ALTERNATIVE CONCEPTIONS CONCERNING INTERFERENCE AND DIFFRACTION OF LIGHT

by

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A RESEARCH REPORT

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Abstract

The aim of this study was to determine whether alternative conceptions about interference and diffraction do indeed exist, to identify the most important of these conceptions and to determine whether these conceptions relate to textbooks, as one of the main sources of students' knowledge. An analysis of secondary level textbooks and tertiary level non-calculus textbooks revealed that presentations of constructive and destructive interference, diffraction and other related aspects are treated inconsistently and in some cases contradictorily by different authors. The research instrument was a Physical Optics test which Physics students of the Technikon Pretoria wrote. This test revealed that alternative conceptions on elementary principles of interference and diffraction of light do exist and that they relate to textbook presentations. This study reveals that (i) the terms *in phase* and *out of phase* are not consistently used in different textbooks; (ii) the definitions of *constructive* and *destructive interference* in terms of phases cause major alternative conceptions; (iii) the interrelation between *interference* and *diffraction* is not clarified.

Declaration

I declare that this research report, titled

ALTERNATIVE CONCEPTIONS CONCERNING INTERFERENCE AND DIFFRACTION OF LIGHT

is my own work and that all sources that I have used or quoted have been indicated and acknowledged by means of complete references.

It is being submitted for the degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

A COETZEE
31 March 1998

Opgedra aan my pa

Jan Joubert

vir die voorbeeld wat hy
nog altyd vir my gestel het om
met toewyding en oorgawe Wetenskap te onderrig

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1 MOTIVATION FOR THE STUDY

Personal experiences as a physics lecturer at the Technikon Pretoria suggested that tertiary level students experience problems with the concepts of interference and diffraction of waves.

In particular, in analytical chemistry, the diffraction grating is a fundamental component of the spectrometer. The operation of the diffraction grating is based on the fundamental principles of interference and diffraction of light. This study investigates students' conceptualisations on interference and diffraction to determine if these alternative conceptions could lead to problems when applied to the diffraction grating.

The researcher is of the opinion that different textbook presentations of these phenomena lead to alternative conceptions.

The aim of the study is to:

- determine whether alternative conceptions about interference and diffraction do indeed exist;
- identify the most important of these alternative conceptions;
- consider whether textbooks, as one of the main sources of students' knowledge, contribute to alternative conceptions.

2 DEFINITION OF TERMS

The terms defined in this section are the researcher's definitions to clarify their use in this study, except where otherwise noted.

Alternative conceptions: The wide range of ideas held by students, and sometimes even by educators, that differ from the consensus model developed by the scientific community. The term *alternative conceptions* is being used in preference to *misconceptions*. Modern science educators believe that students' prior notions may have some utility in anchoring new conceptions, while the term *mis*-conceptions implies that these ideas are completely wrong (*mis* = wrong).

Optics: The study of light subdivided into geometrical optics and physical optics. For geometrical optics the rectilinear propagation, described by the ray model, is the principal characteristic of light needed for understanding. This includes the formation of images by mirrors and lenses. For physical optics the *wave nature of light* is essential for complete understanding. This includes the total effect of a number of waves arriving at one point. Interference and diffraction, and therefore this study, focus on physical optics.

Secondary education: The South African school system requires twelve years of education. The first seven years are referred to as primary education, and the last five years as secondary education. Secondary education is completed at the end of grade 12 (previously standard 10) by the writing of a public examination which gives the student a matriculation exemption certificate, subject to certain minimum pre-conditions.

Tertiary education: Tertiary institutions in South Africa include universities and technikons. This is an education level beyond grade 12. The matriculation exemption certificate is a prerequisite to study at a tertiary institution.

Textbook: A book designed for students (and teachers) as a written guide to the subject content of a course of study. It presents data, explains the relationships among presented data, illustrates by means of graphs, diagrams, photographs and drawings and evaluates by means of application of concepts in exercises, study questions and practice materials (Deighton, 1971:210).

Wave motion: This includes the motion of all kinds of sinusoidal waves e.g. water waves, sound waves and electromagnetic waves, which have a number of properties in common. Although this study is about light, which is an electromagnetic wave, it is sometimes helpful to refer to other types of waves for better understanding.

3 LITERATURE REVIEW

3.1 Origin and Sources of Alternative Conceptions

Children do not come to classrooms with empty minds, because they develop beliefs about the things that happen in their surroundings from the very earliest days of their lives (Driver, 1983).

The origin of alternative conceptions is experience and observation, language and cultural influence, textbooks and traditional teaching (Driver & Head, 1986).

The textbook is the dominant teaching tool in colleges and secondary schools (Ennis & Schlipf, 1966, quoted by Deighton, 1971:214). Since then several studies reveal that science textbooks are one of the major influences on students and teachers (Dall'Alba, Walsh, Bowden, Martin, Masters, Ramsden & Stephanou, 1993; Potter, 1992, quoted by Whiteley, 1996:169; Whiteley, 1996:173).

Dall'Alba *et al.* (1993) state that a single science textbook often provides the syllabus for courses at upper secondary and tertiary levels, and may be used as a principal source of information or explanation. In cases where students rely substantially on a single text in developing their understanding, misleading or inaccurate statements in textbooks may have considerable impact. In his study on acceleration he found that some students' understandings are incomplete in ways that parallel misleading or inaccurate textbook treatments.

According to The Encyclopedia of Education (Deighton, 1971:210-212) a textbook is not the sole instrument of instruction. In the hands of poorly motivated teachers textbooks are capable of misuse. In the first place it is not possible for any written record to be completely current and up-to-date. Supplementary materials, current journals, magazines and reports are needed to update textbook content. In the second place certain kinds of learning experiences cannot be presented through the printed page. In the third place textbooks are produced for a nation-wide market and cannot take into account significant regional variations and student abilities within a given grade level. The pragmatic answer to the problem is that the average textbook be addressed to the large middle group in ability levels and that teachers not rely on the textbook to do all the work but mediate, as necessary, between textbooks and students.

3.2 Alternative Conceptions about Light

During the last decade educators and researchers have become increasingly concerned about the prevalence of alternative conceptions in a number of science subjects. Consequently alternative conceptions have become a focus for studies in science education (Boyes, 1988; Jacobs, 1989; Rowell, Dawson & Lyndon, 1990; Treagust, 1988; Veiga, 1989). Research on science education has been done in various topics of physics, e.g. force (Galili & Bar, 1992), pressure (Rollnick & Rutherford, 1993), energy (Duit & Haeussler, 1994), electricity (Saxena, 1992) and optics (Driver, Squires, Rushworth, Wood-Robinson, 1994; Guesne, 1993; Palacios, Cazorla & Madrid, 1989; Pietersen, 1993; Watts, 1985).

To date little research on students' ideas of physical optics has been done. After a thorough literature search the researcher could not obtain any comprehensive research on students' ideas of interference and diffraction. Some aspects of interference and diffraction are mentioned in the following studies:

(i) Driver *et al.* (1994:128) state that children develop ideas about natural phenomena before they are taught science in school. The term **light** is one of which all youngsters have some informal understanding from a very early age (Watts, 1985). Seldom do teachers or pupil textbooks give a definition of what light is beyond it being a form of energy. The nature of light is taken for granted, whilst its properties are explored. Young people, then, are by and large in the position of having to construct their own conception of the nature of light, unaided by scientific instruction. Common school textbooks do not take into account the possibility of students having their own ideas. For students to accept the correct scientific ideas, they must be intelligible, plausible and fruitful (Hewson, 1981), in terms of their conceptions prior to instruction.

(ii) Watts (1985) mentions the example of the principle of **superposition**, that must be introduced in such a way as to seem a reasonable trade for students' own theories of how light works. He emphasises that the presentation and language must at least be dealt with in a way that makes sense.

(iii) In a study done by Pietersen (1993) on students' conceptions of light, the phenomena of **diffraction and interference** of light received some attention as part of a concept map. In an interview a student mentioned that light does **diffract** around obstacles in their path. He explained diffraction as follows: When radiation strikes an obstacle in its path, part of the radiation is slowed down, while the rest of the radiation stays at basically the same speed, which results in the bending of the light around an obstacle. The researcher did not take this alternative conception on diffraction further.

(iv) In research done by Guesne (1993) on the **rectilinear propagation** of light and shadow formation, diffraction is not even mentioned.

Beyond these peripheral references to diffraction and interference the researcher is of the opinion that the importance of diffraction and interference is neglected in research.

3.3 Interference and Diffraction

3.3.1 Historical Development

The nature and properties of light have been a subject of great interest and speculation since ancient times (Serway & Faughn, 1985:567).

Until the time of Newton (1642-1727) most scientists thought that light consisted of streams of some sort of particles emitted by light sources (Sears, Zemansky & Young, 1991:812). At about the same time it was suggested that light might be a wave phenomenon. Diffraction effects were observed by Grimaldi as early as 1660, but most scientists rejected the wave theory and adhered to Newton's particle theory for more than a century (Serway & Faughn, 1985:570). By contrast Christiaan Huygens was a firm believer in the wave theory of light. In 1678 he stated his famous Huygens' principle, which is a geometrical construction for finding from the known shape of a wave front at some instant, the shape of the wave front at some later time

(Miller, 1982:571; Sears, Zemansky & Young, 1991:830). This principle reinforced a wave theory of light (Mulligan, 1991:620)!

In 1803 the historic double-slit experiment of Thomas Young showed that light beams can interfere with one another, which added further evidence to the growing belief in the wave nature of light (Serway & Faughn, 1985:567). In 1816, Augustin Fresnel presented to the French Academy a wave theory of light that predicted interference and diffraction effects, although much of his work had been done earlier by Young (Giancoli, 1980:569). In 1818 the French mathematician Poisson predicted the existence of a bright spot in the very centre of the shadow of a 3 mm diameter steel ball, and the diffraction pattern was observed almost immediately after that by Arago (Sears, Zemansky & Young, 1991:902). Little opposition to the wave theory remained!

The next great step was taken in 1873 by Maxwell, who predicted the existence of electromagnetic waves and calculated their speed of propagation. This development, along with the experimental work of Hertz starting in 1887, showed conclusively that light is indeed an electromagnetic wave phenomenon (Sears, Zemansky & Young, 1991:812).

The Michelson interferometer, named after the American physicist Albert Michelson, played an interesting role in the history of science during the latter part of the nineteenth century. In 1887, Michelson and Morley used the Michelson interferometer in an attempt to detect the motion of the earth through the ether (the medium in which it was believed [at the time] that the propagation of light waves occurred). This motion was not detected in the Michelson-Morley experiment. This negative result baffled physicists until Einstein developed the special theory of relativity in 1905 (Sears, Zemansky & Young, 1991:898-900).

At the beginning of the 20th century, Albert Einstein returned to the particle theory of light in order to explain phenomena like the photoelectric effect, because the wave nature of light has its limitations (Serway & Faughn, 1985:567). Several phenomena associated with emission and absorption of light reveal particle properties. These apparently contradictory wave and particle properties have been reconciled only since 1930 with the development of quantum mechanical theory which accepts the dual nature of light, having both wave and particle properties. Propagation of light, interference and diffraction are best understood by the wave properties (Sears, Zemansky & Young, 1991:812).

3.3.2 Textbook Presentation

According to Dall'Alba *et al.* (1993), textbooks present a variety of different definitions of a concept, because a definition depends on the situation. Therefore it is difficult to give the ultimate definitions of interference and diffraction.

3.3.2.1 South African Secondary Level Textbook Presentation

Two different series of secondary school textbooks are investigated. The reason for their choice is availability to the researcher from two secondary schools in the vicinity.

These two series are:

(i) Brink B du P & Jones RC. **Natuur- en Skeikunde** (Standerds 8 & 9).

(ii) Heyns GF, De Villiers G, Gibbon DB, Jordaan AS, Naidoo LR & Fowler WG. **Physical Science 2000** (Standards 8 & 9).

The phenomena of interference and diffraction are introduced in grades 10 and 11 (previously known as standards 8 and 9). In grade 10, these phenomena are described as properties of waves. In grade 11, the phenomena of interference and diffraction are explained in more detail.

In grade 10, Heyns *et al.* (1987:19-25) illustrate diffraction patterns around barriers, followed by interference patterns from two point sources, with a ripple tank on an overhead projector, which is projected on a vertical screen. *Diffraction* is the bending of waves around the edges of an aperture. The degree of diffraction depends on the width of the aperture, relative to the wavelength. *Constructive interference* occurs where the waves arrive in phase (where two troughs or two crests meet) and the amplitude is a maximum. On the screen the very bright spots will represent constructive interference due to the crests and the dark spots will represent constructive interference due to the troughs. *Destructive interference* occurs where waves arrive in opposite phase (where a crest meets a trough) and the resultant amplitude is zero, because the disturbances cancel each other. On the screen the grey spots will represent destructive interference. Interference is a result of diffraction.

In grade 11, Heyns *et al.* (1989:67-82) start with the *principle of superposition:* Whenever two or more waves cross each other, the resultant displacement of the particles of the medium at any point and at any time is calculated by adding up the instantaneous displacements which would be produced by the individual waves if they were the only ones present. *Interference* is explained by applying the principle of superposition, as well as the path length differences of waves. Interference occurs when circular waves from two coherent sources intersect. *Constructive interference* takes place when two pulses reinforce each other. When two waves are exactly in phase, constructive interference will result. *Destructive interference* takes place when two pulses diminish each other. When two waves are exactly half a wavelength out of phase, destructive interference will result. Should the two waves have exactly the same amplitudes, the two waves will cancel each other out completely and there will be zero disturbance. Huygens was the first person to realise that diffraction is actually a form of interference. *Diffraction* is the phenomenon that the end of a wave that passes an obstacle changes direction. Heyns *et al.* then discuss interference and diffraction patterns of light in terms of double slit interference, while single slit diffraction is also investigated. The interpretation of the interference pattern of light waves in Young's double slit experiment differs from the pattern produced by water waves in the ripple tank: The bright lines are due to constructive interference, while the dark lines are due to destructive interference.

In grade 10, Brink & Jones (1986a:6-11) illustrate interference patterns (not diffraction) as a property of waves. *Constructive interference* is described as the area of an interference pattern where maximum displacement occurs. A bigger amplitude results when two crests (or troughs) meet. *Destructive interference* is described as the area of an interference pattern where zero displacement occurs. When a crest and a trough meet, they cancel each other. When the amplitudes are equal, complete cancellation results, which is destructive interference.

In grade 11, Brink & Jones (1986b:56-57) start with the *principle of superposition*: When two waves in the same medium meet, the instantaneous displacement of the medium at any point equals the algebraic sum of the displacements of the individual waves. Here the conditions for constructive and destructive interference are described as follows: *Constructive interference* occurs when waves are in phase. *Destructive interference* occurs when waves are out of phase, although cancellation is not complete. Brink & Jones continue with diffraction in terms of Huygens' principle and as a special case of interference. Interference patterns are explained in terms of the path length differences of waves. To see fixed interference patterns, the importance of coherent sources are stressed. Then the wave properties of light are introduced by means of the double slit interference and single slit diffraction patterns. The diffraction grating is introduced as an instrument to produce light spectra.

3.3.2.2 Tertiary Level non-calculus Textbook Presentation

A study done by George (1994) lists the names of the nine most popular textbooks used on one-year, non-calculus physics courses in American and Canadian colleges and universities as follows. (The percentage indicates the number of institutions using that particular textbook.)

(i)	Serway RA & Faughn JS. **College Physics.**	27 %
(ii)	Cutnell JD & Johnson KW. **Physics.**	21 %
(iii)	Giancoli DC. **Physics.**	18 %
(iv)	Jones ER & Childers RL. **Contemporary College Physics.**	8 %
(v)	Sears FW, Zemansky MW & Young HD. **College Physics.**	5 %
(vi)	Beiser A. **Physics.**	3 %
(vii)	Miller F & Schrorer JD. **College Physics.**	2 %
(viii)	Mulligan JF. **Introductory College Physics.**	2 %
(ix)	Nolan PJ. **Fundamentals of College Physics.**	2 %

Although not mentioned as one of the nine most popular textbooks, it is worthwhile adding to these the presentation of interference and diffraction of the following textbook:

Halliday D, Resnick R & Walker J. **Fundamentals of Physics.**

According to the above-mentioned authoritative tertiary level textbooks, interference and diffraction and related concepts are presented as follows:

Sears, Zemansky & Young (1991:889) remark that for the understanding of interference and diffraction phenomena, which are inherently wave phenomena, the principles of *physical optics* are necessary. When several waves overlap at a point, their total effect depends on the phases of the waves as well as their amplitudes.

Two common *features of all waves* are that a wave is a disturbance that propagates with time from one region in space to another with a definite speed, and a wave carries energy from one region in space to another (Beiser, 1986:279; Cutnell & Johnson, 1995:483; Giancoli, 1980:286-287; Jones & Childers, 1993:407; Nolan, 1995:321,323; Sears, Zemansky & Young, 1991:479; Serway & Faughn, 1985:325).

(a) Interference

- *Interference* is described by Giancoli (1980:297) and Sears, Zemansky & Young (1991:500) as the general term used to describe phenomena that result from two or more waves passing through the same region at the same time.
- Interference is the result of superimposing two or more waves on the same medium (Mulligan, 1991:288).
- Interference between two waves results in amplitude variations as a function of distance or as a function of time (Mulligan, 1991:308).
- Two sound waves of slightly different frequencies travelling through space in the same direction cause beats. Beats occur because there is constantly a change from a situation where the two waves interfere constructively to one where they interfere destructively at a later time (Mulligan, 1991:309).

- The principle of linear superposition is used to determine the total displacement at any point and at any instant of time (Sears, Zemansky & Young, 1991:890).
- The principle of superposition governs interference (Beiser, 1986:650).

(b) Linear Superposition

- The *principle of linear superposition* states that when two or more waves of the same nature are present simultaneously at the same place, the resultant displacement at any point and at any instant may be found by adding the instantaneous displacements that would be produced at the point by the individual waves if each were present alone (Beiser, 1986:290; Cutnell & Johnson, 1995:522; Nolan, 1995:336; Sears, Zemansky & Young, 1991:890; Serway & Faughn, 1985:330).
- Beiser (1986:283) describes what happens to the wave energy during complete cancellation, when two pulses move along a string towards each other, with one of the pulses inverted relative to the other. According to the principle of superposition, if the pulses have the same sizes and shapes, their displacements ought to cancel out when they meet, only to reappear later on, after they have passed the crossing point. At the instant of complete cancellation, the total energy of both pulses resides in kinetic energy of the string segment where cancellation occurs.
- According to Jones & Childers (1993:422), if two pulses are started along a rope at opposite ends, the waves will meet, pass through each other, and continue their motion as if nothing had happened.

(c) Constructive Interference

- *Constructive interference* or reinforcement results from the addition of amplitudes of waves, from two or more sources arriving at a point in phase (that is crest-to-crest or trough-to-trough) (Sears, Zemansky & Young, 1991:891).

- According to Beiser (1986:650) constructive interference refers to the reinforcement of waves in phase with one another.
- When two waves are in phase with each other, the waves are said to exhibit constructive interference or a bright fringe (Nolan, 1995:338).
- Serway & Faughn (1985:331) and Mulligan (1991:288) illustrate constructive interference with two overlapping waves having the same amplitude and frequency.
- Serway & Faughn (1985:615) describe constructive interference as a state where the amplitude of the resultant wave is greater than that of either the individual waves.
- The bright lines on the screen of Young's double slit experiment are the result of waves combining constructively (Serway & Faughn, 1985:617).
- Should two waves with the same wavelength come together in such a way that crest meets crest and trough meets trough, the resulting composite wave will have an amplitude greater than that of either of the original waves and the waves interfere constructively with each other (Beiser, 1986:290).
- When waves arrive at a point in the same part of their cycles, they interfere constructively (Beiser, 1986:653).
- According to Jones & Childers (1993:422) when two waves meet and the displacement of the two waves are in the same direction, the resulting wave has a larger amplitude. The two waves are said to be in phase, and the resulting build-up of amplitude is called constructive interference.
- Jones & Childers (1993:660) describe constructive interference as two waves with the same frequencies arriving at the same point with the same phase. The result is an amplitude that is greater than the amplitude of either wave alone. The amplitude of the resulting wave is a maximum when the two contributing wave crests (and subsequently the troughs) arrive at the same time.

- When two waves with the same frequency and amplitude are in phase, they interfere constructively, since at every point the displacements produced by the two waves add constructively (Mulligan, 1991:289).
- Giancoli (1980:297) describes constructive interference with two wave pulses on a string, both crests, travelling towards each other with the same amplitude. In the region where they overlap the resultant displacement is the algebraic sum of their separate displacements. The resultant displacement is greater than that of either pulse and the result is called constructive interference. Where two sets of water waves interfere with one another, constructive interference occurs where crests of one wave meet crests of the other (and troughs meet troughs). The water oscillates up and down with greater amplitude than either wave separately. The two waves are in phase.
- When two sinusoidal waves of the same wavelength and amplitude meet in phase, their interference is *(fully) constructive* (Halliday, Resnick & Walker, 1993:496).
- The *condition for constructive interference* occurs whenever the path length difference for two wave sources vibrating in phase is an integral multiple of the wavelength (Beiser, 1986:654; Cutnell & Johnson, 1995:524-525,870; Giancoli, 1980:567; Jones & Childers, 1993:660; Mulligan, 1991:622; Nolan, 1995:813; Sears, Zemansky & Young, 1991:891).

(d) Destructive Interference

- *Destructive interference* or cancellation results when waves from two sources which are permanently in phase, arrive at a point exactly a half-cycle (180°) out of phase (that is crest-to-trough), and the resultant amplitude which is the difference of the two individual amplitudes, is zero. The amplitudes are equal (Mulligan, 1991:289).

- Destructive interference occurs when waves are 180° out of phase and the resultant wave is zero everywhere, thus producing zero light and a dark fringe (Nolan, 1995:338,814).
- According to Beiser (1986:650) destructive interference refers to the partial or complete cancellation of waves out of phase with one another.
- Cutnell & Johnson (1995:525) say that at locations where neither constructive nor destructive interference occurs, the two waves partially reinforce or partially cancel.
- Describing Young's double slit experiment, Sears, Zemansky & Young (1991:894) again refer to destructive interference as complete cancellation.
- Serway & Faughn (1985:331) illustrate destructive interference with two waves with the same amplitude and frequency where the resultant wave is seen to be a state of complete cancellation
- With sound waves Serway & Faughn (1985:352) illustrate destructive interference where the two path lengths differ with half a wavelength, no sound will be detected at the receiver. Later Serway & Faughn (1985:615) describe destructive interference as the resultant amplitude being less than that of either of the individual waves.
- The dark lines on the screen of Young's double slit experiment are the result of waves combining destructively (Serway & Faughn, 1985:617).
- Should two waves come together in such a way that crest meets trough and trough meets crest, the composite wave will have an amplitude less than that of the larger of the original waves and the waves interfere destructively with each other (Beiser, 1986:290).
- According to Jones & Childers (1993:422) when two waves meet and the displacements are in opposing directions, these waves are said to be out of phase, and their amplitudes tend to cancel. This effect is called destructive interference.
- When waves from two sources with the same frequency arrive exactly out of phase, destructive interference occurs and the resulting wave is

diminished. If the two sources have the same amplitudes, destructive interference results in zero net amplitude (Jones & Childers, 1993:661).

- Giancoli (1980:297-298) describes destructive interference as the result when two wave pulses on a string travelling towards each other with the same amplitude, one a crest and the other a trough. In the region where they overlap the resultant displacement is the algebraic sum of their separate displacements. The two waves oppose one another as they pass by and the result is called destructive interference. Where two sets of water waves interfere with one another, destructive interference occurs where water actually does not move at all; that is where a crest and a trough meet. The two waves are out of phase.
- When two sinusoidal waves of the same wavelength and amplitude meet out of phase their interference is *destructive* (Halliday, Resnick & Walker, 1993:496).
- *Partial destructive interference* is the result in most areas where the relative phases of two waves are intermediate between the two extremes of constructive and destructive interference (Giancoli, 1980:298).
- The *condition for destructive interference* occurs whenever the path length difference for two wave sources vibrating in phase is a half-integer number of wavelengths (Beiser, 1986:654; Cutnell & Johnson, 1995:525; Giancoli, 1980:567; Mulligan, 1991:623; Nolan, 1995:814; Sears, Zemansky & Young, 1991:891).

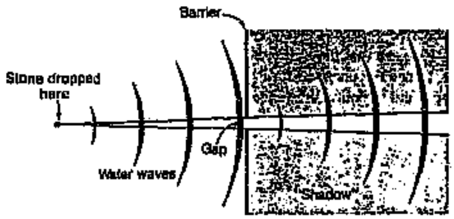
(e) <u>Diffraction</u>

- *Diffraction* is introduced by Sears, Zemansky & Young (1991:901-902) with the complexity of the shadow casted by a point source of monochromatic light. According to geometrical optics, if an opaque object is placed between a point light source and a screen, the edges of the object cast a sharp shadow on the screen. This ray model of light is inadequate to explain the phenomenon of diffraction, where a small amount of light bends around the edge, into the geometrical shadow, which is bordered by alternating bright and dark bands. Diffraction is the resultant effect produced by a limited portion of a wave front, when part of the wave is cut off by some obstacle. Because some light is found within the region of geometrical shadow, diffraction is also defined as the bending of light around an obstacle.

- Serway & Faughn (1985:624) define diffraction as the deviation of light from a straight-line path when waves pass through small openings, around obstacles, or by relative sharp edges.
- Mulligan (1991:632) and Nolan (1995:807) define diffraction as the bending of waves into the shadow region when they pass through apertures or around obstacles comparable in size to the wavelength. All types of waves exhibit diffraction, but it becomes most apparent when the wavelength is large compared with the size of the aperture or obstacle.
- Giancoli (1980:299) refers to diffraction as the fact that waves spread as they travel and when they encounter an obstacle they bend around it somewhat and pass into the shadow region.
- Cutnell & Johnson (1995:880,889) define diffraction as the bending of light around an obstacle or the edges of an opening. Diffraction patterns of bright and dark fringes occur when monochromatic light passes through a single or double slit. Diffraction is described as an interference effect and is explained with Huygens' principle.
- Nolan (1995:808) also explains diffraction with Huygens' principle.
- Mulligan (1991:633) and Serway & Faughn (1985,626) explain diffraction with Huygens' principle: By examining waves coming from various portions of the slit, each portion of the slit acts as a source of waves. Hence, light from one portion of the slit can interfere with light from another portion.
- Jones & Childers (1993:668) define diffraction as the spreading out of light passing through a small aperture or around a sharp edge. The wave fronts interfere with each other, according to Huygens' principle. Although

light always spread out as it travels, diffraction effects become noticeable only when light travels through a small enough aperture or past a sharp edge.

- Beiser (1986:662) illustrates diffraction in water waves where the diffracted waves spread out as though they originated at the gap, in accord with Huygens' principle, with the following diagram:



- Beiser (1986:662) explains diffraction patterns as the result of interference between secondary wavelets from different parts of the same wave front and not from different sources as in Young's double-slit experiment. The wave fronts in a beam of unobstructed light produce secondary wavelets that interfere in such a way as to produce new wave fronts exactly like the old ones. By obstructing part of the wave fronts, points in the shadow region are not reached by secondary wavelets from the entire initial wave fronts but only from part of them, and the result is an interference pattern.
- If any type of wave encounters a barrier that has an opening of dimensions similar to the wavelength, the wave will flare out into the region beyond the barrier. In the case of light waves more than just flaring occurs, because the light produces an interference pattern called a diffraction pattern. This phenomenon is called *diffraction* (Halliday, 1993:1053,1076).
- *Huygens' principle* is a geometrical method for finding, from the known shape of a wave front at some instant, the shape of the wave front at some later time. (Jones & Childers (1993:656) define a wave front as the

surface formed by points of constant phase.) Huygens assumed that every point of a wave front may be considered the source of secondary wavelets that spread out in all directions with a speed equal to the propagation of the waves. The new wave front is then found by constructing a surface tangent to the secondary wavelets (Beiser, 1986:595; Cutnell & Johnson, 1995:880; Giancoli, 1980:563; Jones & Childers, 1993:656; Mulligan, 1991:620; Nolan, 1990:748; Sears, Zemansky & Young, 1991:830; Serway & Faughn, 1985:573).

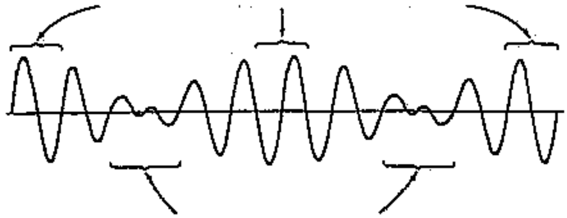
- Huygens' principle shows that plane waves remain planar and spherical waves remain spherical as they move through space (Mulligan, 1991:620).
- Huygens' principle is useful in understanding a variety of optical phenomena other than diffraction, like the laws of reflection and refraction (Beiser, 1986:596; Giancoli, 1980:565; Jones & Childers, 1993:657; Nolan, 1995:765; Sears, Zemansky & Young, 1991:831-832; Serway & Faughn, 1985:583-585).
- Beiser (1986:596,649) emphasises that although it is both proper and convenient to use *rays* in physical optics, an approach based exclusively on rays does not reveal characteristic wave behaviour as diffraction; the motion of *wave fronts* is what is really significant.

(f) Relation between Interference and Diffraction Patterns

- The interference pattern resulting from Young's double slit experiment consists of bright lines where constructive interference occurs and dark lines where destructive interference occurs. At intermediate locations on the screen the interference is only partial, so that the light intensity on the screen varies gradually between the bright and dark lines. The bright lines are actually extremely faint and relatively broad. Diffraction gratings consist of a large number of parallel slits which overcome these difficulties (Beiser, 1986:653,655).

- Interference of two light waves will produce constructive or destructive interference depending on the phase difference between the two waves (Mulligan, 1991:621-622).
- Beiser (1986:298-299) describes the maximum intensity periods and minimum intensity periods of sound waves from two tuning forks with the following diagram:

Maximum intensity (constructive interference)



Minimum intensity (destructive interference)

- Jones & Childers (1993:671) state that *interference and diffraction* are two phenomena which are inseparably linked and are not really different. The pattern that results from diffraction by a single slit could be thought of as the self-interference of light passing through the slit. In double-slit interference, the light is diffracted by each slit. Thus the patterns describe both interference and diffraction at the same time.
- Giancoli (1980: 566,570) describes the combination of interference and diffraction as follows: Because of diffraction at each slit in Young's double-slit experiment, the waves leaving the two small slits spread out to produce the interference pattern. The diffraction pattern formed by a round disc using a point source of light, are due to interference of waves diffracted around different parts of the disk.
- Mulligan (1991:637) describes both interference and diffraction as *superposition effects* which depend on the addition of wave disturbances at a given point, taking account of the phase differences between the

superimposed waves. Interference arises from the superposition of a finite number of waves coming from different coherent sources. Diffraction arises from the superposition of an infinite number of Huygens' wavelets arising from different places on the same original wave front. In double slits and di...action gratings both interference and diffraction occur.

- The theory of a *diffraction grating* is identical with that of Young's double slit. Interference effects are shown. This device is called a diffraction grating because diffraction effects are important in its full explanation (Mulligan, 1991:624-625). Giancoli (1980:572) comments that the term *interference grating* might be as appropriate.

(g) Coherency and Phase Relations

- The importance of *coherent* sources (sources which emit waves with a constant phase relationship between them) to observe visible interference patterns and to continue occurring at a point, is emphasised (Beiser, 1986:650; Cutnell & Johnson, 1995:868; Giancoli, 1980:568; Jones & Childers, 1993:659,662; Mulligan, 1991:621-622; Nolan, 1995:815; Sears, Zemansky & Young, 1991:892; Serway & Faughn, 1985:616).
- Serway & Faughn (1985:616) explain a constant phase relation as follows: If one source emits a crest at some instant, so should the other.
- Mulligan (1991:288) defines the phase of a wave as the specific stage of a cycle that a wave has reached at a particular time or at a particular place.
- Beiser (1986:650) emphasises that it does not matter whether the waves are exactly in step when they leave the source, or exactly out of step, or anything in between; the important thing is that the phase relation stays the same.
- Sears, Zemansky & Young (1991:508) describ... *...ut of phase* waves as waves arriving a half-cycle out of step at a point. Complete cancellation

occurs when the positive crest and negative crest of two waves with the same amplitude, meet at a point. The total amplitude there is zero.

- Serway & Faughn (1985:617) illustrate *in phase* waves with the set up of Young's double slit experiment where the waves from a single light source falls on two narrow parallel slits, which serve as a pair of coherent light sources because waves emerging from them originate from the same wave front and therefore are always in phase.
- Serway & Faughn (1985:616) also emphasise the condition that the sources must be monochromatic.
- Jones & Childers (1993:662) describe coherency as two sources of identical frequency and phase.
- Two waves are in phase if they reach their maximum amplitudes at the same time, are zero at the same time and have their minimum amplitudes at the same time. Two waves are *out of phase* when their maximum, zero and minimum displacements are not at the same place (Nolan, 1995:337).

3.3.3 Summary of Textbook Presentation

The presentation of interference and diffraction and related aspects as discussed in paragraph 3.3.2 is now summarised.

Note that the numbering of the different presentations is used for cross-reference purposes only, and not to indicate any order of preference.

3.3.3.1 Constructive Interference

i. When two or more waves meet *in phase*, they exhibit constructive interference (Beiser, 1986:650; Heyns *et al.*, 1987:25; Jones & Childers, 1993:660; Mulligan, 1991:289; Nolan, 1995:338; Sears, Zemansky & Young, 1991:891).

ii. When waves are in phase, their interference is *(fully) constructive* (Halliday, Resnick & Walker, 1993:496).

iii. Constructive interference is associated with *reinforcement* (Beiser, 1986:650; Heyns *et al.*, 1989:69; Sears, Zemansky & Young, 1991:891). When the resultant displacement is *greater* than that of either of the individual waves, the result is called constructive interference (Giancoli, 1980:297; Jones & Childers, 1993:422; Serway & Faughn, 1985:615). Where maximum displacement occurs, the waves interfere constructively (Brink, 1986a:10; Heyns, 1987:25).

iv. Constructive interference is associated with the *bright fringes* of an interference pattern (Nolan, 1995:338; Serway & Faughn, 1985:617).

v. Constructive interference is illustrated with two overlapping waves with the *same frequency and amplitude* (Mulligan, 1991:288; Serway & Faughn, 1985:331).

vi. For two wave sources vibrating in phase, a *path length difference* which is an integral number of wavelengths leads to constructive interference (Beiser, 1986:654; Cutnell & Johnson, 1995:524-525, 870; Giancoli, 1980:567; Jones & Childers, 1993:660; Mulligan, 1991:622; Nolan, 1995:813; Sears, Zemansky & Young, 1991:891).

vii. On an interference pattern from two point sources of a ripple tank on an overhead projector, projected on a vertical screen, the very bright spots represent constructive interference due to the crests. *The dark spots* *represent constructive interference due to the troughs* (Heyns *et al.*, 1987:21).

viii. When two waves meet and their displacements are in the same direction or in the same part of their cycles, the two waves are in phase and constructive interference results (Beiser, 1986:653; Jones & Childers, 1993:422).

3.3.3.2 Destructive Interference

i. When two or more waves meet *out of phase*, destructive interferenc results (Giancoli, 1980:298).

ii. When two or more waves meet *180° out of phase*, destructive interference results (Mulligan, 1991:289; Nolan, 1995:338,814).

iii. When two or more waves arrive in *opposite phases*, destructive interference results (Heyns *et al.*, 1987:25).

iv. Where two pulses *diminish* each other, destructive interference occurs (Heyns, 1989:69; Serway, 1985:615).

v. Destructive interference is the *partial or complete cancellation* of waves out of phase with one another (Beiser, 1986:290,650; Brink & Jones, 1986 b:57).

vi. Destructive interference is the *complete cancellation* of waves, where the resultant amplitude is zero and dark fringes appear on the screen (Brink, 1986a:10; Heyns *et al.*, 1987:25; Mulligan, 1991:289; Nolan, 1995:338,814; Sears, 1991:894; Serway, 1985:331,617).

vii. *Partial destructive interference* occurs where the relative phases of two waves are intermediate between the two extremes of waves which are in phase and waves which are out of phase (Giancoli, 1980:298).

viii. For two wave sources vibrating in phase, a *path length difference* which is a half-integral number of wavelengths, leads to destructive interference (Beiser, 1986:654; Cutnell & Johnson, 1995:525; Giancoli, 1980:567; Mulligan, 1991:623; Nolan, 1995:814; Sears, Zemansky & Young, 1991:891).

ix. On an interference pattern from two point sources of a ripple tank on an overhead projector, projected on a vertical screen, the dark spots represent constructive interference due to the troughs and the *grey spots represent destructive interference* (Heyns *et al.*, 1987:21).

x. At locations where neither constructive nor destructive interference occurs, the two waves partially reinforce or partially cancel (Cutnell & Johnson, 1995:525).

3.3.3.3 Coherency and Phase Relations

i. Coherent sources emit waves with a *constant phase relationship* between them (Beiser, 1986:650; Cutnell & Johnson, 1995:868; Giancoli, 1980:568; Jones & Childers, 1993:659,662; Mulligan, 1991:621-622; Nolan, 1995,815; Sears, Zemansky & Young, 1991:892; Serway & Faughn, 1985:616).

ii. Two sources are coherent if they have the *same frequency and phase* (Jones & Childers, 1993:662).

iii. A constant phase relation exists between two waves when the two sources emit crests (or troughs) simultaneously (Serway & Faughn, 1985:616).

iv. A constant phase relation does not mean that the waves have to be exactly in step (or out of step) when they leave the source (Beiser, 1986:650).

v. Two waves are out of phase when their *maximum, zero and minimum displacements are not at the same place* (Nolan, 1995:337).

vi. Out of phase waves arrive a *half-cycle out of step* at a point (Jones & Childers, 1993:422; Sears, Zemansky & Young, 1991:508).

3.3.3.4 Diffraction

i. Diffraction is defined as the *bending of light* around obstacles or small openings, into the geometrical shadow region (Cutnell & Johnson, 1995:880,889; Giancoli, 1980:299; Jones & Childers, 1993:668; Mulligan, 1991:632; Nolan, 1995:807; Sears, Zemansky & Young, 1991:902; Serway & Faughn, 1985:624).

ii. Diffraction is the *spreading out of light* waves passing around an obstacle or small opening (Beiser, 1986:662; Giancoli, 1980:299; Jones & Childers, 1993:668).

iii. Diffraction is explained by *Huygens' principle*: By examining waves coming from various portions of a slit, each portion of the slit acts as a source of waves. Hence, light from one portion of the slit can interfere with light from another portion, resulting in diffraction patterns (Beiser, 1986:662; Cutnell & Johnson, 1995:880,889; Mulligan, 1991:633; Nolan, 1995:808; Serway & Faughn, 1985:626).

3.3.3.5 Relation between Interference and Diffraction

i. Diffraction is an interference effect (Cutnell, 1995:880,889).

ii. Interference and diffraction are two phenomena which are not really different. The pattern that results from diffraction by a single slit is due to self-interference of light passing through the slit. In double-slit interference, the light is diffracted at each slit and the pattern describes both interference and diffraction at the same time (Giancoli, 1980:566,570; Jones, 1993:671).

iii. Diffraction patterns of bright and dark fringes occur when light passes through a single or double slit (Cutnell & Johnson, 1995:880,889).

iv. The result of diffraction is an interference pattern (Beiser: 1986:662).

v. The result of diffraction is a diffraction pattern (Cutnell & Johnson, 1995:889).

vi. Interference and diffraction are both superposition effects. Interference arises from superposition of a finite number of waves coming from different coherent sources. Diffraction arises from the superposition of an infinite number of Huygens' wavelets arising from different places on the same original wave front (Mulligan, 1991:637).

vii. In double slits and diffraction gratings both interference and diffraction occur (Mulligan, 1991:637).

viii. When diffraction occurs, light produces an interference pattern called a diffraction pattern (Halliday, 1993:1076).

ix. The term interference grating might be as appropriate as diffraction grating (Giancoli, 1980:572).

It is important to notice that most of these textbook presentations are presented in a font that stands out, such as *italic* or **bold.** This contributes to the association and assumption that a definition is presented, rather than an example or description to explain the concept.

From this summary it is clear that constructive and destructive interference and related aspects are treated inconsistently and in some cases contradictorily by different authors.

The opinion of the researcher is that different descriptions and simplified examples found in textbooks by different authors could misguide students in a way which leads to alternative conceptions on interference and diffraction.

This study investigates these aspects!

4 RESEARCH QUESTIONS

The researcher is of the opinion that alternative conceptions on interference and diffraction exist among students and that these different ideas are related to textbook presentations. Different presentations lead to different interpretations; therefore textbooks are a source of alternative conceptions.

This study investigates the following:

(i) Do students have alternative conceptions concerning interference and diffraction of light?

(ii) Do these alternative conceptions relate to the presentation of interference and diffraction in textbooks?

5 METHODOLOGY

5.1 Sample

5.1.1 Textbook

The South African secondary level textbooks and tertiary level non-calculus textbooks described under the Literature Review (paragraph 3.3.2) are used in this study.

5.1.2 Pilot Study

(i) **Seven** physics lecturers were asked to validate the test: **four** of the researcher's colleagues at Technikon Pretoria, **two** lecturers at the University of the Witwatersrand, and **one** secondary school teacher.

Only **five** tests were received back: **three** from the Technikon Pretoria, **one** from the University of the Witwatersrand and **one** from the secondary school teacher.

(ii) The edited pilot test was administered to **27** Physics students at Technikon Pretoria during the first semester of 1997: **14 Physics II** students enrolled for B Tech in Chemistry; **13 Physics I** students enrolled for N Dip in Surveying.

Although the composition of the students were not investigated, it is worth mentioning that the students used in this pilot study were from different cultural backgrounds, and for most of them English was not their first language.

5.1.3 Main Study

The test for the main study was administered to **191** Physics students enrolled for different courses from three different groups and lecturers at the Technikon Pretoria, during the second semester of 1997. Because these courses are semester courses the students for the pilot study and the main study were not the same students.

The three groups were as follows:

i. **99 Physics I** students enrolled for different science courses i.e. N Dip in Analytical Chemistry, Ceramics Technology, Chemical Engineering, Geotechnology, Metallurgy, Plastic and Rubber Technology;
ii. **84 Physics I** students enrolled for N Dip Electrical Engineering;
iii. **8 Physics II** students enrolled for B Tech in Chemistry.

All students completed the test at the end of their Physics course. Therefore it was assumed that all students were familiar with basic interference and diffraction principles.

Physics I is a six month course which covers different sections of basic physics, including interference and diffraction. Due to time constraints the treatment of the various topics tends to be superficial, and so it is unlikely for alternative conceptions formed by students prior to these Physics I courses to be changed. Even the Physics II course assumes that students are familiar with basic concepts.

Students used in this main study were from different cultural backgrounds. For most of them English was not their first language.

5.2 Research Instrument: Test

The research instrument consisted of a single written test. See Appendix A for the pilot version and Appendix B for the revised version for the main study.

The tests were composed by the researcher, due to the lack of existing research tests or questionnaires to investigate alternative conceptions on interference and diffraction. Some of the questions were developed by the researcher and other questions were totally or partially from other sources, as indicated in paragraphs 5.2.1 and 5.2.2.

The questions are multiple choice questions, based on possible alternative conceptions from the researcher's experience as a lecturer, and misleading or unclear statements in textbooks, as derived by the researcher through the critical analysis of textbooks, as described in the Literature Review (paragraph 3.3.2).

Each multiple choice question is followed by an open-ended question where the answer has to be motivated.

To serve as a motivation for the students to put in an effort to motivate each question properly, marks were allocated to the students' efforts. For each choice a mark out of three was allocated and for each motivation a mark out of two. These tests were therefore modified questionnaires where marks were allocated.

The purpose of each question was to investigate the possible existence of alternative ideas.

Note that these multiple choice items are NOT of the single response type. More than one option can be correct. This was made clear to the students.

5.2.1 Pilot Study

The test contains a total of 21 questions, grouped into seven areas, where each area investigates a possible alternative conception.

The questions are grouped into areas as follows: (The questions which were not developed by the researcher are indicated with the source of the question in brackets.)

(i) AREA 1: Constructive interference

QUESTIONS **1, 4, 5, 6, 19** (Houston, 1971:27), **21**

(ii) AREA 2: Destructive interference

QUESTIONS **2, 4, 6, 14** (Houston, 1971:12), **21**

(iii) AREA 3: Diffraction

QUESTIONS **7, 9, 10, 18** (Damelin, 1978:3), **20** (Hawkins, 1970:21)

(iv) AREA 4: Superposition and interference

QUESTION **4, 9, 10, 17, 18, 20**

(v) AREA 5: Coherency and phase relations

QUESTIONS **6, 12, 13, 15** (Houston, 1971:5), **16, 17** (Damelin, 1978:89)

(vi) AREA 6: Light as a form of energy

QUESTIONS **8, 11**

(vii) AREA 7: Wave nature of light

QUESTION **3** (Muller, 1976:115)

5.2.2 Main Study

The following changes from the pilot were made:

(i) The main test contains a total of 19 questions and not 21 as in the pilot study. Questions 3, 4, 12 and 16 of the pilot study are left out from the main study, and two additional questions, 18 and 19, are added to the main study. Both these questions were set up by the researcher.

(ii) The q[illegible] into five areas and not seven as in the pilot study. T[illegible] *nature of light* is left out in the main study, because it [illegible] inapplicable for the purposes of the research. The qu[illegible] the area *light as a form of energy* are allocated to other areas.

(iii) The amount of options is four for all the questions in the main study and not five as in the pilot study. The option which was chosen the least in the pilot study, was left out.

(iv) The order of the questions is changed to randomise the questions more, and to fit long and short questions to pages.

See Table 5.1 (p. 38) for the questions associated with each area.

AREA	QUESTION NUMBERS OF MAIN STUDY	CORRESPONDING QUESTION NUMBERS OF PILOT STUDY
1 : Constructive interference	1, 4, 5, 12, 13, 16, 18	1, 5, 6, 14, 19, 21, -
2 : Destructive interference	2, 7, 12, 16, 19	2, 8, 14, 21, -
3 : Diffraction	6, 8, 9, 15, 17	7, 9, 10, 18, 20
4 : Superposition and interference	8, 9, 10, 15, 17	9, 10, 13, 18, 20
5 : Coherency and phase relation	3, 5, 10, 14	17, 6, 13, 15

TABLE 5.1: QUESTIONS ASSOCIATED WITH EACH AREA

5.3 Procedure

5.3.1 Pilot Study

The test was scheduled as an assignment to complete in the librar, or at home, after the theory was finished in class. Students were encouraged to make use of the library and references other than the prescribed textbook. They were firmly requested not to work together, or to copy any choice or comment from other students.

5.3.2 Main Study

For the main study the test was scheduled as the last test of the term and this was the students' last chance to improve their semester marks. This was an encouragement for the students to put in an effort. It was an open book test. They could bring any literature or textbooks with them to the test period.

For the three different groups involved (see 5.1.3), the researcher was in control during the test sessions. The three groups wrote separately and at different times.

For better control the test was completed under test conditions during normal lecturing hours. The test was written during a three hours practical session where they had enough time to finish. This was no test against time! Most of the students arrived only with their prescribed textbook: Cutnell JD & Johnson KW. **Physics**.

The test was only in English, although Afrikaans speaking students were present in all the groups. Due to the bilingual nature of the Technikon Pretoria, Afrikaans speaking students could ask for translations where they did not understand terms and terminology. The only translation that was asked for more than once was about the translation of coherency, which is translated as 'koherent'. These students still did not understand the meaning!

6 ANALYSIS OF RESULTS

6.1 Quantitative Analysis

Individual students' responses to the multiple-choice questions were analysed quantitatively, because a fair mark had to be allocated to each student for semester mark purposes.

Since many of the options of the questions are not obviously correct or incorrect, and different textbook interpretations vary, the marking scheme was difficult to compile. The marking was subject to the researcher's opinion, taking into consideration different textbook interpretations, and the presentation of the prescribed textbook. The motivations were difficult to categorise according to marks, for the same reason.

The aim of the quantitative analysis was:

- To motivate the students to put in an effort to complete the test, because marks were allocated.
- To allocate a fair mark to each student for semester mark purposes and not for research purposes.
- To make a relative comparison of the complexity and difficulty of the concept(s) related to each question.

Each answer was assigned a mark of five. Three marks were allocated for the choice(s) and two marks for the motivation:

Choices:
- 3 marks for the correct choice(s)
- 2 marks for a partly correct choice where only one of a possible two obviously correct options was chosen.
- 1 mark for a 'grey' choice, where the obviously correct choice was not chosen.

Motivation:
- 2 marks for a correct motivation
- 1 mark for a partly correct motivation
- 0 marks for no motivation or a motivation which is totally inapplicable.

The final marks students obtained for this test are summarised in Appendix C.

The average mark for this test is 60%.

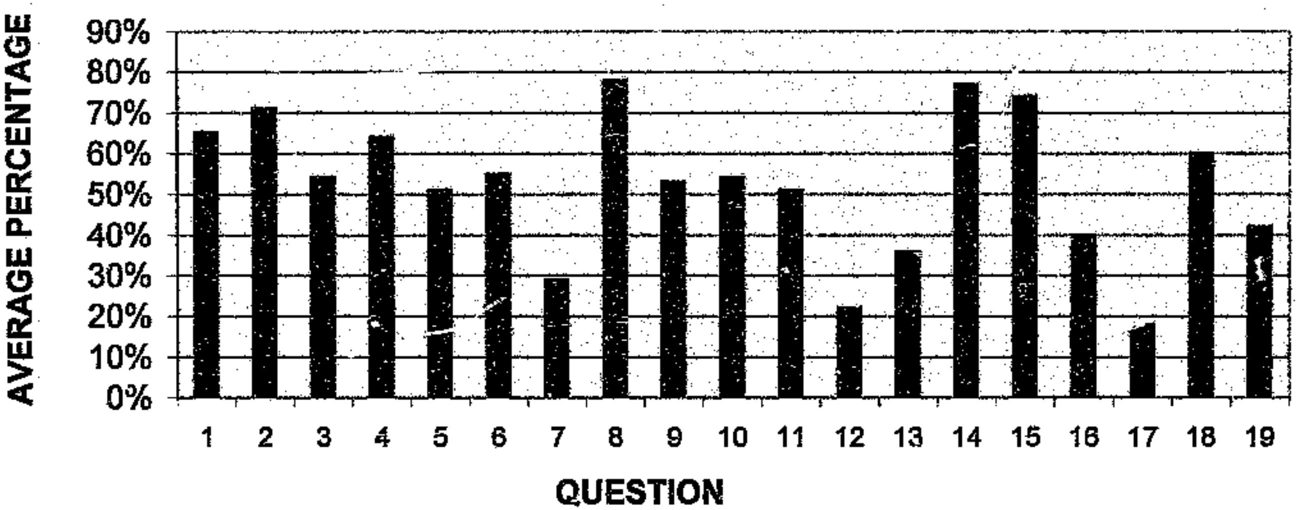
Figure 6 (p. 42) indicates the average mark for each question.

In descending order of <u>complexity and difficulty</u> the questions are found to be:

QUESTION **17**(18%), **12**(22%), **7**(29%), **13**(36%), **16**(40%), **19**(42%), **11**(51%), **5**(51%), **9**(53%), **10**(54%), **3**(54%), **6**(55%), **18**(60%), **4**(64%), **1**(65%), **2**(71%), **15**(74%), **14**(77%), **8**(78%)

These marks were not used further in this study to make conclusions. Although it might seem that this quantitative exercise was useless, it served as a motivation for the students to put in an effort to complete the test.

FIGURE 6
Quantitative analysis of results



6.2 Qualitative Analysis

The analysis is primarily qualitative, since many of the questions do not have an obviously correct or incorrect answer, because of different textbook interpretations.

The answers were sorted according to the choice(s), and then the open-ended motivations were analysed and categorised for each question. See Appendix E for the analysed and categorised test responses to each question of the main study.

From the sorted, analysed and categorised test responses, four graphical representations (b, c and d) were drawn for each question to show the distribution of d .

Figures (a) and) indicate distributions of *options* chosen by students.

igure (a) indicates the percentage of the 191 students who chose a certain option (A, B, C, D or no option, indicated by '-') or combinations of options (e.g. options A, C and D were chosen as correct options, indicated by 'ACD'). These percentages add up to 100% within the limitations of rounding off.

Figure (b) indicates the total percentage of the 191 students who chose the individual options A, B, C, D and '-'. Because students could choose more than one option, these percentages add up to more than 100%. In this presentation a colour coding is used to distinguish between obviously correct options (green), obviously incorrect options (red) and 'grey' options (yellow). If there is any doubt whether an option should be correct or incorrect, due to different textbook interpretations, the option is categorised as 'grey'.

Figures (c) and (d) indicate distributions of categorised *motivations.*

Figure (c) indicates the percentage of the 191 students who motivated the question with a certain motivation, independent of the option(s) chosen. These percentages add up to more than 100%, because one answer could be motivated with more than one statement, which falls in different categories. In this presentation each motivation category is indicated by a unique colour.

The motivation categories were drawn up from the data in Appendix D, which contains the analysed and categorised test responses. All the motivations marked with an asterix '*' in Appendix D are categorised under 'motivations of no use'. This is because the motivations do not make sense, or are inapplicable or insignificant. Where the motivation could be of interest, but is of no use for this research, the motivation is also marked with an asterix.

Take note of the following:

- Not all the motivations are correct or necessarily make sense, even some of them which are not indicated by an asterix. In such cases these invalid motivations are of importance for the research, because alternative conceptions are highlighted.

- Although 'no motivations' and 'motivations of no use' are two categories they are not included in these figures for practical reasons. This information does not add to the aim of the study of what the students' alternative conceptions are, and the more categories, the less clear the graphical representation is.

- Due to space limitations in the figures, the motivations are stated very briefly. The motivation is expanded and clarified under the specific question.

Figure (d) indicates the distribution of categorised motivations for each combination of options. Each category is plotted as a percentage of the 191 students who used this specific motivation for each combination. The same colour coding that is used in figure (c), is used here. Because students could motivate an answer with more than one statement which falls in different categories, percentages may add up to more than 100%.

Some of the figures end up with bars where the colours are not clearly distinguished, due to bars which are too narrow or too short. This is due to two reasons:

- Narrow bars: large number of different combinations of options and large number of motivation categories.
- Short bars, a distribution of data from very low percentages to very high percentages.

Where possible all motivations are represented graphically. Where statistically very small percentages have a trivial visual impact, they are not included in the graphs, but are mentioned in the discussion. They are indicated with a double asterix '**' in the discussion. Because questions differ in the number of combination of options, number of motivation categories and distribution of percentages, it is not practical to apply one rigid rule of what is included and what is excluded.

These figures follow in paragraphs 6.2.1 to 6.2.19, where the analysis of each of the nineteen questions is discussed separately.

categories of Question 1, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.1.d (p. 47B) indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS (3.3.3.1)
IN PHASE (65%)	The waves are in phase or exactly in phase.	i. When two or more waves meet in phase.
IDENTICAL (32%)	The waves are identical. The amplitudes and/or wavelengths are the same.	v. Illustrated with two overlapping waves with the same frequency and amplitude.
REINFORCE (31%)	The resultant wave is reinforced or the amplitude has doubled.	iii. Associated with reinforcement: when the resultant displacement is greater than that of either the individual waves or when maximum displacement occurs.
CRESTS AND TROUGHS (24%)	The waves meet crest-to-crest and trough-to-trough	
SUPERPOSITION (3%)	According to the superposition principle constructive interference occurs	3.3.2.2.b According to the superposition principle the resultant displacement is the addition of the instantaneous displacements.
**BRIGHT FRINGES (0,5%)	Bright fringes are formed on a screen.	iv. Associated with bright fringes of an interference pattern.

TABLE 6.1 : MOTIVATION CATEGORIES FOR QUESTION 1

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 1

FIGURE 6.1.a
Percentage of students who chose a certain combination of options

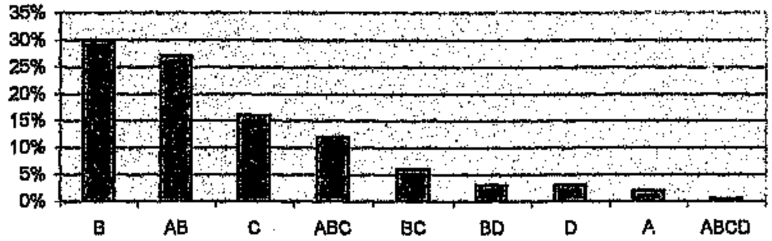


FIGURE 6.1.b
Percentage of students who chose each option

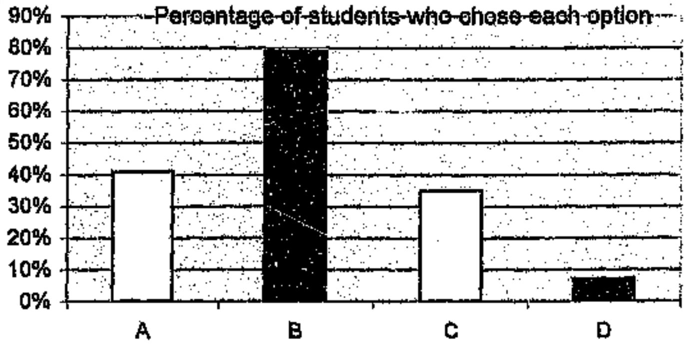


FIGURE 6.1.c
Percentage of students who used the indicated motivations to motivate the question

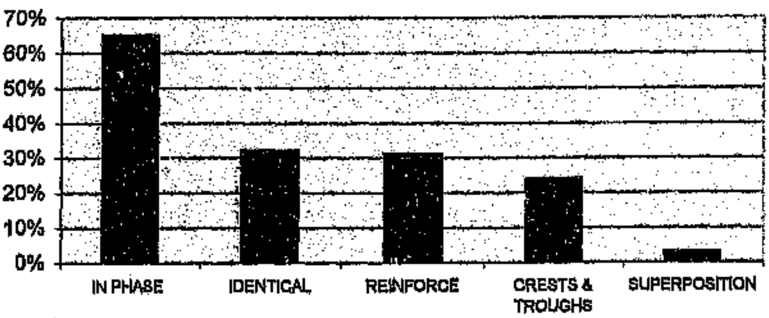
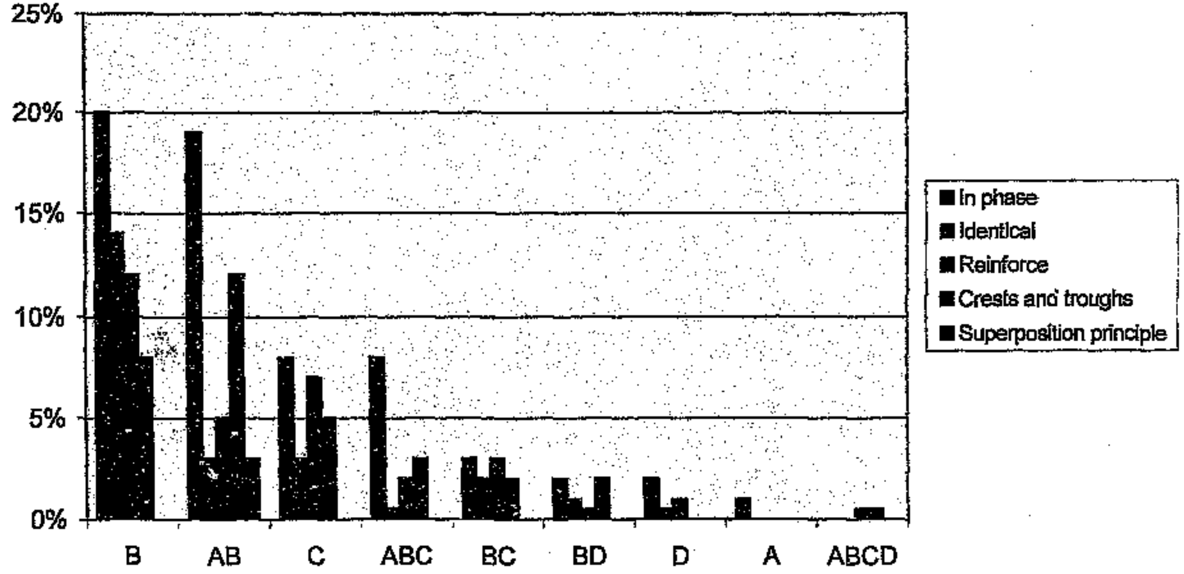


FIGURE 6.1.d
Percentage of students who used the indicated motivation for each combination of options



6.2.2 Analysis of Question 2

See Appendix B for Question 2.

Figure 6.2.a (p. 50A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: D(43%), AD(39%), C(6%), ACD(4%), AC(3%), B(2%), A(2%), BD(2%), AB(0,5%), CD(0.5%).

Figure 6.2.b (p. 50A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. D(87%) is the obviously correct choice, indicated in green. B(4%) is the obviously incorrect choice, indicated in red. The 'grey' options are A(47%) and C(13%), indicated in yellow.

Option D is correct, because it obeys all the criteria the textbooks state for destructive interference. These waves are out of phase (exactly out of phase), they cancel one another completely, and their amplitudes and wavelengths are identical.

Option B is incorrect, because the pulses are in phase (exactly in phase) and constructive interference occurs.

Option A is 'grey' because the pulses are not identical. A significantly lower percentage of students chose this option (47%) than option D (87%).

Option C is 'grey' because the waves are not in phase (not exactly out of phase), although they are identical and cancellation does occur at some instances.

Figure 6.2.c (p. 50A) indicates the distribution of the motivation categories used to motivate the question. Table 6.2 (p. 50) indicates the motivation categories of Question 2, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.2.d (p. 50B) indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS (3.3.3.2)
OUT OF PHASE (57%)	The waves are out of phase, exactly out of phase, 180° out of phase, not in phase.	i.Waves meet *out of phase*. ii. Waves meet 180° out of phase. iii. Waves arrive in opposite phase. v. The *partial or complete cancellation* of waves out of phase with one another.
CANCEL (38%)	The waves cancel each other.	vi. The *complete cancellation* of waves where the resultant amplitude is zero.
CREST-TO-TROUGH (33%)	The waves meet crest-to-trough.	
IDENTICAL (13%)	The waves are identical. The amplitudes, frequencies and/or wavelengths are the same.	ii,vi The amplitudes have to be equal for complete cancellation when waves are 180° out of phase.
SMALLER AMPLITUDE (4%)	The resultant wave has a smaller amplitude.	iv. When two pulses *diminish* each other.
PATH LENGTH (2%)	The path length difference between the waves is an odd number of wavelengths. The wavelengths differ not with an integer number.	viii. For two wave sources vibrating in phase, a *path length difference* which is a half-integer number of wavelengths, leads to destructive interference.
PARTIAL DESTRUCTIVE (2%)	Partial destructive interference occurs at A and complete destructive interference occurs at D.	vii.*Partial destructive interference* occurs where the relative phases of two waves are intermediate between the two extremes of waves which are in phase and waves which are out of phase. x.Where neither constructive nor destructive interference occurs, waves partially cancel or reinforce.
NOT IDENTICAL (2%)	The amplitudes do not have to be the same.	
**TWO TROUGHS (0,5%)	Two troughs interfere destructively.	ix. Dark spots represent destructive interference.

TABLE 6.2 : MOTIVATION CATEGORIES FOR QUESTION 2

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 2

FIGURE 6.2.a
Percentage of students who chose a certain combination of options

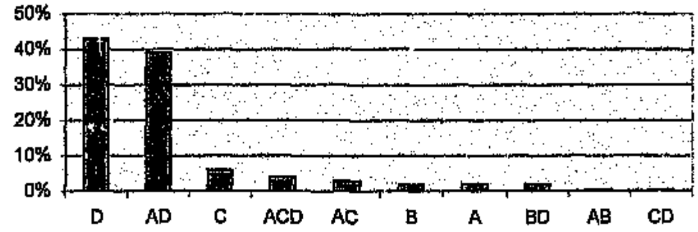


FIGURE 6.2.b
Percentage of students who chose each option

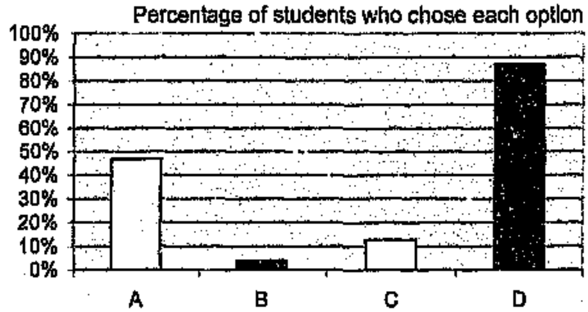


FIGURE 6.2.c
Percentage of students who used the indicated motivations to motivate the question

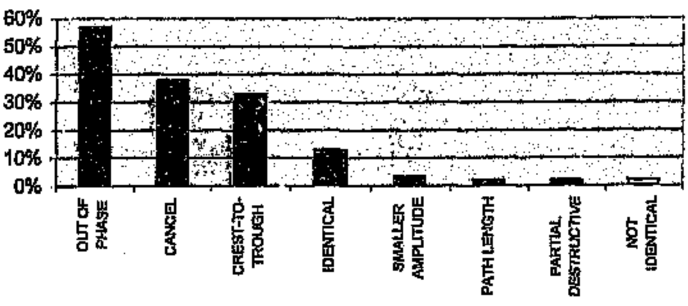
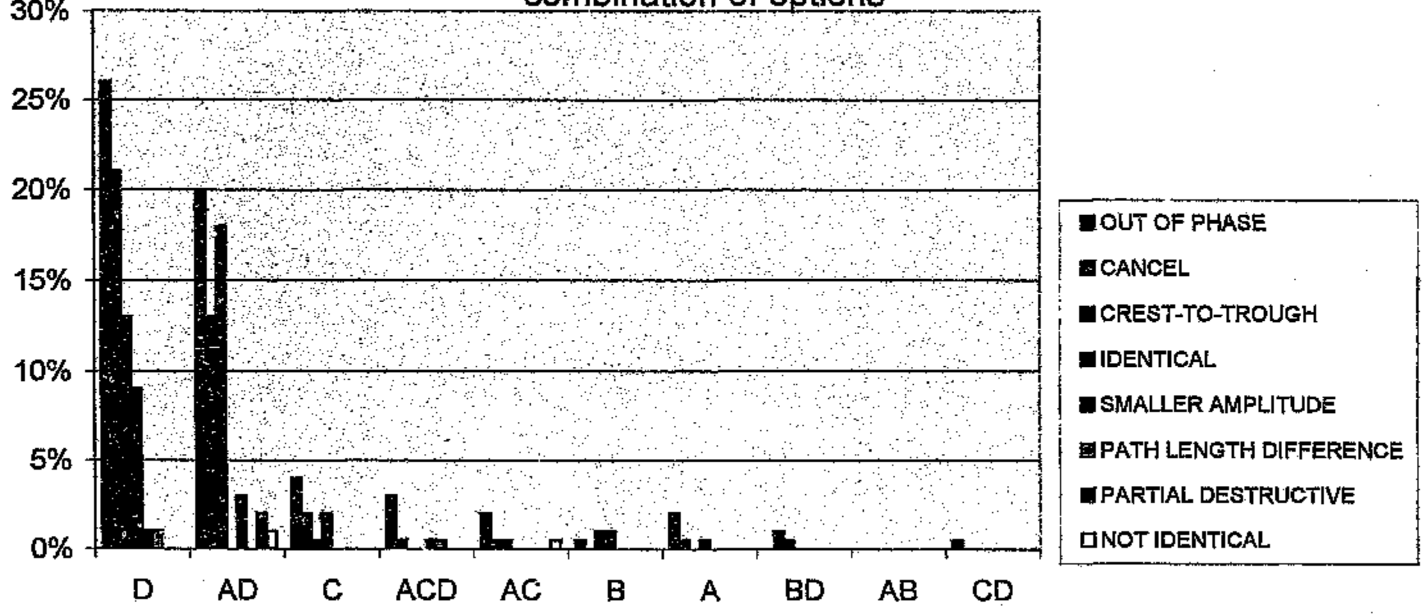


FIGURE 6.2.d
Percentage of students who used the indicated motivation for each combination of options



6.2.3 Analysis of Question 3

See Appendix B for Question 3.

Figure 6.3.a (p. 53A) indicates the distribution of option combinations chosen by students. They follow i. descending order, with the percentage of students who chose the various combinations of options in brackets: B(49%), A(19%), AB(7%), D(6%), '-'(5%), C(5%), BD(3%), ABD(2%), BC(2%), ABC(0,5%), AC(0,5%), AD(0,5%), CD(0,5%).

Figure 6.3.b (p. 53A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. B(63%) is the obviously correct choice, indicated in green. A(29%), C(8%) and '-'(5%) are the obviously incorrect choices, indicated in red. The 'grey' option is D(12%), indicated in yellow.

Option B is correct, because constructive and destructive interference will not continue to happen at the same place when the two beams do not maintain a constant phase relation.

Options A and C are incorrect, because interference and diffraction are properties of all light waves. Even a single beam will undergo diffraction and interference.

Option D is incorrect, because two incoherent waves can have the same speed. The speed of light is a constant in vacuum and for all practical reasons in air.

Figure 6.3.c (p. 53A) indicates the distribution of the motivation categories used to motivate the question. Table 6.3 (p. 53) indicates the motivation categories of Question 3, and how these categories relate to different

textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.3.d (p. 53B) indicates the distribution of categories of motivations for each combination of options.

RESEARCHER'S COMMENT:

- The double negative question makes it difficult to interpret the question clearly.
- Option D is not suitable for this question.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
PHASE RELATION (39%)	The waves do not maintain a constant phase relation.	3.3.3.3.i. Coherent sources emit waves with a constant phase relationship between them.
INTERFERENCE VARIES (18%)	Constructive and destructive interference do not continue to occur at a point.	
COHERENCY CONDITION (9%)	Constructive and destructive interference result from coherent sources.	
NOT IN PHASE (7%)	The waves are not in phase. The waves are out of phase. Their phases differ. They are not exactly out of phase.	3.3.3.3.v. Two waves are out of phase when their maximum, zero and minimum displacements are not at the same place.
WAVELENGTHS DIFFER (7%)	Their wave characteristics (wavelengths and frequencies) differ.	3.3.3.1.v Constructive interference is illustrated with two overlapping waves with the same frequency and amplitude. 3.3.3.3.ii. Two sources are coherent if they have the same frequency and phase.
DIRECTIONS DIFFER (3%)	The waves are from different directions. The one wave is a positive and the other a negative.	3.3.3.3.iii A constant phase relation exists between two waves when the two sources emit crests (or troughs) simultaneously.
DESTRUCTIVE INTERFERENCE (1%)	They undergo destructive interference, because they are out of phase.	3.3.3.2.i When two or more waves meet out of phase, destructive interference results. 3.3.3.3.vi. Out of phase waves arrive a half-cycle out of step at a point.

TABLE 6.3 : MOTIVATION CATEGORIES FOR QUESTION 3

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 3

FIGURE 6.3.a
Percentage of students who chose a certain combination of options

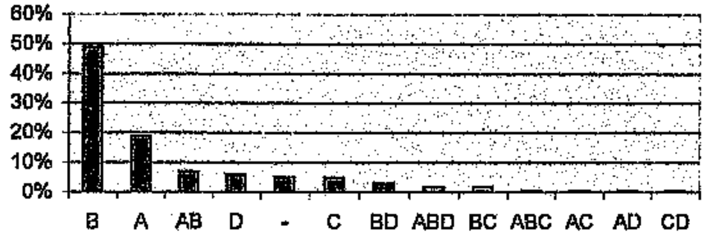


FIGURE 6.3.b
Percentage of students who chose each option

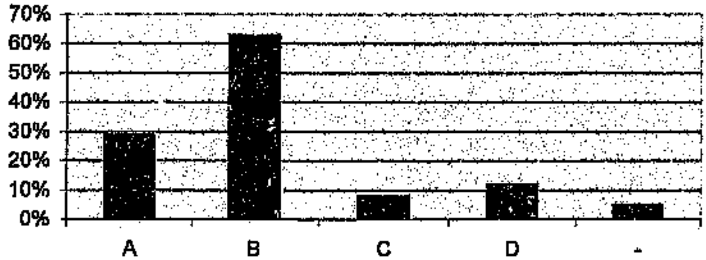


FIGURE 6.3.c
Percentage of students who used the indicated motivations to motivate the question

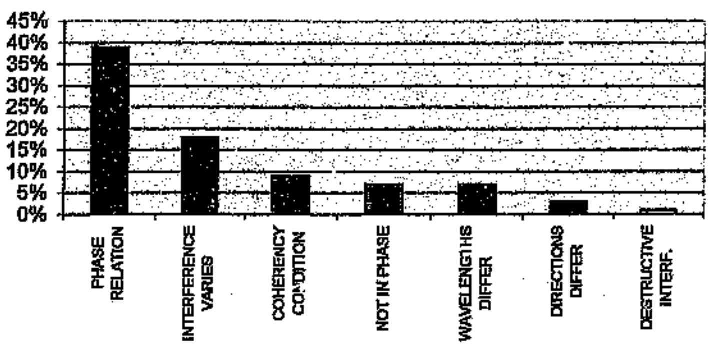
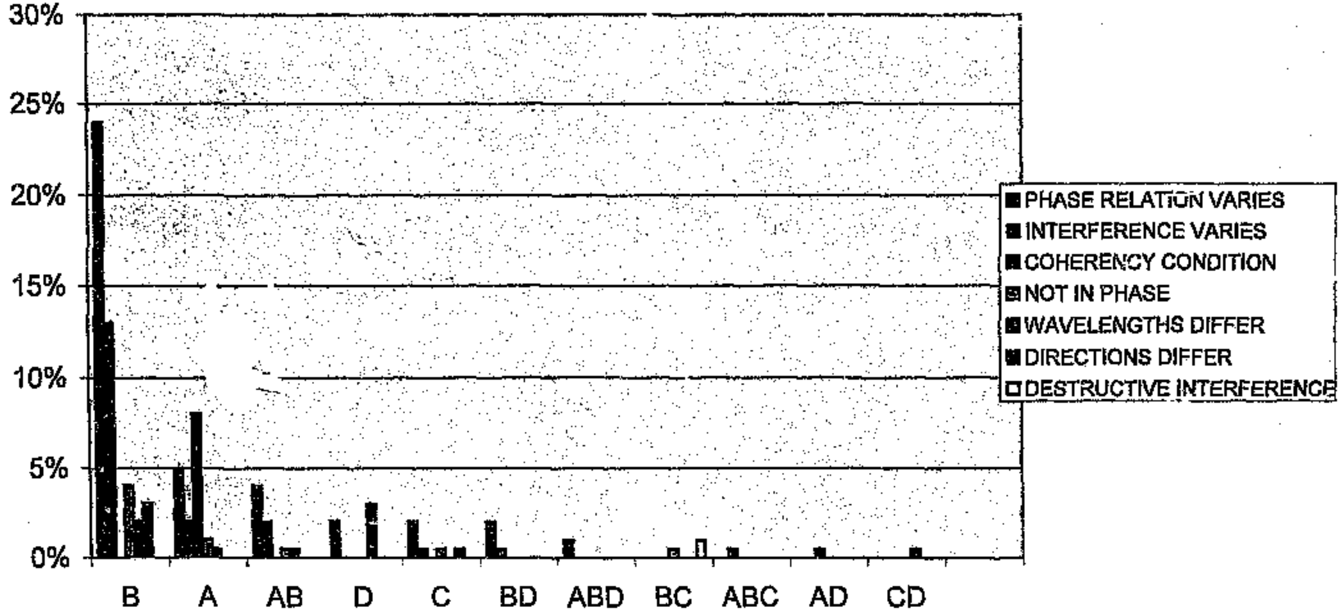


FIGURE 6.3.d
Percentage of students who used the indicated motivation for each combination of options



6.2.4 Analysis of Question 4

See Appendix B for Question 4.

Figure 6.4.a (p. 56A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: B(72%), D(15%), A(6%), C(5%), '-'(1%), BC(1%).

Figure 6.4.b (p. 56A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. D(15%) is the obviously correct choice, indicated in green. A(6%), C(6%) and '-'(1%) are the obviously incorrect choices, indicated in red. The 'grey' option is B(73%) indicated in yellow.

Option D is correct, because two troughs meet at that point. The waves are (exactly) in phase at that point.

Option A is incorrect, because constructive interference occurs at point X. At point W the interference is not fully constructive, because they are not exactly in phase.

Option C is incorrect, because constructive interference does not occur at point Z.

Option B is 'grey', because at point W the waves are not exactly in phase, although reinforcement takes place. Constructive interference occurs at point X.

Figure 6.4.c (p. 56A) indicates the distribution of the motivation categories used to motivate the question. Table 6.4 (p. 56) indicates the motivation

categories of Question 4, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.4.d (p. 56B) indicates the distribution of categories of motivations for each combination of options.

RESEARCHER'S COMMENT:

- The waves which do not meet exactly in phase at point W are not very clear, although the points are indicated. Some students could see these points as being in phase, which would make option B a correct option.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
REINFORCE (51%)	The waves reinforce each other. The amplitude doubles.	3.3.3.1.iii. When the resultant displacement is greater than that of either of the individual waves, they interfere constructively.
IN PHASE (36%)	The waves are in phase (exactly or partially or 90%).	3.3.3.1.i. When two or more waves meet in phase they interfere constructively.
CRESTS AND TROUGHS (27%)	Two troughs meet and two crests meet.	
IDENTICAL (4%)	The waves are identical.	3.3.3.1.v. Illustrations with two overlapping waves with the same frequency and amplitude.
Y AND Z DESTRUCTIVE (3%)	Y and Z are destructive, due to positive and negative crests / resultant wave is smaller.	3.3.3.2.iv When two pulses diminish each other, destructive interference occurs.
SUPERPOSITION (2%)	The sum of the two waves gives a resultant wave.	3.3.2.2.b According to the superposition principle the resultant displacement is the addition of the instantaneous displacements.
PARTIAL CONSTRUCTIVE (2%)	W is partially constructive, partially in phase.	3.3.3.1.ii. When waves are in phase, their interference is (fully) constructive.

TABLE 6.4 : MOTIVATION CATEGORIES FOR QUESTION 4

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 4

FIGURE 6.4.a
Percentage of students who chose a certain combination of options

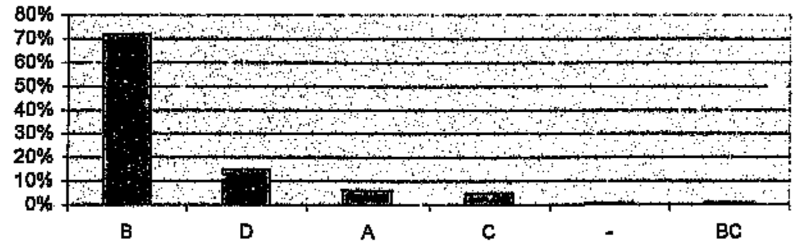


FIGURE 6.4.b
Percentage of students who chose each option

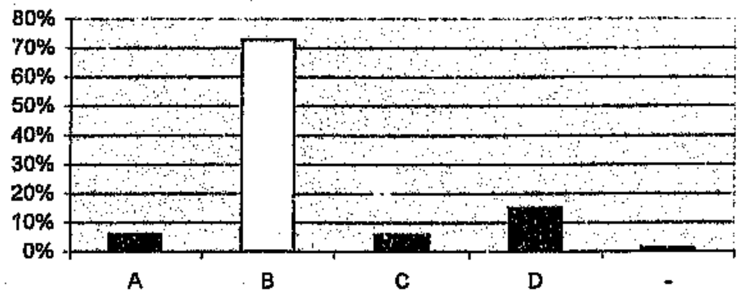


FIGURE 6.4.c
Percentage of students who used the indicated motivations to motivate the question

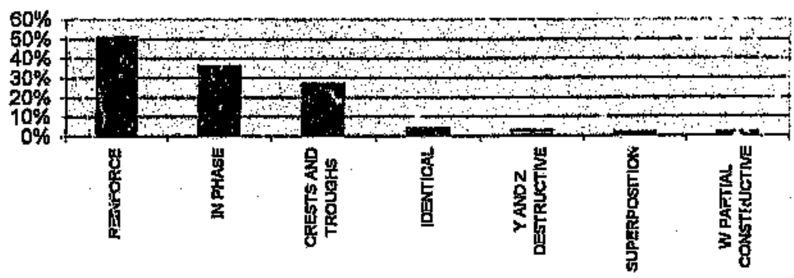
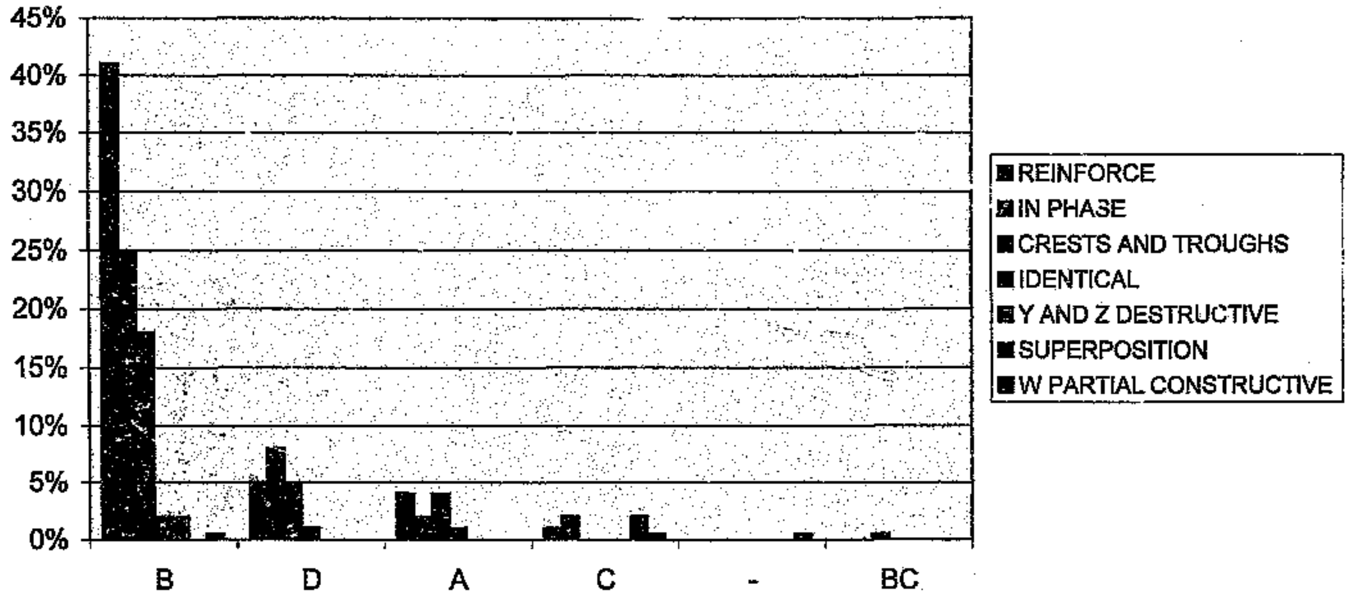


FIGURE 6.4.d
Percentage of students who used the indicated motivation for each combination of options



6.2.5 Analysis of Question 5

See Appendix B for Question 5.

Figure 6.5.a (p. 59A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: ABC(23%), A(19%), B(17%), AB(16%), D(9%), C(7%), AC(3%), BC(2%), '-'(2%), BD(1%), CD(1%), ACD(0,5%).

Figure 6.5.b (p. 59A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. A(62%) and C(36%) are the obviously correct choices, indicated in green. To make no choice, '-'(1%), indicated in red, is obviously incorrect. The 'grey' options are B(59%) and D(12%), indicated in yellow.

Options A and C are correct, because when two troughs always meet, they will be in phase. Waves which are in phase maintain a constant phase relation and will therefore be coherent.

Options B and D are 'grey' because the question is not clearly stated. At that point where the troughs always meet, constructive interference will always occur. A' different points constructive and destructive interference will alternate.

Figure 6.5.c (p. 59A) indicates the distribution of the motivation categories used to motivate the question. Table 6.5 indicates the motivation categories of Question 5, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each

category to motivate an answer appears in brackets after the motivation category.

Figure 6.5.d (p. 59B) indicates the distribution of categories of motivations for each combination of options.

RESEARCHER'S COMMENT:

- The question should read: **'At the point** where two waves with amplitudes A and 2A always meet trough-to-trough, they:'.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
SUMMARY OF CHOICE (42%)	Where more than one option is chosen, the motivation is a summary of the choice and statement in the question (e.g. they are in phase because they meet trough-to-trough)!	
REINFORCE (18%)	The resultant wave is bigger. The amplitude doubles. The amplitude is 3A.	3.3.3.1.iii When the resultant displacement is greater than that of either the individual waves, constructive interference results.
AMPLITUDES (12%)	Amplitudes may differ for constructive interference to occur.	
PHASE RELATION (10%)	The phase relation stays constant.	3.3.3.3.i Coherent sources emit waves with a constant phase relationship between them.
CREST AND TROUGHS (9%)	Their crests will also meet.	3.3.3.3.iii A constant phase relation exists when the two sources emit troughs simultaneously.
IDENTICAL (9%)	Frequencies, wavelengths and speed are the same.	3.3.3.1.v For two overlapping waves the frequency and wavelength are the same. 3.3.3.3.ii Two sources are coherent if they have the same frequency and phase.
OPTION (8%)	Another option is used to motivate one option, without choosing the other option!!	
PATH LENGTH (3%)	A difference of an integer amount of wavelengths leads to constructive interference.	3.3.3.1.vi For two wave sources vibrating in phase, a path length difference which is an integer number of wavelengths leads to constructive interference.
PARTIAL CONSTRUCTIVE (0,5%)	When troughs are not in phase, partial constructive interference.	3.3.3.1.ii When waves are in phase, their interference is (fully) constructive.

TABLE 6.5 : MOTIVATION CATEGORIES FOR QUESTION 5

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 5

FIGURE 6.5.a
Percentage of students who chose a certain combination of options

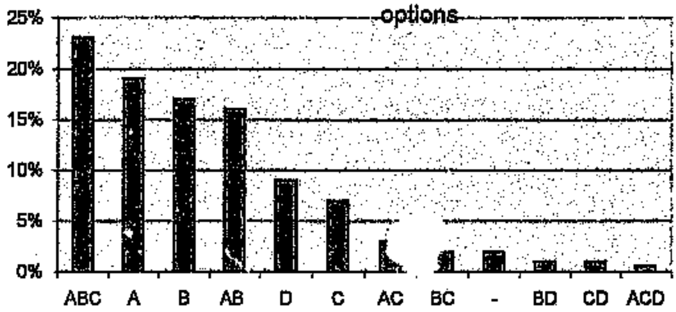


FIGURE 6.5.b
Percentage of students who chose each option

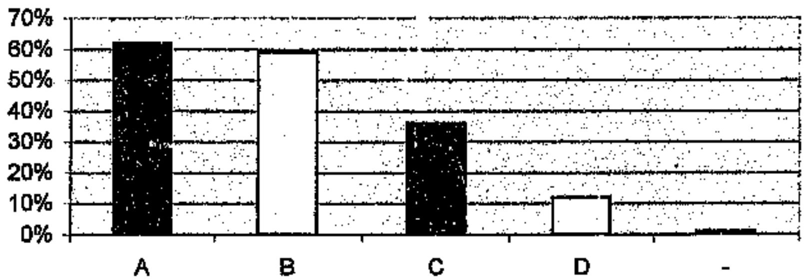


FIGURE 6.5.c
Percentage of students who used the indicated motivations to motivate the question

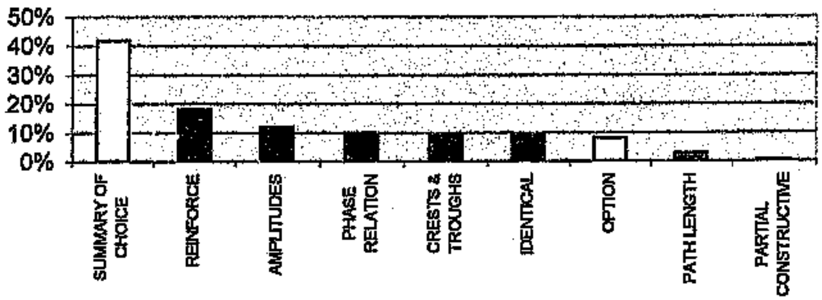
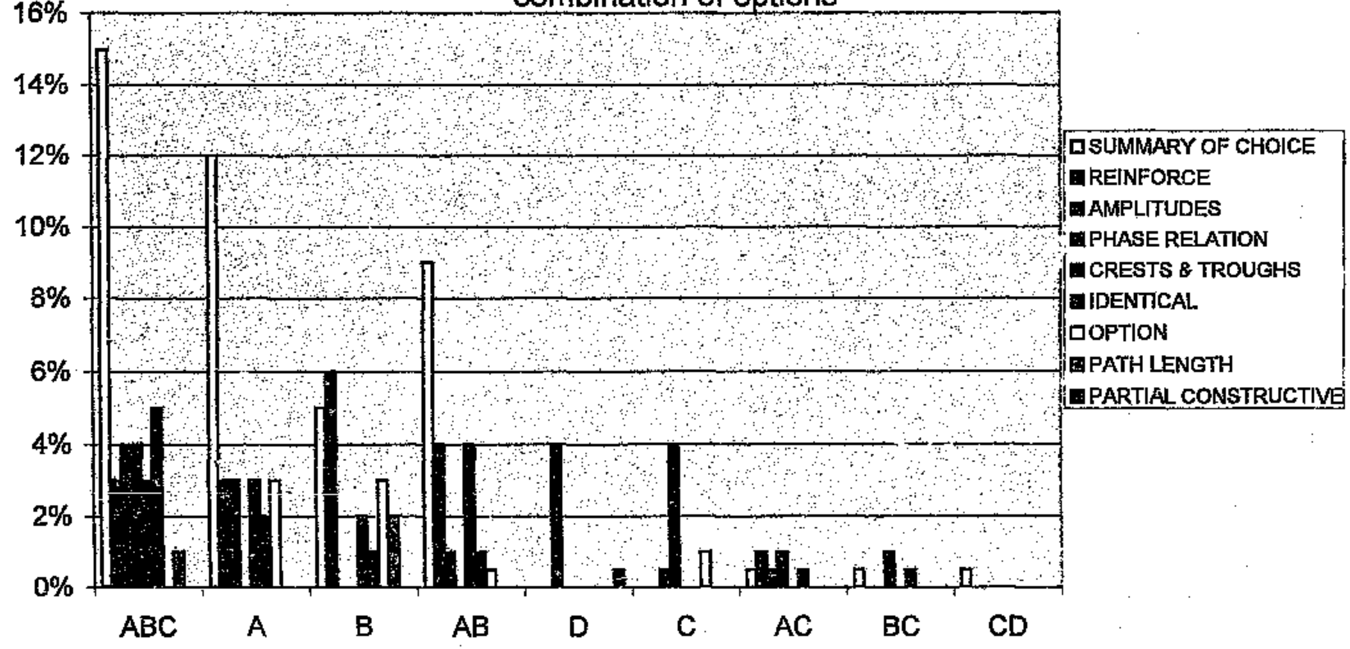


FIGURE 6.5.d
Percentage of students who used the indicated motivation for each combination of options



6.2.6 Analysis of Question 6

See Appendix B for Question 6.

Figure 6.6.a (p. 61A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: B(52%), A(24%), AB(6%), C(5%), AC(4%), D(3%), '-'(2%), BC(2%), ACD(1%), AD(1%), ABC(1%), BD(1%), CD(1%).

Figure 6.6.b (p. 61A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. B(61%) is the obviously correct choice, indicated in green. C(12%) and '-'(2%) are the obviously incorrect choices, indicated in red. The 'grey' options are A(36%) and D(6%), indicated in yellow.

Option B is correct. Diffraction depends on the ratio of wavelength of light to slit width. This relation is too small to observe diffraction.

Option C should be regarded as incorrect. It is a rather general, non-specific statement and does not explain the cause -- effect relationship in the stem of the question.

Options A and D are 'grey', because both *ignore or minimise diffraction* effects with light.

Figure 6.6.c (p. 61A) indicates the distribution of the motivation categories used to motivate the question. Table 6.6 (p. 61) indicates the motivation categories of Question 6, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students

who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.6.d (p. 61B) indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS (3.3.3.4)
BEND TOO LITTLE (23%)	The degree of bending is too small to observe.	
WAVELENGTH / SLITWIDTH (15%)	Diffraction depends on the ratio wavelength to slit width. Light has a shorter wavelength than sound.	
LIGHT DOESN'T DIFFRACT (12%)	Light waves do not bend around an open door, only around narrow slits. Light does not diffract.	i. Diffraction is the bending of light around obstacles or *small* openings. ii. Diffraction is the spreading out of light waves passing around an obstacle or *small* opening.
ALL WAVES DIFFRACT (10%)	All waves, also light, diffract.	
HUYGENS' PRINCIPLE (5%)	According to Huygens' principle sound waves diffract.	3.3.3.4.iii Diffraction is explained by Huygens' principle.
SOUND > LIGHT (4%)	Sound waves diffract much more than light waves.	

TABLE 6.6 : MOTIVATION CATEGORIES FOR QUESTION 6

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 6

FIGURE 6.6.a
Percentage of students who chose a certain combination of options

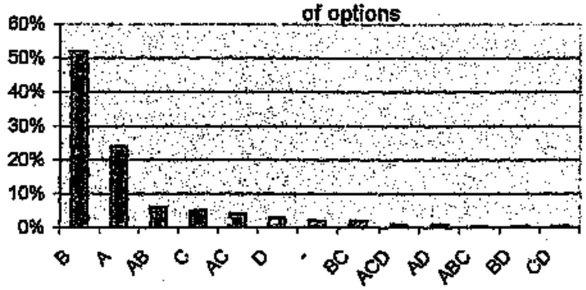


FIGURE 6.6.b
Percentage of students who chose each option

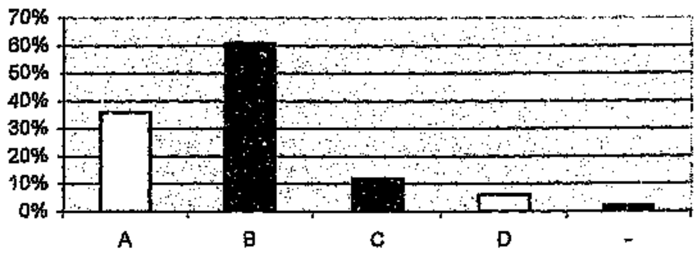


FIGURE 6.6.c
Percentage of students who used the indicated motivations to motivate the question

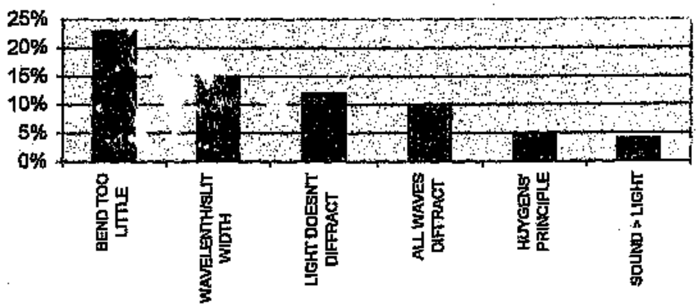
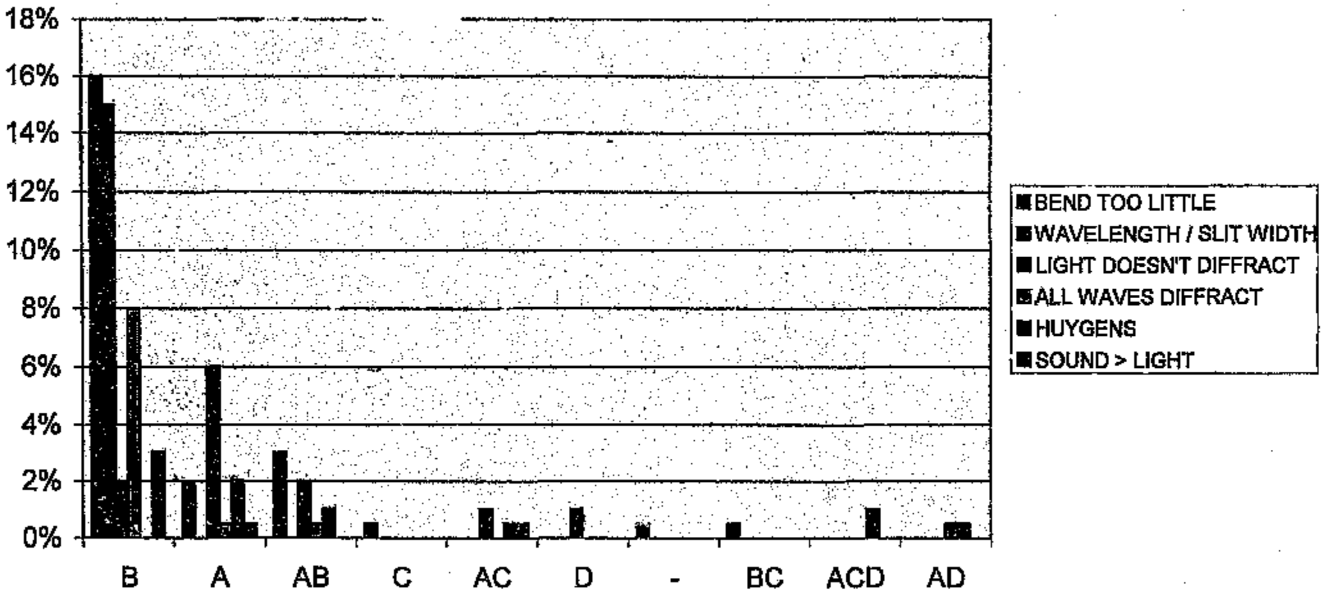


FIGURE 6.6.d

Percen[illegible] students who used the indicated motivation for each combination of options



6.2.7 Analysis of Question 7

See Appendix B for Question 7.

Figure 6.7.a (p. 63A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: A(28%), D(27%), C(17%), '-'(5%), BC(1%), BD(0,5%).

Figure 6.7.b (p. 63A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. A(28%) is the obviously correct choice, indicated in green. B(2%) and '-'(5%) are the obviously incorrect choices, indicated in red. The 'grey' options are C(18%) and D(28%), indicated in yellow.

Option A is correct, because there is no energy in the dark fringes.

Option B is incorrect, because there is no light energy in the dark fringes.

Options C and D are 'grey', because destructive interference is presented differently in textbooks. If the amplitudes differ, then there are problems with deciding about destructive interference. Energy will still be present.

Figure 6.7.c (p. 63A) indicates the distribution of the motivation categories used to motivate the question. Table 6.7 indicates the motivation categories of Question 7, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.7.d (p.63B) indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
NO ENERGY IN DARK (14%)	No energy is present in dark fringes. No light energy is present in dark fringes.	
LAW OF CONSERVATION (12%)	According to the law of conservation of energy.	
ENERGY TO BRIGHT (8%)	Energy is redistributed to bright fringes where constructive interference occurs.	
LESS ENERGY IN DARK (7%)	Dark fringes have less energy. Some energy is used for destructive interference.	
ENERGY ABSORBED (5%)	Some of the energy is absorbed. Dark fringes absorb energy.	
PATH LENGTH (4%)	Constructive and destructive interference depend on path length difference.	For two sources vibrating in phase, a path length difference which is: 3.3.3.1.vi an integer number of wavelengths leads to constructive interference. 3.3.3.2.viii a half-integer number of wavelengths leads to destructive interference.
CONVERT TO HEAT (3%)	Energy is converted to heat energy.	
YOUNG'S PATTERN (2%)	Young's interference pattern shows the redistribution of energy.	
INTENSITY : ENERGY (2%)	Intensity of fringes is directly proportional to light energy.	
NO LIGHT, OTHER FORMS (1%)	Because no light is present in dark fringes, conversion to other forms took place.	3.3.3.2.ix Dark spots represent constructive interference and grey spots destructive interference.

TABLE 6.7 : MOTIVATION CATEGORIES FOR QUESTION 7

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 7

FIGURE 6.7.a
Percentage of students who chose a certain combination of options

FIGURE 6.7.b
Percentage of students who chose each option

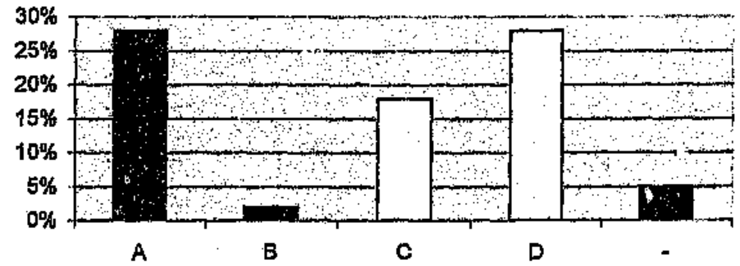


FIGURE 6.7.c
Percentage of students who used the indicated motivations to motivate the question

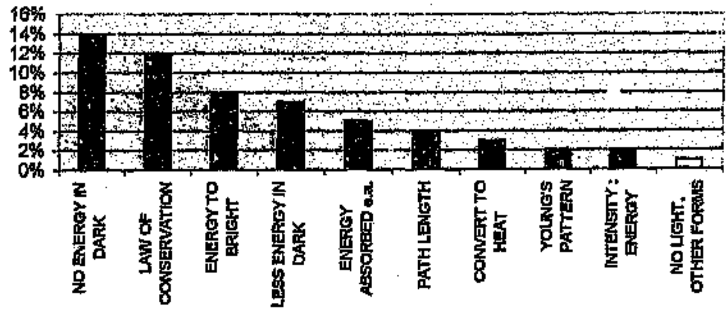
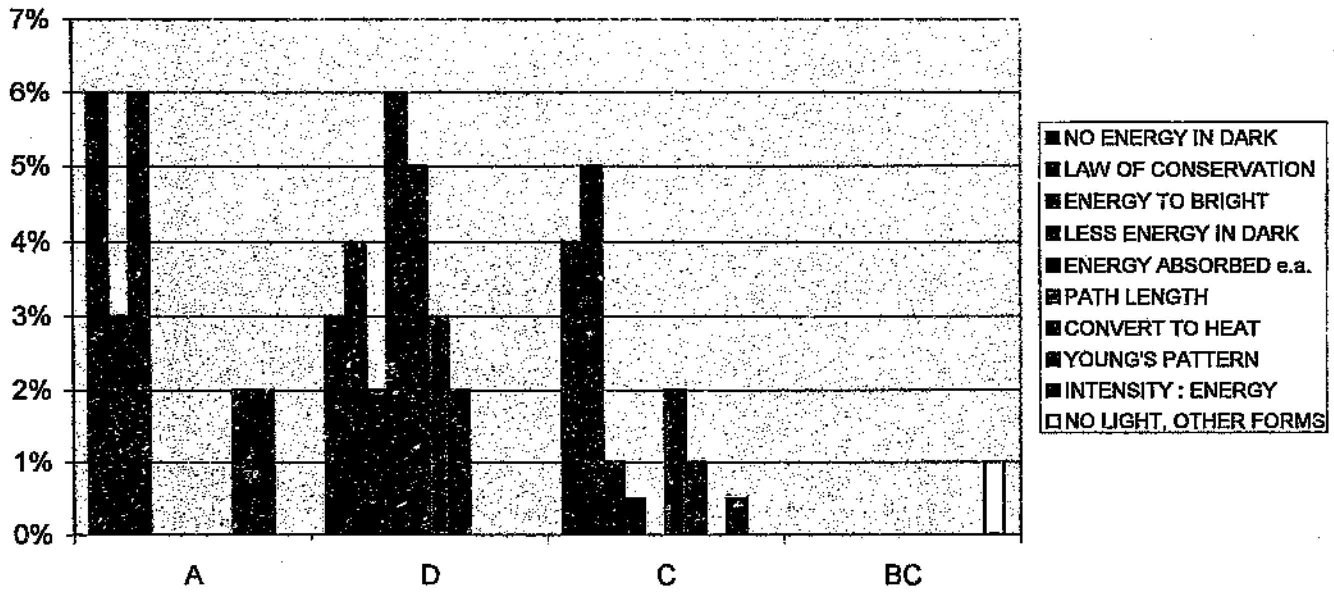


FIGURE 6.7.d
Percentage of students who used the indicated motivation for each combination of options



6.2.8 Analysis of Question 8

See Appendix B for Question 8.

Figure 6.8.a (p. 65A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: C(68%), B(23%), A(6%), D(2%), '-'(1%), AB(0,5%).

Figure 6.8.b (p. 65A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. C(68%) is the obviously correct choice, indicated in green. A(7%), B(23%), D(2%) and '-'(1%) are the obviously incorrect choices, indicated in red.

Option C is correct. When light passes through each slit, diffraction occurs. Due to interference of light from the two slits (now regarded as sources), an interference pattern of dark and bright fringes form on the screen.

Options A, B and D are incorrect, because both interference and diffraction occur.

Figure 6.8.c (p. 65A) indicates the distribution of the motivation categories used to motivate the question. Table 6.8 indicates the motivation categories of Question 8, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.8.d (p. 65B) indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
INTERF. PATTERN (58%)	An interference pattern with dark and bright fringes forms on the screen.	3.3.3.1.iv Constructive interference is associated with the bright fringes of an interference pattern. 3.3.3.2.vi Destructive interference is associated with the dark fringes.
COHERENT SOURCES (24%)	Waves from two coherent sources interfere.	
LIGHT BENDS (22%)	When light moves through a slit, it bends around the edges.	3.3.3.4.i Diffraction is the bending of light around small openings.
DIFFRACT THEN INTERF. (6%)	After diffraction, constructive and destructive interference occurs.	3.3.3.1.iv Constructive interference is associated with the bright fringes of an interference pattern. 3.3.3.2.vi Destructive interference is associated with the dark fringes. 3.3.3.5.vii In double slits both interference and diffraction occur.
INTERFERENCE EFFECT (4%)	Diffraction is an interference effect.	3.3.3.5.i Diffraction is an interference effect.
WAVE NATURE (3%)	Wave nature of light.	
YOUNG'S EXPERIMENT (2%)	According to Young's double slit experiment.	
HUYGENS' PRINCIPLE (1%)	According to Huygens' principle.	3.3.3.4.iii Diffraction is explained by Huygens' principle.
DIFFRACTION PATTERN (1%)	The result is a diffraction pattern with dark and bright fringes.	3.3.3.5.iv Diffraction patterns of bright and dark fringes occur when light passes through a single or double slit.

TABLE 6.8 : MOTIVATION CATEGORIES FOR QUESTION 8

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 8

FIGURE 6.8.a
Percentage of students who chose a certain combination of options

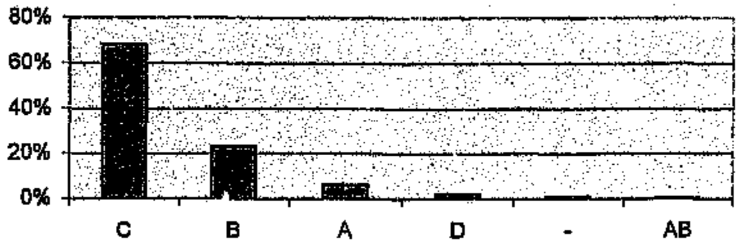


FIGURE 6.8.b
Percentage of students who chose each option

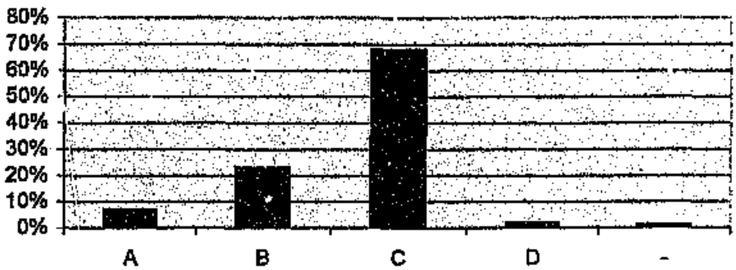


FIGURE 6.8.c
Percentage of students who used the indicated motivations to motivate the question

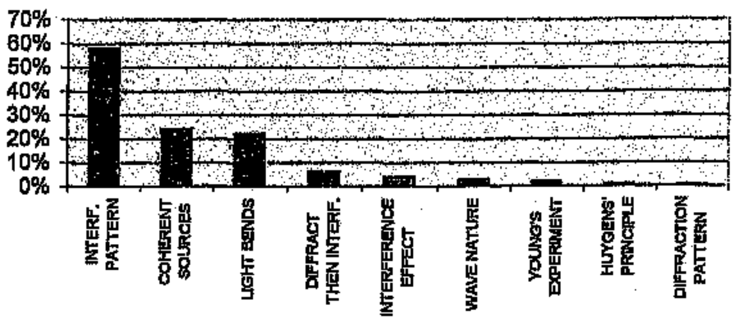
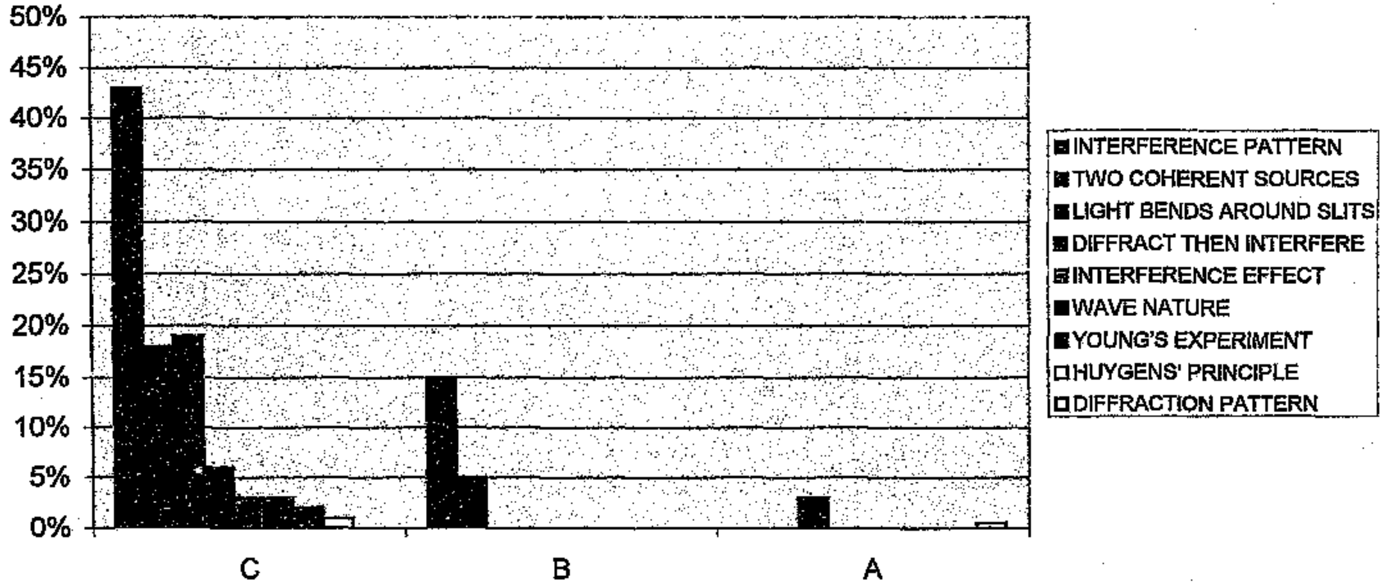


FIGURE 6.8.d
Percentage of students who used the indicated motivation for each combination of options



6.2.9 Analysis of Question 9

See Appendix B for Question 9.

Figure 6.9.a (p. 68A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: A(49%), C(34%), B(6%), D(7%), '-'(2%), BC(1%), AC(1%), AD(1%).

Figure 6.9.b (p. 68A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. C(36%) is the obviously correct choice, indicated in green. A(50%), B(7%), D(8%) and '-'(2%) are the obviously incorrect choices, indicated in red.

Option C is correct. When light moves through a single slit, diffraction occurs. Due to Huygens' principle, different wavelets interfere to form a diffraction pattern of dark and bright fringes on the screen.

Options A, B and D are incorrect, because both interference and diffraction occur.

Figure 6.9.c (p. 68A) indicates the distribution of the motivation categories used to motivate the question. Table 6.9 (p. 68) indicates the motivation categories of Question 9, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.9.d (p. 68B) indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
LIGHT BENDS AROUND SLITS (43%)	When light moves through a slit, it bends around the edges. The light spreads out.	3.3.3.4.i Diffraction is the bending of light around small openings. 3.3.3.4.ii Diffraction is the spreading out of light passing small openings.
INTERFERENCE PATTERN (18%)	A pattern of alternating dark and bright fringes forms on the screen. Constructive and destructive interference occur.	3.3.3.1.iv Constructive interference is associated with the bright fringes of an interference pattern. 3.3.3.2.vi Destructive interference is associated with the dark fringes.
NO INTERFERENCE (17%)	Because there is only one light source, no interference occurs. No interference pattern forms.	3.3.2.2.a Interference describes the phenomena that result from two or more waves passing through the same region at the same time.
DIFFR. PATTER[illegible]	A single slit diffraction pattern forms.	3.3.3.5.iv Diffraction patterns of bright and dark fringes occur when light passes through a single or double slit.
ONE DIRECTION LIGHT (4%)	According to Young's experiment, the single slit is to ensure that light from one direction falls on the double slit.	
INTERFERENCE EFFECT (3%)	Diffraction is an interference effect.	3.3.3.5.i Diffraction is an interference effect.
DIFFRACTION THEN INTERF. (2%)	After diffraction, the light waves interfere constructively and destructively.	3.3.3.1.iv Constructive interference is associated with the bright fringes of an interference pattern. 3.3.3.2.vi Destructive interference is associated with the dark fringes. 3.3.3.5.vii In double slits both interference and diffraction occur.
NO DIFFRACTION (2%)	Diffraction can't occur. Light propagates in a straight line through the slit and an image of the slit is formed on the screen.	Research done by Guesne (1993) on rectilinear propagation of light does not mention diffraction!
DESTRUCTIVE INTERF. (1%)	Destructive interference forms at the single slit.	
WAVE NATURE (1%)	Due to the wave nature of light.	
HUYGENS' PRINCIPLE (1%)	According to Huygens' principle.	3.3.3.4.iii Diffraction is explained by Huygens' principle.

TABLE 6.9 : MOTIVATION CATEGORIES FOR QUESTION 9

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 9

FIGURE 6.9.a
Percentage of students who chose a certain combination of options

FIGURE 6.9.b
Percentage of students who chose each option

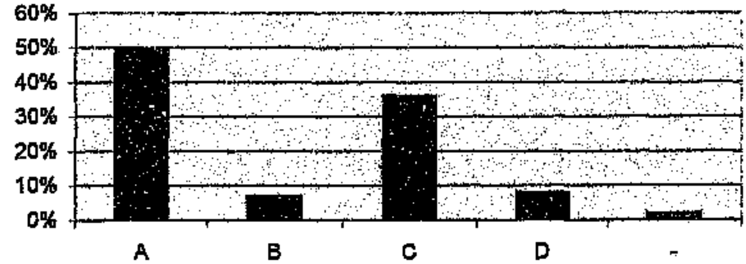


FIGURE 6.9.c
Percentage of students who used the indicated motivations to motivate the question

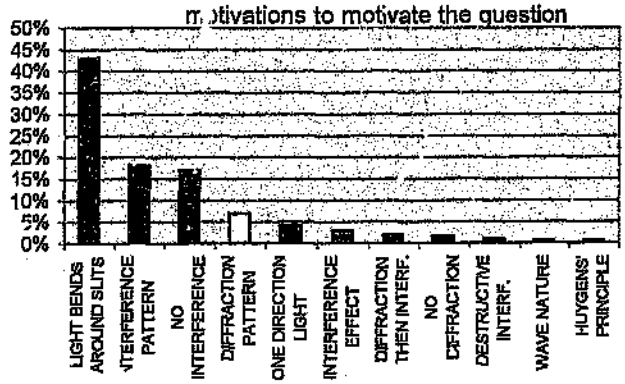
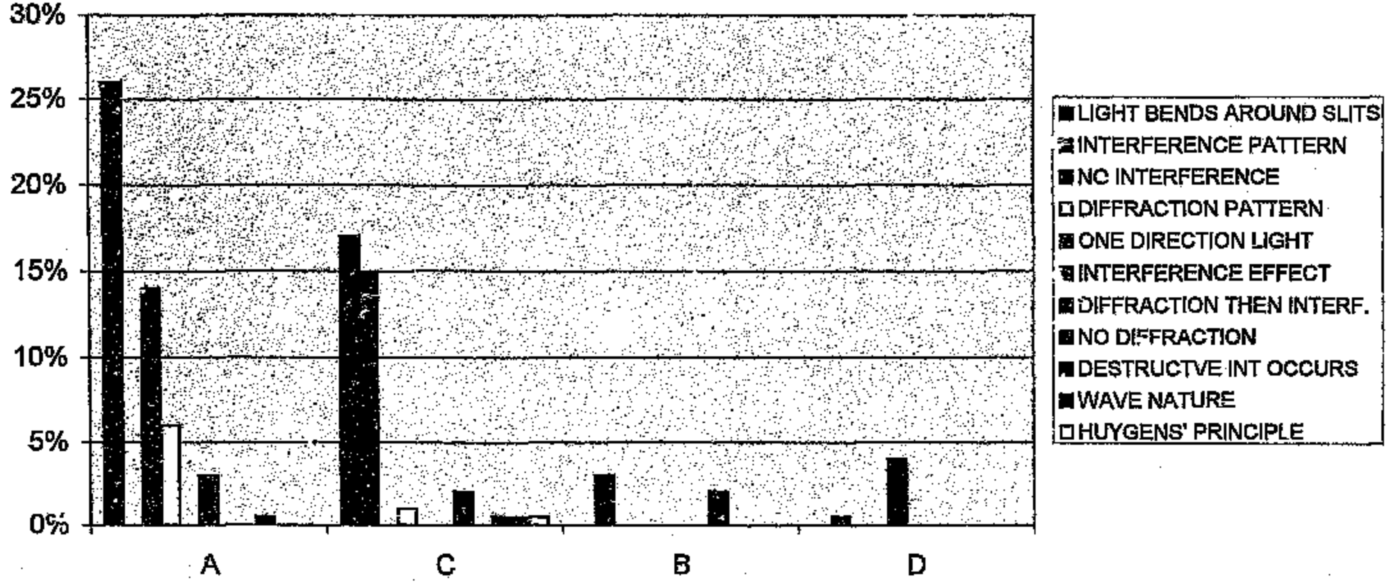


FIGURE 6.9.d
Percentage of students who used the indicated motivation for each combination of options



6.2.10 Analysis of Question 10

See Appendix B for Question 10.

Figure 6.10.a (p. 71A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: C(33%), B(18%), BC(15%), AD(8%), A(7%), AB(4%), CD(3%), ABD(3%), D(2%), BCD(2%), '-'(2%),

Figure 6.10.b (p. 71A) indicates the distribution of individual option choices The percentage of students who chose that option is shown in bracket C(54%) is the obviously correct choice, indicated in green. A(23%) and '-'(2%) are the obviously incorrect choices, indicated in red. The 'grey' options are B(46%) and D(19%).

Option C is correct, because there exists a phase difference between the waves.

Option A is incorrect, because the waves are not in phase.

Option B is 'grey' because of different textbook interpretations (see 3.3.3.3)

Option D is 'grey' because of different textbook interpretations. The waves are not (exactly) in phase (see 3.3.3.1), although reinforcement occurs in some instances.

Figure 6.10.c (p. 71A) indicates the distribution of the motivation categories used to motivate the question. Table 6.10 (p. 71) indicates the motivation categories of Question 10, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the

paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.10.d (p. 71B) indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
PHASE RELATION (23%)	The waves maintain a constant phase relation.	3.3.3.3.i Coherent sources emit waves with a constant phase relationship between them.
ORIGIN DIFFERS (15%)	The waves do not originate at the same point or time.	
CRESTS DON'T MEET (13%)	They do not meet crest-to-crest or trough-to-trough.	
NEITHER C. NOR D. INTERF. (8%)	Neither constructive nor destructive interference occurs. Not 100% constructive interference occurs. They do not cancel each other.	3.3.3.1.i When waves meet in phase, they exhibit constructive interference. 3.3.3.1.ii When waves are in phase, their interference is (fully) constructive. 3.3.3.2.ii When waves meet 180° out of phase, destructive interference results. 3.3.3.2.x Waves partially cancel and reinforce.
C. AND D. INTERF. OCCUR (7%)	Constructive and destructive interference take place. A stable interference pattern forms.	3.3.3.2.v Destructive interference is the partial or complete cancellation of waves out of phase with one another.
IDENTICAL (6%)	The waves have the same properties. They are nearly the same.	3.3.3.1.v *Constructive interference* is illustrated with two overlapping waves with the same properties.
REINFORCE (5%)	The waves reinforce each other.	3.3.3.1.iii Constructive interference is associated with reinforcement.
CRESTS AND TROUGHS MEET (5%)	They meet crest-to-crest and trough-to-trough.	
NOT COHERENT (4%)	They are not coherent.	3.3.3.3.ii Two sources are coherent if they have the same frequency and *phase*.
NOT EXACTLY OUT OF PHASE (4%)	They are not exactly out of phase or in phase. They are 90° out of phase. They are (slightly) out of phase. They are (exactly) in phase.	3.3.3.1.i When waves meet in phase constructive interference occurs. 3.3.3.2.i When waves meet out of phase destructive interference occurs.
SYNCHRONISED (4%)	Coherent means synchronised. The waves come after the other.	
** STABLE INTERF. PATTERN (0,5%)	A stable interference pattern forms.	
**AMPLITUDE (0,5%)	Resultant amplitude doesn't double.	

TABLE 6.10 : MOTIVATION CATEGORIES FOR QUESTION 10

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 10

FIGURE 6.10.a
Percentage of students who chose a certain combination of options

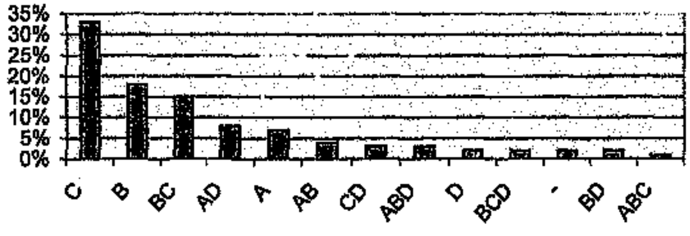


FIGURE 6.10.b
Percentage of students who chose each option

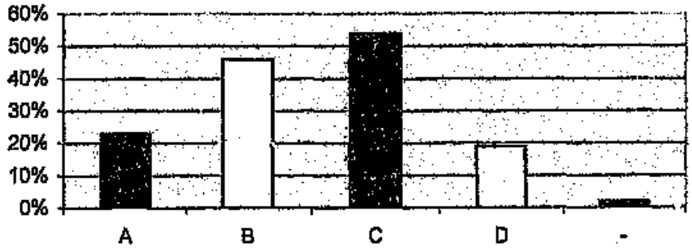
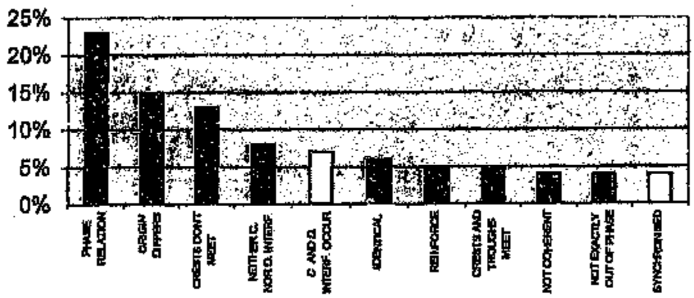


FIGURE 6.10.c
Percentage of students who used the indicated motivations to motivate the question



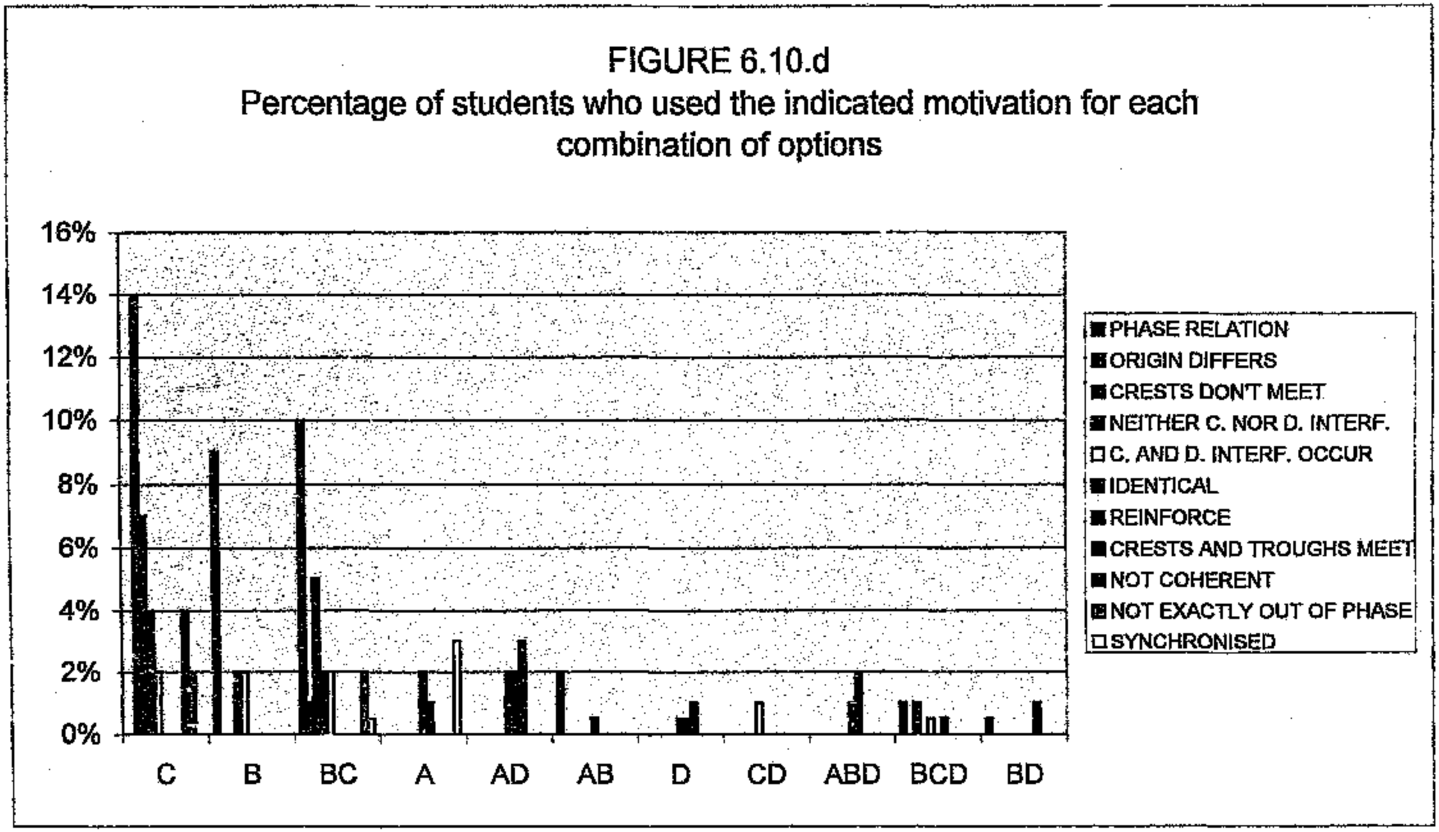


FIGURE 6.10.d
Percentage of students who used the indicated motivation for each combination of options
16%
14%
12%
10%
8%
6%
4%
2%
0%
C
B
BC
A
AD
AB
D
CD
ABD
BCD
BD
PHASE RELATION
ORIGIN DIFFERS
CRESTS DON'T MEET
NEITHER C. NOR D. INTERF.
C. AND D. INTERF. OCCUR
IDENTICAL
REINFORCE
CRESTS AND TROUGHS MEET
NOT COHERENT
NOT EXACTLY OUT OF PHASE
SYNCHRONISED

6.2.11 Analysis of Question 11

See Appendix B for Question 11.

Figure 6.11.a (p. 73A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: D(40%), AC(26%), C(23%), AC(7%), '-'(4%).

Figure 6.11.b (p. 73A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. C(48%) is the obviously correct choice, indicated in green. B(0%), D(40%) and '-'(4%) *are the obviously incorrect choices, indicated in red.* The 'grey' option is A(33%), indicated in yellow.

Option C is correct . One common feature of a wave is that it carries energy from one region in space to another.

Options B and D are incorrect, because a wave definitely does not carry matter.

Option A is 'grey' due to textbook presentations which describe a wave as a propagating disturbance.

Figure 6.11.c (p. 73A) indicates the distribution of the motivation categories used to motivate the question. Table 6.11 (p. 73) indicates the motivation categories of Question 11, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

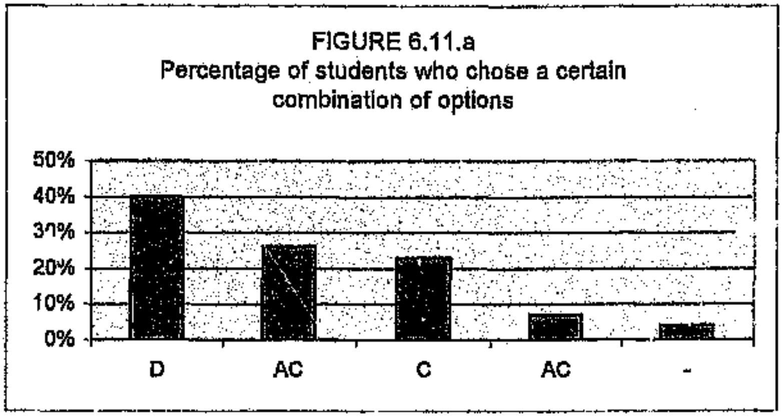
Figure 6.11.d (p. 73B) indicates the distribution of categories of motivations for each combination of options.

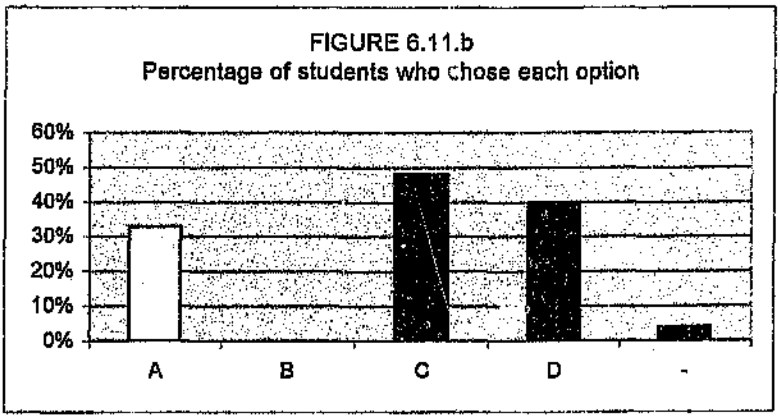
COMMENT: The analysis of this question revealed that this information does not contribute to the research and is therefore left out in the discussion.

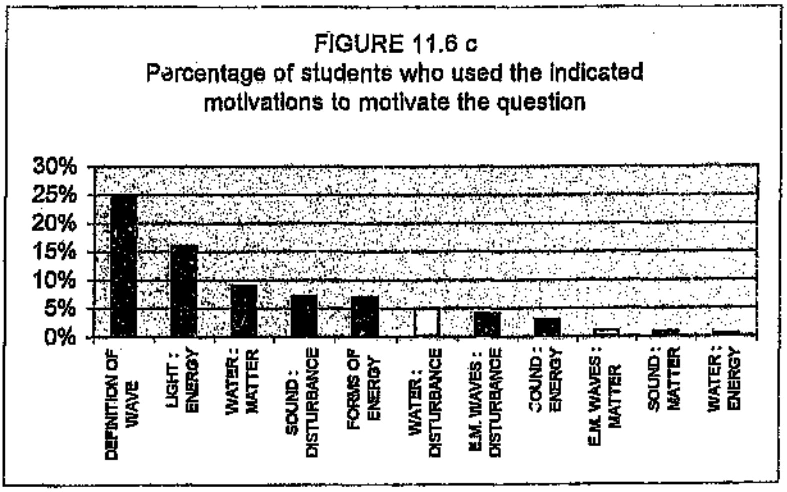
CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
DEFINITION OF WAVE (25%)	A wave is a travelling disturbance that carries energy from place to place. The energy of a disturbance is transferred by means of a wave.	3.3.2.2 A wave is a travelling disturbance that propagates and carries energy with time from one region in space to another.
LIGHT : ENERGY (16%)	Light waves transfer energy. The energy is carried by the electric and magnetic fields of the wave.	
WATER : MATTER (9%)	Water waves transfer matter.	
SOUND : DISTURBANCE (7%)	Sound waves transfer disturbances.	
FORMS OF ENERGY (7%)	Waves carry different forms of energy, e.g. light, sound, heat, potential energy, matter.	
WATER : DISTURBANCE (5%)	Water waves transfer disturbances e.g. stone dropped in dam.	
E.M. WAVES : DISTURBANCE (4%)	Electromagnetic waves e.g. light transfer disturbances.	
SOUND : ENERGY (3%)	Sound waves transfer energy.	
E.M. WAVES : MATTER (1%)	Electromagnetic waves transfer matter.	
SOUND : MATTER (1%)	Sound waves transfer matter.	
WATER : ENERGY (1%)	Water waves transfer energy.	

TABLE 6.11 : MOTIVATION CATEGORIES FOR QUESTION 11

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 11







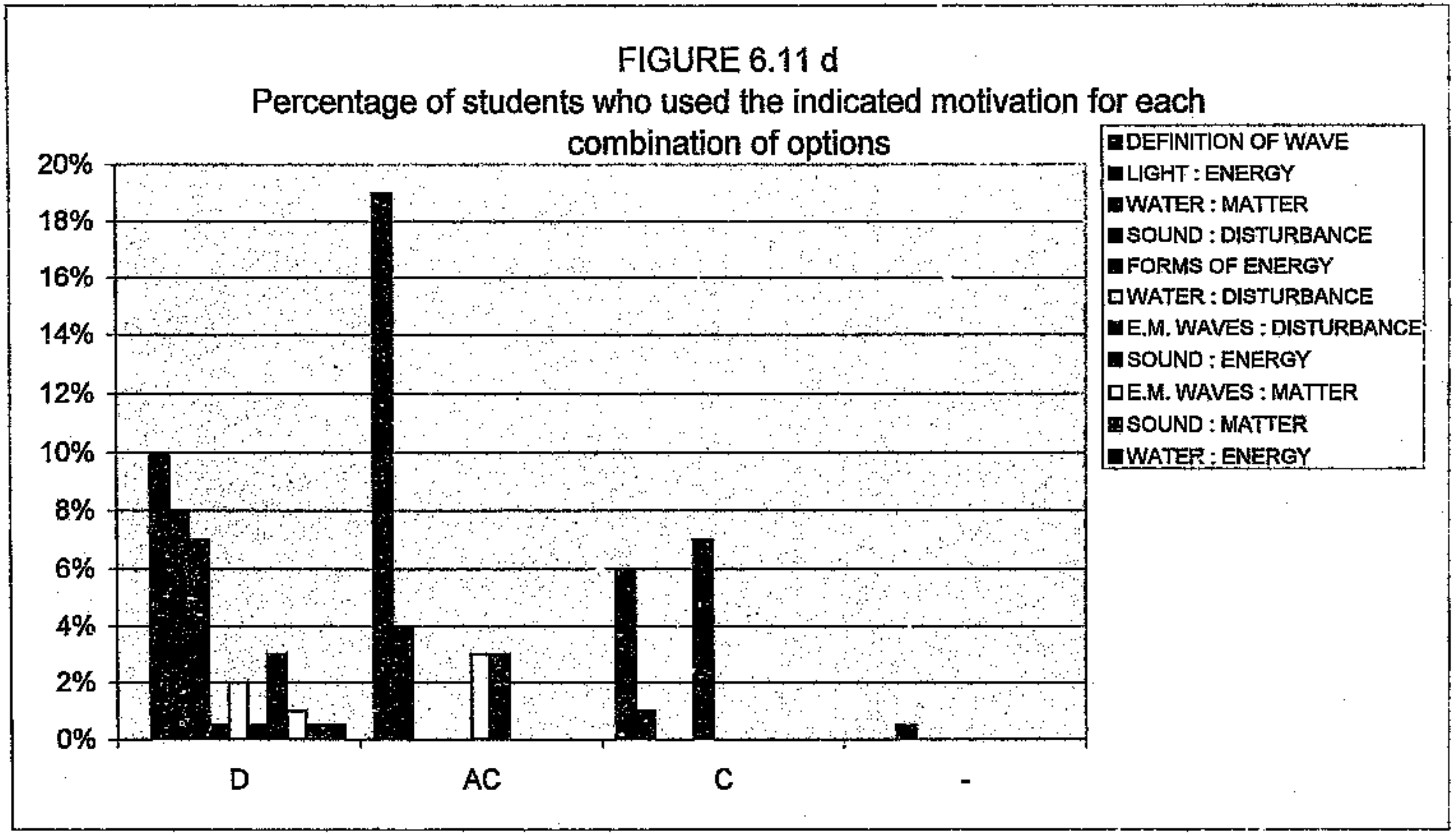


FIGURE 6.11 d
Percentage of students who used the indicated motivation for each combination of options

6.2.12 Analysis of Question 12

See Appendix B for Question 12.

Figure 6.12.a (p. 75A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: A(57%), C(14%), D(11%), B(9%), AD(3%), AC(3%), '-'(2%), ACD(1%), BC(1%), BD(1%).

Figure 6.12.b (p. 75A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. C(18%) is the obviously correct choice, indicated in green. B(10%), D(15%) and '-'(2%) are the obviously incorrect choices, indicated in red. Option A(63%) is 'grey', indicated in yellow.

Option C is correct. Destructive interference occurs at both these points, because crests and troughs fall together.

Options B and D are incorrect, because both undergo destructive interference and they are the same pathlengths from their sources.

Option A is 'grey', because the two points will experience the same loudness, which is in theory zero!

Figure 6.12.c (p. 75A) indicates the distribution of the motivation categories used to motivate the question. Table 6.12 (p. 75) indicates the motivation categories of Question 12, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students

who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.12.d (p. 75B) indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
DESTRUCTIVE INTERF. (27%)	Destructive interference occurs at both, because they meet trough-to-crest, out of phase, not in phase, not exactly out of phase.	3.3.3.2.i They meet out of phase.
IN PHASE (17%)	The points are in phase, because crests and troughs meet, with the same frequency and wavelength.	3.3.3.1.i They are in phase and exhibit constructive interference. 3.3.3.1.v They have the same frequency and amplitude.
PATH LENGTH (16%)	Their distances from the sources are the same.	3.3.3.1.vi A path length difference of an integer number of wavelengths leads to constructive interference.
CONSTRUCTIVE INTERF. (15%)	Constructive interference occurs at both due to path length differences, or crests that meet.	3.3.3.1.vi A path length difference of an integer number of wavelengths leads to constructive interference.
NO INTERFERENCE (10%)	No interference, neither constructive nor destructive.	
SAME SOURCE (7%)	Both speakers are connected to the same signal generator.	
IDENTICAL AMPLITUDES (2%)	*Their amplitudes are the same.*	*3.3.3.1.v Waves have the same frequency and amplitude.*
INTERFERENCE OCCURS (2%)	Equal interference occurred.	
SOUND Y > X (2%)	The sound is louder at Y.	
** INTENSITY REDISTRIBUTES (1%)	Sound intensity is redistributed.	

TABLE 6.12 : MOTIVATION CATEGORIES FOR QUESTION 12

6.2.13 Analysis of Question 13

See Appendix B for Question 13.

Figure 6.13.a (p. 77A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: D(27%), B(22%), C(20%) A(18%), '-'(7%), BD(4%), AB(1%), ABCD(1%), ABD(1%), AC(1%), A'

Figure 6.13.b distribution of individual option choices. The percentage c se that option is shown in brackets. D(32%) is the obviously indicated in green. A(20%), B(27%), C(21%) and '-'(7%) are the obviously incorrect choices, indicated in red.

Option D is correct. P is the second order bright fringe. Therefore the pathlength difference is two times the wavelength.

Options A, B and C are incorrect, because the difference in pathlengths at the second order bright fringe is two wavelengths.

Figure 6.13.c (p. 77A) indicates the distribution of the motivation categories used to motivate the question. Table 6.13 (p. 77) indicates the motivation categories of Question 13, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 12

FIGURE 6.12.a
Percentage of students who chose a certain combination of options

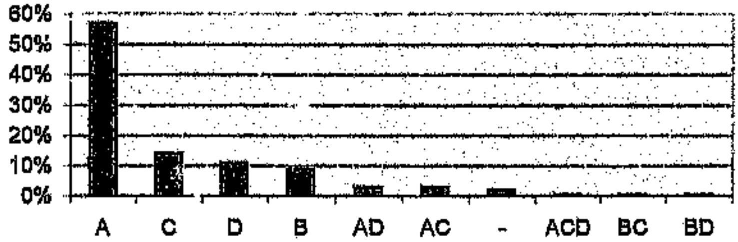


FIGURE 6.12.b
Percentage of students who chose each option

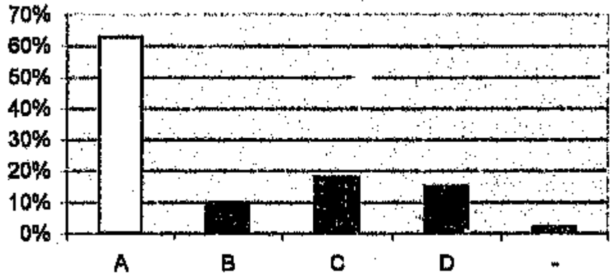


FIGURE 6.12.c
Percentage of students who used the indicated motivations to motivate the question

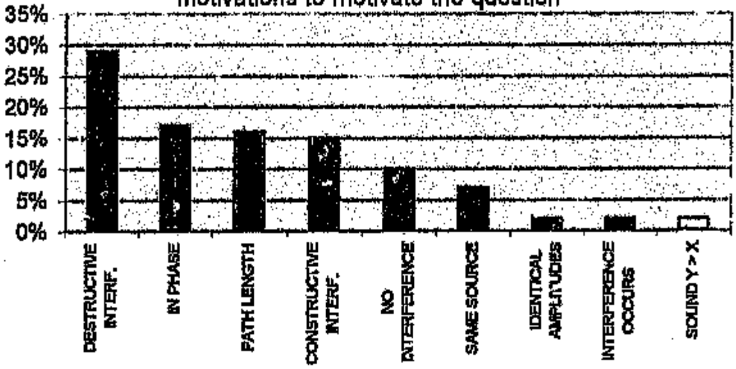
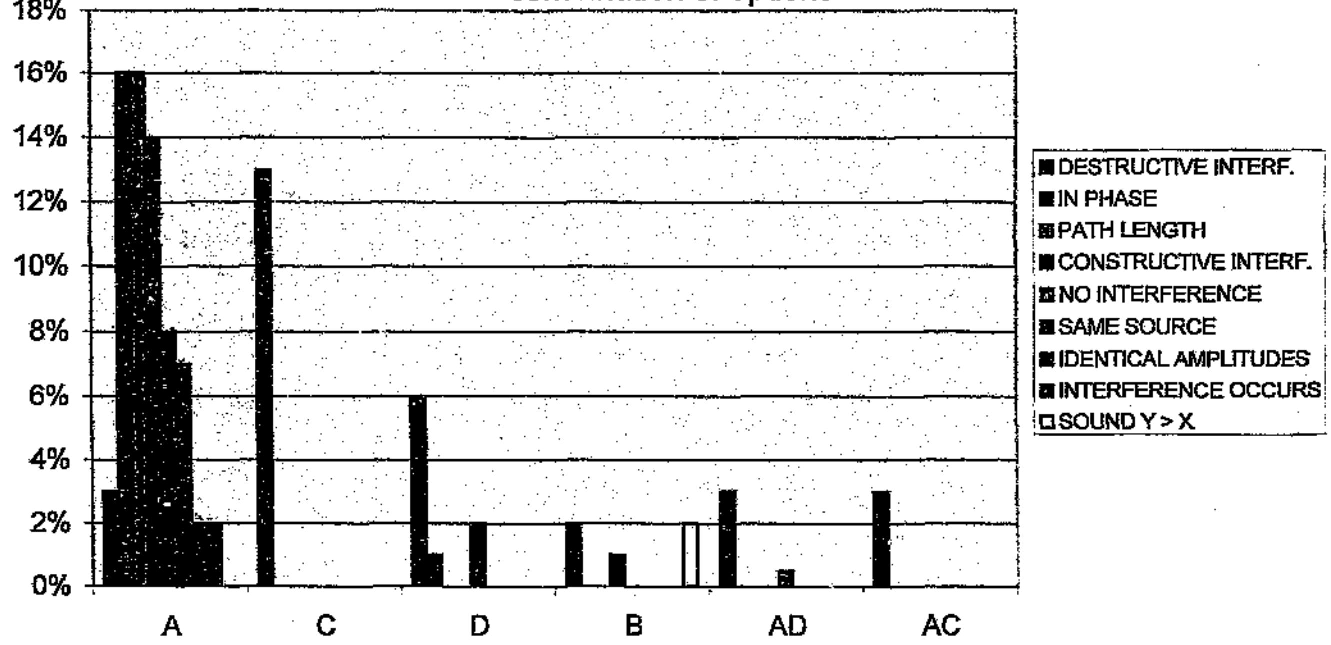


FIGURE 6.12.d
Percentage of students who used the indicated motivation for each combination of options



6.2.13 Analysis of Question 13

See Appendix B for Question 13.

Figure 6.13.a (p. 77A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: D(27%), B(22%), C(20%), A(18%), '-'(7%), BD(4%), AB(1%), ABCD(1%), ABD(1%), AC(1%), AD(1%).

Figure 6.13.b (p. 77A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. D(32%) is the obviously correct choice, indicated in green. A(20%), B(27%), C(21%) and '-'(7%) are the obviously incorrect choices, indicated in red.

Option D is correct. P is the second order bright fringe. Therefore the pathlength difference is two times the wavelength.

Options A, B and C are incorrect, because the difference in pathlengths at the second order bright fringe is two wavelengths.

Figure 6.13.c (p. 77A) indicates the distribution of the motivation categories used to motivate the question. Table 6.13 (p. 7') indicates the motivation categories of Question 13, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.13.d (p. 77B) indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
INTEGER NUMBER (12%)	Path length difference is an integer amount of wavelengths. Pathlength difference is one wavelength.	3.3.3.1.vi A path length difference of an integer number of wavelengths leads to constructive interference.
SECOND ORDER (12%)	This is a second order bright fringe with m = 2. PY is 2 wavelengths longer than PX.	3.3.3.1.vi A path length difference of an integer number of wavelengths leads to constructive interference.
PY = PX + Y (9%)	PY is 1 wavelength longer than PX.	
PY = 2PX (4%)	PY is double PX.	
PY = PX + Y/2 (4%)	PY is half a wavelength longer than PX.	
OTHER ORDERS (3%)	P is the third order bright fringe.	
SAME PHASE (3%)	They are in the same phase. The wavelength of PY is two times out of phase to PX.	
PY < PX (3%)	PY is shorter than PX.	
WAVELENGTHS DIFFER (2%)	PY has double the wavelength of PX.	
PY = 3/2 PX (2%)	PY is 1,5 times longer than PX.	
PX = PY (2%)	X and Y are very close together. Their wavelengths are equal. PX and PY are parallel and far away from screen.	

TABLE 6.13 : MOTIVATION CATEGORIES FOR QUESTION 13

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 13

FIGURE 6.13.a
Percentage of students who chose a certain combination of options

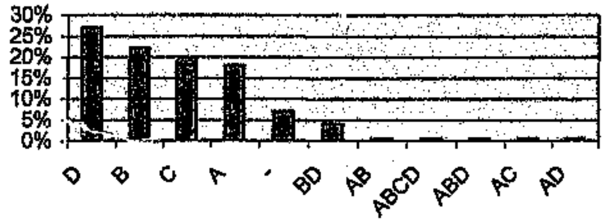


FIGURE 6.13.b
Percentage of students who chose each option

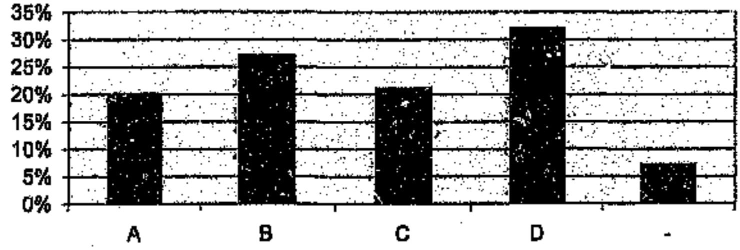


FIGURE 6.13.c
Percentage of students who used the indicated motivations to motivate the question

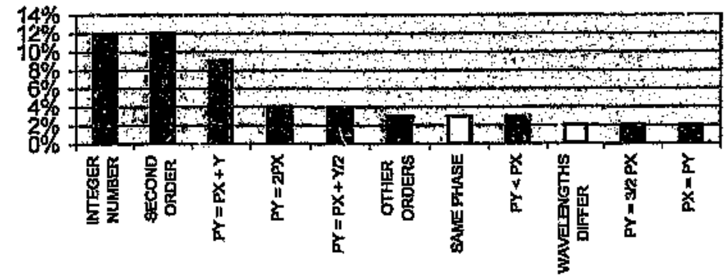
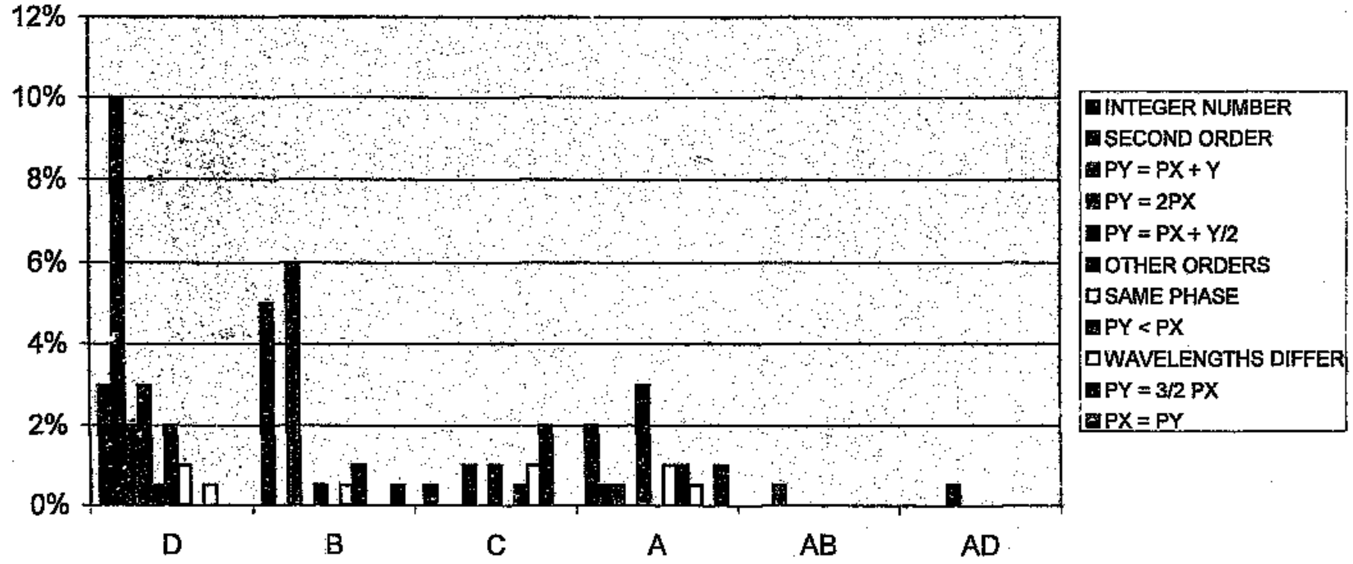


FIGURE 6.1[illegible] d

Percentage of students who used the indicated motivation for each combination of options



6.2.14 Analysis of Question 14

See Appendix B for Question 1.

Figure 6.14.a (p. 79A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: D(75%), C(7%), B(5%), A(4%), AD(3%), '-'(2%), AC(2%), ACD(1%), AB(1%), ABD(1%), CD(1%).

Figure 6.14.b (p. 79A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. D(81%) is the obviously correct choice, indicated in green. A(11%), B(6%), C(10%) and '-'(2%) are the obviously incorrect choices, indicated in red.

Option D is correct. The two points are exactly one wavelength apart.

Options A, B and C are incorrect, because neither of those pairs of points are exactly one wavelength apart.

Figure 6.14.c (p. 79A) indicates the distribution of the motivation categories used to motivate the question. Table 6.14 (p. 79) indicates the motivation categories of Question 14, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.14.d indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
SAME ORIENTATION (39%)	They are at the same position (place) of the wave. They are the same distance from the undisturbed position.	
FULL WAVELENGTH (29%)	They are exactly one wavelength apart. They are 360° out of phase.	
CRESTS AND TROUGHS (10%)	They will meet crest-to-crest and trough-to-trough. They are both at the positive (rising) side of the wave.	3.3.3.3.iii A constant phase relation exists between two waves when the two sources emit crests (or troughs) simultaneously.
CONSTRUCTIVE INTERF. (7%)	Constructive interference will result.	
IDENTICAL (5%)	The waves have the same properties (amplitude, speed and wavelength).	
REINFORCE (2%)	They reinforce each other.	
MAX. & MIN. DISTURBANCE (2%)	The one is a minimum and the other is a maximum.	
COHERENT (1%)	They are coherent.	3.3.3.3.ii Two sources are coherent if they have the same frequency and phase.
**OTHERS CANCEL (0,5%)	The others cancel each other, except points A and C.	
**NOT SIMULTANEOUS (0,5%)	None are in phase, because none meet at the same point at the same time.	3.3.3.3.vi Two waves are in phase if they reach their maximum amplitudes at the same time, are zero at the same time and have their minimum amplitudes at the same time.

TABLE 6.14 : MOTIVATION CATEGORIES FOR QUESTION 14

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 14

FIGURE 6.14.a
Percentage of students who chose a certain combination of options

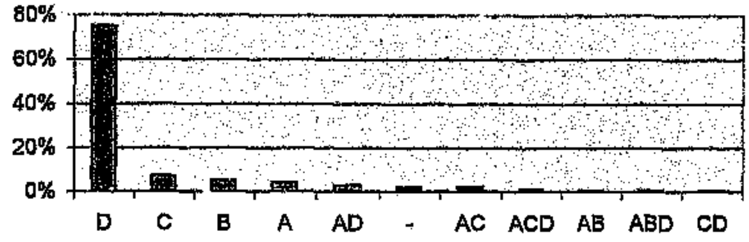


FIGURE 6.14.b
Percentage of students who chose each option

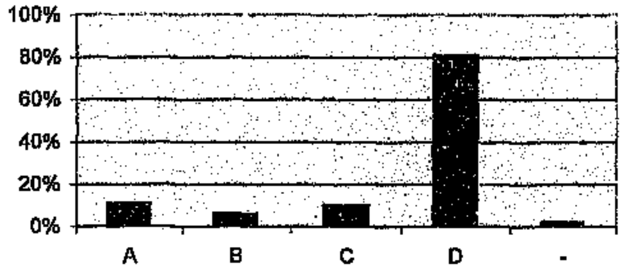
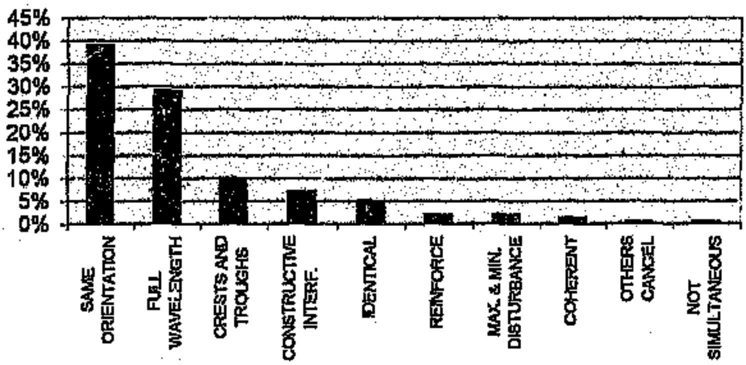


FIGURE 6.14.c
Percentage of students who used the indicated motivations to motivate the question



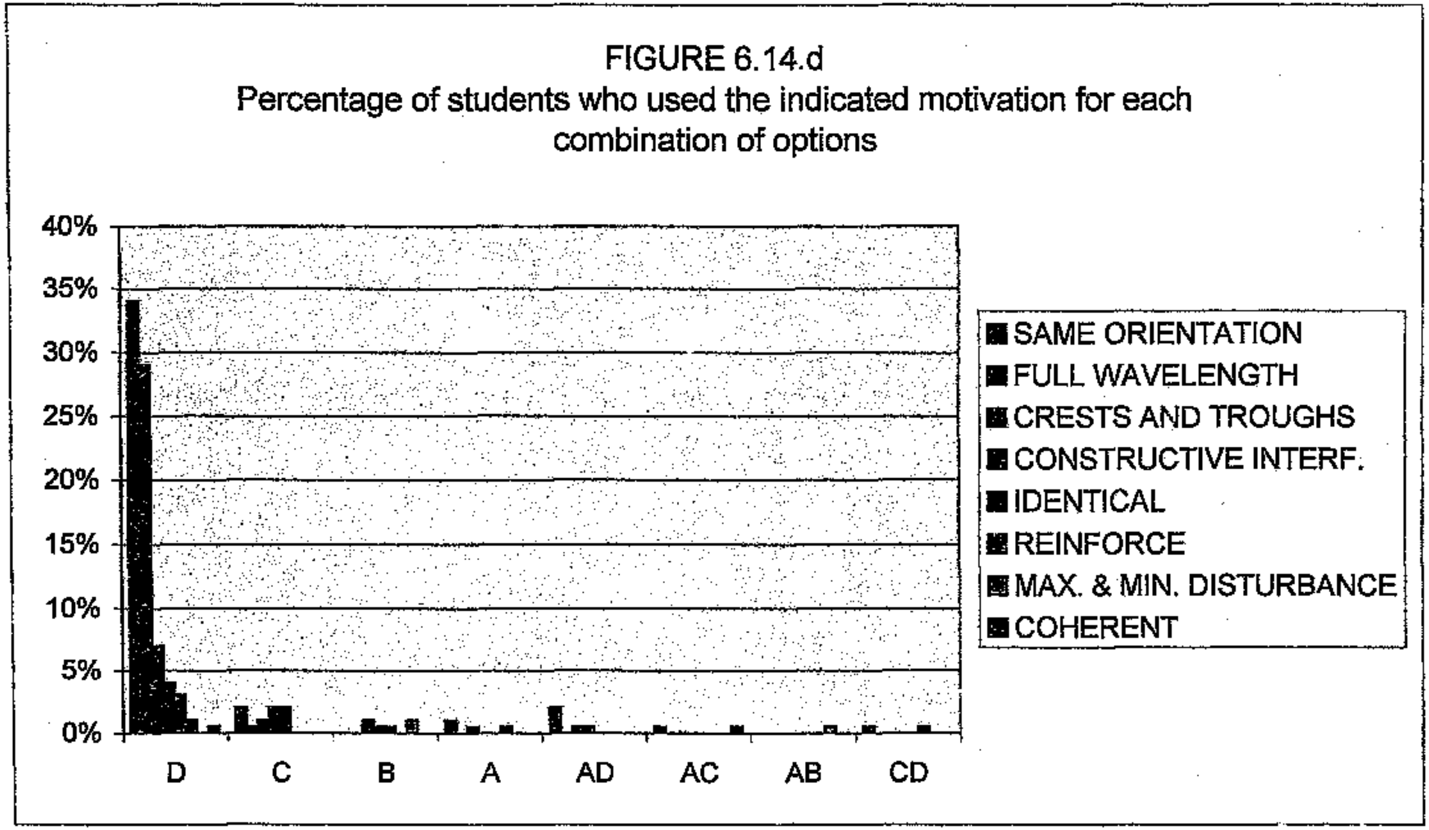


FIGURE 6.14.d
Percentage of students who used the indicated motivation for each combination of options
40%
35%
30%
25%
20%
15%
10%
5%
0%
D
C
B
A
AD
AC
AB
CD
SAME ORIENTATION
FULL WAVELENGTH
CRESTS AND TROUGHS
CONSTRUCTIVE INTERF.
IDENTICAL
REINFORCE
MAX. & MIN. DISTURBANCE
COHERENT

6.2.15 Analysis of Question 15

See Appendix B for Question 15.

Figure 6.15.a (p. 82A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: C(61%), A(18%), AC(8%), '-'(3%), BC(3%), BD(2%), AB(1%), ACD(1%), BCD(1%), D(1%), ABC(1%), ABCD(1%), CD(1%).

Figure 6.15.b (p. 82A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. A (29%) and C(75%) are the obviously correct choices, indicated in green. The obviously incorrect option is no choice (3%). B(7%) and D(6%) are the 'grey' options, indicated in yellow.

Options A and C are correct. Light bends and spreads around obstacles, and constructive and destructive interference follow. Diffraction is an interference effect!

Options B and D are 'grey'. They should serve as distractors. The scattering of dust particles and the irregular reflection from a not perfectly smooth screen can both contribute to the blurred image, but these conceptions are not applicable for this test or the research.

Figure 6.15.c (p. 82A) indicates the distribution of the motivation categories used to motivate the question. Table 6.15 (p. 82) indicates the motivation categories of Question 15, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students

who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.15.d (p 82B) indicates the distribution of categories of motivations for each combination of options.

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 15

FIGURE 6.15.a
Percentage of students who chose a certain combination of options

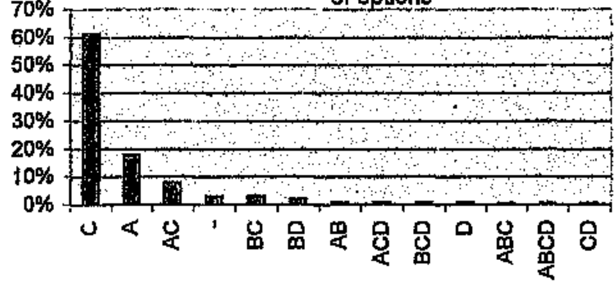


FIGURE 6.15.b
Percentage of students who chose each option

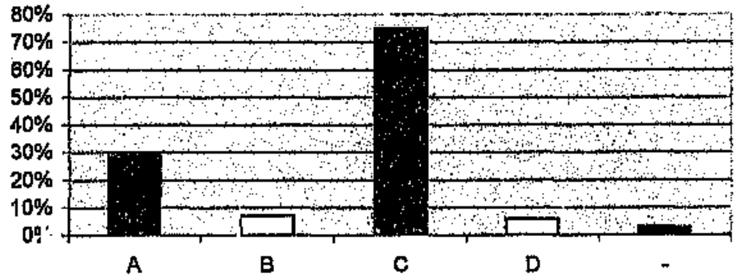


FIGURE 6.15.c
Percentage of students who used the indicated motivations to motivate the question

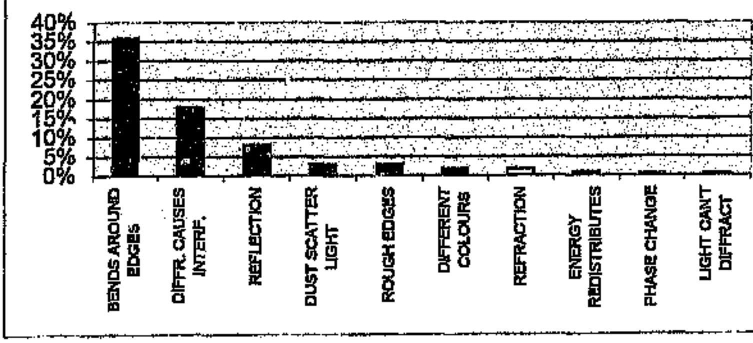
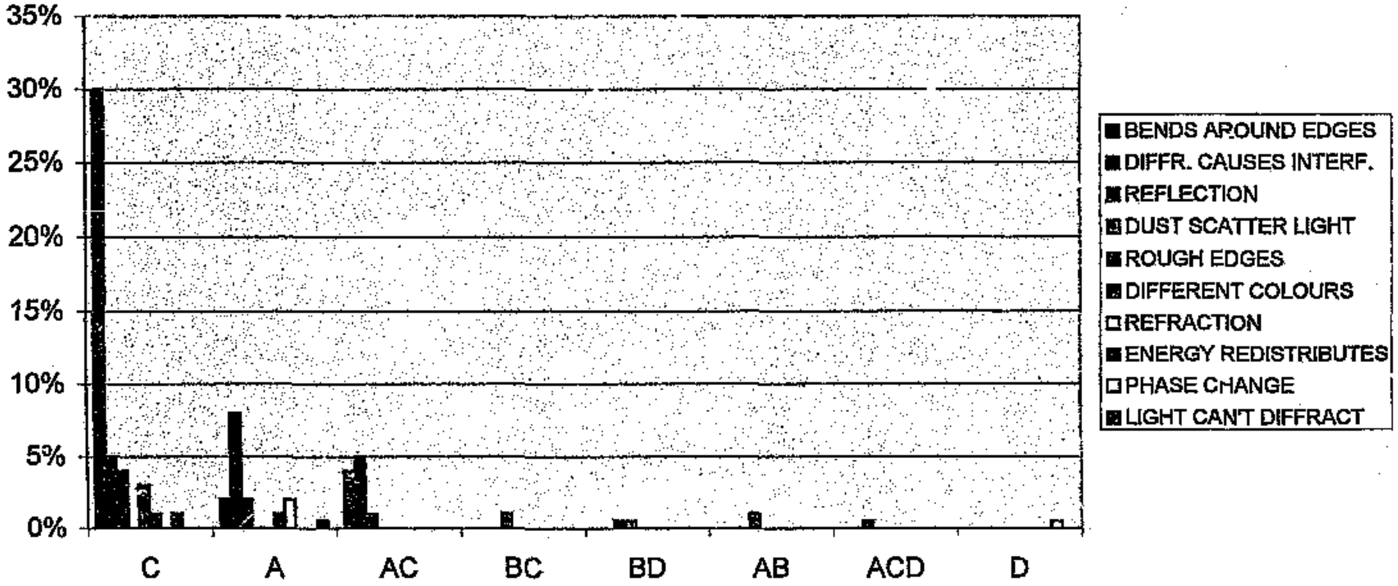


FIGURE 6.15.d
Percentage of students who used the indicated motivation for each combination of options



6.2.16 Analysis of Question 16

See Appendix B for Question 16.

Figure 6.16.a (p. 84A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: D(29%), A(23%), C(17%), AC(15%), B(8%), '-'(4%), BC(3%), ABCD(1%), BCD(1%).

Figure 6.16.b (p. 84A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. D(30%) is the obviously correct choice, indicated in green. A(38%), B(12%), C(36%) and '-'(4%) are the obviously incorrect choices, indicated in red.

Option D is correct. At point Y two crests meet and at point Z two troughs meet. Therefore both represent constructive interference.

Options A, B and C are incorrect, because point X does not undergo interference yet and points Y and Z undergo constructive interference.

Figure 6.16.c (p. 84A) indicates the distribution of the motivation categories used to motivate the question. Table 6.16 (p. 84) indicates the motivation categories of Question 16, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.16.d (p. 84B) indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
CRESTS MEET FOR C.I. (41%)	At Y 2 crests meet for constructive interference, therefore reinforcement.	3.3.3.1.iii When the resultant displacement is greater than either of the individual waves, constructive interference results.
TROUGHS MEET FOR C.I. (19%)	At Z 2 troughs meet for constructive interfe[illegible]e. A light fringe will form.	3.3.3.1.iv Constructive interference is associated with the bright fringes of an interference pattern.
WAVES IN PHASE (12%)	The waves meet in phase. The sources are in phase, therefore constructive interference. The waves meet exactly one wavelength out of phase.	3.3.3.1.i Constructive interference results when two waves meet in phase.
TROUGHS MEET FOR D.I. (8%)	Two troughs represent a dark fringe. Two troughs cancel each other. The troughs are in between two crests, therefore destructive interference.	3.3.3.1.vii On the interference pattern of a ripple tank the dark spots represent constructive interference due to the troughs.
Z CREST & TROUGH FOR D.I. (6%)	At Z a crest and trough meets for destructive interference.	
MAKE CONTACT FOR C.I. (5%)	The point where 2 waves make contact, constructive interference takes place.	
NO INTERF. AT Z (4%)	No interference at Z, because the waves don't make contact.	
PATH LENGTH (4%)	It depends on the distance / amount of wavelengths between the slits and sources (1 wavelength, equal amount of wavelengths, an integer amount of wavelengths difference).	3.3.3.1.vi For two sources vibrating in phase, a path length differen[illegible]e which is an integer number of wavelengths leads to constructive interference.
OUT OF PHASE FOR D.I. (1%)	The waves are out of phase. The two crests are out of phase.	
COHERENT SOURCES (1%)	The two slits act as coherent sources.	
SMALLER AMP. FOR D.I. (1%)	The resultant amplitude is smaller for destructive interference.	3.3.3.2.iv Where two pulses diminish each other, destructive interference occurs.
DIFFR. AT TWO SLITS (1%)	No interference through a double slit, because a diffraction pattern occurs.	3.3.3.5.iii Diffraction patterns of bright and dark fringes occur when light passes through a double slit.

TABLE 6.16 : MOTIVATION CATEGORIES FOR QUESTION 16

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 16

FIGURE 6.16.a
Percentage of students who chose a certain combination of options

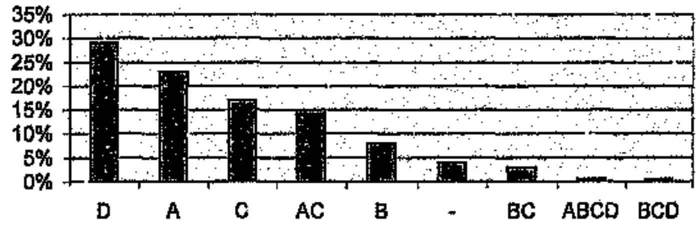


FIGURE 6.16.b
Percentage of students who chose each option

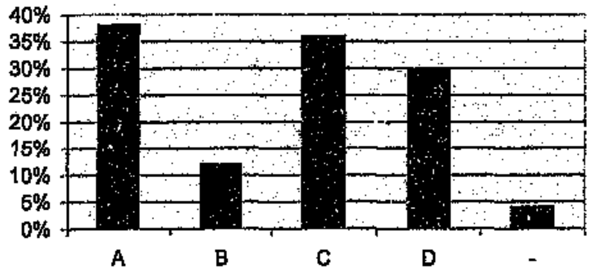


FIGURE 6.16.c
Percentage of students who used the indicated motivations to motivate the question

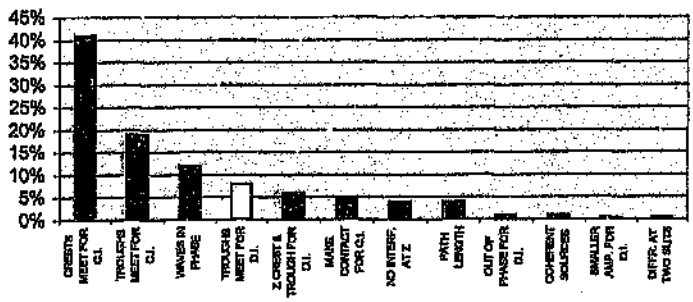
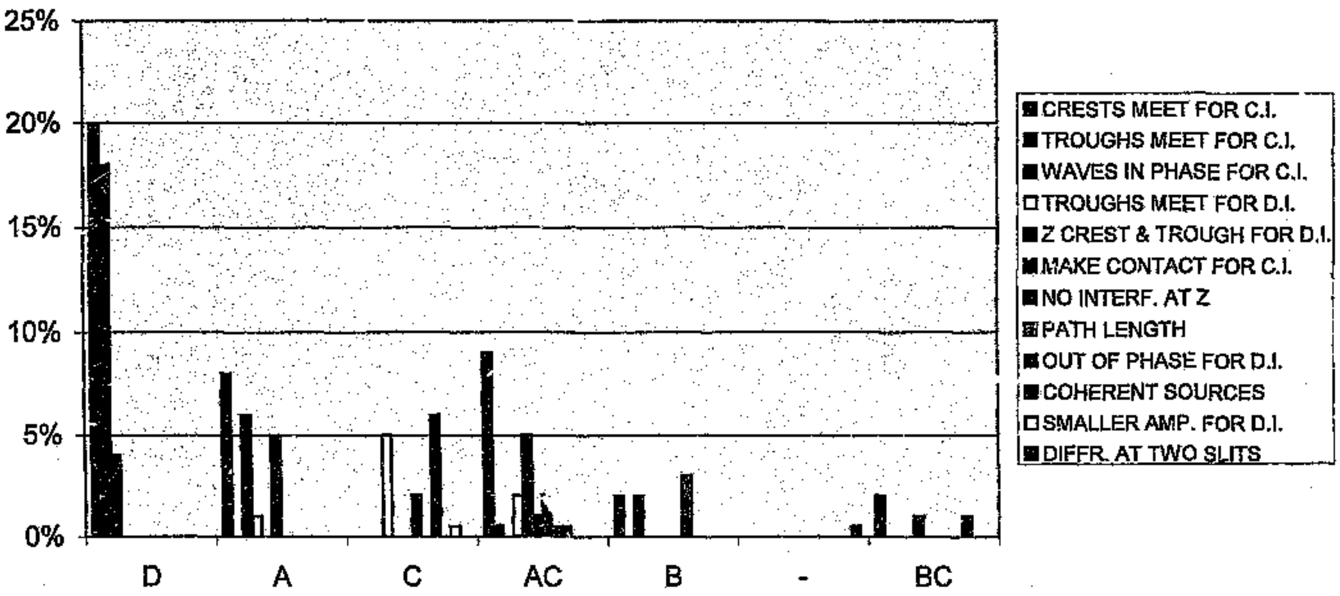


FIGURE 6.16.d
Percentage of students who used the indicated motivation for each combination of options



6.2.17 Analysis of Question 17

See Appendix B for Question 17.

Figure 6.17.a (86A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: D(31%), BC(15%), A(10%), AD(10%), C(9%), '-'(6%), BC(6%), ABC(5%), ABCD(3%).

Figure 6.17.b (p. 86A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. The obviously correct choices are A(28%), B(29%), C(32%) and D(44%), indicated in green. The obviously incorrect option is no choice (6%), indicated in red.

Options A, B, C and D are correct.

Figure 6.17.c (p. 86A) indicates the distribution of the motivation categories used to motivate the question. Table 6.17 (p. 86) indicates the motivation categories of Question 17, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.17.d (86B) indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
DOUBLE SLIT INTERF. (27%)	At the double slit bright and dark fringes appear. Interference occurs between two light waves. Diffraction does not occur.	3.3.3.5.vi Interference arises from superposition of a finite number of waves coming from different coherent sources.
SINGLE SLIT DIFFRACT (20%)	At the single slit only diffraction occurs, because light bends around the slit.	3.3.3.4.i *Diffraction is the bending of light* around small openings. 3.3.3.5.iii *A diffraction pattern of bright and* dark fringes occurs when light passes through a single slit. 3.3.3.5.v The result of diffraction is a diffraction pattern. 3.3.3.5.vi Interference arises from superposition of a finite number of waves coming from different coherent sources.
DIFFRACT THEN INTERF. (17%)	Light bends around each slit and spreads out, and waves and wavelets will interfere constructively and destructively.	3.3.3.5.iv The result of diffraction is an interference pattern. 3.3.3.5.viii When diffraction occurs, light produces an interference pattern called a diffraction pattern.
SINGLE SLIT INTERF. (8%)	At the single slit only interference occurs which causes bright and dark lines.	
DOUBLE SLIT INTERF. & DIFF. (7%)	At the double slit interference and diffraction occurs.	3.3.3.5.ii Light is diffracted at each slit and the pattern describes both interference and diffraction at the same time. 3.3.3.5.vii In double slits both interference and diffraction occur.
DOUBLE SLIT DIFFRACT (3%)	At the double slit only diffraction occurs.	3.3.3.5.iii A diffraction pattern of bright and dark fringes occurs when light passes through a double slit.
WAVE NATURE (2%)	Interference and diffraction properties of light waves.	
INTERFERENCE EFFECT (2%)	Diffraction is an interference effect.	3.3 3.5.i Diffraction is an interference effect.
** COHERENT SOURCES (1%)	Coherent sources lead to bright and dark fringes.	

TABLE 6.17 : MOTIVATION CATEGORIES OF QUESTION 17

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 17

FIGURE 6.17.a
Percentage of students who chose a certain combination of options

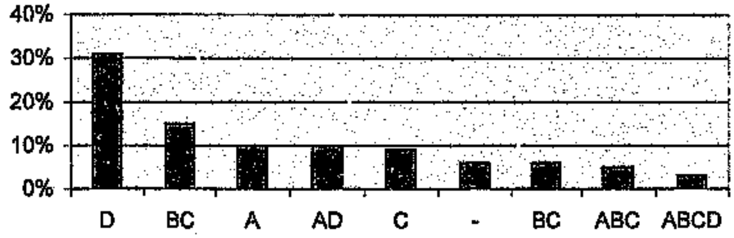


FIGURE 6.17.b
Percentage of students who chose each option

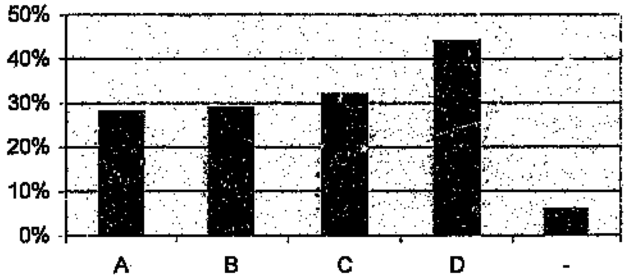
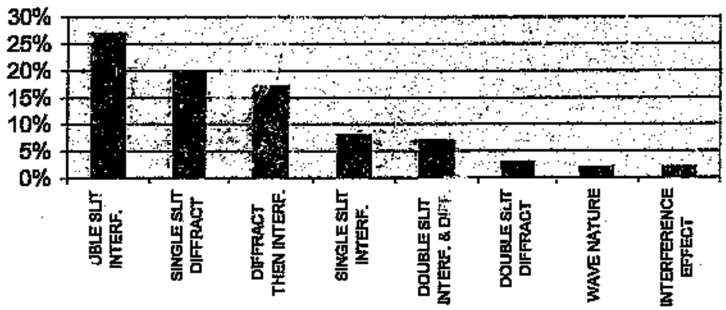


FIGURE 6.17.c
Percentage of students who used the indicated motivations to motivate the question



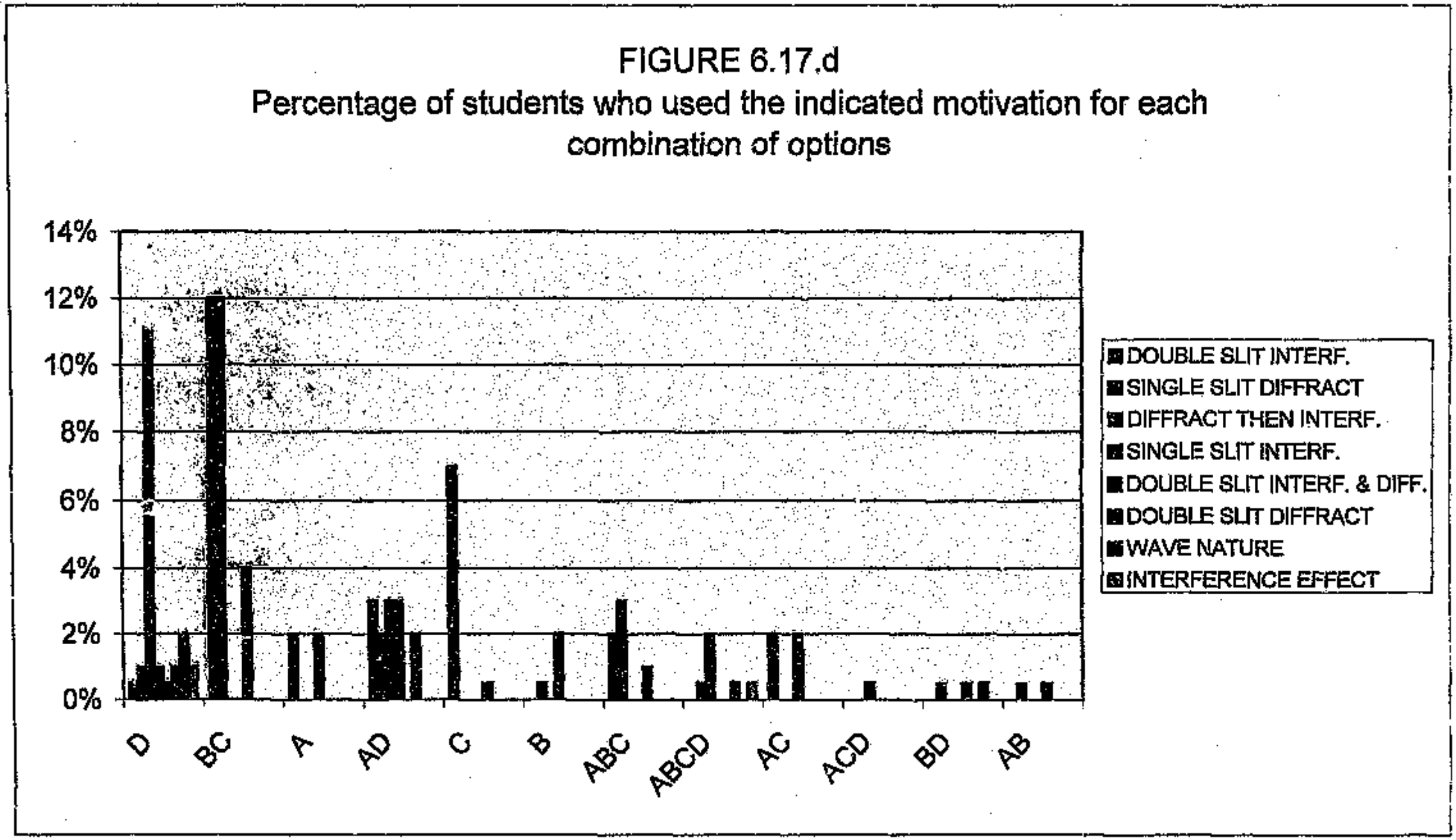


FIGURE 6.17.d
Percentage of students who used the indicated motivation for each combination of options
14%
12%
10%
8%
6%
4%
2%
0%
D
BC
A
AD
C
B
ABC
ABCD
AC
ACD
BD
AB
DOUBLE SLIT INTERF.
SINGLE SLIT DIFFRACT
DIFFRACT THEN INTERF.
SINGLE SLIT INTERF.
DOUBLE SLIT INTERF. & DIFF.
DOUBLE SLIT DIFFRACT
WAVE NATURE
INTERFERENCE EFFECT

6.2.18 Analysis of Question 18

See Appendix B for Question 18.

Figure 6.18.a (p. 89A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: ABD(28%), AD(18%), A(13%), B(12%), ABD(9%), D(8%), BD(3%), ABCD(2%), BC(2%), '-'(2%), C(1%), CD(1%), ABCD(1%).

Figure 6.18.b (p. 89A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. A(71%) and D(60%) are the obviously correct choices, indicated in green. The obviously incorrect option is no choice (2%), indicated in red. B(57%) and C(7%) are the 'grey' options, indicated in yellow.

Options A and D are correct, because waves which meet in phase interfere constructively, according to all the textbook presentations. Waves meeting crest-to-crest also meet trough-to-trough and are therefore in phase.

Option B is 'grey' due to different textbook interpretations (see 3.3.3.1).

Option C is 'grey' because the waves are not (exactly) in phase., although reinforcement does occur at some instances.

Figure 6.18.c (p. 89A) indicates the distribution of the motivation categories used to motivate the question. Table 6.18 (p. 89) indicates the motivation categories of Question 18, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students

who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.18.d (p. 89B) indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
TROUGHS ALSO MEET (19%)	When crests meet, troughs will also meet.	
IDENTICAL (9%)	Wave properties are identical (amplitude and wavelength).	3.3.3.1.v Illustrated with two waves with the same frequency and amplitude.
AMPLITUDES DOUBLE (8%)	When waves are in phase, reinforcement occurs. The amplitudes double.	3.3.3.1.iii *Constructive interference* is associated with reinforcement.
EXACTLY IN PHASE (6%)	The waves are exactly in phase when they meet crest-to-crest.	3.3.3.1.i When two waves meet in phase, constructive interference occurs.
SUPERPOSITION (4%)	According to the principle of linear superposition, constructive interference will occur when two waves meet in phase.	
NOT IN PHASE D.I. (4%)	Waves not completely in phase will have some destructive interference. Waves not in phase undergo destructive interference. Destructive interference results when the waves are more than 90° out of phase.	3.3.3.2.v *Destructive interference* is the partial or complete cancellation of waves out of phase with one another. 3.3.3.3.v Two waves are out of phase when their maximum, zero and minimum displacements are not at the same place. 3.3.3.3.vii Out of phase waves arrive a half-cycle out of step at a point.
BOTH IN + OR – CYCLE (3%)	For constructive interference they have to cross each other in the same direction or both in the positive or both in the negative cycle.	3.3.3.1.viii When the displacements of two waves are in the same direction or in the same part of their cycles, constructive interference results.
COHERENT SOURCES (2%	For constructive interference sources have to be coherent.	3.3.3.3.ii Sources are coherent if they have the same phase.
DON'T CANCEL C.I. (1%)	When resultant is not zero, destructive interference does not occur.	3.3.3.2.vi Destructive interference is the complete cancellation of waves.
PATH LENGTH (1%)	The difference in path length is an integer number of wavelengths.	3.3.3.1.vi For two waves *vibrating in phase*, a path length difference of an integer number of wavelengths leads to constructive interference.
PARTIALLY IN PHASE (1%)	If they are partially in phase, partial constructive interference occurs. Waves must be at least partially in phase for constructive interference to occur.	3.3.3.1.ii When waves are in phase their interference is fully constructive.

TABLE 6.18 : MOTIVATION CATEGORIES OF QUESTION 18

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 18

FIGURE 6.18.a
Percentage of students who chose a certain combination of options

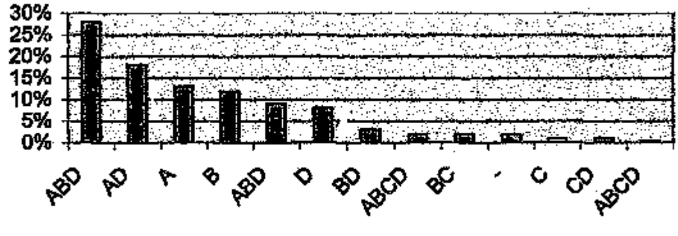


FIGURE 6.18 b
Percentage of students who chose each option

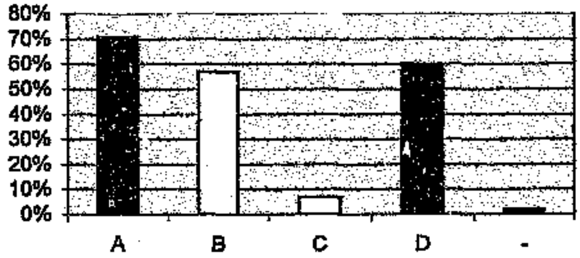


FIGURE 6.18.c
Percentage of students who used the indicated motivation for each combination of options

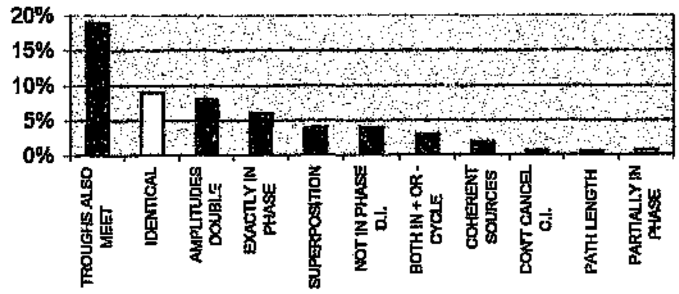
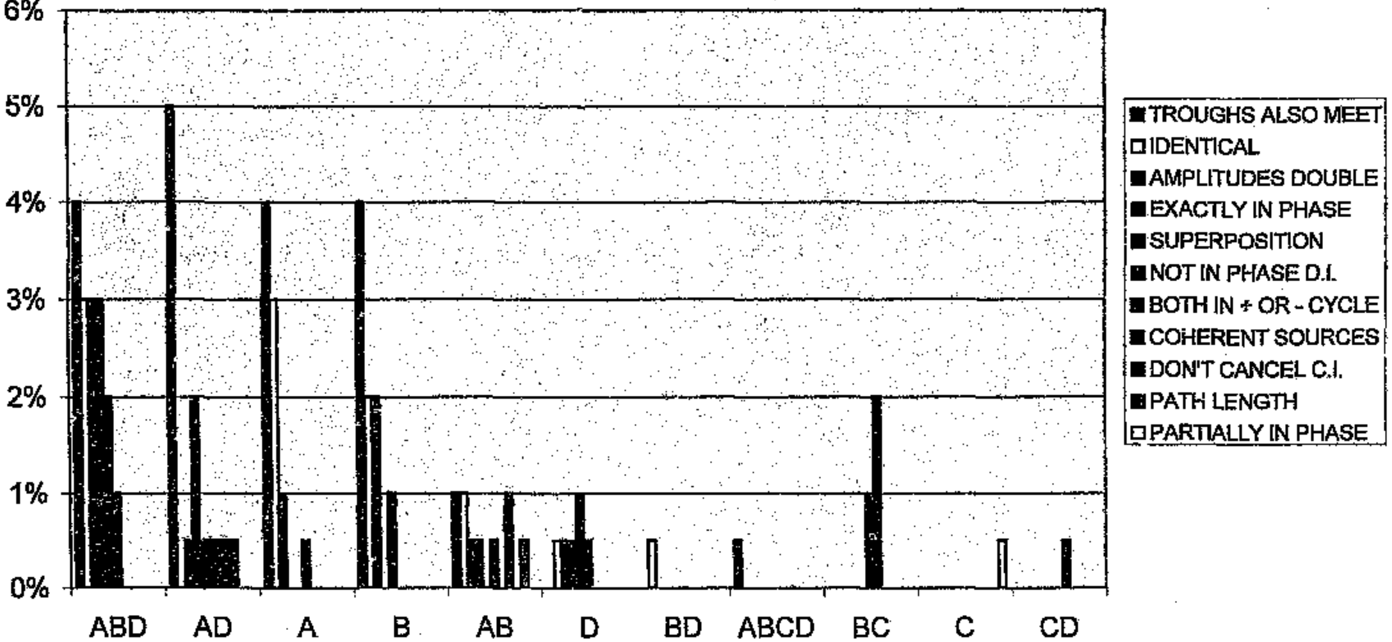


FIGURE 6.18.d
Percentage of students who used the indicated motivation for each combination of options



6.2.19 Analysis of Question 19

See Appendix B for Question 19.

Figure 6.19.a (p. 91A) indicates the distribution of option combinations chosen by students. They follow in descending order, with the percentage of students who chose the various combinations of options in brackets: A(40%), C(35%), D(14%), AC(4%), B(3%), '-'(2%), AB(1%), ABC(1%), AD(1%), BC(1%), CD(1%).

Figure 6.19.b (p. 91A) indicates the distribution of individual option choices. The percentage of students who chose that option is shown in brackets. A(46%) is the obviously correct choice, indicated in green. B(5%), C(40%), D(15%) and '-'(2%) are the obviously incorrect choices, indicated in red.

Option A is correct. According to the principle of linear superposition their displacements cancel out when they meet, reappear after they have passed the crossing point and continue their motion as nothing had happened.

Options B, C and D are incorrect, because they indicate a change in energy, which is not in accordance with the law of conservation of energy.

Figure 6.19.c (p. 91A) indicates the distribution of the motivation categories used to motivate the question. Table 6.19 (p. 91) indicates the motivation categories of Question 19, and how these categories relate to different textbook presentations. Each textbook presentation refers back to the paragraph in this report where it is discussed. The percentage of students who used each category to motivate an answer appears in brackets after the motivation category.

Figure 6.19.d (p. 91B) indicates the distribution of categories of motivations for each combination of options.

CATEGORIES OF MOTIVATIONS	SUMMARY OF MOTIVATIONS GIVEN BY STUDENTS	CORRESPONDING TEXTBOOK PRESENTATIONS
CANCEL : OUT OF PHASE (39%)	The two pulses meet out of phase and cancel each other out.	3.3.3.2.i & vi When two waves meet out of phase, destructive interference results, which is the complete cancellation of waves.
CANCEL MOMENTARILY (37%)	The pulses momentarily cancel	
CONFORM TO ORIGINAL (37%)	The pulses conform to their original shapes and directions.	3.3.2.2.b If two pulses move along a rope from opposite ends, the waves will meet, pass through each other, and continue as before.
SUPERPOSITION (5%)	According to the principle of linear superposition.	3.3.2.2.b When two waves are present simultaneously at the same place, the resultant displacement is the sum of the instantaneous displacements.
ENERGY LOST (5%)	The pulses loose some energy. The energy cancels out. The energy is displaced.	
ENERGY CONSERVATION (2%)	According to the principle of conservation of energy.	
ONE WAVE FORMS (2%)	The two pulses form one wave moving in the same direction.	
PHASE CHANGE (2%)	The pulses undergo a phase change.	
ROPE NOT AS TIGHT (1%)	The rope won't be as tight as before.	
CANCEL PARTLY (1%)	The pulses become weaker. They cancel out partly.	
**FREQUENCIES DECREASE	The resulting frequencies decrease.	

TABLE 6.19 : MOTIVATION CATEGORIES FOR QUESTION 19

GRAPHICAL PRESENTATION OF RESULTS OF QUESTION 19

FIGURE 6.19.a
Percentage of students who chose a certain combination of options

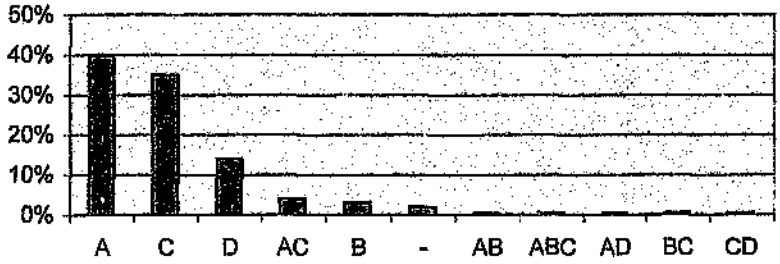


FIGURE 6.19.b
Percentage of students who chose each option

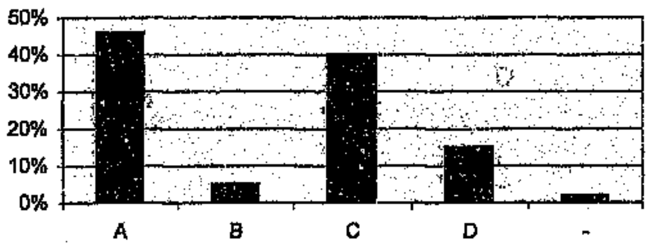


FIGURE 6.19.c
Percentage of students who used the indicated motivations to motivate the question

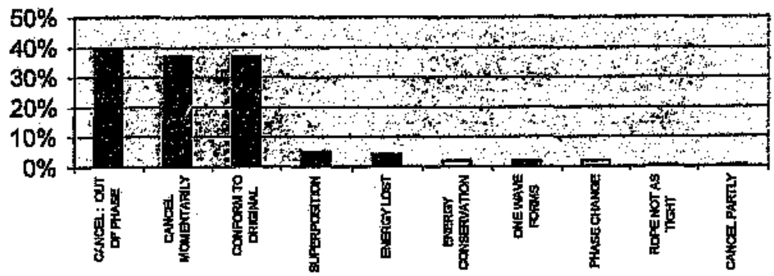
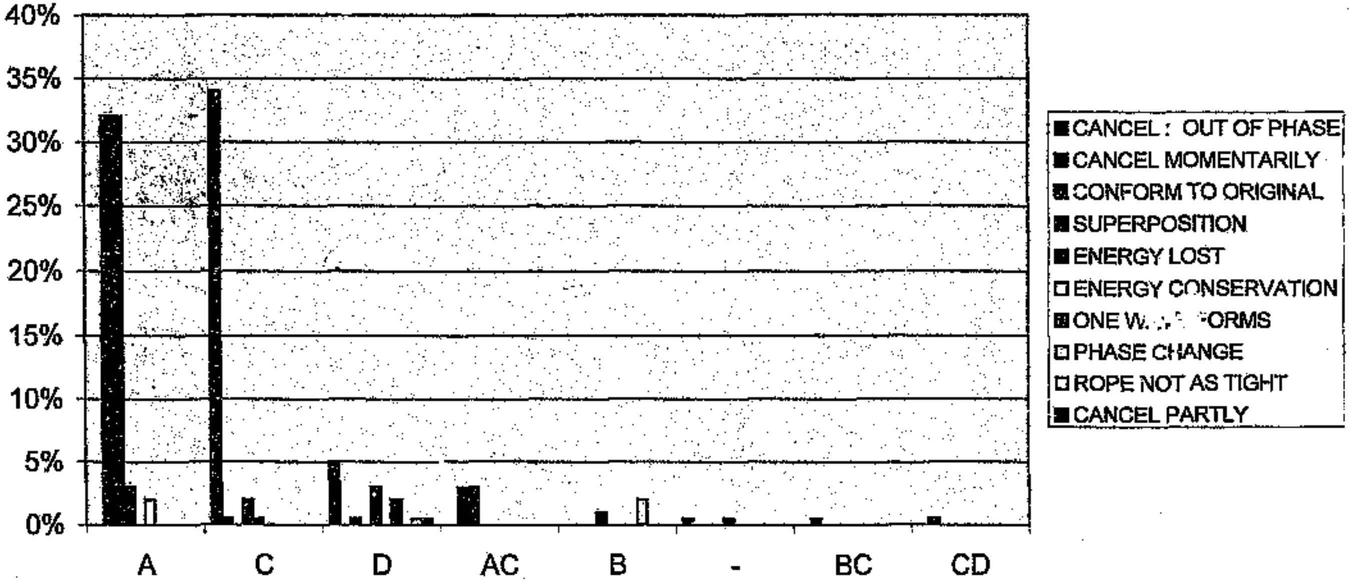


FIGURE 6.19.d
Percentage of students who used the indicated motivation for each combination of options



6.3 Validity and Reliability and Limitations

The study has limitations that jeopardise the validity and reliability of the study. These limitations are summarised as follows:

The study is limited to students of Technikon Pretoria. The prescribed textbook for all students in this research is Cutnell & Johnson: **Physics.** It is obvious that most of the students used their prescribed textbook to complete the open book test.

The researcher has done every thing possible to diminish the effects of these limitations, and to improve the validity and reliability of the study in other ways. The following aspects improve the validity and reliability:

- Prior to the pilot study, feedback from five *lecturers*, including one schoolteacher, were used to validate the pilot. They had to comment on clarity of wording, purity and accuracy of content, usefulness of questions, overlapping of questions and length.

- The edited *pilot test* was conducted to test the validity and reliability of the research instrument, in particular:

  (i) Do the questions ask what the researcher wants to establish?
  (ii) Are the questions consistent in what they ask?

  The edited pilot test was administered to 27 Physics students from two different groups (see 5.1.2). Problems on interpretation of questions were sorted out to improve the validity and reliability of the test of the main study.

- The *final test* for the main study was administered to 191 Physics students from three different groups of students. Two of the three groups were students from other lecturers, which contributes making the results less biased due to the influence of the researcher. All three groups wrote the test under supervision of the researcher to *maintain similar test conditions.*

- The *motivations*, which are open-ended questions, contribute to the validity and reliability of each question, because misinterpretations can be picked up and remarks give more information on alternative conceptions.

- The *size of the sample group* is large for a qualitative analysis and students come from a variety of different backgrounds. These factors contribute to the validity and reliability of the project and its results.

- The grouping of the19 questions into five *areas*, where the questions of an area test the same concept, improves the validity.

- Students were encouraged to use *other textbooks* then their prescribed textbook for the open book test. The library has plenty of other sources.

7 DISCUSSION

From the analysis of each question in the previous section, each area is now discussed.

7.1 AREA 1: Constructive Interference

This area involves the following questions: 1, 4, 5, 12, 13, 16, 18

The average student agrees that waves which are (exactly) in phase or waves which meet crest-to-crest and trough-to-trough (because they are (exactly) in phase) interfere constructively. Bright fringes on a screen represent constructive interference.

From the motivations given by students for each of the above-mentioned questions, a [illegible] of different alternative conceptions for *constructive interferer* [illegible] ated in Table 7.1 (p. 95). Motivations related to textbook pre [illegible] are indicated as well.

STUDENTS' ALTERNATIVE CONCEPTIONS FOR CONSTRUCTIVE INTERFERENCE	CORRESPONDING TEXTBOOK PRESENTATIONS
When waves meet **in phase** or exactly in phase or crest-to-crest or trough-to-trough or partially in phase or 90% in phase or slightly out of phase or exactly one wavelength out of phase, or both in the positive or both in the negative cycle, constructive interference occurs.	3.3.3.1.i,viii
When the waves have **identical** properties (e.g. wavelength, amplitude and speed), constructive interference occurs. When the wave properties differ, constructive interference does not occur.	3.3.3.1.v
When the resultant wave is **reinforced** or the amplitude has doubled, constructive interference occurs.	3.3.3.1.iii
Two **troughs represent a dark fringe** and cause constructive interference or destructive interference, because a dark fringe has no energy. COMMENT: This is applicable with the ripple tank experiment with water waves! Only one tertiary level textbook mentions this ripple tank experiment (Sears, 1991:894).	3.3.3.1.vii
When waves are partially in phase or not in phase, **partial constructive interference** occurs.	3.3.3.1.ii
A **path length difference** of an integral amount of wavelengths or an equal amount of wavelengths or one wavelength, leads to constructive interference. When their distances from the sources are the same, constructive interference results. COMMENT: This last motivation is totally a wrong interpretation of this condition for constructive interference.	3.3.3.1.vi

TABLE 7.1 STUDENTS' ALTERNATIVE CONCEPTIONS FOR CONSTRUCTIVE INTERFERENCE

The following issues are ignored or inconsistently treated or left unresolved by textbooks and so contribute to alternative conceptions about constructive interference:

- Do waves which are not exactly in phase, but reinforcement still results, experience constructive interference?
- Can waves which are not identical, e.g. waves with different frequencies and amplitudes, experience constructive interference?
- On an interference pattern with alternating dark and bright fringes, there is a gradation of a fringe from bright to dark. Constructive interference is represented by the bright fringes. Does this include only the centre spot of the bright fringe where the fringe is at the brightest?
- How can two troughs represent a dark fringe?
- Is partial constructive interference a valid concept for waves which are partially in phase?

Students DO have alternative conceptions about constructive interference!

The alternative conceptions about constructive interference relate to the presentations in textbooks!

7.2 AREA 2: Destructive Interference

This area involves the following questions: 2, 7, 12, 16, 19

The average student agrees that identical waves which are 180° out of phase or identical waves which meet crest-to-trough (because they are 180° out of phase) interfere destructively, because complete cancellation occurs.

From the motivations given by students for each of the above-mentioned questions, a summary of different alternative conceptions for *destructive interference* is indicated in Table 7.2 (p. 98). Motivations related to textbook presentations are indicated as well.

The following issues are <u>ignored</u> or <u>inconsistently treated</u> or <u>left unresolved</u> by textbooks and so contribute to alternative conceptions about destructive interference:

- Do waves which are not 180° out of phase, but cancellation results, because the amplitudes differ, experience destructive interference?
- Does destructive interference occur when waves partially cancel each other, because a smaller amplitude results?
- Is partial destructive interference a valid concept for waves which are partially out of phase?
- On an interference pattern with alternating dark and bright fringes, there is a gradation of a fringe from bright to dark. Destructive interference is represented by the dark fringes. Does this include only the centre spot of the dark fringe where the fringe is at the darkest?
- How can a dark fringe represents two troughs?

Students DO have alternative conceptions about destructive interference!

The alternative conceptions about destructive interference relate to the presentations in textbooks!

STUDENTS' ALTERNATIVE CONCEPTIONS FOR DESTRUCTIVE INTERFERENCE	**CORRESPONDING TEXTBOOK PRESENTATIONS**
When waves meet **out of phase** or exactly out of phase or 180° out of phase or crest-to-trough or not in phase or not exactly out of phase or more than 90° out of phase, destructive interference occurs.	3.3.3.2.i,ii,iii
When waves **cancel** each other out completely, destructive interference results.	3.3.3.2.vi
The resultant wave has a **smaller amplitude.**	3.3.3.2.iv
Waves can only undergo destructive interference when their **amplitudes are the same.**	3.3.3.2.ii,vi
A **pathlength difference** between the waves of an odd number of wavelengths, leads to destructive interference. The wavelengths differ not with an integer number. COMMENT: This motivation is used very seldom correctly and often in a context where it is not applicable.	3.3.3.2.viii
When waves are not exactly out of phase or not completely in phase, **partial destructive interference** occurs.	3.3.3.2.vii
Two troughs represent a dark fringe, because they cancel each other. The troughs are in between two crests, therefore destructive interference occurs. There is no light energy at the dark spots.	3.3.3.2.ix
In the dark fringes where destructive interference occurs, all the **light energy** is converted to other forms or redistributed to the bright fringes, but other forms of energy exist in the dark fringes.	

TABLE 7.2 STUDENTS' ALTERNATIVE CONCEPTIONS FOR DESTRUCTIVE INTERFERENCE

7.3 AREA 3: Diffraction

This area involves the following questions: 6, 8, 9, 15, 17

The average student agrees that light bends around the edges of an obstacle or a small opening, which results in a diffraction pattern with dark and bright fringes.

From the motivations given by students for each of the above-mentioned questions, a summary of different alternative conceptions for *diffraction* is indicated in Table 7.3 (p. 100). Motivations related to textbook presentations are indicated as well.

The following issues are ignored or inconsistently treated or left unresolved by textbooks and so contribute to alternative conceptions.

- Does light diffract around a wide opening like an open door?
- Is Huygens' principle only applicable when waves reach obstacles or openings?
- Can a diffraction pattern form without interference?
- What role does diffraction play in the formation of the interference pattern of Young's double slit experiment?
- Is interference a diffraction effect or is diffraction an interference effect?
- Does diffraction disobey the rectilinear propagation of light?

Students DO have alternative conceptions about diffraction!

The alternative conceptions about diffraction relate to the presentations in textbooks!

STUDENTS' ALTERNATIVE CONCEPTIONS FOR DIFFRACTION	CORRESPONDING TEXTBOOK PRESENTATIONS
According to **Huygens' principle** all waves diffract. COMMENT: This principle is never explained by students. The researcher is of the opinion that students do not understand this principle.	3.3.3.4.iii
Light does not diffract around an open door, because diffraction occurs around **small openings.**	3.3.3.4.i,ii
Diffraction is an **interference effect.** COMMENT: This statement is never explained by students. The researcher is of the opinion that students do not understand this statement.	3.3.3.5.i
When light passes through a double (or single) slit, a **diffraction pattern** results.	3.3.3.5.iii
When light passes through a single slit, an **interference pattern** of bright and dark fringes results. COMMENT: This is called a diffraction pattern!	3.3.3.5.viii
Light can not bend around an opening or obstacle, because light **propagates in a straight line**.	Guesne, 1993

TABLE 7.3 STUDENTS' ALTERNATIVE CONCEPTIONS FOR DIFFRACTION

7.4 AREA 4: Superposition and Interference

This area involves the following questions: 8, 9, 10, 15, 17

From the motivations given by students for each of the above-mentioned questions, a summary of different alternative conceptions *for superposition and interference* is indicated in Table 7.4 (p. 102). Motivations related to textbook presentations are indicated as well.

The following issues are <u>ignored</u> or <u>inconsistently treated</u> or <u>left unresolved</u> by textbooks and so contribute to alternative conceptions.

- Is destructive interference due to superposition?
- Is interference possible from a single light source?
- Does interference occur at a point where neither constructive nor destructive interference occurs at that point?
- Can wave sources which are out of phase but coherent, present points where the waves arrive in phase, and therefore constructive interference results at these points?
- How do the interpretations of interference patterns produced by water waves in a shallow ripple tank and interference patterns produced by light in Young's double slit experiment differ?

Students DO have alternative conceptions about superposition and interference!

The alternative conceptions about superposition and interference relate to the presentations in textbooks!

STUDENTS' ALTERNATIVE CONCEPTIONS FOR SUPERPOSITION AND INTERFERENCE	CORRESPONDING TEXTBOOK PRESENTATIONS
According to the **superposition principle**, which is the addition of instantaneous displacements, constructive interference occurs. COMMENT: In this research superposition is never associated with destructive interference!	3.3.2.2.b
Constructive and destructive interference result from **coherent sources.**	
Only interference and not diffraction occurs at a double slit, because an interference pattern results.	
Only diffraction and not interference occurs at a single slit, because there is only one light source and a diffraction pattern results.	3.3.2.2.a 3.3.3.5.v
When waves are not in phase, neither constructive nor destructive interference results. Therefore **interference does not take place.**	3.3.3.1.i 3.3.3.2.ii
When waves are coherent and not in phase, a **stable interference pattern** forms, which consists out of bright and dark fringes. Constructive and destructive interference therefore occurs when waves are not in phase.	
Interference occurs when either **constructive or destructive interference** occurs.	
Interference patterns are interpreted as follows: • Interference occurs where waves make contact. • Where crests are drawn, the troughs are recognised as no interference or destructive interference. • Where crests are presented on an interference pattern, constructive interference occurs at any point on the crest. COMMENT: The interpretation of interference patterns are done very poorly.	

TABLE 7.4 STUDENTS' ALTERNATIVE CONCEPTIONS FOR SUPERPOSITION AND INTERFERENCE

7.5 AREA 5: Coherency and Phase Relation

This area involves the following questions: 3, 5, 10, 14

The average student agrees that *coherent* waves maintain a constant phase relation and that the following have the same meaning:

i. waves meeting exactly in phase and waves meeting crest-to-crest and waves meeting trough-to-trough;
ii. waves meeting 180° out of phase, waves meeting exactly out of phase and waves meeting crest-to-trough.

From the motivations given by students for each of the above-mentioned questions, a summary of different alternative conceptions for coherency and phase relations is indicated in Table 7.5 (p. 104). Motivations related to textbook presentations are indicated as well.

STUDENTS' ALTERNATIVE CONCEPTIONS FOR COHERENCY AND PHASE RELATION	CORRESPONDING TEXTBOOK PRESENTATIONS
Coherent sources cause constructive and destructive **interference** to occur at a point.	
Waves which are not coherent are not in phase; they are out of phase; their phases differ; they are not exactly out of phase. Partial or complete cancellation of waves result. Therefore they undergo destructive interference.	3.3.3.2.i,v 3.3.3.3.v,vi
Coherent waves have the same properties (e.g. frequency, wavelength, speed, phase).	3.3.3.3.ii
When waves are not coherent, one wave is a positive and the other a negative.	3.3.3.3.iii
When two crests (or two troughs) meet always at a point, a constant phase relation exists.	3.3.3.3.i,iii
When the phases differ, the waves are not coherent.	
Waves are in phase when they are the same distance from the undisturbed position.	
Waves are in phase when they are both at the positive (or negative) side.	3.3.3.1.viii
Waves are in phase when they meet at the same point at the same time.	3.3.3.3.vi

TABLE 7.5 STUDENTS' ALTERNATIVE CONCEPTIONS FOR COHERENCY AND PHASE RELATION

The following issues are ignored or inconsistently treated or left unresolved by textbooks and so contribute to alternative conceptions.

- Are coherent sources always in phase?
- Are sources which are in phase always coherent?
- Does a constant phase relation imply that waves have to have the same phase?
- Is a constant phase relation a prerequisite for a constant interference pattern to occur at a point and not for interference to take place?
- Does *in phase* mean *exactly in phase*?
- Does *out of phase* mean *180° out of phase*?
- Are waves in phase when they meet both in the same cycle (positive or ne[illegible]?
- Are waves with different amplitudes in phase when they meet at the same point at the same time?

Students DO have alternative conceptions about coherency and phase relations!

The alternative conceptions about coherency and phase relations relate to the presentations in textbooks!

8 CONCLUSIONS AND RECOMMENDATIONS

The following issues are summarised to be the main issues to be ignored or inconsistently treated or left unresolved by textbooks and so contribute to alternative conceptions.

- The meaning of ***in phase*** and ***out of phase***

Constructive and destructive interference and related aspects like coherency are explained and defined in terms of the phases. The different terms (e.g. exactly in or out of phase, partially in or out of phase, 180° out of phase, more than or less than 90° out of phase, not in phase) used by students and textbooks show the need for clarifying these terms.

- Definition of interference

Interference is the result of superimposing two or more waves on the same medium. Students can not understand how interference can result from a single source, where light comes through a narrow slit.

- Definition of diffraction

Diffraction is the bending of light around obstacles or small openings. This leads to the conception that light does not diffract through a wide opening like an open door. Therefore Huygens' principle is not understood as a continuous action that occurs at all wave fronts.

- The interdependence of interference and diffraction

This issue is under- emphasised.

- Ripple tank interference patterns

The difference in the interpretation of the dark fringes produced by water waves in a shallow ripple tank and the dark fringes produced by Young's double slit experiment should be addressed. During secondary education where children meet interference patterns for the first time, the illustration of the ripple tank is used. There the dark fringes represent the troughs which is constructive interference. Students in the tertiary phase should be warned that interference patterns for light differ.

The conclusion of this research is that:

i. **Students DO have alternative conceptions about interference and diffraction of light!**

ii. **The alternative conceptions about interference and diffraction of light relate to the presentations in textbooks!**

The researcher is of the opinion that the concepts of interference and diffraction are more complex and deserve more care and attention in order to understand phenomena like the diffraction grating better.

The researcher hopes that the findings of this research are brought to the urgent attention of teachers, lecturers and authors to tighten up their terminology and explanations and also to alert them again to the presence of alternative conceptions in all aspects of science education.

It is the hope of the researcher that this study will be used as an introduction to further research on alternative conceptions on interference and diffraction of light.

This research project has focused mainly on the alternative conceptions linked to inadequacies in textbooks. Evidence was found of other alternative conceptions, as mentioned in Tables 6.1–6.19, but not commented on further.

This research focused on a question by question analysis without checking on interna. consistencies within individual students' responses.

Further research is indeed needed in this field of Physical Optics!

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10 APPENDICES

APPENDIX A : PHYSICAL OPTICS TEST : PILOT STUDY

APPENDIX B : PHYSICAL OPTICS TEST : MAIN STUDY

APPENDIX C : QUANTITATIVE RESULTS : MAIN STUDY

APPENDIX D : ANALYSED TEST RESPONSES : MAIN STUDY

APPENDIX A

PHYSICAL OPTICS TEST

PILOT STUDY

TEST : PHYSICAL OPTICS

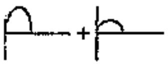
Choose the appropriate statement(s) for each question, and indicate your choice(s) by means of a circle around the characters (A, B, C D and E). **More than one choice is possible in some answers.**

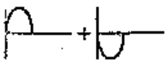
Give a brief **motivation** (reason) in the space provided, for your choice.

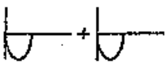
Three marks will be allocated for choices, and two marks for the motivation.

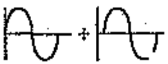
QUESTION 1

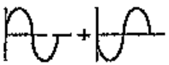
The following pulses or waves have the same wavelengths. Which pairs interfere **constructively**, when they exist at the same place at the same time?

A. 

B. 

C. 

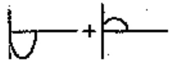
D. 

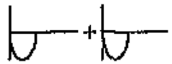
E. 

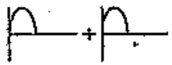
Motivate your answer: ____________________

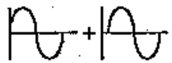
QUESTION 2

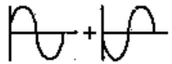
The following pulses or waves have the same wavelengths. Which pairs interfere **destructively**, when they exist at the same place at the same time?

A. 

B. 

C. 

D. 

E. 

Motivate your answer: ____________________

QUESTION 3

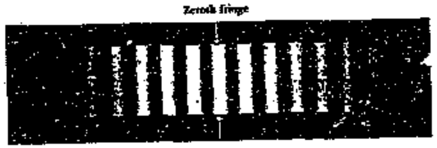
Which one of the following is the best proof for the wave nature of light?

A. reflection
B. interference
C. photoelectric effect
D. refraction
E. spectrum of white light

Motivate your answer: ___

QUESTION 4

Monochromatic light that falls on a double slit produces bright and dark fringes on a screen (see the photograph). Choose the correct statement(s) about the interference pattern formed on the screen.



A. The bright fringes represent constructive interference and the dark fringes represent destructive interference.

B. The bright and dark fringes both represent destructive interference.

C. The bright and dark fringes both represent constructive interference.

D. Light waves don't give an observable interference pattern.

E. Destructive interference is not observable.

Motivate your answer: ___

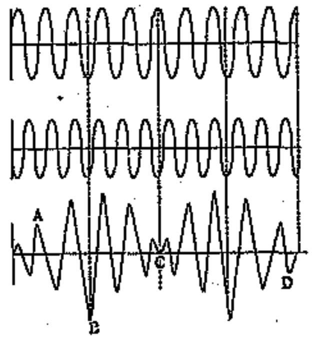
QUESTION 5

The drawing displays graphical representations of the displacement of two waves with different frequencies, against time (diagrams 1 & 2), as well as the displacement that results when the two overlap (diagram 3), according to the principle of linear superposition. Of the indicated points A, B, C and D, constructive interference occurs at the following points:

Diagram1 :

Diagram 2 :

Diagram 3 :



A. Only A

B. A and B

C. A, B and D

D. Only B

E. B and C

Motivate your answer: ___

QUESTION 6

When two waves with amplitudes A and 2A always meet trough-to-trough, they

A. are in phase
B. always interfere constructively
C. always interfere destructively
D. are coherent
E. interfere sometimes constructively and sometimes destructively

Motivate your answer: ______________________________

QUESTION 7

One can hear around an open door, but one can't see around an open door. The reason is given by the following explanation:

A. Sound waves diffract, but light travels in a straight line through an opening.
B. Due to the short wavelength of light compared to the opening, the diffraction is not observable, although it is present..
C. Light waves do not diffract.
D. Sound waves fill the whole space.
E. Under all conditions light waves travel in straight lines.

Motivate your answer: ______________________________

QUESTION 8

In the dark fringes of an interference pattern where destructive interference occurs:

A. all the energy is redistributed to other regions.
B. the same amount of energy is present as in the bright fringes.
C. the law of conservation of energy is not valid.
D. the energy is converted to another form of energy.
E. some of the energy is converted to other forms of energy and some energy is redistributed to other regions.

Motivate your answer: ______________________________

QUESTION 9

When light moves through two slits, the following occur:

A. Only diffraction.
B. Only interference.
C. Both interference and diffraction.
D. Neither interference nor diffraction

Motivate your answer: ______________________________

QUESTION 10

When light moves through a single slit, the following occur:

A. Only diffraction.
B. Only interference.
C. Both interference and diffraction.
D. Neither interference nor diffraction.

Motivate your answer:

QUESTION 11

Waves transfer

A. disturbances
B. oscillating motion.
C. matter.
D. energy.
E. any of these mentioned above, depending on the type of wave.

Motivate your answer:

QUESTION 12

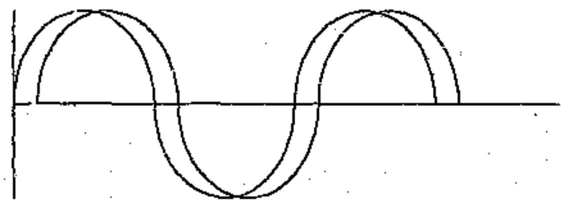
The general condition for light waves to be coherent, is that:

A. the waves are in phase
B. the waves maintain a constant phase relation
C. the amplitudes of the waves are the same
D. the frequencies of the waves are the same
E. the light is monochr

Motivate you

QU 3

Wh. ...s suit the two waves represented in the following displacement-time graph?



A. They are in phase.
B. They are coherent.
C. They are not in phase.
D. They undergo constructive interference.
E. They have different frequencies

Motivate your answer: ______________________________

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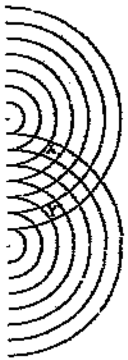
QUESTION 14

Two lousdpeakers are connected to the same signal generator. The crests of the sound waves coming from the loudspeakers are shown in the figure. How does the loudness of the sound at X compare with the loudness at Y?



A. same and steady
B. same but varying
C. greater at X and steady
D. greater at Y and steady
E. no sound at all at X or Y
F. nearly no sound

Motivate your answer: ______________________________

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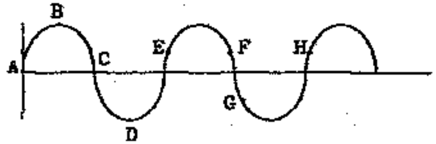
QUESTION 15

The figure shows a profile of a transverse wave. Which two points are in phase?



A. A and C
B. B and D
C. E and F
D. E and H
E. G and H

Motivate your answer: ______________________________

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QUESTION 16

Which of the following sources are NOT in phase?

A. Two identical laser sources.
B. Two agitators driven by the same vibrating mechanism in a ripple tank.
C. Two loudspeakers driven by the same amplifier.
D. Two small appertures in an opaque screen, illuminated by one monochromatic light source.
E. Two identical incandescent light bulbs.

Motivate your answer:

QUESTION 17

Two light beams which are not coherent cannot

A. interfere
B. produce a stable interference pattern
C. be refracted
D. be diffracted
E. have the same speed

Motivate your answer:

QUESTION 18

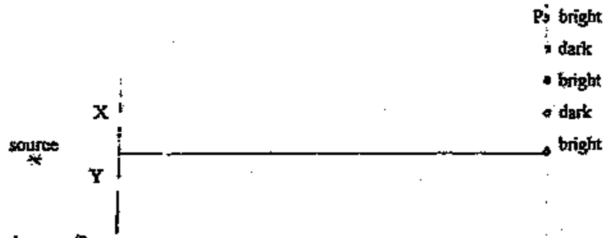
If a razor blade is illuminated with a parallel beam of light and the image of the blade projected on to a white screen, then the image is not sharp but slightly blurred. This is maily due to

A. interference of the light
B. dust particles in the air
C. diffraction of light by the edges of the blade
D. the fact that the screen is not perfectly smooth
E. vibrations in the earth's crust causing the blade to vibrate

Motivate your answer:

QUESTION 19

In a Young's interference experiment, an interference pattern of light and dark fringes is formed on a screen, as shown in the figure, by light of wavelength y coming from two narrow slits X and Y. What is the difference between the path lengths PX and PY?

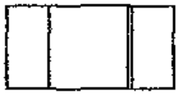


A. y/2
B. y
C. 3y/2
D. 2y
E. 5y/2

Motivate your answer:

QUESTION 20

A blackened photographic plate has straight cuts made through its emulsion. P is a single slit and Q is a pair of slits 0,25 mm apart. The plate is held close to the eye with the slits vertical and is used to view a narrow vertical source of white light several meters away in a dark room, looking in turn through P and Q. Which of the following statements about the patterns seen through P and Q is false?



P Q

A. Each pattern shows alternate light and dark lines.
B. P is due to the diffraction of light.
C. Q is due to the interference of light.
D. Each has a central bright band which is brighter than the other bright bands.
E. Interference and diffraction play a role at both P and Q.

Motivate your answer: ______________________________

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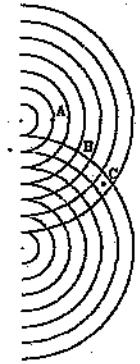
QUESTION 21

Monochromatic light that falls in on a double slit produces bright and dark fringes on a screen (see diagram). Choose the correct statement(s) about the indicated points on the diagram.



A. Only B represents constructive interference
B. A and B represent constructive interfernece
C. A, B and C represent constructive interference
D. C represents destructive interference
E. B and C represent constructive interference

Motivate your answer: ______________________________

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TOTAL : 105

APPENDIX B

PHYSICAL OPTICS TEST

MAIN STUDY

TEST : PHYSICAL OPTICS

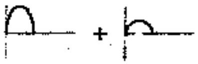
Choose the appropriate statement(s) for each question, and indicate your choice(s) by means of a circle around the characters (A, B, C, D). **More than one choice is possible in some answers.**

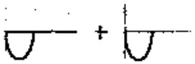
Give a brief motivation (reason) in the space provided, for your choice.

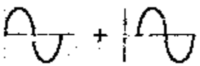
Five marks will be allocated to each question: three marks for choice(s), and two marks for the motivation.

QUESTION 1

The following pulses or waves have the same wavelengths. Which pair(s) interfere constructively, when they exist at the same place at the same time?

A. 

B. 

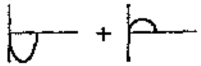
C. 

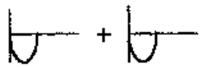
D. 

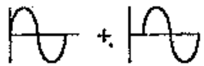
Motivate your answer: ______________________________

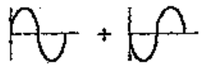
QUESTION 2

The following pulses or waves have the same wavelengths. Which pairs interfere destructively, when they exist at the same place at the same time?

A. 

B. 

C. 

D. 

Motivate your answer: ______________________________

QUESTION 3

Two light beams which are not coherent cannot:

A. interfere.
B. produce a stable interference pattern.
C. be diffracted.
D. have the same speed.

Motivate your answer: ______________________________

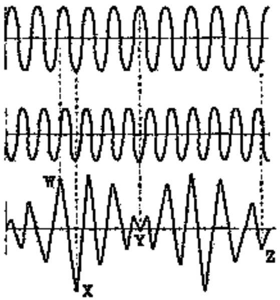
QUESTION 4

The drawing displays graphical representations of the displacement of two waves with different frequencies, against time (diagrams 1 & 2), as well as the displacement that results when the two overlap (diagram 3), according to the principle of linear superposition. Concern the points indicated as W, X, Y and Z. Constructive interference occurs at the following points:

Diagram 1 :

Diagram 2 :

Diagram 3 :



A. Only W
B. W and X
C. W, X and Z
D. Only X

Motivate your answer: ______________________________

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QUESTION 5

When two waves with amplitudes A and 2A always meet trough-to-trough, they:

A. are in phase.
B. always interfere constructively.
C. are coherent.
D. interfere sometimes constructively and sometimes destructively.

Motivate your answer: ______________________________

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QUESTION 6

One can hear around an open door, but one can't see around an open door. The reason is given by the following explanation:

A. Sound waves diffract, but light travels in a straight line through an opening.
B. Due to the short wavelength of light compared to the opening, the diffraction is not observable although it is present.
C. Sound waves fill the whole space.
D. Under all conditions light waves travel in straight lines.

Motivate your answer: ______________________________

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QUESTION 7

In the dark fringes of an interference pattern of light waves, where destructive interference occurs:

A. all the energy is redistributed to other regions.
B. the same amount of energy is present as in the bright fringes.
C. the energy is converted to another form of energy.
D. some of the energy is converted to other forms of energy and some energy is redistributed to other regions.

Motivate your answer: ______________________________

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QUESTION 8

When light moves through two slits, the following occur:

A. Only d[illegible]action.
B. Only interference.
C. Both interference and diffraction.
D. Neither interference nor diffraction.

Motivate your answer: ______________________________

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QUESTION 9

When light moves through a single slit, the following occur:

A. Only diffraction.
B. Only interference.
C. Both interference and diffraction.
D. Neither interference nor diffraction.

Motivate your answer: ______________________________

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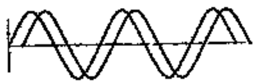
QUESTION 10

What prop[illegible]rti[illegible] suit the two waves represented in the fo[illegible]ng displacement-time graph?



A. They are in phase.
B. They are coherent.
C. They are not in phase.
D. They undergo constructive interference.

Motivate your answer: ______________________________

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QUESTION 11

Waves transfer:

A. disturbances.

B. matter.

C. energy.

D. any of these mentioned above, depending on the type of wave.

Motivate your answer: ______________________________

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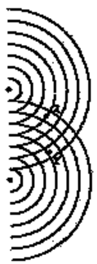
QUESTION 12

Two lousdpeakers are connected to the same signal generator. The crests of the sound waves coming from the loudspeakers are shown in the figure. How does the loudness of the sound at X compare with the loudness at Y?



A. Same loudness.

B. Varying loudness.

C. No sound at all at X or Y.

D. A soft sound at X and Y.

Motivate your answer: ______________________________

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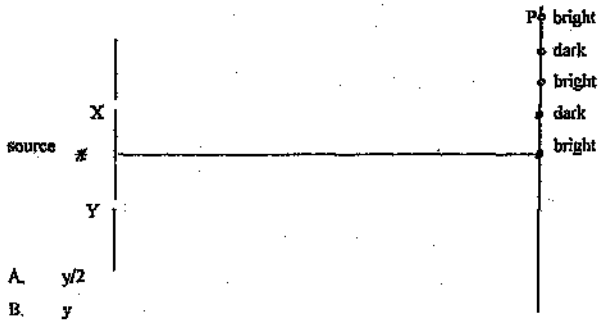
QUESTION 13

In a Young's interference experiment, an interference pattern of light and dark fringes is formed on a screen, as shown in the figure, by light of wavelength y coming from two narrow slits X and Y. What is the difference between the path lengths PX and PY?



A. y/2

B. y

C. 3y/2

D. 2y

Motivate your answer: ______________________________

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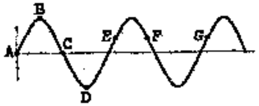
QUESTION 14

The figure shows a profile of a transverse wave. Which two points are in phase with each other?



A. A and C

B. B and D

C. E and F

D. E and G

Motivate your answer: ______________________

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QUESTION 15

If a razor blade is illuminated with a parallel beam of light and the image of the blade projected on to a white screen, then the image is not sharp but slightly blurred. This is mainly due to:

A. interference of the light.

B. dust particles in the air.

C. diffraction of light by the edges of the blade.

D. the fact that the screen is not perfectly smooth.

Motivate your answer: ______________________

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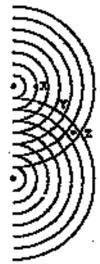
QUESTION 16

Monochromatic light passes through two slits. The diagram shows the crests of the waves at a certain time. Choose the correct statement(s) about the indicated points on the diagram.



A. *Only Y represents constructive interference.*

B. X and Y represent constructive interfernece.

C. Z represents destructive interference.

D. Y and Z represent constructive interference

Motivate your answer: ______________________

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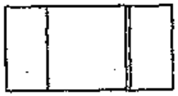
QUESTION 17

A blackened photographic plate has straight cuts made through its emulsion. P is a single slit and Q is a pair of slits 0,25 mm apart. The plate is held close to the eye with the slits vertical and is used to view a narrow vertical source of white light several meters away in a dark room, looking in turn through P and Q. Which of the following statements about the patterns seen through P and Q is true?



P Q

A. Each pattern shows alternate light and dark lines.
B. P is a diffraction pattern.
C. Q is an interference pattern.
D. Interference and diffraction play a role at both P and Q.

Motivate your answer: ____________________

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QUESTION 18

Which of the following are criteria for constructive interference of two waves?

A. The waves are in phase.
B. The waves reinforce each other.
C. The phase difference between the two waves is less than 90°.
D. The waves meet crest-to-crest.

Motivate your answer: ____________________

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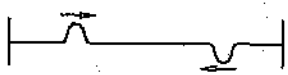
QUESTION 19

Two single pulses move in opposite directions along a rope, as indicated in the diagram.



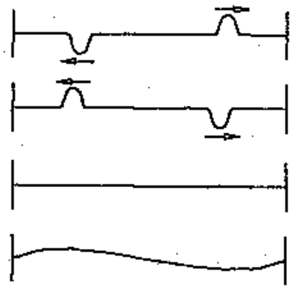
After they have passed one another, the following pattern will be observable:

A.

B.

C.

D.



Motivate your answer: ____________________

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TOTAL : 95

APPENDIX C

QUANTITATIVE RESULTS

MAIN STUDY

MARKS ALLOCATED TO STUDENTS FOR THE PHYSICAL OPTICS TEST

Student	Mark as %	Student	Mark as %	Student	Mark as %	Student	Mark as %
1	46	49	29	97	47	145	74
2	49	50	49	98	49	146	74
3	51	51	61	99	54	147	70
4	46	52	59	100	35	148	86
5	41	53	42	101	72	149	66
6	47	54	58	102	58	150	68
7	46	55	66	103	70	151	86
8	11	56	59	104	70	152	70
9	55	57	55	105	86	153	67
10	67	58	64	106	59	154	62
11	54	59	57	107	74	155	68
12	76	60	70	108	57	156	67
13	57	61	55	109	89	157	72
14	54	62	55	11[illegible]	67	158	70
15	61	63	42	111	50	159	6[illegible]
16	51	64	51	112	84	160	[illegible]
17	41	65	66	113	67	161	53
18	47	66	67	114	63	162	78
19	42	67	50	115	82	163	63
20	61	68	59	116	63	164	72
21	57	69	50	117	78	165	68
22	64	70	41	118	80	166	50
23	68	71	50	119	71	167	53
24	61	72	66	120	74	168	70
25	54	73	55	121	58	169	61
26	57	74	54	122	79	170	74
27	70	75	70	123	80	171	51
28	50	76	66	124	83	172	66
29	45	77	42	125	79	173	66
30	53	78	53	126	68	174	63
31	54	79	41	127	71	175	62
32	76	80	45	128	89	176	75
33	64	81	67	129	68	177	67
34	49	82	55	130	84	178	76
35	62	83	26	131	61	179	64
36	53	84	53	132	84	180	57
37	55	85	42	133	74	181	68
38	47	86	58	134	86	182	71
39	55	87	42	135	72	183	67
40	42	88	54	136	78	184	72
41	66	89	55	137	78	185	45
42	59	90	49	138	59	186	45
43	45	91	57	139	74	187	62
44	57	92	51	140	89	188	41
45	62	93	54	141	63	189	76
46	57	94	63	142	61	190	46
47	42	95	47	143	64	191	39
48	46	96	57	144	71		

Average: 60,4%

APPENDIX D

ANALYSED TEST RESPONSES

MAIN STUDY

ANALYSIS

Question 1

CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
B	29,8%	57	39: They are in phase. (3: They are exactly in phase.)
			16: The resultant wave is reinforced.
			14: Identical waves.
			12: They meet crest-to-crest and trough-to-trough. (1: Condensation meets condensation and rarefaction meets rarefaction; 1: Minima and maxima meet.)
			7: The amplitude doubles.
			6: Identical wavelengths.
			4: Both wavelength and amplitude are identical.
			4: They meet crest-to-crest.
			2: They meet trough-to-trough.
			2: Identical amplitudes.
			1: Bright fringes on the screen.
			COMMENT: Although crests are not applicable here, more references to crests than to troughs.
AB	27,2%	52	37: They are in phase. (9: They are exactly in phase.)
			18: They meet crest-to-crest or trough-to-trough. (3: Condensation meets condensation and rarefaction meets rarefaction; 1: Two negatives or two positives meet.)
			9: The sum of the waves is bigger than either of the original waves. (1: Amplitudes double.) COMMENT: Constructive interference is associated with reinforcement.
			5: Identical wavelengths.
			5: Superposition principle.
			5: They meet crest-to-crest. (1: Two maxima meet; 1: Two positives meet.)
			2: Amplitudes don't have to be the same.
			1: Identical amplitudes.
			1: The waves are exactly one wavelength out of phase.
			1: C and D have a 180° or a few degrees phase shift, therefore destructive interference.
			1: C is out of phase.
C	16,2%	31	15: They are in phase. (1: They are exactly in phase.)
			9: They meet crest-to-crest and trough-to-trough. (3: Condensations and rarefactions.)
			9: Resultant wave is reinforced.
			5: Amplitude doubles.
			3: Identical wavelengths.
			2: Identical waves.
			1: Identical wavelengths and amplitudes.
			1: They are not going to cancel.
			1: Light waves passing through this wavelength does not give a complete electric field (*).
ABC	11,5%	22	16: They are in phase. (2: Exactly in phase.)
			8: They meet crest-to-crest and trough-to-trough. (1: Condensation meets condensation and rarefaction meets rarefaction; 1: Two positives and two negatives meet.)
			4: The sum of the waves results in a bigger wave than either of the original waves. (1: Amplitude doubles.)
			1: Identical waves.
			1: C and D are out of phase.
			2: C is half a wavelength out of phase.
			1: C will undergo constructive interference at a later instant.
			1: C undergoes constructive interference in both directions, A only positive and B only negative.
BC	6,3%	12	6: They are in phase. (1: C is exactly in phase.)
			6: Reinforcement of resultant wave. (2: The amplitude doubles.)
			6: Identical waves. (2: Identical amplitudes; 2: Identical wavelengths.)
			4: They meet crest-to-crest and trough-to-trough. (1: Two condensations and two rarefactions meet.)
			1: They are out of phase.
BD	3,1%	6	4: They are in phase. (1: They are exactly in phase.)
			3: They meet crest-to-crest and trough-to-trough. (1: Two condensations and two rarefactions meet; 1: Two positives and two negatives meet.)
			2: Identical waves. (1: Identical amplitudes.)
			1: Reinforcement : The wavelength doubles.
D	3,1%	6	3: They are in phase. (1: Exactly in phase.) COMMENT: They are not in phase!
			2: Reinforcement. (1: Double amplitude; 1: Brighter colour.)
			1: Identical wavelength.
			1: D is destructive and A, B and C are constructive.
			1: COMMENT : Motivation of no sense.
A	2,1%	4	3: Two crests in phase. COMMENT: Constructive interference is associated with in phase crests only (not troughs).
			1: The amplitude is twice that of either wave (*).
ABCD	0,5%	1	1: They meet crest-to-crest and trough -to-trough.
			1: They reinforce each other.

ANALYSIS
Question 2

CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
D	42,9%	82	50: The waves are out of phase. (5: Exactly out of phase; 2: 180° out of phase; 1: They differ by half a wavelength.)
			41: The waves cancel each other.
			24: The waves meet crest-to-trough. (4: They meet condensation-to-rarefaction.)
			18: The waves are identical. (3: Same wavelength; 2: Same amplitude; 1: Same frequency.)
			2: They don't reinforce each other.
			2: They begin with the same phase and end out of phase(*).
			2: The pathlengths difference between the waves differs by an odd number of wavelengths.
			1: The waves arrive at a point in phase(*).
AD	38,7%	74	38: The waves are out of phase. (12: Exactly out of phase; 5: 180° out of phase; 5: Half a wavelength out of phase.)
			34: The waves meet crest-to-trough. (5: The waves are in opposite directions; 5: They meet condensation-to-rarefaction; 5: A positive and a negative wave meet.)
			24: The waves cancel each other.
			5: The resultant wave has a smaller amplitude.
			3: Only partial destructive interference occurs at A and complete destructive interference at D.
			2: The amplitudes don't have to be the same.
			1: Sometimes constructive and sometimes destructive interference will occur(*).
			1: The waves are exactly in phase(*).
C	5,8%	11	7: The waves are out of phase. (1: Exactly out of phase.)
			3: The waves cancel each other.
			3: The amplitudes are identical.
			1: The waves meet crest-to-trough.
			1: They are exactly in phase(*).
ACD	3,7%	7	5: The waves are out of phase. (1: Exactly out of phase; 1: Not in phase)
			1: The resultant wave has a smaller amplitude.
			1: They cancel each other out.
			1: The wavelengths differ not with an integer number.
			1: Wave forms exhibit both constructive and destructive interference(*).
AC	2,6%	5	4: They are out of phase. (1: The wavelengths differ with half a wavelength.)
			1: They cancel each other.
			1: They meet crest-to-trough.
			1: They are not identical waves.
B	2,1%	4	2: They meet crest-to-trough.
			2: The waves are identical.
			1: They are out of phase
			1: Two troughs interfere destructively.
			1: The waves reinforce each other crest-to-trough(*).
A	1,6%	3	3: The waves are out of phase. (1: Exactly out of phase.)
			1: They cancel each other.
			1: They are identical waves.
BD	1,6%	3	2: They cancel each other.
			1: They meet crest-to-trough.
AB	0,5%	1	1: The crest and trough will cancel each other(*).
CD	0,5%	1	1: They start out of phase.

ANALYSIS			
Question 3			
CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
B	49,2%	94	46: They don't maintain a constant phase relation.
			24: Constructive and destructive interference don't continue to occur at a point.
			8: The waves are not in phase.
			5: The one waves is in the positive cycle and the other in the negative.
			4: Wavelengths differ.
			3: No motivation.
			9: Motivations of no use(*).
A	18,8%	36	15: Constructive and destructive interference result from coherent sources.
			10: They do not maintain a constant phase relation.
			4: Constructive and destructive interference don't continue to occur at a point.
			2: The waves are not in phase.
			1: There is always some form of interference when two waves meet(*).
			1: Their wavelengths differ.
			3: No motivation.
			2: Motivations of no use(*).
AB	7,3%	14	8: They do not maintain a constant phase relation.
			3: Constructive and destructive interference don't continue to occur at a point.
			1: They are out of phase.
			1: Their wavelengths differ.
			1: No motivation.
D	6,3%	12	6: Their wave characteristics (wavelength and frequency) differ.
			3: They don't maintain a constant phase relation.
			1: Only in vacuum their speeds will be equal(*).
			1: Don't understand the meaning of coherent(*).
			1: No motivation.
-	5,2%	10	4: Don't understand the meaning of coherent(*).
C	5,2%	10	4: They don't maintain a constant phase relation.
			1: The pattern on the screen will be washed out.
			1: Neither constructive nor destructive interference will occur.
			1: The waves are from different directions.
			1: They produce different patterns of light.
			1: Their phases differ.
			3: Motivations of no use(*).
BD	2,6%	5	4: They don't maintain a constant phase relation.
			1: Constructive and destructive interference don't continue to occur at a point.
ABD	1,6%	3	2: They do not maintain a constant phase relation.
			1: Motivation of no use(*).
BC	1,6%	3	2: They undergo destructive interference, because they are out of phase.
			1: They don't undergo constructive or destructive interference because they are not exactly out of phase.
ABC	0,5%	1	1: No pattern is observed.
AC	0,5%	1	1: The waves can't bend, therefore no interference(*).
AD	0,5%	1	1: Constructive and destructive interference result from coherent sources.
CD	0,5%	1	1: Their frequencies differ.

ANALYSIS

Question 4

CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
B	71,7%	137	79: The waves reinforce each other. (25: Amplitude doubles; 1: For X the amplitude doubles and for W the amplitude increases.)
			46: They are in phase. (5: They are exactly in phase; 1: X is exactly in phase and W is partially in phase.)
			35: Crest meets crest and trough meets trough. (1: Two condensations and two rarefactions meet.)
			4: Identical waves.
			3: No motivation.
			3: Y and Z are destructive. (1: Due to positive and negative crests; 1: Because resultant wave is less than individual waves.)
			2: Y and Z are out of phase.
			1: The sources are coherent(*).
			1: Constructive and destructive interference occur when two waves with the same frequency overlap(*).
			1: The frequency is the same(*).
D	15,2%	29	15: They are in phase. (1: They are exactly in phase; 1: W and Z are out of phase and Y undergoes destructive interference; 1: The rest are out of phase.)
			9: The waves meet trough-to-trough. (2: They meet rarefaction-to-rarefaction.)
			8: The resultant amplitude is reinforced. (7: The amplitude doubles.)
			2: The waves are identical.
A	6,3%	12	7: The waves meet crest-to-crest. (4: The positive side or maximum.)
			7: They reinforce each other. (3: The amplitude doubles.)
			4: They are in phase.
			2: Identical waves. (1: Identical frequencies.)
C	4,7%	9	4: The sum of the two waves gives a resultant wave.
			3: They are in phase. (1: X is exactly in phase, W 90% in phase and Z very little.)
			2: Reinforcement. COMMENT: Z is not reinforced!
-	1,0%	2	1: No motivation
			1: WXY correct, W partial constructive interference, X constructive interference, Y two waves cancel each other.
BC	1,0%	2	1: No motivation.
			1: They meet crest-to-crest and trough-to-trough, except Z.

ANALYSIS

Question 5

CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
ABC	22,5%	43	25: When two waves meet trough-to-trough they are exactly in phase. Therefore the sources are coherent and constructive interference occurs. COMMENT: This is a summary of the choice.
			9: Frequencies or wavelengths are the same. (5: Same frequencies; 4: Same wavelengths.)
			8: The two waves maintain a constant phase relation.
			7: Constructive interference has nothing to do with the amplitudes of the waves, as long as they are in phase. (1: As long as the amplitudes have the same sign.)
			6: Reinforcement: the resultant wave is the sum of the individual waves. (3: Resultant amplitude is 3A; 1: Resultant amplitude is 2A.)
			6: Their crests will also meet. (1: The maxima meet.)
			2: An integer number of wavelengths leads to constructive interference.
			1: Out of phase waves can also be coherent if they are exactly out of phase(*).
A	19,4%	37	22: They are in phase because they meet trough-to-trough. COMMENT: This is a summary of the choice.
			6: The waves interfere constructively. COMMENT: Constructive interference was another option to choose!
			6: They reinforce each other. (4: Amplitude doubles.)
			6: They will also meet crest-to-crest. (1: They will meet condensation-to-condensation and rarefaction-to-rarefaction.)
			5: Although their amplitudes differ they are still in phase. (1: The frequency will not change.)
			3: Their wavelengths are the same.
			1: No motivation.
			1: Coherency is for constructive and destructive interference, because amplitudes differ no constructive or destructive interference occurs(*).
			1: Even though the amplitudes change from minimum to maximum the waves are in phase(*).
			1: The difference in amplitude is an integer number(*).
			1: The distance differs by an integer number(*).
			1: They differ by one wavelength(*).
B	17,3%	33	12: They reinforce each other. (6: Amplitude doubles.)
			10: Constructive interference occurs when waves meet trough-to-trough. (1: Two troughs interfere constructively in a negative direction.)
			6: The waves are in phase.
			4: A difference in an integer number of wavelengths leads to c. interference.
			3: They also meet crest-to-crest.
			1: The waves have the same speed.
			1: The waves have the same wavelength.
			1: Because their amplitudes differ, they don't have a constant phase and interfere constructively or destructively(*).
			1: Their frequencies differ(*).
AB	16,2%	31	18: Because the waves meet trough-to-trough they are in phase and interfere constructively. COMMENT: This is a summary of the choice.
			8: They reinforce each other. (4: Amplitude is 3A; 1: Amplitude is 2A.)
			4: They also meet crest-to-crest. (1: They meet condensation-to-condensation.)
			3: No motivation.
			2: Constructive interference has nothing to do with the size of the amplitude.
			1: Their sources are also coherent. COMMENT: Coherency was an option!
			1: Their wavelengths are the same.
			1: Coherent sources can be out of phase but their amplitudes must be the same(*).
			1: The amplitudes of the waves do not have a canceling effect, therefore constructive interference(*).
			1: The waves are in phase because they have the same speed(*).
			1: When two identical waves arrive at a point in phase constructive interference occurs.
D	8,9%	17	7: Their amplitudes differ. (1: The speed of A is faster than 2A.)
			1: Wavelengths can differ(*).
			1: It depends on the frequency(*).
			1: Their phase can reinforce or weaken each other(*).
			2: It depends whether they meet in phase or out of phase(*).
			2: No motivation.
			1: Constructive interference only occurs when troughs are in phase, otherwise constructive to some extent or destructive.
			1: Waves can meet trough-to-trough when they are in phase or out of phase(*).
			1: When the amplitude is doubled waves will interfere destructively(*).
			1: Light waves will not be bright, because the distance through which they travel differ by one wavelength(*).
			1: When they meet trough-to-trough they interfere destructively(*).
C	7,3%	14	7: They maintain a constant phase relation.
			2: They interfere constructively. COMMENT: Constructive interference was an option!
			2: No motivation.
			1: Difference in amplitude doesn't affect phase relation.
			1: Each wave maintains its amplitude(*).
			1: Constructive and destructive interference continue occurring at a point(*).
			1: Wavelengths are not the same(*).
AC	3,1%	6	2: They reinforce each other. (1: Amplitude is 3A.)
			2: The two waves have a constant phase relation.
			1: If they always meet trough-to-trough they are in phase and coherent. COMMENT: This is a summary of the choice.
			1: Constructive interference has nothing to do with the amplitudes of the waves, as long as they are in phase.
			1: Their speed is the same.
			1: There is some interference that occurs(*).
BC	1,6%	3	2: They have a constant phase relation.
			1: The frequency remains constant.
			1: If the waves are not coherent they will only interfere constructively at this point.
			1: The waves will be coherent if the amplitude remains constant(*).
-	1,0%	2	No motivation.
BD	1,0%	2	2: It depends on the frequency of the waves. (1: B applies when frequencies are the same, D applies when frequencies differ(*).
CD	1,0%	2	1: For constructive and destructive interference to continue occurring at a point the wave sources must be coherent.
			1: They move through each other and will cross each other at a point, because the one amplitude is A and the other 2A(*).
ACD	0,5%	1	1: They interfere destructively resulting in a wave with amplitude A. COMMENT: Troughs are associated with destructive interference!)(*)

ANALYSIS			
Question 6			
CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
B	51,8%	99	31: The degree of bending is too small to observe.
			29: Diffraction depends on the ratio wavelength to slit width. Light has a shorter wavelength than sound.
			14: All waves, also light, diffract.
			6: Sound waves diffract much more than light waves.
			4: Light waves do not bend around an open door.
			2: Light bends around narrow slits.
			8: No motivation.
			10: Motivations of no use(*).
A	23,6%	45	11: Light waves can't diffract.
			4: In the case of light, the degree of bending is too small to observe.
			3: According to Huygens' principle for sound waves.
			1: Light moves too fast(*).
			1: Sound diffracts more than light.
			1: Light waves do bend.
			15: No motivation.
			9: Motivations of no use(*).
AB	6,3%	12	5: In the case of light, the degree of bending is too small to observe.
			4: Sound bends around an opening.
			2: According to Huygens' principle for sound waves.
			1: All waves bend around openings.
			2: No motivation.
			1: Motivations of no use(*).
C	4,7%	9	1: The degree of bending is too small to observe.
			1: Sound waves vibrate(*).
			1: Sound waves make echoes(*).
			1: Sound waves are not transverse waves(*).
			1: Constructive interference occurs(*).
			1: Sound waves can't be seen(*).
			3: Motivations of no use(*).
AC	3,7%	7	2: Only sound waves bend around the doorway.
			1: Sound waves change in the opening to longitudinal waves(*).
			1: According to Huygens' principle for sound waves.
			1: A light wave won't illuminate the whole area.
			1: Only sound reflects in doorway(*).
			1: Motivations of no use(*).
D	2,6%	5	1: Due to the wave nature of light(*).
			1: Only sound waves diffract.
			1: Otherwise we would be able to see around corners.
			2: Motivations of no use(*).
-	2,1%	4	1: In the case of light, the degree of bending is too small to observe.
			3: No motivation.
BC	1,6%	3	1: The degree of bending is too small to observe.
			1: Motivations of no use(*).
ACD	1,0%	2	2: According to Huygens' principle sound waves diffract.
AD	1,0%	2	1: According to Huygens' principle sound waves diffract.
			1: Waves bend around openings.
ABC	0,5%	1	1: No motivation.
BD	0,5%	1	1: Due to the short wavelength of light, and travels in a straight line(*).
CD	0,5%	1	1: No motivation.

ANALYSIS			
Question 7			
CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
A	28,3%	54	12: No energy (no light) is present at dark fringes, because the waves cancel one another.
			12: The energy is redistributed to regions where constructive interference (bright fringes) occurs.
			6: No motivation.
			5: According to the law of conservation of energy.
			4: Young's experiment has shown the redistribution of energy.
			3: The brightness of the fringes is directly proportional to the light energy.
			1: The energy is lost(*).
			16: Motivations of no use(*).
D	27,2%	52	12: The dark fringes have less energy.
			11: No motivation.
			7: Some of the energy is absorbed.
			6: No energy is present at dark fringes.
			5: Constructive and destructive interference depend on pathlength difference.
			5: Law of conservation of energy.
			4: Energy is converted to bright fringes.
			3: Energy is converted to heat energy.
			3: Some of the energy is used for destructive interference to occur.
			2: Diffraction occurs(*).
			7: Motivations of no use(*).
			3: The waves stay the same after destructive and constructive interference.
			1: A brighter pattern is not associated with more (light) energy(*).
			7: Motivations of no use(*).
C	16,8%	32	10: Law of conservation of energy.
			8: In dark region no energy, therefore to other regions.
			3: Constructive and destructive interference depend on pathlength difference.
			3: No motivation.
			2: Energy is associated with slit width(*).
			2: Energy is converted to heat energy.
			2: Energy is converted to bright fringes.
			1: The dark fringes have less energy than the bright fringes.
			1: Intensity is directly proportional to energy.
-	5,2%	10	8: No motivation.
			2: Motivations of no use(*).
BC	1,0%	2	2: Because no light is present in dark fringes, energy conversion took place.
BD	0,5%	1	1: Motivation of no use(*).

ANALYSIS			
Question 8			
CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
C	68,1%	130	83: An interference pattern with da.. and bright fringes forms on the screen.
			38: When light moves through a slit, it bends around the edges.
			35: Waves from two coherent sources interfere.
			11: After diffraction. The waves interfere constructively and destructively.
			6: Diffraction is an i: terference effect.
			6: Due to the wave n. ture of light.
			3: According 'o Young's double slit experiment.
			2: According to Huygens' principle.
			8: No motivation.
			23: Motivations of no use(*).
B	22,5%	43	26: Constructive and destructive interference occur to produce a pattern of alternating bright an. dark fringes.
			10: Light sources are coherent.
			2: Light waves can't diffract(*).
			2: No motivation.
			6: Motivations of no use(*).
A	6,3%	12	6: Light waves bend around the slits.
			1: The result is a diffraction pattern of bright and dark fringes.
			3: No motivation.
D	1,6%	3	3: Motivations of no use(*).
-	1,0%	2	2: No motivation.
AB	0,5%	1	1: Motivation of no use(*).
			COMMENT: Choice makes no sense.

			ANALYSIS
			Question 9
CHOICE	% of 191 students	NUMBER OF STUDENTS	**MOTIVATION**
A	48,7%	93	42: Diffraction occurs at the slit where the light bends around the edges of the slit.
			26: There is no other light source for interference to occur.
			6: The light spreads out.
			5: A pattern of alternating bright and dark fringes forms on the screen.
			5: A single slit diffraction pattern forms.
			4: No interference pattern of dark and bright fringes forms on a screen.
			1: Only dark fringes occur(*).
			1: Scattered bright and dark fringes form.
			7: No motivation.
			13: Motivations of no use(*).
C	34,0%	65	29: Diffraction occurs at the slit where the light bends around the edges of the slit.
			29: Dark and bright interference patterns form on the screen.
			6: Diffraction is an interference effect.
			4: The light is spread out.
			3: After diffraction the waves interfere constructively and destructively.
			2: A single slit diffraction pattern appears.
			1: Huygens' principle.
			1: Destructive interference is formed at the single slit.
			1: Due to the wave nature of light.
			7: No motivation.
			8: Motivations of no use(*).
B	6,3%	12	5: Constructive and destructive interference take place.
			2: Diffraction can't occur.
			1: Light will pass through the slit without bending and form an image of the slit on the screen.
			1: No diffraction, because the slit doesn't have a round shape.
			1: No motivation.
			4: Motivations of no use(*).
D	7,3%	14	8: A single slit is to ensure that light from one direction only falls on the double slit.
			1: Only one bright fringe is observed.
			1: The light becomes polarized(*).
			1: A pattern of bright and dark fringes forms because of tiny wavelets.
			1: No motivation.
			2: Motivations of no use(*).
-	1,6%	3	2: No motivation.
			1: Motivation of no use(*).
BC	1,0%	2	2: Motivations of no use(*).
			COMMENT: Choice makes no sense.
AC	0,5%	1	1: Motivations of no use(*).
			COMMENT: Choice makes no sense.
AD	0,5%	1	1: Motivations of no use(*).
			COMMENT: Choice makes no sense.

ANALYSIS

Question 10

CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
C	33,0%	63	17: They do not originate at the same point. (5: ... although their wavelengths are the same.)
			13: They do not meet trough-to-trough or crest-to-crest.
			10: They do not start at the same time.
			8: Neither constructive nor destructive interference occurs. (1: On average none of them occur; 1: Not 100% constructive interference; 1: Not always constructive interference.)
			7: They are not coherent.
			4: The waves cancel each other which results in destructive interference.
			3: They are not exactly out of phase.
			1: The waves are 90° out of phase.
			1: The amplitude of the resultant wave doesn't double
			3: No motivation.
B	18,3%	35	17: The waves maintain a constant phase relation.
			4: Constructive or destructive interference will never occur.
			3: Constructive and destructive interference take place.
			1: Coherent means coming after another.
			3: No motivation.
			6: Motivations of no use(*).
BC	15,2%	29	10: The waves maintain a constant phase relation.
			9: They do not meet crest-to-crest or trough-to-trough.
			3: Constructive or destructive interference will never occur.
			3: They are out of phase. (1: Slightly out of phase; 1: Not exactly on phase.)
			2: They do not start at the same point.
			2: They only undergo destructive interference.
			1: Coherent means synchronized.
			1: Constructive interference will eventually occur.
			1: Motivation of no use(*).
A	7,3%	14	8: They do not shift relative to one another.
			3: The waves have the same properties.
			2: The waves reinforce each other.
			1: They do not have a constant phase relation(*).
			1: No motivation.
			2: Motivations of no use(*).
AD	8,0%	15	4: The waves have the same properties.
			4: They meet crest-to-crest and trough-to-trough.
			3: They reinforce each other.
			1: They do not cancel each other.
			1: They interfere approximately at the same time.
			3: No motivation.
AB	4,2%	8	4: The waves maintain a constant phase relation.
			1: The waves have the same properties.
			1: No motivation.
			2: Motivations of no use(*).
D	2,0%	3	2: They meet crest-to-crest and trough-to-trough.
			1: The waves reinforce each other.
			1: They are nearly the same.
			1: They form one wave when they interfere(*).
CD	3,1%	6	2: They undergo constructive interference at some times.
			4: Motivations of no use(*).
ABD	2,6%	5	3: The waves reinforce each other.
			2: The waves have the same properties.
			1: A stable interference pattern forms.
			1: The sources are coherent(*).
BCD	2,1%	4	2: The waves maintain a constant phase relation.
			2: They do not meet crest-to-crest and trough-to-trough.
			1: There is a reinforcement.
			1: Sometimes they undergo constructive and other times destructive interference.
-	1,6%	3	1: No motivation.
			2: Motivations of no use(*).
BD	2,0%	4	2: They cross at the ups and downs.
			1: The waves maintain a constant phase relation.
			1: No motivation.
ABC	1,0%	2	2: Motivations of no use(*).
			COMMENT: Contradictable choice!

ANALYSIS
Question 11

CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
D	40,3%	77	20: Light waves transfer energy.
			16: Water waves transfer matter.
			14: Sound waves transfer disturbances.
			10: It depends on the properties of the waves(*). COMMENT: Part of option!
			6: A wave carries energy.
			5: A wave is a disturbance.
			5: Sound waves transfer energy.
			3: Water waves transfer disturbances.
			2: Electromagnetic waves transfer matter.
			1: Different kinds of energy are transferred.
			1: Waves are a movement of any nature(*).
			1: Sound waves transfer matter.
			1: Electromagnetic waves transfer disturbances.
			1: Water waves transfer energy.
			1: It depends on the medium of the wave(*).
			7: No motivation.
			15: Motivations of no use(*).
AC	25,7%	49	36: A wave is a traveling disturbance that carries energy from place to place.
			6: Light waves and water waves transfer disturbances, electromagnetic waves (light waves) transfer energy.
			2: The energy is carried by the electric and magnetic fields that comprise the wave.
			1: A cork stays at same spot in waves.
			1: When a stone is dropped into a dam, disturbances occur in the form of waves.
			1: No motivation.
			4: Motivations of no use(*).
C	22,5%	43	12: Waves transfer energy from place to place.
			11: The energy of a disturbance is transferred by means of a wave.
			9: Waves transfer energy in different forms e.g. light, sound, potential energy to do work, heat.
			3: Waves transfer energy in forms of matter e.g. objects, charged particles.
			2: The energy is carried by the electric and magnetic fields of the wave.
			3: No motivation.
			6: Motivations of no use(*).
A	7,3%	14	6: Waves are traveling disturbances.
			3: According to the principle of linear superposition(*).
			2: No motivations.
			3: Motivations of no use.
-	4,2%	8	1: Only water waves carry matter.
			1: Different kinds of energy are transferred.
			6: No motivation.

ANALYSIS
Question 12

CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
A	57,1%	109	31: These points are in phase. (10: Same frequency and wavelength.)
			23: Constructive interference occurs at both. (12: Crests interfere)
			30: Their distances from the sources are the same.
			15: No interference: neither constructive nor destructive. (9: No interference; 6: Neither constructive nor destructive.)
			14: Both speakers are connected to the same signal generator.
			8: No motivation.
			5: Destructive interference occurs at both.
			3: Their amplitudes are the same.
			3: Interference occurred. (They interfered equally)
C	14,1%	27	24: They both experience destructive interferenc (8: Trough and crest meet; 4: Total destructive interference; 2: Rarefaction and cond[illegible]ation; 1: Not in phase; 1: Out of phase.)
			2: Motivation of no use(*).
			1: No motivation.
D	10,5%	20	10: They both experience destructive interference. (2: Not complete destructive interference; 2: Out of phase; 1: Not exactly out of phase; 1: Not in phase; 1: Only in theory no sound.)
			3: No interference.
			2: Intensity of sound waves inversely proportional to distance traveled(*).
			2: No motivation.
			1: They meet crest-to-trough and not trough-to-trough.
B	9,4%	18	4: They meet out of phase.
			7: At Y the sound is louder.
			2. Constructive interference occurs.
			COMMENT: No valid motivations!
AD	3,1%	6	5: Both undergo destructive interference.
			1: They don't interfere.
AC	2,6%	5	5: Destructive interference occurs and no sound will be heard.
-	1,6%	3	3: No motivation.
ACD	0,5%	1	COMMENT: Invalid choice!
BC	0,5%	1	1: Sound intensity is redistributed.
BD	0,5%	1	1: Sound intensity is between maximum and minimum.

ANALYSIS

Question 13

CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
D	26,7%	51	20: This is the second order bright fringe with m=2
			15: Pathlength PY > PX. (6: PY = 2PX; 4: PY is 1 wavelength longer than PX; 1: PY is 2 wavelengths longer than PX; 1: PY is half a wavelength longer than PX.)
			9: No motivation.
			6: Constructive interference occurs at bright fringe, therefore waves are in phase and path length difference is integer amount of wavelengths.
			3: P is the third order bright fringe.
			2: They are in the same phase.
			1: X and Y are very close together.
			1: Wavelength travels along different paths from X and Y to reach P(*).
			1: PY has double the wavelength of PX.
			1: Y moves five times and X moves three times(*).
B	21,5%	42	11: Pathlength PY > PX with 1 wavelength
			10: Constructive interference occurs at bright fringe, therefore waves are in phase and pathlength difference is an integer amount of wavelengths, therefore 1 wavelen...
			5: No motivation.
			1: Between each dark fringe there is a bright fringe.
			1: No diffraction, because the same wavelength.
			1: Since the two slits act as coherent sources the phase is constant.
			1: The distance is the same because of same wavelength.
			1: There has to be ..ive a wavelength in between in order to have constructive and destructive interference.
			1: There is only one wavelength so the distance differs by one wavelength.
			1: Y starts from the negative side to the positive side, that is from the dark side to the bright fringes.
			2: PY is one wavelength shorter than PX, because it fails to reach where X reaches.
			1: According to Young's interference experiment, light has a specific wavelength which is the same at any point(*).
			1: The waves have to cancel each other(*).
			1: The same amount of energy moves through X and Y(*).
			1: Different directions of light waves(*).
C	20,4%	39	13: No motivation.
			10: Pathlength PY > PX. (4: 1,5 times; 2: less than twice longer.)
			3: There are 3 bright spots(c. interference) and 2 dark spots(d. interface)
			2: Distances are not the same.
			1: Constructive interference occurs at bright fringe, and pathlength difference is an integer amount of wavelengths.
			1: P is the first order dark fringe(*).
			1: P is the third order bright fringe(*).
			1: Pathlength PX = 3/2 PY(*).
			1: Wavelength PX = 3/2 wavelength PY(*).
			1: Wavelength PX = 2 wavelength PY(*).
			5: Motivations of no use.
A	17,8%	34	10: Pathlength PX < PY. (The difference is: 4: Half a wavelength; 2: 1 wavelength; 1: Double; 1: Pathlength PY is one wavelength and pathlength PX is half a wavelength.)
			4: Constructive interference occurs when distance differs by an integer number of wavelengths and destructive interference when distance is half an integer.
			2: Sources have to be coherent.
			1: Constructive interference falls on bright side and destructive interference on dark side.
			1: m=2
			1: P is 2 times weaker than the center.
			1: A wavelength and a half wavelength make a dark spot.
			1, Because there are no bright and dark fringes in Y part.
			1: The amplitude is twice the amplitude of the others.
			4: No motivation.
			2: PX is longer than PY because Y deflects more than X(*).
			2: The pathlengths PX and PY are equal(*).
			1: Angle will not be the same(*).
			1: Wavelength of PX is 2 times smaller than PY(*).
			1. Wavelength from X travels a shorter distance(*).
			1: Wavelengths differ(*).
-	7,9%	13	1: The wavelet from source X travels shorter than Y.
			1: Central fringe PX is brighter than PY(*).
			11: No motivation.
BD	3,7%	7	5: Because constructive interference occurs at P the difference is an integer number.
			1: PX and PY parallel and far away from screen.
			1: No motivation.
AB	0,5%	1	1: Pathlength PY > PX.
			1: Difference is half a wavelength for destructive interference and one wavelength for constructive interference.
ABCD	0,5%	1	1: Interference occurs in integers and half integers.
ABD	0,5%	1	1: The central bright fringe has by far the greatest intensity.
AC	0,5%	1	1: Waves are out of phase. Phase difference is half a wavelength when m=0 and 3λ/2 when m=1.
AD	0,5%	1	1: XP is 2x nearer than YP.

ANALYSIS

Question 14

CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
D	75,4%	144	55: They are exactly one wavelength apart.
			38: They are at the same position (place) of the wave.
			23: They will meet crest-to-crest and trough-to-trough. (8: They interfere constructively; 2: They reinforce each other.)
			13: They are both at the positive (rising) side of the wave.
			10: They have the same direction of propagation.
			5: They are the same distance from the undisturbed position.
			6: The waves have the same properties (amplitude, wavelength, speed).
			4: They are out of phase. (2: 180°; 1: 360°; 1: 90°)
			1: They are coherent.
			8: No motivation.
			11: Motivations of no use(*).
C	6,8%	13	4: They have the same amplitude.
			3: Constructive interference will result.
			3: They are the same distance from the undisturbed position.
			2: They meet crest-to-crest.
			1: They are exactly one wavelength apart.
			1: No motivation.
B	4,7%	9	2: The one is a minimum and the other is a maximum.
			2: They will meet crest-to-crest.
			2: After interference they form one wave(*).
			1: Constructive interference will result.
			1: They have the same amplitude.
			1: Motivation of no use(*).
A	4,2%	8	2: They are at the same point.
			1: The waves meet crest-to-crest.
			1: The waves reinforce each other.
			1: Interference is possible(*).
			1: The others cancel each other.
			2: No motivation.
AD	3,1%	6	2: They are at the same point.
			1: They are the same distance from the undisturbed position.
			1: Constructive interference will occur.
			1: The waves meet crest-to-crest.
			1: The new wavelength starts there(*).
-	1,6%	3	1: Not one, because none meet at the same point at the same time.
			2: No motivation.
AC	1,6%	3	1: They travel the same distance.
			1: They are coherent.
			1: Motivation of no use(*).
ACD	1,0%	2	2: Motivations of no use(*).
AB	0,5%	1	1: They have maximum and minimum disturbance.
ABD	0,5%	1	1: Motivation of no use(*).
CD	0,5%	1	1: They are at the same distance from the undisturbed position.
			1: They will reinforce each other.

ANALYSIS
Question 15

CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
C	60,7%	116	53: The light bends around the edges of the blade.
			9: Diffraction causes constructive and destructive interference (bright and dark fringes).
			8: The blade reflects the light.
			4: The blade has rough edges.
			4: The light spreads out.
			2: The light energy is redistributed.
			2: Different colours will be noticed.
			1: The amount of diffraction that occurs is very small(*).
			1: The edges of the blade are not parallel.
			24: No motivation.
			12: Motivations of no use(*).
A	18,3%	35	8: Constructive and destructive interference occur, causing bright and dark fringes.
			8: Destructive interference forms a dark fringe which causes the blurred image.
			3: Due to the bending of waves.
			3: Due to reflection of waves on the blade.
			3: Due to refraction (change of medium), which causes change in direction.
			2: Different colours will be noticed.
			1: Light waves can't diffract. This is the only choice left.
			10: No motivation.
AC	7,9%	15	6: The light bends around the edges of the blade. The wavelets interfere to form bright and dark fringes.
			2: Reflection of light from the blade causes interference.
			1: Diffraction causes the blurred image(*).
			1: Destructive interference forms a dark fringe which causes the blurred image.
			1: No motivation.
			2: Motivations of no use(*).
-	3,1%	6	2: Motivations of no use(*).
			4: No motivation.
BC	2,6%	5	2: Dust particles are always present, which disturb waves.
			3: Motivations of no use(*).
BD	1,6%	3	1: Reflection on blade is not 100%.
			1: Dust in air causes rough screen surfaces.
			1: No motivation.
AB	1,0%	2	2: Dust particles cause scattering of light, which interferes constructively and destructively.
ACD	1,0%	2	1: Due to reflection of light from blade.
			1: Motivation of no use(*).
BCD	1,0%	2	1: All of them contribute to blurred image(*).
			1: No motivation.
D	1,0%	2	1: The distances traveled by light waves will differ between the source and the screen, which will cause phase changes.
			1: No motivation.
ABC	0,5%	1	1: Motivation of no use(*).
ABCD	0,5%	1	1: All of them contribute to blurred image(*).
CD	0,5%	1	1: Motivation of no use(*).

ANALYSIS			
Question 16			
CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
D	28,8%	55	33: At Y to crests meet and at Z two troughs.
			7: The waves meet in phase.
			5: Crest meets crest.
			1: The sources are in phase.
			1: Rarefaction meets rarefaction.
			1: Both are situated at interference points of waves.
			2: No motivation.
			3: Motivations of no use(*).
A	22,5%	43	5: Two crests meet. (1: A bigger amplitude results.)
			1: The waves are in phase. (1: The others are out of phase.)
			3: This is the only point where the two waves make contact (interfere).
			2: The two waves cancel; it is a dark fringe pattern.
			5: No motivation.
C	17,3%	33	11: The waves are out of phase.
			5: It represents a dark fringe.
			4: The waves cancel each other.
			3: Z lies next to the point where 2 crests pass.
			1: Their troughs meet.
			1: It represents a light fringe.
			1: The resultant amplitude is less.
			4: No motivation.
AC	15,2%	29	17: At Y the waves meet crest-to-crest or in phase.
			9: At Z the waves meet crest-to-trough or out of phase.
			3: At Z two troughs meet.
			2: Z is in-between two crests.
			2: At Z the waves don't interfere (intersect).
			1: It depends on the distance between the slits and sources.
			1: Constructive interference occurs where two troughs or two crests meet.
			1: At Z the two crests are out of phase.
			3: No motivation.
B	7,9%	15	5: Because of their amount of wavelengths from the source. (2: One wavelength difference; 2: Equal amount of wavelengths; 1: An integer number of wavelengths difference.)
			4: They are in phase. (1: Exactly one wavelength out of phase.)
			3: They meet crest-to-crest.
			2: No motivation.
			2: Motivations of no use(*).
-	4,2%	8	1: None of the above. When monochromatic light passes through a double slit diffraction patterns occur.
			7: No motivation.
BC	3,1%	6	3: For X and Y two crests fall together. (1: They are in the same phase.)
			2: The two slits act as coherent sources.
			2: For Z a crest and trough fall together. (1: Out of phase.)
			1: No motivation.
ABCD	0,5%	1	1: Because it differs from wave to wave it can be any thing.
BCD	0,5%	1	1: Motivation of no use(*).
			COMMENT: Choice contradicts.

ANALYSIS

Question 17

CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
D	30,9%	59	21: Light bends around each slit and wavelets will interfere constructively and destructively.
			3: Interference and diffraction are properties of light waves.
			2: Diffraction is an interference effect.
			2: At single slit interference and at double slit diffraction occur.
			1: At single slit diffraction and at double slit interference occur.
			1: At single slit diffraction and at double slit interference and diffraction occur.
			1. Due to reflection of light.
			16: No motivation.
			6: Motivations of no use(*).
BC	14,7%	28	23: At the single slit the light bends around the slit and at the double slit bright and dark fringes appear.
			7: At the double slit the diffracted waves interfere.
			3: No motivation.
			2: Motivations of no use(*).
A	9,9%	19	3: Constructive and destructive interference occur at both.
			2: At both slits the sources are coherent.
			1: According to Young's experiment.
			1: Through the single slit one bright fringe is seen.
			1: Through the single slit only a dark fringe is seen.
			9: No motivation.
			2: Motivations of no use(*).
AD	9,9%	19	6: The light and dark fringes are due to interference and diffraction.
			6: Bright and dark fringes are due to interference.
			3: Diffraction occurs through any slit.
			3: No motivation.
			5: Motivations of no use(*).
C	8,9%	17	8: Interference occurs between two light waves.
			5: Constructive and destructive interference will occur to produce bright and dark fringes.
			2: According to Young's experiment.
			1: After diffraction, interference will take place.
			3: No motivation.
			2: Motivations of no use(*).
-	5,8%	11	1: Only diffraction, and not interference, plays a role at both P and Q.
			10: No motivation.
B	5,8%	11	3: A pattern of alternating bright and dark fringes form.
			1: No interference at single slit.
			1: Due to small width the pattern is observable.
			3: No motivation.
			3: Motivations of no use(*).
ABC	5,2%	10	4: Diffraction occurs at the single slit and interference at the double slit.
			2: Diffraction occurs at the single slit and interference and diffraction at the double slit.
			4: Motivations of no use(*).
ABCD	3,1%	6	4: Light bends around each slit and wavelets will interfere constructively and destructively to form bright and dark fringes.
			1: Diffraction patterns are observed when light moves through a single or double slit.
			1: Diffraction is an interference effect.
AC	3,1%	6	3: Light waves from the slits interfere constructively and destructively to produce bright and dark fringes.
			2: No motivation.
			1: Motivations of no use(*).
ACD	1,0%	2	1: Diffraction causes the light to bend and spread out so that light waves interfere to form bright and dark fringes.
			1: Motivation of no use(*).
BD	1,0%	2	1: Interference and diffraction are properties of light waves.
			1: At single slit only diffraction occurs, at double slit both interference and diffraction occur.
AB	0,5%	1	1: Only diffraction occurs at the single slit and diffraction and interference occur at the double slit.

ANALYSIS

Question 18

CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
ABD	28,3%	54	23: All three these conditions are criteria for constructive interference. COMMENT: When two waves are in phase they meet crest-to-crest and trough-to-trough and will reinforce each other.
			23+23: They are in phase. (6: Exactly in phase.) COMMENT: The 23 is included in the choice which contains all three options.
			14+23: They meet crest-to-crest. (7: They meet crest-to-crest and trough-to-trough; 1: Positive and negative peaks meet.)
			13+23: Reinforcement. (6: Amplitude doubles.)
			6: Identical waves. (2: Same amplitude and wavelength.)
			3: According to the principle of linear superposition, constructive interference will occur.
			1: No motivation.
			2: If the phase difference is less than 90° destructive interference will still occur at times.
			1: The phase difference is an integer(*).
AD	17,8%	34	19: These two conditions are criteria for constructive interference. COMMENT: When waves meet crest-to-crest they are in phase.
			6+19: They are in phase. (4: Exactly in phase.)
			2+19: The waves meet crest-to-crest. (9: They meet crest-to-crest and trough-to-trough; 1: Rarefactions meet.)
			6. The waves reinforce each other. (1: The resultant amplitude doubles.)
			1: According to the principle of linear superposition constructive interference occurs when 2 waves meet in phase and crest-to-crest and trough-to-trough.
			1: For constructive interference sources have to be coherent.
			1: The sum is not zero.
			1: They have a point of overlap.
			1: If they are out of phase constructive interference will maybe happen partly or not, maybe destructive interference will take place.
			1: No motivation.
A	13,1%	25	9: They reinforce each other. (2: Amplitude doubles.)
			7: They meet crest-to-crest and trough-to-trough. (2: They meet crest-to-crest; 2: They meet condensation-to-condensation.)
			5: In phase is the condition for constructive interference.
			5: Identical waves. (1: Identical wavelength and amplitude.)
			1: If they are not in phase destructive interference will occur.
B	12,0%	23	16: They reinforce each other. (4: Amplitudes double; 3: When waves reinforce each other they meet crest-to-crest and trough-to-trough.)
			7: They are in phase.
			5: They meet crest-to-crest and trough-to-trough. (1: Two positive and two negative amplitudes meet; 1: They meet crest to-crest.)
			3: Identical waves
			2: Superposition principle
			1: No motivation.
			1: Waves in phase construct and destruct each other.
AB	8,4%	16	9: When two waves arrive at a point in phase, they reinforce each other. COMMENT: This is a summary of the chosen conditions.
			9: A bigger wave will result. (1: A wave with double the amplitude.)
			2: The waves are coherent.
			2: They meet crest-to-crest and trough-to-trough.
			2: They are identical waves.
			1: The difference in path length is an integer number of wavelengths.
			1: They are exactly in phase, with no phase difference.
			1: No motivation.
			1: Waves must be in phase for interference to occur.
			1: If they are not in phase destructive interference will occur.
D	8,0%	16	7: When waves meet crest-to-crest constructive interference occurs.
			5: They reinforce each other. (1: Amplitude doubles.)
			4: They are in phase. (1: Exactly in phase.)
			2: The principle of superposition is stated.
			2: No motivation
			1: The waves are identical.
			1: If the waves don't meet crest-to-crest destructive interference occurs.
BD	2,6%	5	5: Constructive interference can only take place when the waves reinforce each other.
			3: When waves meet crest-to-crest they reinforce each other.
			1: Identical waves.
			1: The waves are in phase.
ABCD	2,1%	4	3: All statements are true.
			1: Frequency is the same if waves meet crest-to-crest and trough-to-trough. COMMENT: Nothing is mentioned about the option C of the phase difference!
BC	2,0%	4	3: Constructive interference takes place when both the waves meet in the positive or in the negative cycle
			2: Destructive interference occurs when the waves are more than 90° out of phase.
-	1,6%	3	3: No motivation
C	1,0%	2	1: Waves must be at least partially in phase for constructive interference to occur.
			1: If they are in phase, they can't have a phase difference(*).
ABC	0,5%	1	1: If the waves meet crest-to-crest destructive interference will occur(*).
CD	1,0%	2	2: Constructive interference will occur at certain times.

ANALYSIS

Question 19

CHOICE	% of 191 students	NUMBER OF STUDENTS	MOTIVATION
A	40,3%	77	62: The pulses momentarily cancel, but conform to their original shapes and directions.
			6: According to the principle of linear superposition.
			4: According to the principle of conservation of energy
			1: Because they are in opposite directions they will never meet.
			5: No motivation.
			5: Motivations of no use(*).
C	34,6%	66	64: The two pulses meet out of phase and cancel each other out.
			3: According to the principle of linear superposition.
			1: They momentarily cancel.
			1: The energy is cancelled out.
			1: No motivation.
D	13,6%	26	8: Two identical pulses meet out of phase; they cancel.
			3: The two pulses form one wave moving in the same direction.
			2: The pulses become weaker.
			2: The pulses loose some energy.
			1: Each pulse tries to move in the same direction as before.
			1: The resulting frequencies decrease.
			1: The energy is displaced and the wave propagates.
			1: The rope won't be as tight as before.
			1: The waves destroy one another.
			1: When they meet they cancel each other out partly.
			2: No motivation.
AC	3,7%	7	6: The pulses momentarily cancel but conform to their original shapes and directions.
			1: No motivation.
B	3,1%	6	3: The pulses undergo a phase change.
			2: Each pulse retains its initial properties.
			1: Motivation of no use(*).
-	2,1%	4	1: Their energies cancel out.
			1: They meet out of phase.
			2: No motivation.
AB	0,5%	1	1: Motivation of no use(*).
ABC	0,5%	1	1: Motivation of no use(*).
AD	0,5%	1	1: Motivation of no use(*).
BC	0,5%	1	1: C is for the total overlap and B is for the receding pulse.
CD	0,5%	1	1: When they meet they cancel each other. The continuation of momentum causes the final form.