the tools of our force in efficient readiness.

We have entered a new era, an era of scientific revolution, as C. P. Snow terms it, in which science and technology are transforming our way of life and the relations between nations. As practicing scientists, we cannot stand aside and simply watch this process, regardless of where it takes us; we must and we can use science and technology to achieve the humanistic goals of our free society. Let us learn to take greater advantage of the opportunities science offers us to contribute to the striving for peace in international relations and to improve the lot of man throughout the world.

Preparation of High School Science Teachers

The AAAS Cooperative Committee on the Teaching of Science and Mathematics recommends the adoption of certification standards.

The concern for better preparation of teachers in the field of science and mathematics (hereafter referred to in this report as the sciences) has been growing during the last several years. Very recently this concern has been intensified considerably as the result of new developments both nationally and internationally. A statement was made by the Cooperative Committee of the AAAS in 1946 with reference to recommended minima for the preparation of science teachers in content material (*1*). In that same report a general statement was given with reference to the breadth of preparation that was to be desired (*2*).

Purpose

It seems that it is now time (i) to re-examine our original statements, (ii) to take cognizance of the impact of those events that have transpired in the last ten years on the requirements for the preparation of science teachers, and (iii) to make additional recommendations which result from the demands of the changing circumstances.

It is well recognized that changes in state certification laws may not always be made quickly. It is our hope, however, that this information and these recommendations, even though not immediately written into certification codes, will be studied by college and university departments of education, teachers colleges, state departments of education, certification bureaus and accrediting agencies, school administrators who select science teachers, colleagues in subject matter areas, and finally by those students and teachers who are preparing to do a more effective job in teaching science in our secondary schools.

New Developments To Be Considered

Several important factors have influenced the type of recommendation we now make on the course content that prospective teachers should have.

1) *The rapid changes that have occurred in a number of the sciences in the last decade.* Astronomy, biology, chemistry, geology, mathematics, meteorology, and physics have all advanced considerably in the last ten years. Word of new advances spreads by newspapers, magazines, public lectures, and television. This stimulates the curiosity of students who then seek answers to many questions. Teachers must be prepared to stimulate further the interest in such questions, to provide sound answers for them, and to direct effective reading at the level of the student's background. The course work taken by the teachers should prepare them to keep abreast of the new developments which are often highly complex, to answer questions about them, and to direct discussion of them.

2) *College entrance with advanced standing* (*3*). A concerted move was made (beginning in 1954) by a number of the colleges and universities of this country to work with secondary schools in developing college-level courses for their most able students. In the resulting program, for example, mathematics starting in the 10th grade leads to calculus in the 12th. In chemistry, the time-equivalent of at least three semesters permits instruction at the college level, with college texts. Thus students qualify for sophomore courses on college entrance, thereby reducing duplication. In physics similar programs have been available, but unless calculus is also taken, the policy has been to recommend advanced mathematics instead of advanced physics, thus making it possible for the student to start his sophomore physics (using calculus) during his freshman year in college. Similar programs have been in effect in biology, English, languages, and history. This program, expressing confidence in our secondary schools, places

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The members of the Cooperative Committee are J. W. Buchta, American Institute of Physics, chairman; Wayne Taylor, Academy Conference of the AAAS, vice-chairman; Bernard B. Watson, Operations Research Office, Johns Hopkins University, Bethesda, Md., secretary; Leonard Olsen, American Association of Physics Teachers; Thornton L. Page, American Astronomical Society; C. L. Agre, American Chemical Society; Theodore Woodward, American Geological Institute; Richard L. Weaver, American Nature Study Society; John W. Cell, American Society for Engineering Education; Arthur L. Howland, Association of Geology Teachers; Alfred B. Garrett, Board of Directors of the AAAS; Fred H. Norris, Botanical Society of America; John R. Mayor, director of education, AAAS; Harry F. Lewis, Division of Chemical Education, American Chemical Society; W. E. Restemeyer, Engineers Joint Council; Phillip S. Jones, Mathematical Association of America; Brother G. Nicholas, National Association of Biology Teachers; George G. Mallinson, National Association for Research in Science Teaching; Bruce Meserve, National Council of Teachers of Mathematics; Robert T. Lagemann, National Science Teachers Association; and Harold E. Wise, Section Q (Education) of the AAAS.

This report contains minor revisions of the subcommittee report which was published in April 1959 in *School Science and Mathematics*. Many of the suggestions that were gathered as the result of the wide distribution of the original report have been incorporated in this final report. The major change involves an increase in the number of hours in the area of earth science (now referred to as "related science").

emphasis on the results of good teaching in high school which in turn may be rewarded by credit toward college graduation, or time for more advanced work in college. This reward is made on the basis of the college-level course programs referred to above and on examinations prepared and graded by committees of school and college teachers. Selected groups of college freshmen have taken the same examinations for use in setting grade standards.

3) *Demonstrated proficiency versus "16" credits.* More and more of the colleges and universities are emphasizing demonstrated proficiency in subject matter areas rather than merely demanding a specified number of units as a requirement for college entrance. Also more colleges over the country are adopting some kind of entrance examination as part of the method of selecting their students.

4) *More content courses to meet the problem of complexity.* The increased complexity of the fields of science makes it important for teachers to elect a greater number of hours of subject matter related to their teaching fields than has been the case in the recent past. A teacher so prepared should be able to teach an interesting, meaningful course and to answer questions posed by the better students. Hopefully, empirical presentation of subject matter will occur much less frequently. There may be other factors, but certainly these are some which should be recognized.

Pertinent Considerations

In formulating a set of recommendations for the training of high school teachers of science we are immediately confronted with several conflicting circumstances.

1) Most science teachers are required to teach several sciences, often including a course in general science, rather than just one science. This means that a teacher must have depth of preparation in a variety of areas.

2) Because of the impact of science on other areas, the science teacher should have preparation in the social sciences and humanities to help give him the kind of perspective that we like the scholar and citizen to have.

3) There are certain elements in professional education which should be helpful in giving the best performance in the classroom. These elements may be provided by courses in such areas as the psychology, philosophy, and methodology of education and especially by experience in student teaching.

The problem. Our problem, then, is (i) to recognize, in an objective manner, the role of these several new developments in the last decade, (ii) to recognize the problems that we face in building a realistic academic program for preparation of science teachers, and (iii) to make recommendations with reference to the best type of program that can be achieved to meet these changing needs.

The academic program to meet these three facets of our problem will certainly be a full one. However, if a minimum of 120 semester hours of academic work is assumed for graduation, these requirements may be met and still leave approximately one-half of the student's academic program free for the humanities, social sciences, and professional educational courses. Many students can or will have more than 120 hours of academic credit. One-half of the student's time for preparation in his teaching area seems reasonable to expect if he is to be properly prepared. Furthermore, this amount of concentration can give him such depth that it will be possible for him to build on it later with a fifth year or more of content material to improve further his competence in the science area.

In a 4-year program for teachers it seems almost impossible to prepare them to teach in widely divergent areas: for example, English teachers to teach physics, or social science teachers to teach chemistry, or physical education teachers to teach mathematics. If multiple teaching assignments are necessary, there are favorable combinations such as physics and mathematics, chemistry and physics, and biology and health.

Recommendations for Each Science Area

The courses which are recommended in each teaching area, together with supporting courses, are outlined in the following sections. Each course is designated in terms of semester hours of credit; this designation is intended only to indicate the general proportion of time and the minimum requirements.

The supporting courses which are recommended should be the basic courses in that science area and should in each case include laboratory work.

The related science courses should include geology, astronomy, and meteorology. (This area is sometimes referred to as earth science.) It is highly desirable that students have as much experience in the related sciences as possible. This can be a combined course or it may be separate courses in these areas.

The description of each course in the following subsections and tables is merely suggestive or illustrative of the possible topics and makes no attempt to prescribe all that could or should be included.

Biology

A summary of the suggested courses in biology and other sciences (in semester hours) for the preparation of high school teachers of biology is given in Table 1.

Notes

1) Description of biology courses

A) Principles of biology: characteristics of living organisms, cell theory, structural system of plants and animals, metabolism, maintenance of individual (health and disease)

B) Plant and animal physiology, anatomy, and morphology: comparative study of functional processes of cells and tissues, structure, and behavior among the major groups of plants and animals, including the microorganisms. "At least four hours should be devoted to a study of microbiology, with emphasis on principles of bacteriology, virology, and protozoology."

C) Ecology and conservation: environment, soil, populations, relationships of species, distribution of communities. Field work should be an integral part of this course. The course could be coordinated with the work in related science.

D) Developmental anatomy and genetics: growth and development, principles of heredity, evolution

E) Preparation and use of biological materials: This course should be conducted by one thoroughly conversant with the problems of biology teachers. Consideration should be given to problems of microtechnique, cell and tissue culture, field collections, and preparation and care of small organisms.

2) Fifth year. There should be a minimum of mandated semester hours in biology to permit more flexible selection of the courses

Table 1. Suggested courses in biology and other sciences for the preparation of high school teachers of biology. (For annotation, see subsection "Biology.")

Subject	Suggested courses (semester hours)							
	A	B	C	D	E	4-year total	5th year	5-year total
Biology	10	10	4	5	4	33	14	47
Chemistry						10	6	16
Physics						8	4	12
Related science						6		6
Mathematics						6	4	10
Total						63	28	91

Table 2. Suggested courses in chemistry and other sciences for the preparation of high school teachers of chemistry. (For annotation, see subsection "Chemistry.")

Subject	Suggested courses (semester hours)						
	A	B	C	D	4-year total	5th year	5-year total
Chemistry	8	8	4	8	28	15	43
Physics					8	6	14
Biology					8		8
Related science					3	3	6
Mathematics					12	6	18
Total					59	30	89

Table 3. Suggested courses in physics and other sciences for the preparation of high school teachers of physics. (For annotation, see subsection "Physics.")

Subject	Suggested courses (semester hours)					
	A	B	C	4-year total	5th year	5-year total
Physics	10	12	6	28	15	43
Chemistry				8	6	14
Biology				8		8
Related science				3	3	6
Mathematics				12	6	18
Total				59	30	89

Table 4. Suggested courses in physics, chemistry and other sciences for the preparation of high school teachers of both physics and chemistry or of physical science. (For annotation, see subsection "Physics and Chemistry; Physical Science.")

Subject	Suggested courses (semester hours)					
	A	B	C	4-year total	5th year	5-year total
Physics	8	6	4	18	12	30
Chemistry				18	12	30
Biology				6		6
Related science				12		12
Mathematics				12	6	18
Total				66	30	96

Table 5. Suggested courses in mathematics and supporting areas for the preparation of high school teachers of mathematics in grades 7 to 12. (For annotation, see subsection "Mathematics.")

Subject	Suggested courses (semester hours)								
	A	B	C	D	E	F	4-year total	5th year	5-year total
Mathematics	12	3	3	6	3	3	30	15	45
Physics							8		8
Supporting areas							22	15	37
Total							60	30	90

which will be of most benefit to the teachers. "Cultural" courses in general science should be allowed (history of science, problems of the atomic age, laboratory techniques in more than one science, and so on). However, 25 percent of the year should be devoted to definitely biological topics such as radiation biology, microbiology, and taxonomy. It is to be understood that the taking of further courses in the biological sciences as electives should be encouraged.

3) Description of courses in other sciences recommended for biology majors. Principles of inorganic and organic chemistry, particularly as it applies to living things. Laboratory work should be included. Biochemistry is recommended in the fifth year. It is expected that standard courses in physics, earth science, and mathematics will be taken.

Chemistry

A summary of the suggested courses in chemistry and other sciences (in semester hours) for the preparation of high school teachers of chemistry is given in Table 2.

Notes

1) Description of chemistry courses
   - A) General principles: composition and structure of matter, atomic and molecular theory, states and transitions of matter, stoichiometry, nature of solutions, periodic tables and relationships, rates of reactions and equilibrium, ionic equilibrium and properties of electrolytes, oxidation-reduction and electrochemistry, energy relationships and colloidal state
   - B) Organic chemistry: nomenclature, hydrocarbon series, functional groups and their basic reactions, typical methods of preparation, application
   - C) Analytical chemistry: gravimetric and volumetric and instrumental methods, their applications and limitations
   - D) Physical chemistry: determination of precise physical properties and the application of these data to problems of reaction rates, equilibrium systems, and structure determinations.
2) Fifth year. For the fifth year the chemistry courses should include advanced inorganic chemistry (re-

Table 6. Suggested courses for the teacher who is preparing to teach mathematics as a second subject. (For annotation, see subsection "Mathematics as a second subject.")

Subject	Suggested courses (semester hours)					
	A	B	C	4-year total	5th year	5-year total
Mathematics	12	3	3	18	12	30
Physics, chemistry, or other "second" subject				18	12	30
Supporting courses for mathematics and second subject				24	6	30
Total	12	3	3	60	30	90

lation of structure to properties, periodic system, typical reactions, and the application of physical chemical principles to inorganic systems); biochemistry (fundamental reaction systems of living organisms); and radiochemistry (general principles, including some simple measurements).

3) Description of supporting courses. The other supporting courses should be the basic courses in physics, biology, mathematics, and related science.

Physics

A summary of the suggested courses in physics and other sciences (in semester hours) for the preparation of high school teachers of physics is given in Table 3.

Notes

1) Description of physics courses

A) Introductory course: this should be a course which pursues in depth the important and basic principles of physics. Some of the most important topics are Newton's laws of motion; conservation of mass, energy, and momentum; conservation of charge; waves and fields; molecular structure of matter; and structure of the atom. Problem solving and laboratory experience are important aspects of this course. The laboratory especially must give the student first-hand knowledge of the way in which a physicist approaches an experimental problem.

B) Intermediate courses: The prospective high school physics teacher should have one-semester courses in each of the following subjects: physical mechanics, heat and thermodynamics, optics, and electricity and magnetism. Emphasis should be on thorough quantitative treatment of a limited number of important topics in these areas of classical physics. There should be some advanced laboratory work associated with these courses. Institutions which are able to offer this material in one substantial, integrated course should do so, but it must not be a survey course. It would be most desirable for these courses to be based on calculus as a prerequisite.

C) Modern physics: The development of atomic and nuclear physics should be traced through study of the phenomena, concepts, and experiments which are important to the understanding and appreciation of this newer area of physics. Again, the number of topics considered should be consistent with the goal of understanding emphasized in paragraphs A and B above. This course should utilize the mathematics background of the student and should have a well-developed laboratory program.

2) Description of chemistry courses. The chemistry courses should include general, organic, and physical chemistry. Laboratory and problem work should be stressed. Emphasis should also be placed upon the principles which unify the many facts of chemistry.

3) Description of other suggested courses. The related science course should be selected from the special list appearing in this report.

Physics and Chemistry; Physical Science

A summary of the suggested courses in physics, chemistry, and other sciences (in semester hours) for the preparation of high school teachers of both physics and chemistry or of physical science is given in Table 4.

Note

1) In many of this country's schools it is necessary for the science teacher to teach several sciences—for example, both physics and chemistry. Some teachers must be prepared to do this in spite of the fact that it is not possible to include in an undergraduate program all the work listed as essential to a strong preparation in both areas. Table 4 outlines a reasonable though not ideal program for these teachers. To follow this program it is necessary to allocate to the sciences a few of the hours which are considered highly desirable for preparation in the social sciences and the humanities. It must also be recognized that, in spite of this, this program may not provide a completely adequate background for graduate study in a particular science.

Mathematics

A summary of the suggested courses in mathematics (in semester hours) for the preparation of high school teachers of mathematics is given in Table 5.

Notes

1) Teaching area. In this day of changing curricula, as never before, a thorough preparation in mathematics is imperative for all mathematics teachers in grades 7 to 12. Since, as with the sciences, there are schools which must employ persons to teach another subject in addition to mathematics, and since such persons often cannot complete in an undergraduate program all the work essential to strong preparation in two areas, an initial program for these people is suggested in the next subsection.

2) Description of mathematics courses. On the undergraduate level, minimum requirements in several areas of mathematics are specified. On the graduate level, only the additional number of hours is specified.

A) Analysis: Whether done in high school or college, adequate work in trigonometry, college algebra, analytic geometry, and calculus (with at least 6 semester hours in calculus) must be included in the teacher's preparation. For many undergraduate programs this will necessitate more than the 12 hours listed. Additional hours, if available within the 12-hour minimum, may be selected from

Table 7. Suggested courses for teachers of general science. (For annotation, see the subsection "General Science.")

Suggested courses	Semester hours
Biology*	10
Chemistry*	10
Physics*	12
Related science	6
Mathematics†	6
Subtotal	44
Other‡	16
Grand total	60

*These areas should include some work in genetics, organic chemistry, and modern physics. †Where possible this should include an introduction to the calculus. ‡These 16 semester hours of upper division work should be selected from two or more of the four science fields (excluding mathematics) listed.

advanced calculus, differential equations, and infinite series.

B) Algebra: courses selected from abstract algebra (groups, rings, fields, linear algebra, vector spaces), matrices, theory of equations, and number theory. (See also the courses described in paragraph D.)

C) Geometry: courses selected from metric and other geometries (projective, affine, inversive), non-Euclidean geometries, differential geometry, and topology. (See also the courses described in paragraph D.)

D) Foundations of mathematics: theory of sets, mathematical or symbolic logic, postulates for geometry, postulates for algebra, postulates for arithmetic, the real and complex number systems, the history of the development of mathematical ideas. (Some of the material and course hours specified here could be included under paragraphs B and C if a school chose to do so.)

E) Probability and statistics: emphasizing probability and statistical inference

F) Applications: courses from mechanics, mathematical physics, mathematical astronomy, actuarial mathematics (finite differences, empirical formulas and interpolation, numerical analysis), and mathematics as used in the behavioral sciences (theory of games, linear programing, operations analysis, econometrics)

3) Description of courses in supporting areas: The undergraduate requirement should include a year's course in physics and a course in at least one other science. The student's work in the foundations of mathematics suggested in paragraph D above should be further supported by study in philosophy, logic, and symbolic logic. In addition, his perceptions of the nature of mathematical models and the relationships between mathematics and the areas in which it is most used should be sharpened by additional work in science, such as courses in chemistry, astronomy, biology, geology, and meteorology and the other courses mentioned in paragraph F above.

Mathematics as a Second Subject

A summary of the suggested courses in mathematics and other sciences (in semester hours) for teachers who are preparing to teach mathematics as a second subject is given in Table 6.

Notes

1) As noted in the previous subsection, we believe that 4-year programs providing partial preparation in several areas are necessary at this time in order to staff small junior and senior high schools. We urge that teachers with such a "minor" in mathematics extend their training as rapidly as possible via extension courses, summer sessions, and "in-service" or summer institutes.

2) The courses under the column headings A, B, and C are the same here as in Table 5. A "minor" in mathematics should never contain less than an introductory calculus course and some experience in algebra and geometry beyond college algebra and analytic geometry.

General Science

A summary of the suggested courses (in semester hours) for the preparation of high school teachers of general science is given in Table 7.

Assumptions. The suggested requirements are predicated on the following assumptions.

1) A teacher who has completed the specified major in any of the fields previously listed in this report (biology, chemistry, physics, and physical science) will, with a minimum of additional background, be qualified to teach general science.

2) There is need for teachers to specialize in the teaching of general science at the junior high school level.

3) The science courses for the general science specialist should be such as to permit him to begin graduate work in one of the sciences if he later decides to do so.

4) The teachers of general science should have a broad background in science and mathematics plus specialization in one or more areas of science.

Miscellaneous

1) *The science methods course.* It is assumed that a science methods course will be available in each of these curricula. The two essential conditions for this to be a valuable course are centered in the qualifications of the instructor. He must be a person who is a scholar, well and solidly informed in the field of science; and he must be cognizant of and intelligently sympathetic toward the problems of secondary education. Given these qualities as a *sine qua non,* the question of the department or school in which the course should be taught becomes irrelevant and is a matter to be decided in terms of local institutional circumstances.

2) It is recommended that student-

Table 8. Summary of the requirements.

Suggested courses	Common foundation	Major in				
		Biology	Chemistry	Physics	Physical science	General science
Biology	6	27	2	2		4
Chemistry	8	2	20		10	2
Physics	8			20	10	4
Related science	3	3			9	3
Mathematics	6		6	6	6	
Subtotal	31	32	28	28	35	13
Common total		31	31	31	31	31 + 16*
Grand total		63	59	59	66	60

* Sixteen units of upper division work selected from two or more of the four science fields (excluding mathematics) listed above.

teachers receive training in preparing and planning materials for laboratory work and demonstration purposes.

3) *The fifth year.* A fifth year of work is strongly recommended. At least half of the course work during this year should be in science courses.

4) *Related science.* The elements suggested for inclusion of the earth science course are enumerated in the previous section. No statement is made about preparation of teachers to teach related science alone. Recommendations for preparation of teachers in such basic sciences as chemistry, physics, biology, mathematics, and physical or general science have been considered of major concern at this time.

5) *Credit to maintain certification.* Teachers who are required to take a certain number of credit hours to maintain their certificates after several years of teaching should take basic science courses in their teaching field unless they can show sufficient background of *recent* course work in that field.

6) *A synoptic view.* A survey of the requirements for the five science majors in this report (biology, chemistry, physics, physical science, and general science) shows that there exists a pattern of background common to all. Thus, each science major can be thought of as consisting of this common foundation plus certain additional preparation.

Specifically, the pattern of background common to all of the science preparations (but not including preparation for mathematics teaching) is, in semester hours, as follows: (i), biology, 6; (ii), chemistry, 8; (iii), physics, 8; (iv), related science, 3; (v), mathematics, 6—or a total of 31 semester hours.

Because there is so much in common among the five curricula in science, it is quite practical for the prospective teacher to qualify in at least two of the five science areas involved in this report. Specifically, it is quite practical for the prospective teacher of biology, chemistry, physics, or physical science to add a few more courses and qualify also as a teacher of general science. This combination, known in some places as a "comprehensive science major," is an ideal preparation for the modern teacher of science to high school students, although it must be recognized that it does *not* prepare him for more advanced study.

For the four-year programs, the requirements are summarized in Table 8. This synthesis of recommendations also suggests multiple qualification in secondary school science—for example, a teacher prepared in biology could also qualify in general science by taking four additional units in physics and three additional units in related science. By the addition of 10 units in physics and 9 units in related science, the major in chemistry could qualify for teaching physical science.

References and Notes

1. *School Science and Mathematics* (Feb. 1946).
2. The recommendations were as follow. (i) A policy of certification in closely related subjects within the broad area of science and mathematics should be established and put into practice. (ii) Approximately one-half of the prospective teacher's 4-year program should be devoted to courses in science. (iii) Certification to teach general science at the 7th, 8th, and 9th grade levels should be granted on the basis of a broad preparation including college courses in all the subjects concerned in general science. (iv) Colleges and certification authorities should work toward a 5-year program for the preparation of high school teachers. (v) Curriculum improvements in the small high schools should go hand in hand with improvement in teacher preparation.
3. "Bulletin on Advanced Placement Program" (College Entrance Examination Board, New York); B. Norton, "College admission with advanced standing," *J. Chem. Educ.* **33**, 232 (1956).

Milton Charles Winternitz, Pupil of William Henry Welch

In setting down the above title I felt no temptation to write "Milton Charles Winternitz, Pathologist." For if Winternitz were so described, where today would we find pathologists?

Four inscriptions adorn the walls of the School of Medicine at Yale. The first, over the main portal, announces: "The Institute of Human Relations–The Sterling Hall of Medicine." Here, high enough and plain for all to see, is set forth the great objective Winternitz set for medical science and the central ideal for which he strove—medicine, a study of the total man. To Winternitz, catching up the sparks of this lofty concept from his great teachers, endowed with youth, with brains, and with the courage and energy of a crusader, it mattered little that material assets at Yale were few when he arrived. You know the exciting story: bricks and mortar, the men, and always the ideas—ideas born of the happiness of constant work, of constant thought, and of steadily accumulating experience. "Yale will study man—total man," he said. With bewildering rapidity there came into existence, besides the magnificent medical school, a conception of the enormous importance of preventive medicine and public health, broad applications for psychiatry, the neurological study unit, the atypical-growth research unit, the dental study unit, the School of Nursing, and above all, the concept for the Institute of Human Relations. In each major field young men of extraordinary promise were assembled. But Winternitz, the dean, was not complacent. Often he said, "It's easy enough to grow apples, but can we grow better apples?" For him, any idea of a template for replication was unthinkable; all was new—spontaneous generation, or as some have said, "spontaneous combustion"! There is no doubt that things caught fire in New Haven. With what pride must he have viewed in 1932—side by side—the magnificent Institute of Human Relations and the Sterling Hall of Medicine, symbolizing then as they do today the ideals and ideas of many generations of teachers and students yet to come.

Over the inner doorway of the Sterling Hall of Medicine in the Greek of Plato is written: "Carrying torches,