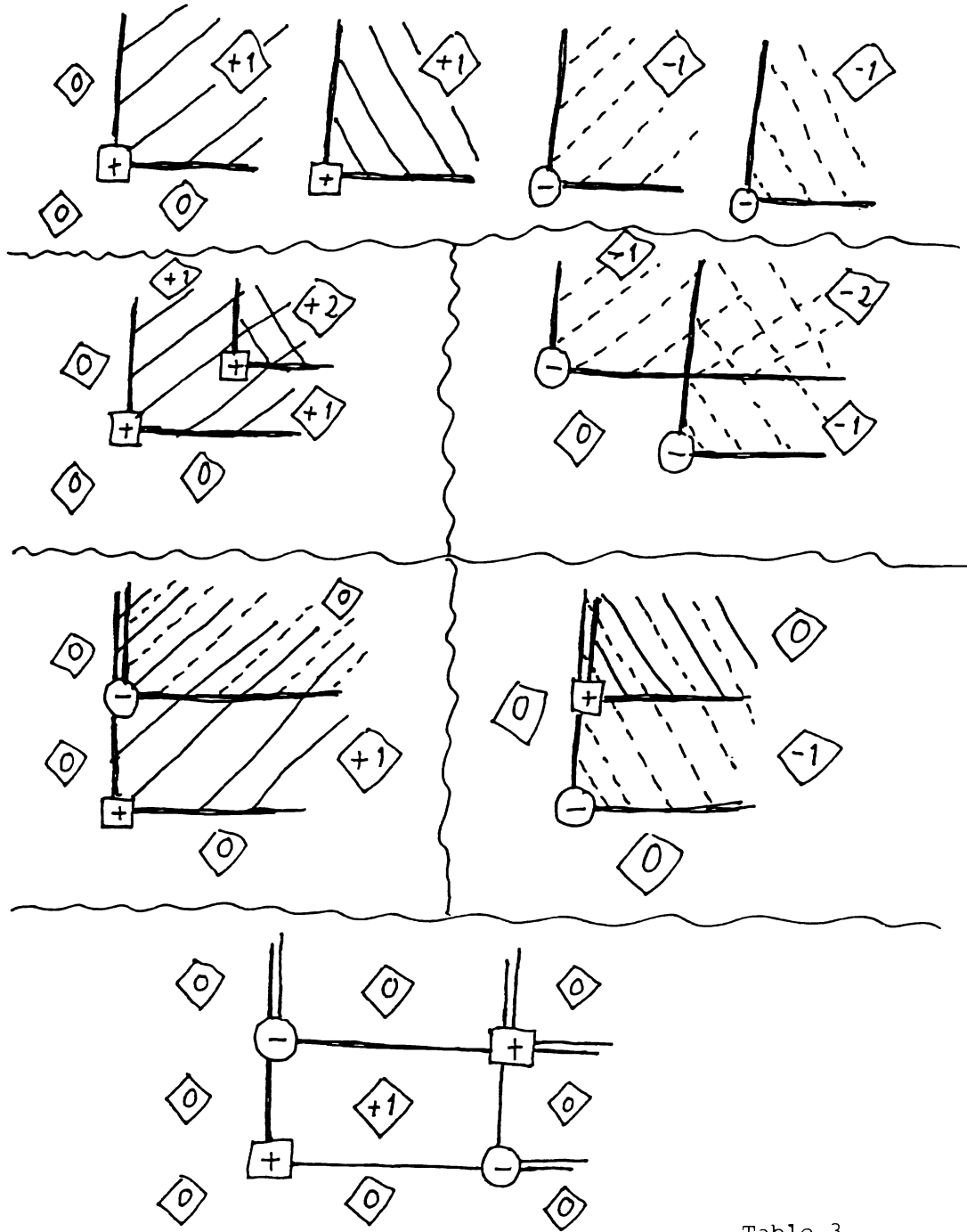


Table 3

ESPECIALLY USEFUL, BUT NOT EXCLUSIVELY
 IF $U(X,Y)$ PIECE-WISE CONSTANT,
 WITH CARTESIAN BOUNDARIES

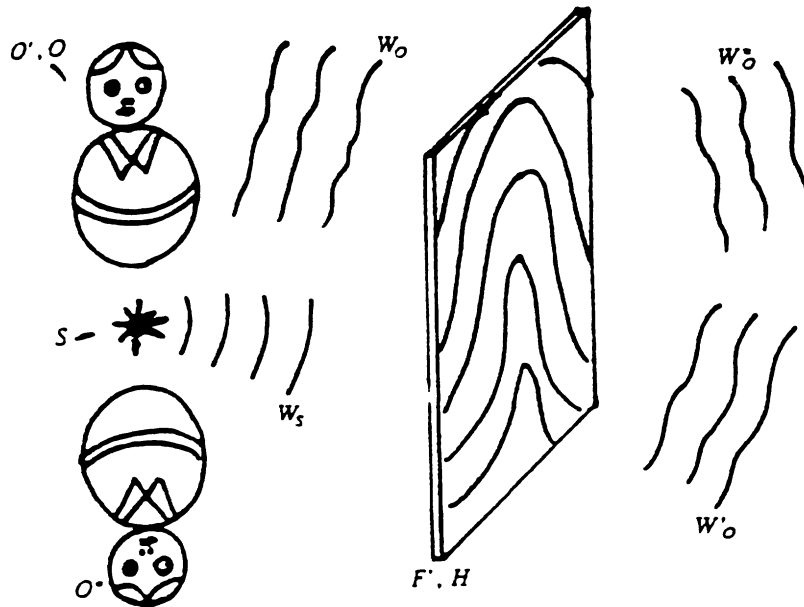
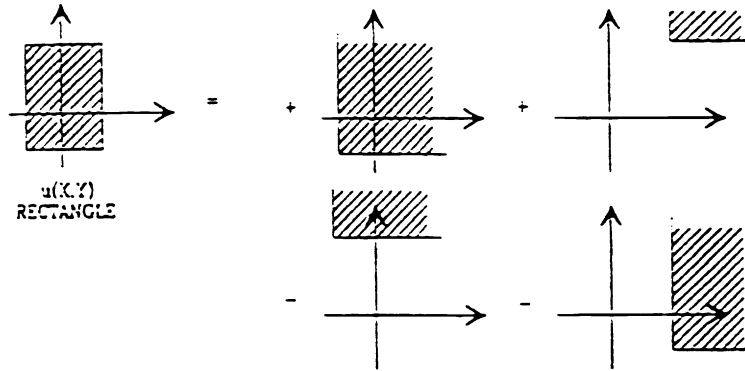


Table 4. Upper part: a computerized version of "Synthesis of a rectangle from 4 corner elements"

IS IT POSSIBLE TO TEACH
HOW TO INVENT ?

IN MY OPINION : YES

FIRST STEP : CATEGORIZATION

- (1) FLASH OF GENIUS
- (2) UTILIZATION OF WASTE PRODUCTS
- (3) TRANSLATION OF CONCEPTS
- (4) NEW COMBINATION OF OLD ELEMENTS
- (5) INTRAPOLATION
- (6) EXTRAPOLATION

Table 5

AN EXAMPLE OF :

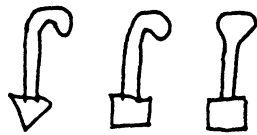
INVENTING BY INTRAPOLATION

STEP 1 : DEFINE A GOAL , HERE :
A NEW WALKING STICK

STEP 2 : WHAT EXISTS ALREADY ?



STEP 3 : SORTING



STEP 4 : DETERMINE DEGREE OF COMPLEXITY
OF THE SET OF WALKING STICKS:

$N = 2 \text{ BITS} : \uparrow \text{ OR } \downarrow \text{ AND } \square \text{ OR } \square$

STEP 5 : COMPARE NUMBERS OF EXISTING
ELEMENTS (3) WITH NUMBER OF POSSIBLE
ELEMENTS $2^N = 4$. : $4 > 3$

STEP 6 : IDENTIFY MISSING ELEMENT

	\uparrow	\downarrow	
\square	✓	✓	
\downarrow	✓	*	

STEP 7 :
FIND
CUSTOMER

Table 6

WHAT IS LIGHT?

RAYS (FERMAT)

RAYS (SNELLIUS + REFLEXION)

RAYS (POINTS IN $(x, \tan \alpha)$ -DOMAIN)

WAVES (HUYGENS, YOUNG, FRESNEL)

PHOTONS (PLANCK, EINSTEIN, BOSE)

WIGNER STUFF

KIRCHHOFF:

A "WHAT IS" - QUESTION IS NON-SENSE,
IN THE REALM OF NEO-POSITIVISTIC
PHILOSOPHY.

SCIENCE DESCRIBES NATURE,
BUT DOES NOT EXPLAIN IT.

NEVERTHELESS:

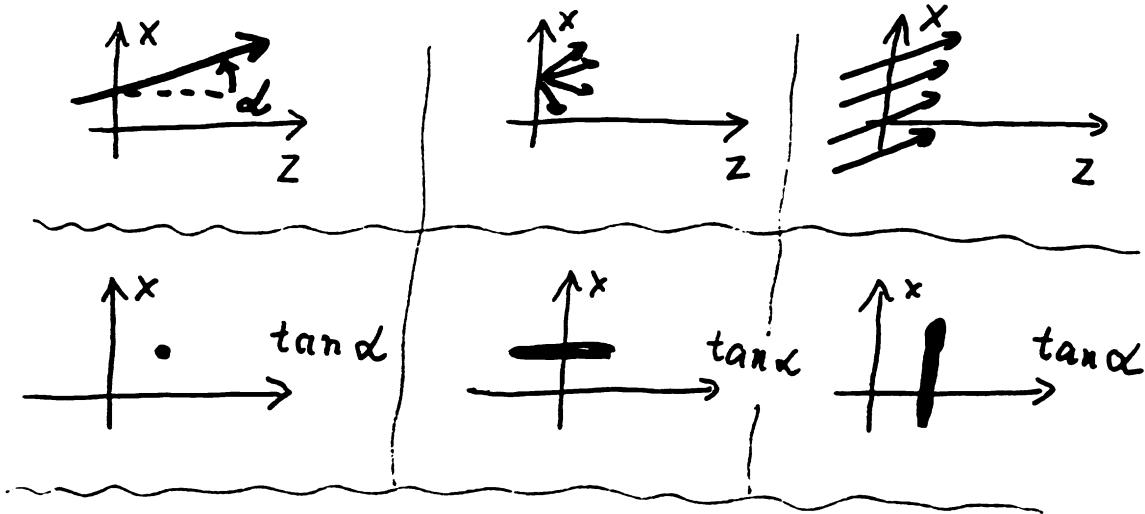
CONTEMPLATING ABOUT "WHAT IS"
MAY BE FRUITFULL.

♣ ILLEGAL ANSWERS BETTER THAN NO ANSWER

Table 7

LIGHT IN $(x, \tan \alpha)$

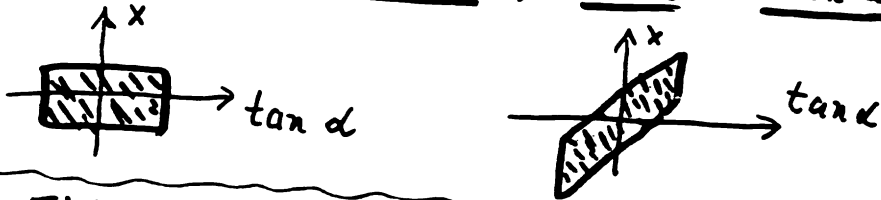
EXAMPLES



3 PROCESSES, PRESENTED IN $(x, \tan \alpha)$

PROPAGATION FROM $Z=0$ TO PLANE Z

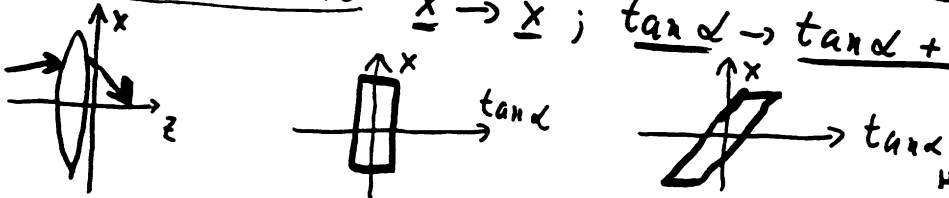
$$\underline{x} \rightarrow \underline{x + Z \tan \alpha}; \quad \underline{\tan \alpha} \rightarrow \underline{\tan \alpha}$$



VERTICAL SHEAR

THROUGH LENS

$$\underline{x} \rightarrow \underline{x}; \quad \underline{\tan \alpha} \rightarrow \underline{\tan \alpha + x/f}$$

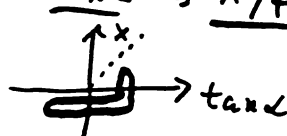
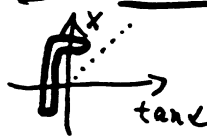
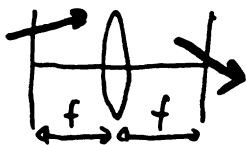


HORIZONTAL SHEAR

2f-SYSTEM

$$\underline{x} \rightarrow \underline{f \tan \alpha}$$

$$\underline{\tan \alpha} \rightarrow \underline{x/f}$$



45° FLIP

Table 8

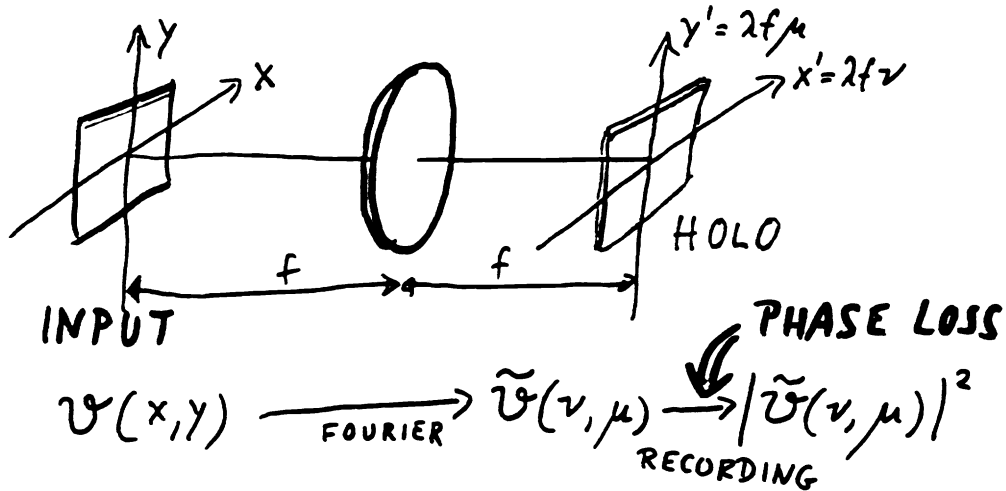
10 EXPLANATIONS OF HOLOGRAPHY

- (1) CONVOLUTION WITH ZONE PLATE
- (2) AS DEFORMED GRATING
- (3) AS SPATIAL MODULATION
- (4) INTEROGRAMS ARE HOLOGRAMS
- (5) FROM $Z = -0$ TO $Z = +0$ IN 3 STEPS:
ADD REFERENCE ; $|\dots|^2$; MULTIPLY BY REFERENCE
- (6) MONTGOMERY'S "POLARIZATION IDENTITY"
GENERALIZATION OF $(A+B)^2 - (A-B)^2 = 4AB$
- (7) PRECOMPENSATING FOR PHASE-
BLINDNESS BY ADDING REDUNDANCY
- (8) POLARIZATION HOLOGRAPHY
= 2x MULTIPLEXING
- (9) COLOR HOLOGRAPHY
= 3x MULTIPLEXING
- (10) AS 4-WAVE MIXING

Table 9

HOLOGRAPHY

REVERSIBLE INSPITE OF PHASE BLINDNESS
BY ADDING REDUNDANT BALLAST.



LOSS OF $\frac{1}{2}$ INFO

HOW CAN $\frac{1}{2}$ OF \tilde{U} -INFO BE ENOUGH
TO RECOVER U IN AMPL. AND PHASE?

ANSWER: ONLY $\frac{1}{2}$ OF U -INFO IS
ALLOWED TO BE UNKNOWN. HOW?

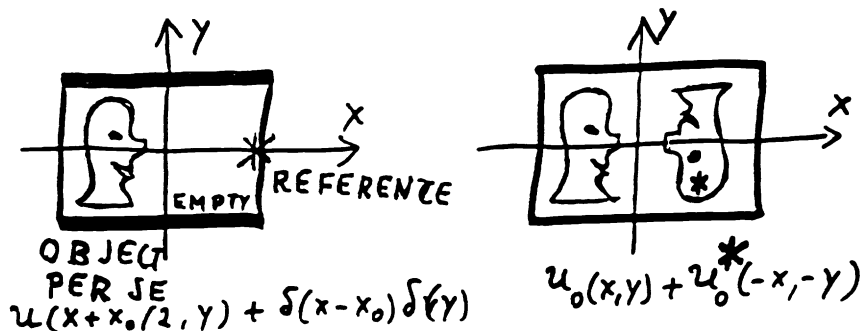


Table 10

HOMWORK ASSIGNMENTS

PROBLEMS { WELL CONFINED ?
OPEN ENDED ?

JUDGMENT { OBJECTIVE ?
SUBJECTIVE ?

EXAMPLES:

(1) HUYGENS PRINCIPLE

WHY DOES THE LIGHT GO FORWARD ONLY?

(2) WHY DON'T WE OBSERVE DIFFRACTION PATTERN WITH 5-FOLD SYMMETRY ?

(3) IS THE 99% WASTE OF LIGHT IN ESPI* UNAVOIDABLE ?

(4) IS IT POSSIBLE TO STORE $(B/\lambda)^3$ DATA WITHIN A B^3 CUBE ?

(5) PERFORM A MARKET SURVEY OF SEMICONDUCTOR LASERS. DEFINE A "FIGURE OF MERIT" AND A PRICE / PERFORMANCE RATIO

* ELECTRONIC SPECKLE PATTERN INTERFEROMETRY

Table 11