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METHOD AND TECHNIQUE OF EXPERIMENT FOR OPTICS

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The offered textbook contains the main educational material from the sections «Development of STEM-education in the process of teaching physics in technical educational institutions of higher education», «Waves and their characteristics», «Geometric optics», «Wave properties of light», «Practical use of waves properties of light», «Special applications of light», «Polarization of light» and «Quantum properties of light». The textbook corresponds to the current curriculum and is recommended by the Ministry of Education and Science of Ukraine for foreign students in higher education.

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INTRODUCTION

According to the Law of Ukraine «On Higher Education», the priority directions of the reform of higher education are the updating of the content of basic methodological training; introduction of effective innovative technologies; creation of a new system of methodological and informational support of the higher school taking into account the concept of development of STEM-education.

The normative legal basis for the introduction of STEM-education is a number of laws of Ukraine: «On Education», «Higher Education», «On General Secondary Education», «On Extracurricular Education», «On Preschool Education», «On Scientific, Scientific and Technical activity», «On innovation activity», «Strategy of innovative development of Ukraine for 2010-2020 in the context of globalization challenges». Separately, we will highlight the decision of the Collegium of the Ministry of Education and Science of Ukraine dated January 21, 2016 (Minutes No. 1 / 1-4) «On Foresight of Socio-Economic Development of Ukraine in the Medium-Term (up to 2020) and Long-Term (up to 2030) Time-Based Horizons (in the Context preparation of human capital), in particular, paragraph 9 «To develop tools for evaluating the indicators of the real employment of graduates and the formation of forecast indicators on their labor market needs based on them. Provide an increase in the percentage of graduates in the areas of STEM education (science, technology, engineering, mathematics) in accordance with the needs of industry in the country».

Fundamentalization of education in higher educational establishments is of particular importance for raising the scientific level of students' training in subjects of professional importance.

Attention should be drawn to the complexity and versatility of STEM education, which leads to the development of programs, in different areas and complexity, to address issues related to the lack of STEM-literacy, taking into account the integrated approach. Let's highlight the main directions for their development: 1) Expand the learning experience of individual STEM subjects using problem-oriented learning activities, in which analytical concepts are applied to real world problems. 2) Integrating the knowledge of STEM subjects to create a deep understanding of their content, which will expand the ability of students in the future to choose a technical or scientific career path. Representatives of technical universities believe that in the STEM-education should dominate a multi-profile approach, which uses the integration in the training of STEM disciplines [96].

The issue of introducing an integrated approach to the educational process of higher educational institutions taking into account the concept of STEM education is relevant, as it enables:

- to combine the related material of several subjects around one theme, eliminate duplication in the study of a number of issues;
- to compress knowledge, that is, to reconstruct the fragment of knowledge in such a way that less time is spent on its assimilation, as well as to draw attention to the formation of equivalent general educational and technological skills of the subjects of instruction;
- to learn with students a significant volume of educational material, to achieve the integrity of knowledge;
- involve students in the process of obtaining knowledge;
- to form the student's creative personality and his ability;
- to enable students to apply the acquired knowledge of

various subjects in their professional activities.

Consequently, the introduction of STEM education is important, priority and inevitable for today's education. At the same time, there are a number of problems that require a first-rate solution: the updating of the regulatory framework, the establishment of a network of regional STEM-centers (laboratories), the development of scientific and methodological support and special means of training, training and retraining of scientific and pedagogical workers, development and testing integrated STEM-oriented programs, creation of an information base for STEM-education development in Ukraine with the use of state-of-the-art information technologies, etc.

The middle of the twentieth century for Ukrainian science is a new stage in its development. Physical and technical institutes resumed their work in Kharkiv, Kyiv, Dnipropetrovsk and Odessa. Constructed accelerators of elementary particles (cyclotron U-120), electrostatic and neutron generators. At the Institute of Physics of the Academy of Sciences of Ukraine, research has begun on an experimental nuclear reactor of the WWRM with a thermal power of 10 MW. Research and production laboratories and institutes for the study of superconductivity, super hardness, spectral laws, ultralow temperatures, crystals, liquid state, and metal physics have been constructed. In 1947, work was begun in 1951 to create the first domestic computer in Ukraine [82].

Significant contribution to the development of rocket and space technology has made Y.V. Kondratyuk, G.E. Lanhamak, V.P.Glushko, S.P. Korolov, M.K. Yangel.

In Dnipropetrovsk, since 1954, the main enterprise of the USSR for the creation and production of strategic combat missiles and space systems functioned. His first general designer was M.K. Yangel. In the CB «Pivdenne» and Pivdenmash, strategic missiles R12, P14, P16 and others were developed and manufactured, as well as spacecraft Kosmos, Interkosmos, Proton and Salyut stations.

Science as a whole develops continuously, systematically, constantly. The development of productive forces of society has always lagged behind the introduction of new achievements in the practice of life. Just a regulator of such a gap is the education system. The given historical evolution of development, in particular, optics, was completed in the 60's of the present century. The developed courses of physics for the system of secondary education and higher education largely complete the achievements of the physical science of this period [82].

Optics at the beginning of the twenty-first century differs significantly from the optics of the 60-s of the twentieth century. Nevertheless, the content of the educational material has undergone minor changes in school manuals, has been slightly updated and remained for the most part in the positions of the XIX century. For the past 30 years, the theory of spectra has been created, holography has been discovered, radio spectroscopy, lasers constructed, quantum electronics and coherent optics have emerged, physics has made its own step in the study of the universe.

The system of experimental activity covers various types of experiments [82]:

1 An ideal experiment with ideal subjects. The process of theoretical experimentation is accompanied by ideal objects and ideal conditions. The idealized object is the dominant aspect of the real subject of the study, along with the visual side of the theoretical concept. Acting mentally with the ideal photons, quanta, light beams, emptiness (vacuum), electronic orbits, the experimenter-teacher and the apprentice seek in the process of learning the general definitions of the real world of nature: the basic principles,

elementary forms, fundamental concepts, and lawfulness.

Thus the principles, hypotheses are formed. For example, the well-known principle of Huygens-Fresnel, Planck's hypothesis, Bohr's postulates, and the concepts of black discovery as a result of the original experiment, are embodied in the form of idealized events. They function themselves not only in the form of subject-matter, the theoretical ideal, according to which the experimental scheme was constructed, the experimental results were worked out, and the concepts were formed, but led to the discovery of its internal boundaries, to the discovery and the possibility of the development of a radically new theory of cognition. Such an evolution of quantum physics and, in particular, quantum optics, physics of the universe.

Similar «ideological» rebirth is not included in the analysis of the formation of a specific theoretical concept and somewhat narrows the problem of experiment. It seems that the concepts schematised in an ideal image combine everything that can objectively be said about an object. The rest of the characteristics of an object are random or subjective not to the very essence of the phenomenon, but to the conditions and circumstances. The theoretical thinking itself manifests itself as conditionality in that it finds artificial limitations, unpredictable prerequisites in its exchangeable ideal.

2 Theoretical experiment (theoretical observation). Subject-sensory observation does not affect the subject of studying his existence and tries to fix for him the basic law of this being. Moreover, the practitioner remembers the repetition of the detected regularities, and the theorist predicts new laws. In the end, the experiment itself without much theory is worthless. A. Einstein emphasized that it is simply impossible to allocate experimental and theoretical methods in the development of physical science.

The solution of the problem requires the wider use of theoretical experimentation, which combines experimental and theoretical methods. In determining the content and structure of school education (theoretical and experimental), it is useful to use the proposed V.V. Multanovskiy principle of scientific generalizations. This is not just about the amount of knowledge and their systematization, but also about the synthesis of their system, about new approaches to the study of the main exchange generalizations. Most scientists-methodists are inclined to believe that the basic and the leading form of knowledge is a scientific theory. In the quality of the first task, along with the transfer of the amount of knowledge from the foundations of science is seen the transfer of modern scientific and theoretical way of thinking, produced by generations. The last one without an experiment is almost impossible. Therefore, in the structure of the methodology of studying physics it is necessary to introduce the concept of «ways of thinking and the form of its transmission in the learning process».

In this tutorial, the opsian system of democrats, fpantals, tvopchi, doclides and compositions with wave and quantum optics is in the opposite to the pivne diffusion. The specification of the physical expetence makes it possible to collect and provide for the development of laboratory labels and the posture of physical activity, which is different from the traditional ones. Doklidsy disappointed in such a way that their subcontractor did not cause large matepical witts or cumbersome equipments.

An extract of the project is based on the typical type control of the physical cabinets with the expense of having the most suitable properties. Their schemas, inscriptions and introduction technology are illustrated by drawings.

The offered textbook contains the main educational material from the sections «Development of STEM-education in the process of teaching physics in technical educational institutions of higher education», «Waves and their characteristics», «Geometric optics», «Wave properties of light», «Practical use of waves properties of the light», «Special applications of light», «Polarization of light» and «Quantum properties of light».

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Chapter 1
DEVELOPMENT OF STEM- EDUCATION IN THE PROCESS OF TEACHING PHYSICS IN TECHNICAL EDUCATIONAL INSTITUTIONS OF HIGHER EDUCATION

1.1The concept STEM education and development in the world

Science, Technology, Engineering and Mathematics ***(STEM)****,* previously Math, Engineering, Technology, and Science (***METS***) is the academic discipline ofscience, technology, engineering and mathemat ics [1]. This term is typically used when addressing education policy and curriculum choices in schools, to improve competitiveness in science and technology development. It has implications for workforce development, national security concerns and immigration policy [1]. Education systems and schools play a central role in determining girls' and boys' interest in STEM subjects and in providing equal opportunities to access and benefit from quality STEM education [2].

The acronym arose in common use shortly after an interagency meeting science education held at the US National Science Foundation chaired by the then NSF director Rita Colwell [3]. A director from the Office of Science division of Workforce Development for Teachers and Scientists, Peter Faletra, suggested the change from the older acronym METS to STEM. Colwell, expressing some dislike for the older acronym, responded by suggesting NSF to institute the change. One of the first NSF projects to use the acronym was STEMTEC, the Science, Technology, Engineering and Math Teacher Education Collaborative at the University of Massachusetts Amherst, which was funded in 1998 [4].

Here are examples of the derivatives of the concept of STEM in table 1.1.

Table 1.1

Abbreviation	**Concept**
STM	Scientific, Technical, and Mathematics;[4] or Science, Technology, and Medicine; or Scientific, Technical, and Medical.
eSTEM	environmental STEM [8; 9]
iSTEM	invigorating Science, Technology, Engineering, and Mathematics; identifies new ways to teach STEM-related fields.
STREM	Science, Technology, Robotics, Engineering, and Mathematics; adds robotics as a field.
STREAM	Science, Technology, Robotics, Engineering, Arts, and Mathematics; adds robotics and arts as fields.
STEAM	Science, Technology, Engineering, Arts, and Mathematics [10].
STREM	Science, Technology, Robotics, Engineering, and Multimedia; adds robotics as a field and replaces mathematics with media.
GEMS	Girls in Engineering, Math, and Science); used for programs to encourage females to enter these fields [12; 11].
STEMM	Science, Technology, Engineering, Mathematics, and Medicine
AMSEE	Applied Math, Science, Engineering, and Entrepreneurship.

In the United States, the acronym began to be used in education and immigration debates in initiatives to begin to address the perceived lack of qualified candidates for high-tech jobs. It also addresses concern that the subjects are often taught in isolation, instead of as an integrated curriculum [12]. Maintaining a citizenry that is well versed in the STEM fields is a key portion of the public education agenda of the United States [13]. The acronym has been widely used in the immigration debate regarding access to United States work visas for immigrants who are skilled in these fields. This version of the term is accredited to Texas. It has also become commonplace in education discussions as a reference to the shortage of skilled workers and inadequate education in these areas [14]. The term tends not to refer to the non-professional sectors of the fields that remain more invisible such as electronics assembly line work, for example.

Many organizations in the United States follow the guidelines of the National Science Foundation on what constitutes a STEM field. The NSF uses a broader definition of STEM subjects that includes subjects in the fields of chemistry, computer and information technology science, engineering, geosciences, life sciences, mathematical sciences, physics and astronomy, (anthropology, economics, psychology and sociology), and STEM education and learning research [1; 15]. Eligibility for scholarship programs such as the CSM STEM Scholars Program use the NSF definition [16].

The NSF is the only American federal agency whose mission includes support for all fields of fundamental science and engineering, except for medical sciences [17]. Its disciplinary program areas include scholarships, grants, fellowships in fields such as biological sciences, computer and information science and engineering, education and human resources, engineering, environmental research and education, geosciences, international science and engineering, mathematical and physical sciences, social, behavioral and economic sciences, cyberinfrastructure, and polar programs [15].

An exhaustive list of STEM disciplines does not exist because the definition varies by organization. The U.S. Immigration and Customs Enforcement lists disciplines including [21] physics, actuarial science, chemistry, biology, mathematics, applied mathematics, statistics, computer science, computational science, psychology, biochemistry, robotics, computer engineering, electrical engineering, electronics, mechanical engineering, industrial engineering, information science, information technology, civil engineering, aerospace engineering, chemical engineering, astrophysics, astronomy, optics, nanotechnology, nuclear physics, mathematical biology, operations research, neurobiology, biomechanics, bioinformatics, acoustical engineering, geographic information systems, atmospheric sciences, educational/instructional technology, software engineering, and educational research.

STEM supports broadening the study of engineering within each of the other subjects, and beginning engineering at younger grades, even elementary school. It also brings STEM education to all students rather than only the gifted programs. In his 2012 budget, President Barack Obama renamed and broadened the «Mathematics and Science Partnership (MSP) » to award block grants to states for improving teacher education in those subjects [23].

STEM education often uses new technologies such as RepRap 3D printers to encourage interest in STEM fields [24].

In 2006 the United States National Academies expressed their concern about the declining state of STEM education in the United States. Its Committee on Science, Engineering, and Public Policy developed a list of 10 actions. Their top three recommendations were to:

- Increase America's talent pool by improving K-12 science and mathematics education.
- Strengthen the skills of teachers through additional training in science, mathematics and technology.
- Enlarge the pipeline of students prepared to enter college and graduate with STEM degrees [25].

The National Aeronautics and Space Administration also has implemented programs and curricula to advance STEM education in order to replenish the pool of scientists, engineers and mathematicians who will lead space exploration in the 21st century [25].

Individual states, like California, have run pilot after-school STEM programs, for example, to learn what the most promising practices are and how to implement them to increase the chance of student success [26]. Another state to invest in STEM Education is Florida, where Florida Polytechnic University, Florida's first public university for engineering and technology dedicated to science, technology, engineering and mathematics (STEM), was established [27].

Continuing STEM education has expanded to the post-secondary level through masters programs such as The University of Maryland's STEM Program [28] as well as the University of Cincinnati [29].

The eCybermission is a free, web-based science, mathematics and technology competition for students in grades six through nine sponsored by the U.S. Army. Each webinar is focused on a different step of the scientific method and is presented by an experienced eCybermission CyberGuide. CyberGuides are military and civilian volunteers with a strong background in STEM and STEM education, who are able to provide valuable insight into science, technology, engineering, and mathematics to students and team advisers.

STARBASE is a premier educational program, sponsored by the Office of the Assistant Secretary of Defense for Reserve Affairs. Students interact with military personnel to explore careers and make connections with the «real world». The program provides students with 20–25 hours of stimulating experiences at National Guard, Navy, Marines, Air Force Reserve and Air Force bases across the nation.

SeaPerch is an innovative underwater robotics program that trains teachers to teach their students how to build an underwater remotely operated vehicle (ROV) in an in-school or out-of-school setting. Students build the ROV from a kit composed of low-cost, easily accessible parts, following a curriculum that teaches basic engineering and science concepts with a marine engineering theme.

Hong Kong. STEM education has not been promoted among the local schools in Hong Kong until recent years. In November 2015, the Education Bureau of Hong Kong released a document entitled *Promotion of STEM Education*, [30] which proposes the strategies and recommendations on promoting STEM education.

Africa. Around the world, STEM education initiatives vary in scope, size, type, target populations and funding sources. A list of organizations that are currently engaged in STEM Education activities and outreach across Sub-Saharan Africa has emerged. The organizations range in size, scope, funding mechanisms, and mission statements. However, they are all focused on improving STEM Education in the continent.

Australia. There have been numerous programs and attempts to establish a national approach to STEM education in Australia.

Canada.Canada ranks 12th out of 16 peer countries in the percentage of its graduates who studied in STEM programs, with 21.2%, a number higher than the United States, but lower than countries such as France, Germany, and Austria. The peer country with the greatest proportion of STEM graduates, Finland, has over 30% of their university graduates coming from science, mathematics, computer science, and engineering programs [31].

Scouts Canada. Scouts Canada has taken similar measures to their American counterpart to promote STEM fields to youth. Their STEM program began in 2015 [32].

Schulich Leader Scholarships. In 2011 Canadian entrepreneur and philanthropist Seymour Schulich established the Schulich Leader Scholarships, $100 million in $60,000 scholarships for students beginning their university education in a STEM program at 20 institutions across Canada. Each year 40 Canadian students would be selected to receive the award, two at each institution, with the goal of attracting gifted youth into the STEM fields [32]. The program also supplies STEM scholarships to five participating universities in Israel [33]

Turkey. Turkish STEM Education Task Force (or FeTeMM-Fen Bilimleri, Teknoloji, Mühendislik ve Matematik) is a coalition of academicians and teachers who show an effort to increase the quality of education in STEM fields rather than focussing on increasing the number of STEM graduates [34; 35].

Qatar. In Qatar, AL-Bairaq is an outreach program to high-school students with a curriculum that focuses on STEM, run by the Center for Advanced Materials (CAM) atQatar University. Each year around 946 students, from about 40 high schools, participate in AL-Bairaq competitions [36]. AL-Bairaq make use of project-based learning, encourages students to solve authentic problems, and inquires them to work with each other as a team to build real solutions.[36; 37]. Research has so far shown positive results for the program [37].

Ukraine. In Ukraine, June 22, 2015, the Ministry of Education and Science of Ukraine hosted a roundtable on the development of STEM education, attended by representatives of leading institutions, initiatives, projects in the field of education of all levels (general, profile, extracurricular, preschool, higher), as well as a working group on the implementation of STEM-education in Ukraine. Order of the Ministry of Education and Science of Ukraine dated February 29, 2016, No. 188.

1.2 STEM–education implementation in the process of physics training in higher educational staff of technical profile

As you know, the reform of higher education in Ukraine is based on the following principles:

- firstly, it is a national idea of higher education, the content of which is to preserve and increase national educational traditions. Higher education is intended to educate a citizen of Ukraine, a harmoniously developed person, for which the need for fundamental knowledge and raising the general and professional level is associated with the strengthening of their state;
- secondly, the development of higher education should be subject to the laws of a market economy;
- thirdly, the development of higher education should be considered in the context of trends in the development of world educational and European systems.

Taking into account the above mentioned principles, let us pay attention to the new tendency of education development, as STEM - an education that is actively developing in the EU countries, and is gaining momentum in Ukraine, which is an urgent problem for the development of new programs and methods of training for higher educational institutions of technical education.

It should be noted that during the first decade of the XXI century, the needs of STEM-educated skilled specialists who possess not only theoretical knowledge but also practical skills of working with complex technological objects have changed significantly.

It is worth noting the complexity and versatility of STEM education, which leads to the development of programs in different areas and complexity to address the lack of STEM literacy. Let's distinguish the basic approaches to their development taking into account the training needs of specialists in physics:

1) expand the learning experience of individual STEM subjects using problem-oriented learning activities, in which analytical concepts are applied to real world problems.

2) integrate knowledge of STEM subjects in order to create a deep understanding of their content, which will increase the ability of subjects in the future to choose a technical or scientific career path.

3) implement STEM-innovations in the methodology of teaching physics to each with the use of an integrated approach to learning, where the basic concepts of science, technology, engineering, and mathematics are transferred to one curriculum.

Prospects for further exploration are the development of a methodology for teaching physics, taking into account STEM - technologies.

1.3 STEM–education and inter-dissiplical communications in the educational process of physics in higher educational students

STEM is a curriculum based on the idea of teaching four disciplines - science, engineering, engineering, and mathematics, taking into account interdisciplinary and applied approaches.

The tasks of studying physics in technical institutes within the framework of the development of the concept of STEM-education vary with the students mastering a certain amount of knowledge to the formation of creative thinking. To this end, in our opinion, it is advisable to form students in the course of studying the general course of physics in a holistic view of science based on the study of fundamental concepts in higher education institutions of technical profile.

Physics also makes a significant contribution to the development of new technologies arising from theoretical achievements. For example, advances in the understanding of electromagnetism or nuclear physics led directly to the development of new products that were sharply transformed by modern society, such as television, computers, home appliances and nuclear weapons [38; 39]; the achievements of thermodynamics led to the development of industrialization and the achievement of mechanics inspired the development of computing.

The young generation must think and think carefully so that they have the chance to become innovators, educators, scholars and leaders capable of solving the most pressing challenges facing our nation and our world today and tomorrow. However, insufficient number of training subjects has access to quality STEM learning opportunities, and too few students consider these disciplines as a foundation for their careers.

The conducted theoretical and experimental researches allow to distinguish between two forms of relations between the idea of intersubject links in the process of teaching physics and professional disciplines and principles of learning, namely:

1) interdisciplinary connections as one way of

implementing each of the principles of learning;

2) interdisciplinary connections as an independent principle of constructing local teaching didactic systems in the subject system of learning. Interpersonal relationships are an integral component, which requires compliance with the principles of scientific, systematic, consciousness. It is in the role of an independent principle that the idea of intersubject relationships performs its organizing role: it influences the construction of programs, the structure of educational material, textbooks, the selection of methods and forms of training in the process of teaching physics in higher educational establishments technical profile.

In the tasks of teaching it is necessary to reflect the application, development, consolidation and generalization of knowledge and skills received by students in the study of professional subjects. It is important to highlight the content of the educational material, the study of which requires the reliance on previously acquired (on other subjects) knowledge, as well as issues that will be further developed in the further study of disciplines in a professional direction.

The principle of interdisciplinary connections aims at formulating the problem, questions, and tasks for students in physics, focused on the application and synthesis of knowledge and skills from various subjects of the prophylactic direction. The systematic use of interdisciplinary connections creates opportunities for widely used teaching materials and means of visibility (textbooks, tables, instruments, maps, diafilms, films) that belong to one subject, while studying other disciplines.

In the organization of training, there is a need for complex forms - seminars, excursions, conferences with interdisciplinary content. Such forms require coordinating the activities of teachers, studying curricula in disciplines of a professional nature.

1.4 Physical experiment as a factor of STEM development – education in higher educational staff of technical profile

The problems of modern education concern the whole society. This is due not only to the need for substantial modernization of the industry, but also to the multidimensional vision, assessments of the state of education and approaches to its qualitative improvement in the methodology of teaching natural sciences in the context of the development of STEM education.

According to the Law on Higher Education, one of the main directions of updating the content of higher education is to ensure its quality on the basis of the latest achievements of science, culture and social practice. This document accordingly states that the educational branch of «technology» serves the functions of providing technical and technological education, based on the laws and laws of man, nature, society, culture and production, which are studied by educational subjects from the foundations of science.

In the system of natural sciences, the leading role is played by physics, because it as a science plays a leading role in the development of productive forces of society. The modern educational process of studying the course of physics is based on an experimental basis and combined with the theoretical method. In this regard, regardless of the method of knowledge, which is the basis of the process of teaching physics, physical physical experiment is an obligatory element of it and at the same time is an integral part of the methodology of teaching physics as a scientific discipline capable of ensuring the effective mastering of knowledge by subjects of study.

The transition to STEM-training requires the improvement of the methodology of teaching physics, which involves: use of new methods, techniques, teaching aids, which would help to solve a number of methodological tasks from the sections of physics; application and introduction in the educational process of physics of interesting and important scientific achievements, as well as strengthening those aspects that stimulate and activate the independent cognitive activity of students of the Kirovohrad Flight Academy of the National Aviation University.

Consequently, for the formation of convincing representations of the general course of physics, it is necessary to create and develop an appropriate methodology for teaching physics that would improve the level of knowledge and skills and stimulate active cognitive-search and independent work of students in the study of physics in the context of the development of STEM-training.

The purpose of the section is to highlight the development and introduction of innovative technologies of STEM education, namely, the physical experiment in the process of teaching physics in higher educational establishments of a technical profile.

The problem of forming a student's creative activity is one of the most urgent in the theory of pedagogical science and in the practice of higher education education. Scientists-didactics argue that the greatest role in the development of students' creative activity belongs to the physical experiment in which the subjects of the studying learn to observe phenomena: determine the conditions under which these phenomena occur and occur; qualitatively and quantitatively evaluate them or find phenomena; to find causal relationships between them.

The importance of a physical experiment in the educational process in the context of the development of STEM education also follows from the fact that in the process of psychological development of a person is ascending its practical activity.

In the system of educational physical experiment, a special place belongs to laboratory works, which carry out practical training of students of the Academy in the process of studying physics as a fundamental science.

The main objective of the laboratory work is to familiarize students with the experimental method of studying physical phenomena, forming an understanding of the principles of measuring physical quantities, mastering methods and techniques of measurements, and methods of analysis of errors.

Possibility of conducting an educational experiment in conditions of the modern development of education, in particular STEM-technologies, is related to the physical equipment of the physical cabinet. In the given article we propose to consider new devices and on their basis to give a list of experiments on optics, as well as to formulate the conceptual principles of the development of the methodology of teaching physics, in particular optics, in higher educational establishments in the technical direction of studying. Physical experiment on optics is provided by various new sets and devices.

We believe that the methods of teaching physics, in particular optics, in the development of STEM education, should be consistent with the use of STEM equipment, technical means of teaching, reflect the current level of scientific advances in physics, and take into account the individual characteristics of students to improve knowledge, skills and abilities in performing various levels of complexity of tasks in physics in higher education aviation direction and properly addressing the tasks of the formation and development of each student's personality.

Prospects for further research are the improvement of this educational equipment, which consists in the development of the methodology and techniques for the implementation of a training experiment in physics in the higher educational establishment of a technical profile in the context of the development of STEM education.

Chapter 2
WAVES AND THEIR CHARACTERISTICS

2.1 Theories of light in the 17-th and 18-th centuries

Many scientists proposed a wave theory of light based on experimental observations, including Robert Hooke, Christian Huygens and Leonhard Euler [41], Isaac Newton, who did many experimental investigations of light, had rejected the wave theory of light and developed his corpuscular (or particle) theory. According to it light is emitted from a luminous body in the form of tiny particles.

This theory held sway until the beginning of the nineteenth century. In despite of the fact that many phenomena, including diffraction effects at edges or in narrow apertures, colours in thin films and insect wings, and the apparent failure of light particles to crash into one another when two light beams crossed, could not be adequately explained by the corpuscular theory. It nonetheless, had many eminent supporters, including Pierre Simon de Laplace and Jean Baptiste Biot.

Youngs' work on wave theory. While studying medicine in the 1790-s, Young wrote a thesis on the physical and mathematical properties of sound and in 1799, he presented a paper to the Royal Society where he argued that light was also a wave motion. His idea was furiously opposed because it contradicted Newton, whose views were considered sacred.

Nonetheless, he continued to develop his ideas. He believed that a wave model could much better explain many aspects of light propagation than the corpuscular model:

A very extensive class of phenomena leads us still more directly to the same conclusion. They consist chiefly of the production of colours by means of transparent plates, and by diffraction. While on the other hand all of them may be *at once understood, from the effect of the interference of double lights.*

According to historian of science Paul Harman, «the mechanical theory of the optical ether established a paradigm for the programme of mechanical explanation». However, until this paradigm was firmly in place, debates raged over the nature of light and the possible mechanisms of its transmission.

Before the wave theory was established as the canonical explanation of optical phenomena, scientists involved in debates over the production and the interpretation of these phenomena could be divided into two groups: emissionists and wave theorists. Emissionists believed light to be a sequence of rapidly moving particles subject to forces exerted by material bodies. Wave theorists, however, thought of light as a spreading disturbance in the omnipresent ether. By the 1830-s, most optics-oriented members of the scientific community recognized the power of the wave theory for explaining contemporary experiments; emissionists could boast no such success.

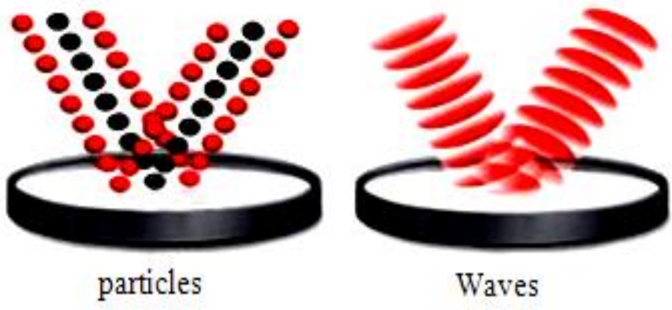


Figure 2.1

However, as historian Jed Buchwald has pointed out, the rise of the wave theory of light was more complicated than that. Although it is certainly true that waves replaced light particles in this conceptual shift, another, deeper process also occurred. If waves in the ether became new tools of explanation, wave fronts also replaced rays as tools of analysis. In other words, to be considered a competent wave theorist at this time required an understanding not only of light as ethereal disturbance, but also of the nature of rays and their relation to light beams. Specifically, before 1830 many physicists found it difficult to understand how beams, as collections of discrete, countable rays, could be reconciled with waves, and especially wave fronts - an understanding that was crucial to appropriate deployment of the mathematical apparatus that helped make wave theory successful (that is, satisfactorily quantitative).

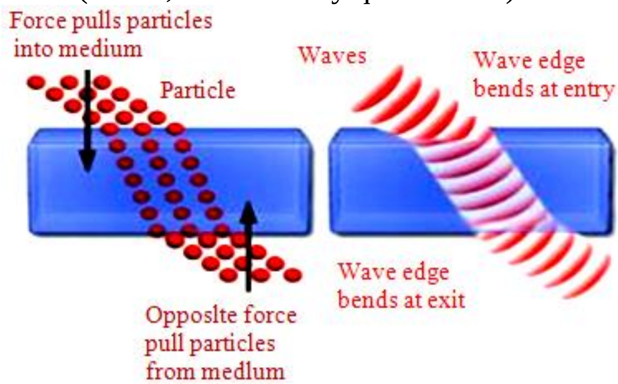


Figure 2.2 Particles and wave

In emission theory, single light rays could not be polarized; polarized light resulted from sufficient numbers of rays in a given beam being lined up in the same way. However, in wave theory, it is possible to say meaningfully that a ray is polarized. In that case, polarization refers only to the state of the wave front (and to a particular asymmetry in it) and each asymmetry can correspond to only one ray. But because, with wave theory, a beam of light is not considered a collection of rays in the first place, the rays (as we're using them here) have only an analytic significance. For emissionists, polarization refers to collections of items (rays), whereas for wave theorists, the beam and the ray are identical and singular - and the wave front is more important than both.

In France, the Laplacian J.B. Biot constructed a quantitative theory of light based on these emissionist assumptions. His colleague and eventual nemesis, D.F.J. Arago, produced a theory that, Biot claimed, merely reproduced his own results. But, as Buchwald has shown, Biot's accusations were misplaced: Biot simply could not understand that the foundations of Arago's theory were not only different from his emissionist principles, but fundamentally incompatible with them. Arago's protoge, D.F.J. Fresnel, later performed a polarization experiment that, at least according to Arago's polemical point of view, conclusively demonstrated the invalidity of Biot's original position. Nevertheless, Biot retained his tenacious selectionism (emissionism) blinded him to Fresnel's implicit (though major) point-Fresnel's principle of interference (that what appears to be polarized light may be made of several different waves, not all of which are necessarily entirely polarized or unpolarized or even partly polarized) meant that rays cannot be counted; it is not possible to divide light.

From 1830, the central problem in optics was to determine the mechanical quantities comprising the light medium. For example, in order to explain light polarization, Fresnel supposed that the vibrations producing light consisted of both longitudinal and transverse vibrations; in polarized light, longitudinal ones are missing. But this meant that transverse waves had to travel through a fluid medium, which was impossible, as S.D. Poisson, another Laplacian, pointed out. Fresnel responded to this objection with the hypothesis that the ether was rigid. Rigid ether was susceptible to mechanical modeling; one could construct it in pieces.

By contrast, A.L. Cauchy pursued a thesis that assumed ether with the properties of an elastic solid, but the mechanical structure of this elastic solid ether was open to question. Despite its immense difficulties, Cauchy's theory allowed for the use of differential equations in the description of wave phenomena. This approach appealed to British physicists such as John Herschel, G.B. Airy, W. Whewell, and especially George Green, because it dispensed with the need to explicitly model and define the material microstructure of the light medium.

After 1860, the rapid development of spectroscopy (the study of radiation by dispersing its component frequencies and attaching a relative intensity to each) and refinements in diffraction gratings increased the validity of the wave theory of light. In keeping with the rise of an electromagnetic, rather than strictly mechanical, ontology characteristic of the later nineteenth century, Maxwell's work explained light waves as oscillations in the equilibrium configuration of electric and magnetic fields, and he derived a wave equation for the spread of electromagnetic effects, the speed of whose propagation came remarkably close, he observed, to that of light. Decisive confirmation of the wave theory of light would wait until 1887/88, however, when Heinrich Hertz demonstrated that Maxwell's waves could be reflected, refracted, and polarized (just like light) and that they travel at light's velocity.

As the implications of quantum physics became apparent, someone argued that the longstanding question of whether light consists of waves or particles could finally be resolved. An experiment was arranged in which fewer and fewer particles were allowed into the interference apparatus. The expectation was that, as the number of particles decreased, a point would be reached where the interference pattern would disappear, because there would be too few particles for even one particle to pass through each slit.

This experiment was the point at which the truly spooky nature of quantum theory became apparent to everyone. It turns out that, even if only one particle is released into the experimental apparatus at a time, that single particle never lands on the dark parts of the original interference pattern. The explanation for this result is that the particle is only a particle while it is being observed, but the rest of the time, it exists as a field of probabilities. Because there is equal probability for the particle to pass through slit *A* or slit *B*, it passes through *both simultaneously*. Consequently, when it gets to the target and becomes a particle again, it will have interfered with itself, and will never land in the dark parts of the pattern [42].

2.2 Investigation property of waves. Energy, Transport and the Amplitude of a Wave

Have you ever watched the waves spreading over the water surface after dropping a small stone into the lake or deep puddle? Wave in this case is a result of oscillation movement spreading in some environment.

The waves in the ocean are the result of energy transferred from the wind to the shore. Water waves are only one kind of wave. Sound, light, radio, microwaves, and *X*-rays are all examples of waves. In this chapter we will start learning about waves with graphic demonstration of wave phenomenon - ***light***. You can describe a wave processes by a whole different set of terms: mass, volume, and other physical properties.

The stone creates a series of waves. The water itself does not move along with the waves, but the waves move across the water. So the water surface moves up and down in a regular way.

Figure 2.3 Waves on the water [43]

Waves transfer energy from one place to another. If a small object is floating on the water, the waves will make it move up and down. On the fig. 2.4 testify investigation property of wave's diverse nature of dependence from the conditional.

The object is given kinetic energy

$$W_k = \frac{m\upsilon^2}{2} = \frac{m\omega^2 A^2}{2}\sin^2(\omega t + \varphi_o), \qquad (2.1)$$

then m – mass, ω - cyclic frequency, φ_o – initial phase.

The energy of a wave does work on anything in its path. Light waves from the sun are the largest source of energy on Earth.

A water wave has many properties that all waves have: amplitude, wavelength, frequency, energy.

Fig. 2.5,*a* and 2.5,*b* is a photo showing water waves at one moment in time.

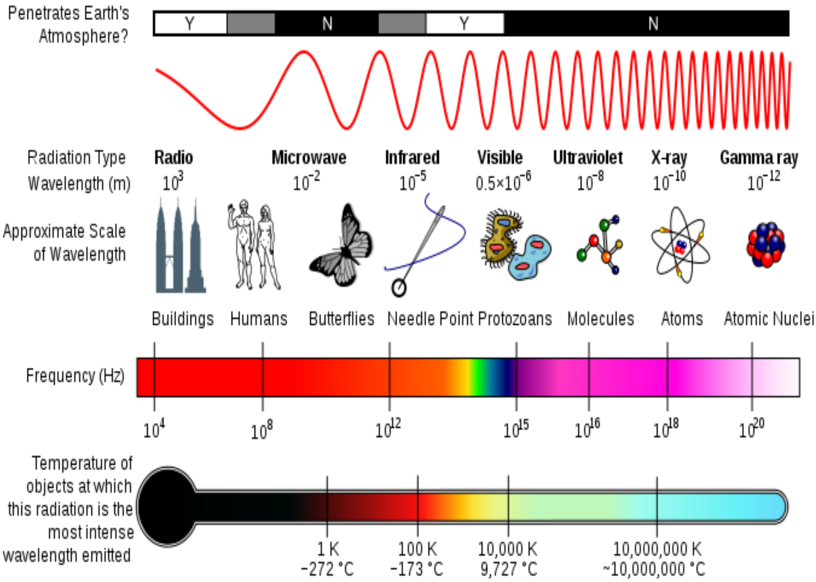


Figure 2.4 Scale of a wave [44]

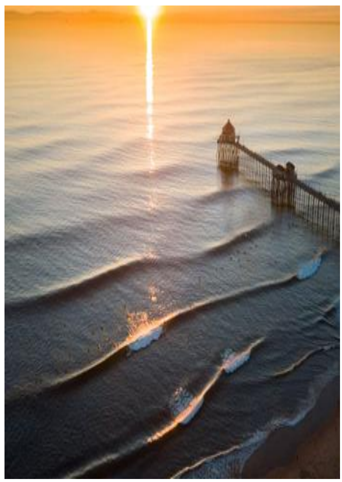



Figure 2.5,a The wave on water *Figure 2.5,b The transverse wave* *[45]*

2.3 Investigation property of waves: amplitude, energy, kinetic energy, transverse pulse, wavelength, longitudinal

The ***amplitude*** of the wave, corresponding to the energy of the wave, is the distance from the baseline to a crest or the baseline to a trough.

As mentioned earlier, a wave is an energy transport phenomenon that transports energy along a medium without transporting matter. A pulse or a wave is introduced into a slinky when a person holds the first coil and gives it a back-and-forth motion.

This creates a disturbance within the medium. This disturbance subsequently travels from coil to coil, transporting energy as it moves. The energy is imparted to the medium by the person as he does work upon the first coil to give it kinetic energy. This energy is transferred from coil to coil until it arrives at the end of the slinky. If you were holding the opposite end of the slinky, then you would feel the energy as it reaches your end. In fact, a high energy pulse would likely do some rather noticeable work upon your hand upon reaching the end of the medium; the last coil of the medium would displace you hand in the same direction of motion of the coil. For the same reasons, a high energy ocean wave can do considerable damage to the rocks and piers along the shoreline when it crashes upon it [45].

The amount of energy carried by a wave is related to the amplitude of the wave. A high energy wave is characterized by high amplitude; a low energy wave is characterized by low amplitude. The amplitude of a wave refers to the maximum amount of displacement of a particle on the medium from its rest position. The logic underlying the energy-amplitude relationship is as follows.

If a slinky is stretched out in a horizontal direction and a transverse pulse is introduced into the slinky, the first coil is given an initial amount of displacement. The displacement is due to the force applied by the person upon the coil to displace it a given amount from rest.

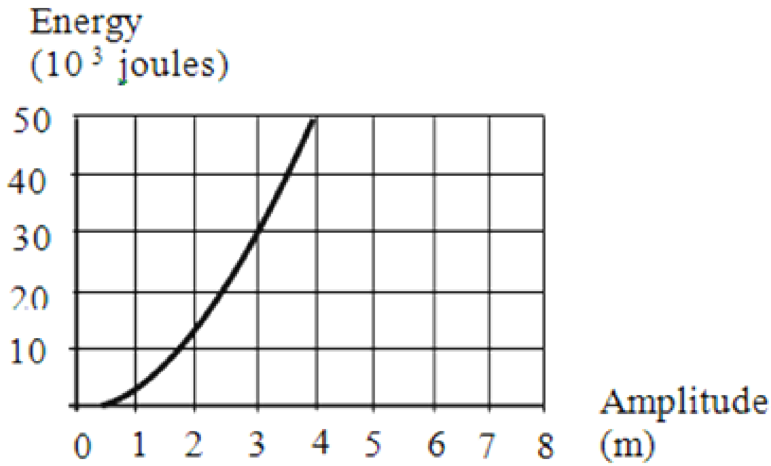


Figure 2.6 Wave energy vs. amplitude

The more energy that the person puts into the pulse, the more work that he will do upon the first coil. The more work that is done upon the first coil, the more displacement that is given to it. The more displacement that is given to the first coil, the more amplitude that it will have. So in the end, the amplitude of a transverse pulse is related to the energy which that pulse transports through the medium.

Putting a lot of energy into a transverse pulse will not affect the wavelength, the frequency or the speed of the pulse. The energy imparted to a pulse will only affect the amplitude of that pulse, fig. 2.6. [45].

The units of the amplitude depend on the type of wave, but are always in the same units as the oscillating variable. A more general representation of the wave equation is more complex, but the role of amplitude remains analogous to this simple case.

$$W_k = \frac{m\upsilon^2}{2}, \tag{2.2}$$

$$E_k = \frac{m\omega^2 A^2}{2}\sin^2(\omega_0 t + \varphi_o), \tag{2.3}$$

$$E_k = \frac{kA^2}{2}\cos^2(\omega t + \varphi_o), \tag{2.4}$$

$$E = \frac{kA^2}{2}[\sin^2(\omega t + \varphi_o) + \cos^2(\omega t + \varphi_o)] = \frac{kA^2}{2}. \tag{2.5}$$

Just as distance and displacement have distinctly different meanings (despite their similarities), so do speed and velocity. Speed is a scalar quantity that refers to «how fast an object is moving». Speed can be thought of as the rate at which an object covers distance. A fast-moving object has a high speed and covers a relatively large distance in a short amount of time. Contrast this to a slow-moving object that has a low speed. It covers a relatively small amount of distance in the same amount of time. An object with no movement at all has a zero speed.

Velocity is a vector quantity that refers to «the rate at which an object changes its position». Imagine a person moving rapidly - one step forward and one step back - always returning to the original starting position. While this might result in a frenzy of activity, it would result in a zero velocity. Because the person always returns to the original position, the motion would never result in a change in position. Since velocity is defined as the rate at which the position changes, this motion results in zero velocity. If a person in motion wishes to maximize their velocity, then that person must make every effort to maximize the amount that they are displaced from their original position. Every step must go into moving that person further from where he or she started. For certain, the person should never change directions and begin to return to the starting position [45].

Consider two identical slinkies into which a pulse is introduced. If the same amount of energy is introduced into each slinky, then each pulse will have the same amplitude.

2.3.1 Investigation property slinkies are different of waves

What if the slinkies are different? What if one is made of zinc and the other is made of copper? Will the amplitudes now be the same or different? If a pulse is introduced into two different slinkies by imparting the same amount of energy, then the amplitudes of the pulses will not necessarily be the same. In a situation such as this, the actual amplitude assumed by the pulse is dependent upon two types of factors: an inertial factor and an elastic factor. Two different materials have different mass densities. The imparting of energy to the first coil of a slinky is done by the application of a force to this coil. More massive slinkies have a greater inertia and thus tend to resist the force; this increased resistance by the greater mass tends to cause a reduction in the amplitude of the pulse. Different materials also have differing degrees of *springiness* or elasticity. A more elastic medium will tend to offer less resistance to the force and allow a greater amplitude pulse to travel through it. Being less rigid (and therefore more elastic), the same force causes a greater amplitude.

The energy transported by a wave is directly proportional to the square of the amplitude of the wave. This energy-amplitude relationship is sometimes expressed in the following manner $E \sim 2A^2$ (see table 2.3.1)

Table 2.3.1

Amplitude	1 unit	2 unit	3 unit	4 unit	5 unit
Energy	2 unit	8 unit	18 unit	32 unit	50 unit

This means that a doubling of the amplitude of a wave is indicative of a quadrupling of the energy transported by the wave. A tripling of the amplitude of a wave is indicative of a nine-fold increase in the amount of energy transported by the wave. And a quadrupling of the amplitude of a wave is indicative of a 16-fold increase in the amount of energy transported by the wave. The table 2.3.1 expresses this `energy-amplitude relationship. Observe that whenever the amplitude increased by a given factor, the energy value is increased by the same factor squared. For example, changing the amplitude from 1 unit to 2 units represents a 2-fold increase in the amplitude and is accompanied by a 4-fold (2^2) increase in the energy; thus 2 units of energy becomes 4 times bigger - 8 units. As another example, changing the amplitude from 1 unit to 4 units represents a 4-fold increase in the amplitude and is accompanied by a 16-fold (4^2) increase in the energy; thus 2 units of energy becomes 16 times bigger - 32 units.

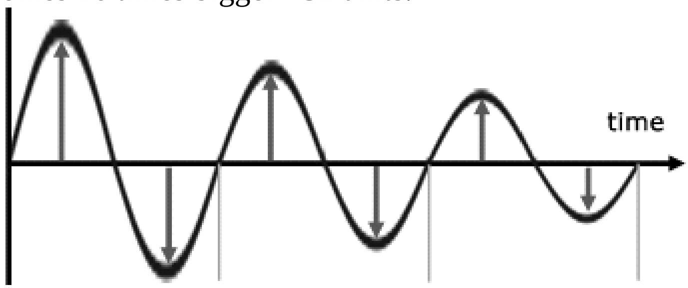


Figure 2.7 Damping describes the loss of energy of an oscillatory motion

The loss of energy is evident in the reduction in amplitude of the wave. Successive waves become smaller; however, the frequency remains the same [40].

One common example is the pendulum. After being set in motion, the distance being swept out by the pendulum bob becomes progressively smaller. Energy is lost to the system due to air resistance and friction at the support.

The «hill top» of a wave is called the ***crest* (*peak*),** and the «valley» is the ***trough*.** Locate these wave parts on fig. 2.9 [40].

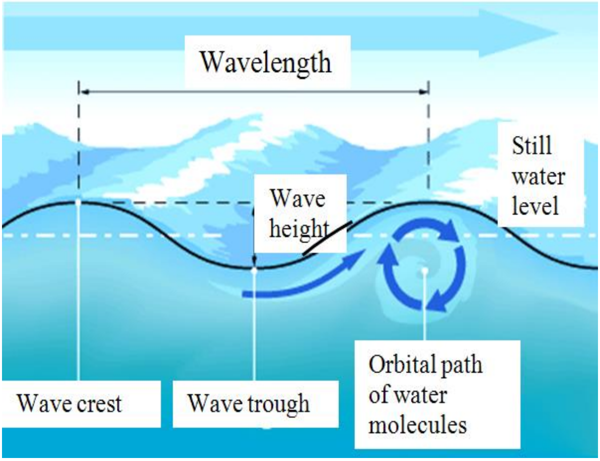


Figure 2.8 The parts of a transverse wave are labelled on this cross section of a water wave [46]

The discovery of the trochoidal shape came from the observation that particles in the water would execute a circular motion as a wave passed without significant net advance in their position. The motion of the water is forward as the peak of the wave passes, but backward as the trough of the wave passes, arriving again at the same position when the next peak arrives.

Actually, experiments show a slight advance of the water with the waves, but that advance is small compared to the overall circular motion.

The illustration above shows the direction of the water motion at different points along the wave.

The elliptical movement of a fluid particle flattens with decreasing depth. Nature of water circulation scaled from data in Basom. The diameter of the orbit of the circulatory motion is about halved at a depth of about 1/9 the wavelength. At twice that depth the orbit becomes flattened and eventually is just a forward and backward surge [46].

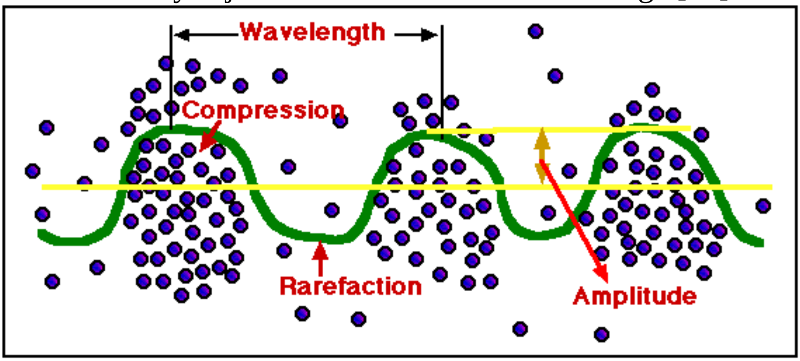


Figure 2.9

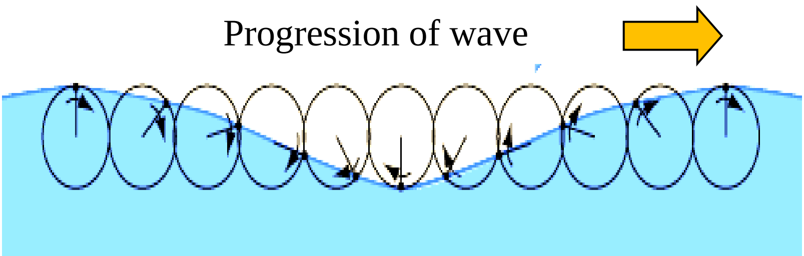


Figure 2.10 Progresion of wave

Bascom describes wavetank experiments where the circulation of the water was studied. The circles summarize the total motion of the medium when a full wavelength passes. It was common practice to inject droplets of oil which were whitened with zinc oxide and adjusted to have the same density as the water. The orbits could then be traced out on the sides of the wavetank. It was found that there was a small progression of the orbits in the direction of the wave propagation.

Waves have a number of characteristics which define their behaviour. Looking at a transverse wave, we can identify specific locations on the wave [47].

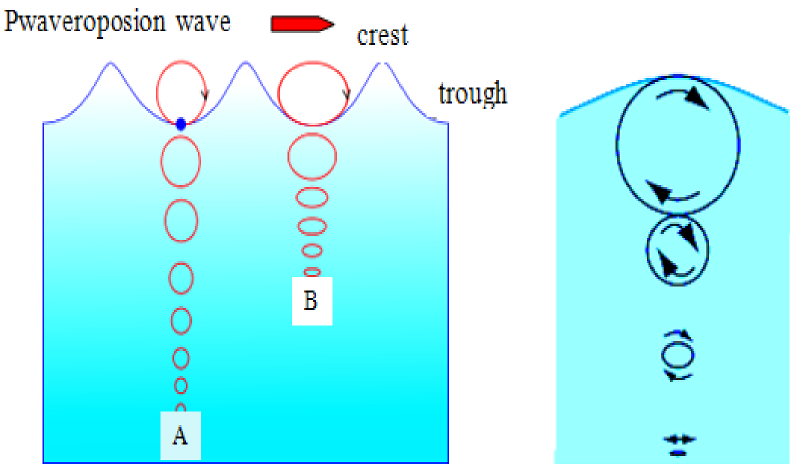


Figure 2.11 Motion of a particle in a wind wave [46]. A - at deep water. The orbital motion of fluid particles decreases rapidly with increasing depth below the surface. B - at shallow water (sea floor is now at B)

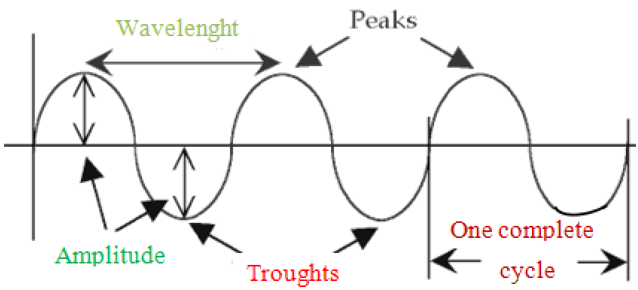


Figure 2.12 Wave`s characteristics [47]

2.3.2 Investigation property of wavelength

The length of the wave, or wavelength, noted with the Greek letter lambda (λ), is the distance between corresponding points on consecutive waves (i.e. crest to crest or trough to trough).

Points on the same wave with the same displacement from equilibrium moving in the same direction (such as a crest to a crest or a trough to a trough) are said to be ***in phase*** (phase difference is 0° or 360°). Points with opposite displacements from equilibrium (such as a crest to a trough) are said to be 180° out of phase.

One ***wavelenth*** is the distance between a point on one wave and the same identical point on the next wave. Wavelength can be measured from crest to crest, or from trough to trough, or between any two corresponding points.

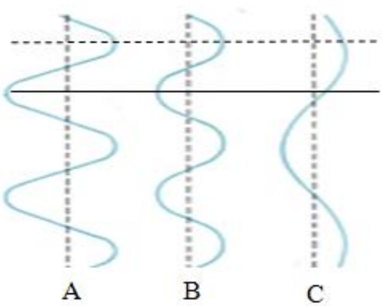


Figure 2.13 [40] Waves A and B have equal amplitudes but different wavelengths. Waves B and C have equal wavelengths but different amplitudes

2.3.3 Investigation property of Amplitude

Amplitude is the greatest distance the particles in a wave rise or fall from their rest position. The energy carried by the wave depends on the amplitude. The larger the amplitude is, the greater the wave energy. In some discussions it is important to distinguish between positive and negative amplitudes. These displacements are shown in the following diagram (fig. 2.14).

Sometimes it is necessary to discuss amplitude at a certain point along the wave. Several of these amplitudes are shown in the diagram. Notice in the above diagram that two of the amplitudes are positive and two are negative. In general, if the question simply is 'What is the amplitude of the wave?', the answer follows the description of amplitude shown in the first of the above four amplitude diagrams. It is the maximum positive displacement of the medium from its undisturbed position to the top of a crest.

In many discussions, though, the term amplitude takes on a slightly more complicated meaning. For example, in a discussion about wave interference the later descriptions of positive and negative amplitudes at certain points would surface. In such contexts, amplitude means the displacement of the medium from its undisturbed position to its disturbed position at a certain point along the wave.

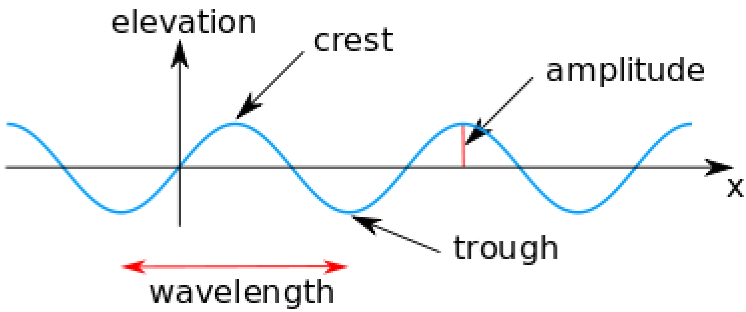


Figure 2.14 Several of these amplitudes

To sum up amplitude, we would say:

- it is the displacement of the medium from its normal position;

- usually this simply means the maximum positive displacement.

Often, especially in discussions about interference, amplitude means the displacement of the medium from its normal position at certain points, and this displacement can be positive or negative.

To quantify mathematically, assume the displacement of a wave at an arbiatary fixed point and variable time is given by the expression *x(t)=Asinωt*, where *A* is the amplitude, and *ω* is the angular frequency given by *ω*=2*πν*. Remembering *υ=νλ* you can express the angular frequency in terms of velocity and wavelength if you want.

So, to find the «vertical velocity» you differentiate the expression for the displacement with respect to time, to give $\upsilon_{vert}=\omega A\cos\omega t$.

This is clearly at a maximum when *cosωt=1*, so the maximum vertical velocity is $\upsilon_{vert}=\omega A$.

If you start from an analysis of origin centred circular motion in the cartesian plane you have the expression y=rcosωt We know that *ω=2π/T*, *ω=2πν* and that *λ=2πr* (circumference of circle). There fore *2π=ων*.

Which gives *λ=ωrν* so f *λ=ωr=ν*.

$S = f(t, x, y, z)...,$

$S(x,t) = S_0 \cos\left[\omega\left(t \mp \frac{x}{\upsilon}\right)\right]$ - equation of running plane wave,

$\omega\left(t \mp \frac{x}{\upsilon}\right)$ - wave phase,

$k = \frac{2\pi}{\lambda}$ - wave number.

The wave number is equal to the number of waves consisting of a segment of length [40].

When considering wave propagation, there are two main kinds of waves, ***transverse*** waves, and ***longitudinal*** waves.

Transverse waves are those in which the wave components (i.e. the individual parts of the medium that is transferring the wave) oscillate in a perpendicular direction to that of the wave motion.

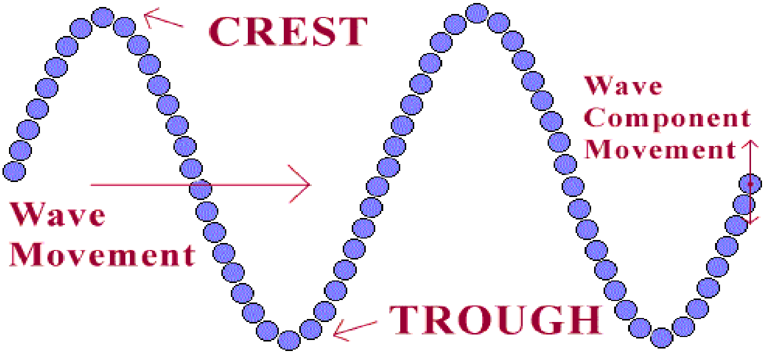


Figure 2.15 Transverse waves [48]

Consider a buoy sitting on the surface of the ocean, for example. As a wave goes by, the buoy rises with the crest of the wave, and falls with the trough. It bobs up and down regularly as the waves pass from one side of it to the other, but it doesn't get carried with the water. The motion of the buoy is in a vertical line, while the water moves horizontally. The ***crest*** of a wave is the highest point that it reaches, while the ***trough*** of the wave is the lowest point. These are respectively the maximum and minimum amplitudes or displacement of the wave.

2.3.4 Investigation property of the compression waves

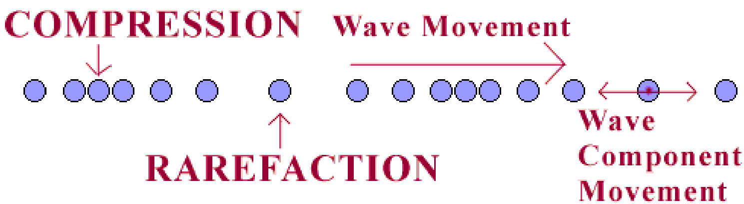


Figure 2.16 Longitudinal waves [48]

So that's for a «physical» wave. We solve Maxwell's equations in free space and we get a nice planar sinusoidal wave as a solution, so the same relation holds.

Some waves are transverse waves. **In** a **transverse wave,** matter moves at right angles to the direction the wave travels.

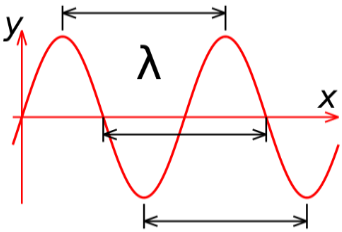


Figure 2.17 Wavelengths transverse wave

Suppose you hold one end of a rubber tourniquet, and fix another one on the immovable article. If you shake your end up and down, a wave will travel along the tourniquet. The tourniquet itself moves only up and down. One up and down motion of the tourniquet at one point is called a vibration.

There are two classes of wave that can distort a physical medium, transverse waves and longitudinal waves.

In transverse waves, the movement of the elements of the medium move orthogonally (at 90°) to the direction of movement of the wave. A typical example of a transverse wave is a wave pattern on the surface of a body of water (eg. on a pond after a stone has been thrown in or ocean waves before they reach the breaking zone). In such a wave the molecules of water move up and down whilst the wave front moves along the surface of the water [41].

In fig. 2.18 a hand induces a transverse wave in a string by periodically moving up and down [49].

This causes the string to move up and down. This movement propagates through the string producing a series of wave fronts which move towards the fixed wall with a velocity *v*. Obviously, individual parts of the string only move up and down (as indicated by the vertical arrows).

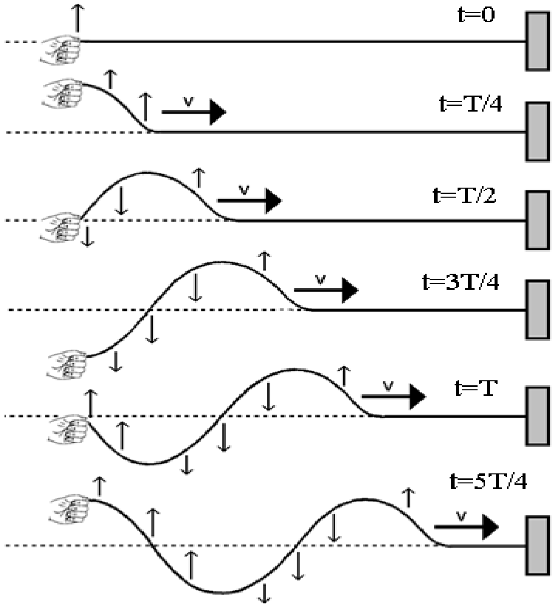


Figure 2.18 transverse wave

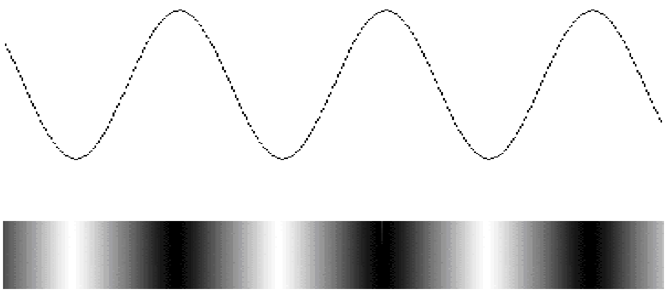


Figure 2.19 Waves are reflected off boundaries

When a wave is reflected from a surface, it usually changes its direction. If you suddenly move your end of the tourniquet up and down, a wave pulse will travel down the tourniquet. When it reaches the article, it will be reflected and returned to you.

In longitudinal waves the elements of the medium move back and forth in line with the direction of propagation of the wave fronts.

In fig.2.19 a hand induces a longitudinal wave in a spring by periodically moving back and forth in line with the direction of the spring [49].

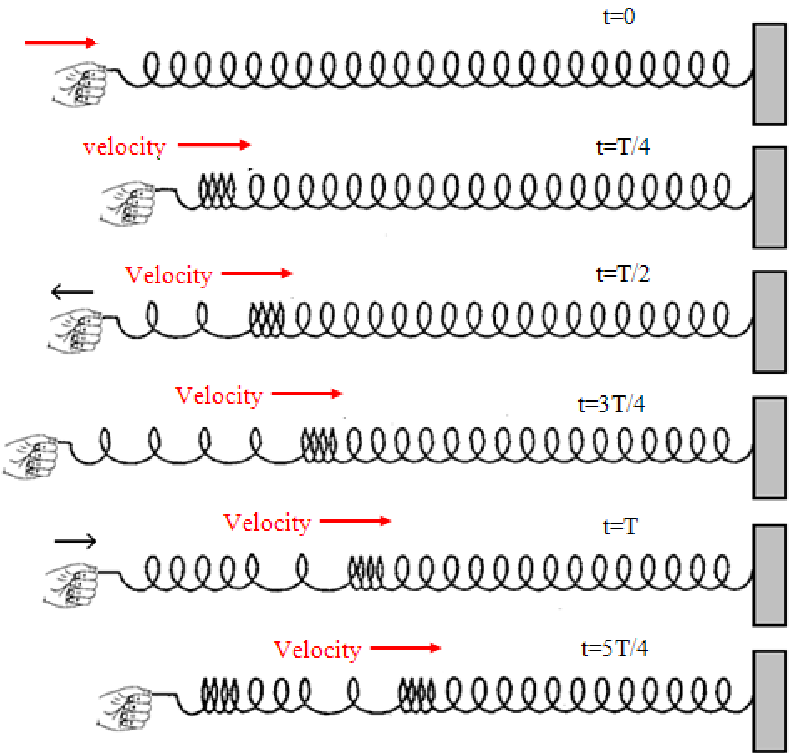


Figure 2.20 Longitudinal wave

This causes the regions of high and low spring compression to move along the spring. This movement propagates through the spring producing a series of wave fronts which move towards the fixed wall with a velocity *v*. Individual parts of the spring only move backwards and forwards short distances in the direction of wave propagation. This causes the coils to periodically come closer to and further from adjacent coils than would be the case for the spring at rest. A longitudinal wave is a compression wave in which particles move back and forth in the direction of wave front movement (i.e. longitudinally) [41].

The tasks for self-checking:

1 Write out the terms that describe or characterize a wave.

2 How to calculate frequency, wavelength and velocity.

3 What is a wave? A crest? A trough?

4 What is a compression wave?

5 What is a transverse wave?

6 What controls the amplitude of a wave?

7 How can the distance travelled by a wave be measured?

8 How is the frequency of a wave expressed?

9 How are the frequency and period of a wave related? In what units are frequency and period measured?

10 Show on the figure: **wavelength,** amplitude, crest, trough of a wave.

2.3.5 Investigation property Frequency of a Wave of waves

The ***frequency*** is a count of the number of waves that pass a given point in one unit of time. As the number of waves that pass a given point in one unit increases, the frequency increases, fig. 2. 21.

Calculating the frequency of a repeating event is accomplished by counting the number of times that event occurs within a specific time period, then dividing the count by the length of the time period.

The frequency of a wave is measured in a unit called a

Hertz. One ***Hertz*** (*Hz*) is one wave per second. The frequency and wavelength of waves at a given velocity are related $\nu = \frac{\upsilon}{\lambda}$. A wave with a long wavelength has a low frequency. As the wavelength decreases, the frequency increases.

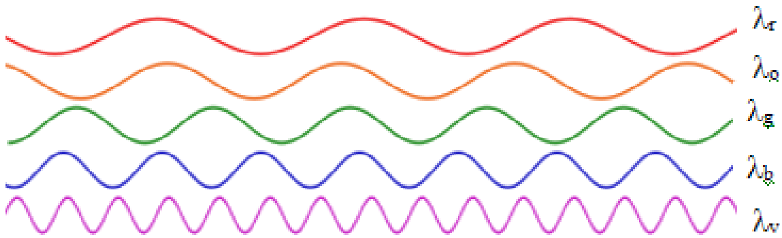


Figure 2.21 Calculating the frequency [50]

Period The time between two adjacent peaks is same and also the time between two adjacent troughs always the same, no matter which two adjacent troughs you pick. The time you have been measuring is the time for one wavelength to pass by. We call this time the period and it is a characteristic of the wave.

Waves have a characteristic time interval which we call the period of the wave and denote with the symbol T. It is the time it takes for any two adjacent points which are in phase to pass a fixed point. The units are seconds (*s*) [40].

2.3.6 Investigation property Velocity of a Wave of waves

The wave velocity is the distance traveled by any point on the wave in one second. The velocity of a wave depends mainly on the material through which it is passing. For example, the velocity of waves along a tourniquet is lower in heavy thick tourniquet than in a thin light tourniquet. The velocity of a wave is equal to the product of its frequency and wavelength.

velocity = wavelength x *frequency*, $\upsilon=\lambda\nu$.

The symbol for the Greek letter «lambda» is λ. It is the symbol for wavelength. You can calculate any one of the three values in the equation above if you know the other two.

Example 1 Calculating the Velocity of a Wave

A tuning fork has a frequency of 256 *Hz*. The wavelength of the sound produced by the fork is 1,32 meters. Calculate the velocity of the wave.

Given: wavelength of wave λ=1,32 *m* wave (υ) **Unknown:** velocity of frequency of wave

Basic Equation: ν=256 Hz $\upsilon=\lambda\nu$

Solution: $\upsilon=\lambda\nu$

υ=1,32*m*x256*Hz*=338 *m/s*

Example 2 Calculating the Frequency of a Wave

A wave has a wavelength of 1,20 meters. Its velocity is 0,5 meters.

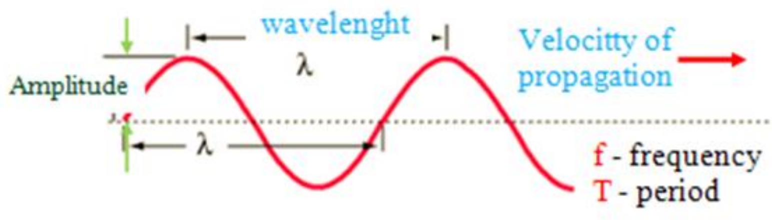


Figure 2.22

The motion relationship «distance = velocity x time» is the key to the basic wave relationship. With the wavelength as distance, this relationship becomes $\lambda = vT$. Then using $f=1/T$ gives the standard wave relationship, $v=f\lambda$.

Given: wavelength of wave **Unknown:** frequency of λ=1,20 wave (ν) velocity of wave.

Equation = 0,75 *m/s* Solution: $\upsilon=\lambda\nu$, $\nu=\upsilon/\lambda$ =

(0,75 *m/s*)/(1,2*m*)= 0,63 *Hz*.

Practice problems

1 What is the velocity of a wave with a frequency of 760 *Hz* and a wavelength of 0.45 *m*?

2 A wave has a velocity of 330 *m*/*s*. Its wavelength is 15 *m*. Calculate the frequency of the wave. How are frequency, wave length, and velocity related?

Review

1 What is the amplitude of a rope wave? What determines it?

2 What do you mean when you say that a certain tuning fork has a frequency of 512 *Hz*?

3 How does increasing the frequency of the wave change the wavelength? The velocity of the wave does not change.

4 A wave has a velocity of 345 *m*/*s*. Its frequency is 2050 *Hz*. Find its wavelength.

5 Draw two transverse waves on a piece of paper. Use a ruler to give both the same wavelength. Make one with an amplitude twice the other, *b*. Now draw two more transverse waves having the same amplitude. Make one with a wavelength twice the other.

2.3.7 Investigation property Compressional Waves

Waves in a rope are transverse waves. You can also produce transverse waves in a coil spring by shaking it from side to side. You can produce a different kind of wave in a coil spring by pinching together several coils and releasing them. The disturbance you created in the spring moves forward along the spring.

Coils of the spring move forward and backward with a rhythmic motion. At times, some of the coils in the spring wave are compressed or squeezed close together. These areas are called compressions. At other times, these same coils are moved apart.

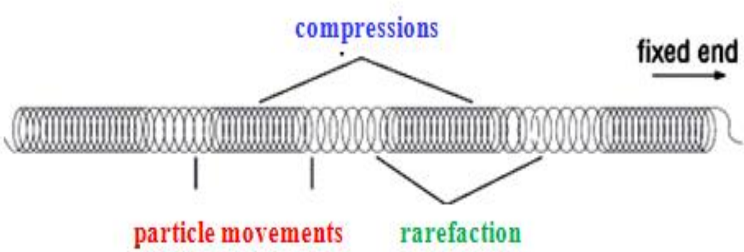


Figure 2.23 Compression wave

These areas are called ***rarefactions***. This type of wave is called a compressional wave. **In** a ***compressional wave,*** matter vibrates in the same direction as the wave travels. Compressional waves are sometimes called longitudinal waves.

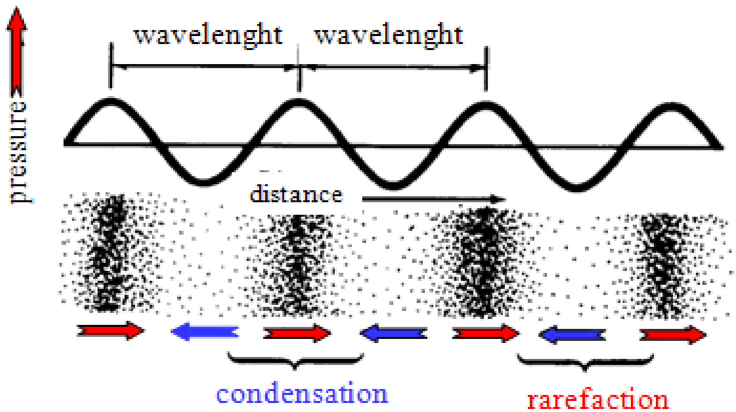


Figure 2.24 Shows the relationship between a transverse wave and a compressional wave

The crest of the transverse wave corresponds to the greatest compression of the compressional wave. The trough corresponds to the greatest rarefaction. Like transverse waves, compressional waves have wavelengths, frequencies, amplitudes, and velocities. The greater the amount of compression of each wave, the greater the amplitude, and hence the greater the energy carried by the wave.

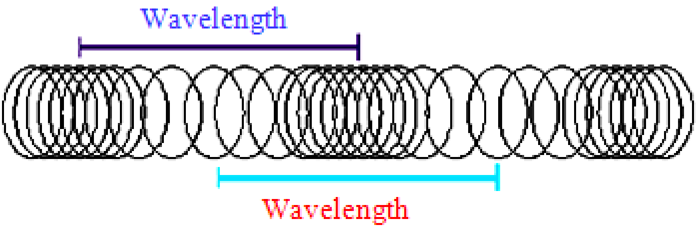


Figure 2.25

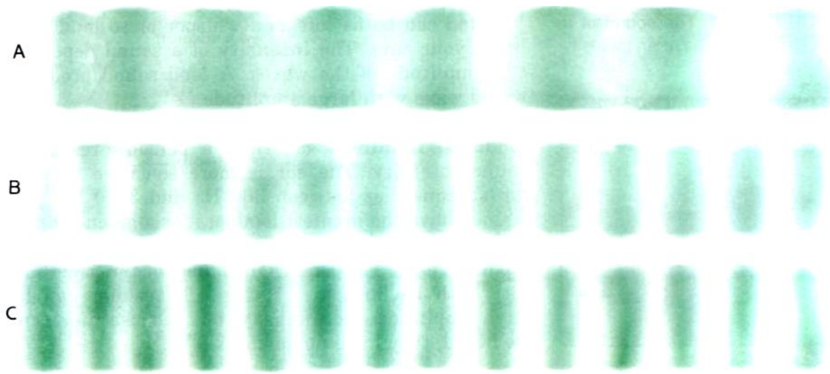


Figure 2.26 A sound wave is a compressional wave traveling through matter

Is sound a wave process? Have you ever considered the many ways humans use sound? Think about the tremendous variety of sounds that are produced, and the ability of the ear and mind to distinguish one from another. Yet we know that sound is only a wave, a rhythmic disturbance of the air that carries energy. The sound waves are characterized by a wavelength, amplitude, a frequency, a period, a velocity, energy. The sound waves are compressional.

Some fish use sound for defense or to attract a mate. By vibrating their swim bladder or rubbing parts of their skeleton together, they can produce squeaks, whistles, coughs, and grinding noises. How is a compressional wave different from a transverse wave?

The diagram compares compressional and transverse waves. The amplitude of a compressional wave depends on the amount of compression.

2.3.8 Investigation property Velocity of wave

The ***velocity of sound*** depends on the matter that carries it. The velocity of sound at 0°*C* in dry air is about 332 *m/s*. Sound travels faster through warm air than through cold air. At 20°*C* sound travels through air at 344 *m/s*. Sound travels much faster through liquids and solids than through gases. The velocity of sound in some common materials is shown in table 2.3.8. Velocity of sound through various substances at 0^{o} C.

Table 2.3.8

	Velocity (*m/s*)		Velocity (*m/s*)
Air	332	Iron	5103
Water	1454	Stone	5971
Wood	3828		

For example, you can discover how far away a thunderstorm is by measuring the time interval between the time you see the lightning and the time you hear the thunder. Suppose you find that the thunder arrived 3 seconds after the lightning that caused it. Using $d = v \times t$, you find that $d = (344\ m/s)(3\ s) = 1032\ m$, or about 1 *km*.

Sound waves are compressional waves produced by vibrating matter. The frequency of sounds that can be heard by most people are between 20 *Hz* and 20 000 *Hz*. Large animals, such as elephants, can hear sounds below 20 *Hz*.

Sounds above 20 000 *Hz* are called ultrasound. Some animals can hear ultrasound. For example, a dog can hear sounds with frequencies over 25 000 *Hz*.

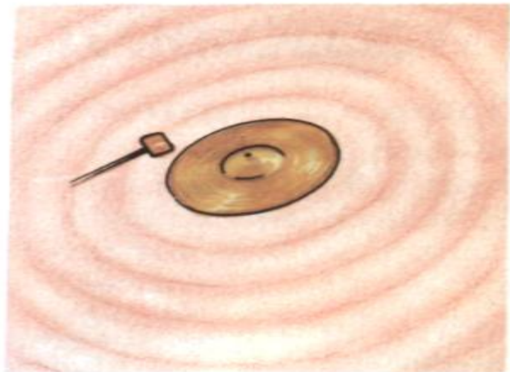


Figure 2.27 Sound waves are produced when objects, such as a cymbal, vibrate

Ultrasounds have many uses. They can be used to produce pictures of hidden parts of an object without damaging the object. For example, they can be used to form an image of a baby in the womb without danger to either mother or unborn child.

Some cameras find the distance to the subject of the photograph in the same way bats find the distance to their prey. The camera emits a short burst of ultrasound, measures the time it takes the pulse to return to the camera, and adjusts the lengths accordingly.

The ultrasound is produced and detected by the same unit, called ***a transducer***. It has a 3-millimeter thick, gold-plated plastic foil that is 38 *mm* in diameter. An electrical signal causes it to vibrate at a frequency of 50 *kHz*. The electronic circuits then listen for the returning echo. Ultrasound waves that bounce off the subject and return to the camera vibrate the foil, producing a tiny electrical signal. Echoes from subjects as close as 40 *cm* and as far as 10 *m* can be detected. The electronic circuits can measure the distance to an accuracy of a few **centi**meters, allowing precise control of the focus of the camera.

Sound can be as soft as a whisper or so loud that it hurts your ears. The **intensity** of a sound depends on the amplitude of the waves. A loud sound produces a sound wave with large amplitude.

Figure 2.28 The sound of a jet engine may have an intensity of 140 decibels

The ear is more sensitive to sounds with frequencies between 300 *Hz* and 3000 *Hz*.

Investigation property Common Noise Sound Levels

- 30 *db* - Whisper
- 60 *db* - Normal conversation
- 80 *db* - Ringing telephone
- 90 *db* - Hair dryer, power lawn mower
- 98 *db* - Hand drill
- 105 *db* - Bulldozer
- 110 *db* - Chain saw
- 120 *db* - Ambulance siren
- 140 *db* - Jet engine take-off
- 165 *db* -12-gauge shotgun blast lower than TV stations.

Radio waves in this range are reflected when they reach Earth's ionosphere. The ionosphere is a layer of plasma, or electrically charged particles, in the atmosphere starting about 80 kilometers above Earth's surface. Shortwave broadcasts can be received at great distances from the station because of this reflection.

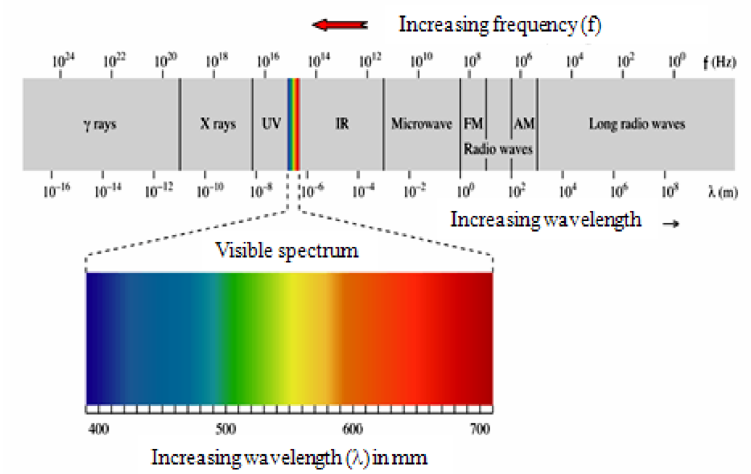


Figure 2.29 [50]

The portion of the electromagnetic spectrum that has frequencies slightly higher than those of radio waves is called the ***microwave*** region [50].

This range is from about 1,000 million *Hz* to 300,000 million *Hz*. Microwaves are often used to send telephone messages, television programming, and computer information across the country or from Earth to a satellite and back. Dish-shaped antennas are used to transmit a narrow beam of microwaves to another dish.

In a microwave oven, the energy travels from the source of the radiation to the food in the oven. When absorbed, the radiation causes the molecules in the food to rotate and vibrate more.

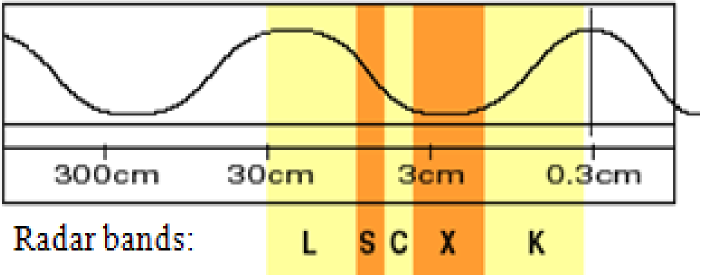


Figure 2.30 Microwave region of the Electromagnetic spectrum

That is, the radiant energy is converted into thermal energy. As this kinetic energy increases, the temperature rises, and the food cook. Microwaves are directly absorbed by the food, not by the container. Glass or paper cooking dishes are used because they allow microwaves to pass through. Metal containers, however, reflect the waves, and cannot be used.

Figure 1.31

Figure 1.32

2.4 Investigation property Infrared Radiation

Electromagnetic radiation with wavelengths just longer than light is called ***infrared***. Most substances produce ***infrared*** waves. Such waves have frequencies higher than those of microwaves. The hotter the object, the greater the infrared radiation. Ordinary incandescent lights produce far more infrared waves than they do visible light.

Infrared radiation has wavelengths between 200 micrometers (0,2 *mm*) and 0,7 micrometers (0,0007 *mm*). Infrared radiation is produced by all hot objects. When an object absorbs infrared radiation, the molecules vibrate, increasing the temperature of the object [52].

Infrared radiation was discovered by the English astronomer Sir William Herschel in 1800. Herschel found, by putting a thermometer at various points in a prismatic spectrum, that ordinary light transmits some heat but that the effect is even more marked beyond the red end of the spectrum.

The amount of infrared radiation produced by an object depends on its temperature.

The higher the temperature, the more radiation. Infrared radiation is just as important to the Earth's weather and climate as sunlight is. This is because, for all of the sunlight that the Earth absorbs, an equal amount of IR radiation must travel from the Earth back to outer space. If this was not the case, there would be global warming or global cooling.

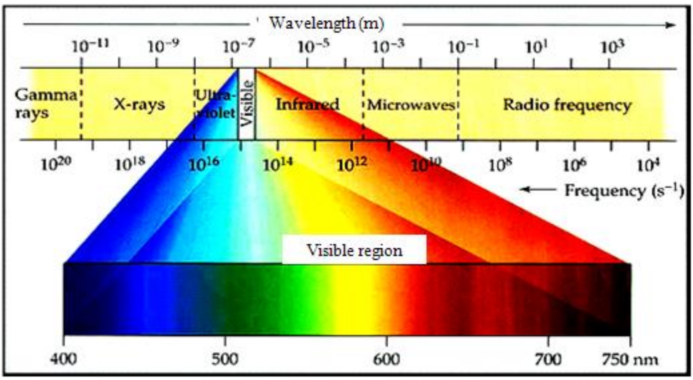


Figure 2.33

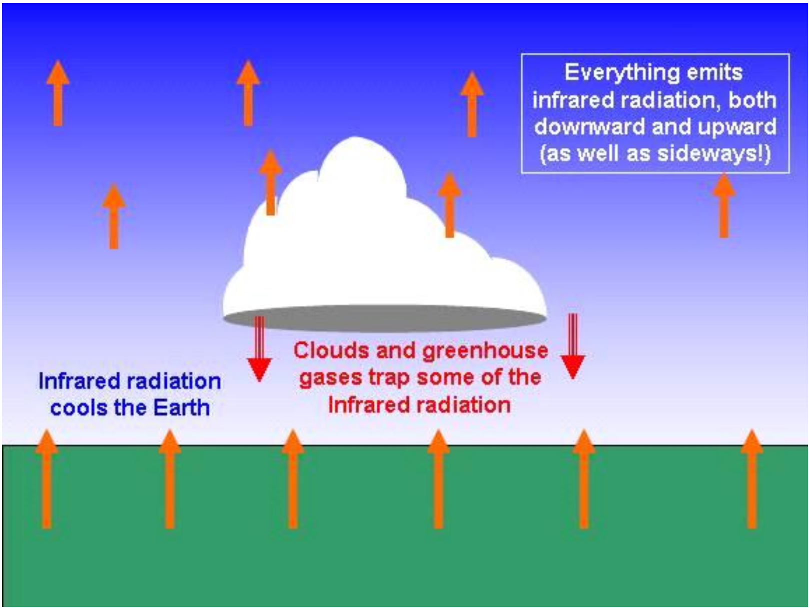


Figure 2.34 Everything emits infrared radiation, both downward and upward [52]

2.4.1 Investigation property Visible Radiation

Visible light is only a small portion of the electromagnetic spectrum. People use other kinds of electromagnetic radiation in television, radio, citizen's band (CB) and shortwave radios, radar, and microwave ovens. The frequencies of these invisible waves are higher or lower than the frequencies of visible waves.

Light, or ***visible radiation,*** has wavelengths between about 700 and 400 10^{-9} nanometers. Light is produced by very hot objects. For example, in an ordinary incandescent lamp the tungsten wire is at about 2400°C. Light is often detected by its effects on molecules and solids. In green plants, light causes a series of chemical reactions called ***photosynthesis***. In the eye, rods and cones contain large molecules that change shape when a tiny amount of light strikes them.

A ***laser*** is a light source that produces a bright narrow beam of light. Light produced by a laser is all of one color or wavelength. Laser light is also coherent. In ***coherent light,*** the crests and troughs of the light waves are all lined up together. A laser pulse may be many millions of wavelengths in length. In these ways, laser light is different from other light sources. Light from the sun or from lamps is a mixture of waves with different wavelengths and directions.

Lasers are made with different kinds of crystals, liquids, and gases. One kind of laser, the helium-neon laser, uses a hollow glass tube with mirrors at two ends. One mirror is totally reflecting while the other allows some light to escape. The tube is filled with a mixture of helium and neon at low pressure. An electrical spark is sent through the gases, turning them into plasma. The electrical energy is changed into energy stored in the neon atoms, which is then released as red light. The light is reflected back and forth between the two mirrors. This light causes other atoms to release their energy as light. The intensity of the light increases, and all the waves have their crests and troughs aligned. The coherent waves leave the partially reflecting mirror at one end of the tube as a narrow beam of red laser light. Some lasers produce blue, green, or yellow light or infrared radiation. Note that lasers are not energy sources. Lasers merely convert one form of energy into light energy. Even though the laser beam is extremely bright, lasers are very inefficient. Most lasers convert less than 1% of their energy source into light energy.

Lasers made of small crystals of alloys of gallium, aluminum, and arsenic are becoming important. They change electrical energy directly into light energy. Opposite faces of the crystal are polished to form the two mirrors.

Crystal lasers produce very tiny beams of light or infrared radiation.

Lasers have an increasing number of uses. The straight narrow beam is used by surveyors as a guide to build tunnels, roads, and bridges. Beams of intense laser light can be used to cut and weld pieces of metal. Lasers can be used in delicate surgery, such as welding a retina to the back surface of the eye. They are used to produce spectacular light shows and in supermarkets to read bar codes on food products. Crystal lasers are used in compact disk players and to transmit messages over optical fibers.

2.4.2 Investigation property Ultraviolet radiation

Investigation property Ultraviolet radiation has wavelengths shorter than light. It therefore has higher energy. It is produced by very hot objects such as the sun, or by special lamps called «black lights». When sunlight strikes your body, the ultraviolet radiation enables cells in your skin to produce vitamin D. This vitamin is needed for healthy.

Ultraviolet radiation can also kill living cells. For this reason, hospitals often use ultraviolet lamps to kill harmful bacteria.

When you tune your radio to your favorite station, you are selecting ***radio waves*** of a certain wavelength. Common radio waves have very long wavelengths from about 1 *m* to 10 *km* long. They have a frequency range between about 30 000 *Hz* and 30 000 000 *Hz*. The number assigned to a station is related to its frequency.

Investigation property X-rays and ***gamma rays*** are electromagnetic waves with the shortest wavelengths, less than 0.1 micrometer, and the highest energy. In an *X*-ray source, electrically charged particles are given large kinetic energy. These particles then crash into other matter, where some of their kinetic energy is changed into *X*-ray radiation.

Gamma rays are produced in the center, or nucleus, of radioactive atoms.

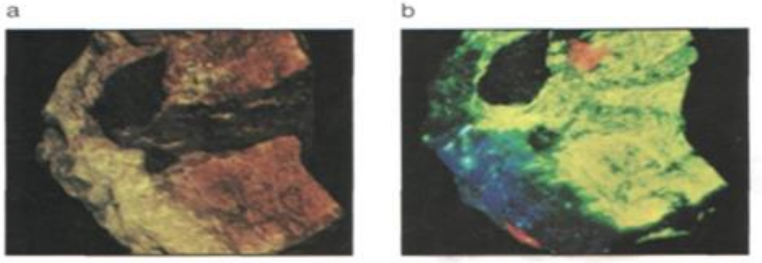


Figure 2.35 Many rocks contain minerals that fluoresce (b) under ultraviolet radiation bones and teeth

On the 8th of November 1895, the German scientist W.K. Roentgen investigated cathodic rays. He noticed that a fluorescent-coated plate near the glass glowed with green light. He did not know what kind of radiation made the plate glow, so he called the unknown radiation, *X*-rays. He made the first *X*-ray photo of his wife's hand with a ring. In 1901 he got Nobel Prize. Today doctors use sensitive photographic film rather than a fluorescent plate to detect *X*-rays.

Figure 2.36

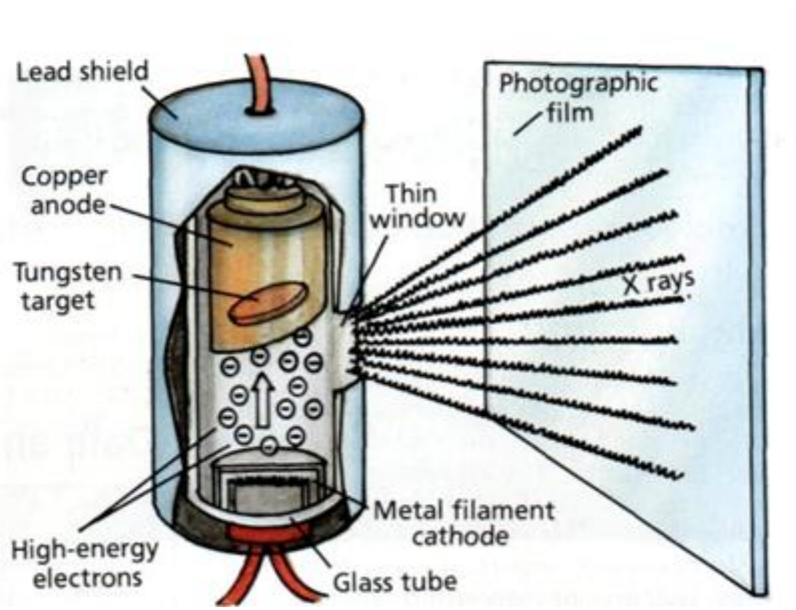


Figure 2.37 X rays are absorbed more by bone than by soft tissue (a). High-speed electrons striking the tungsten target causes its atoms to give off X rays (b) [40]

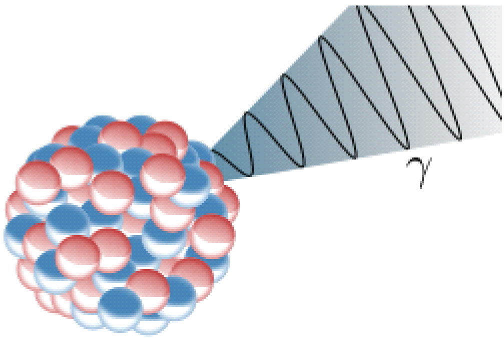


Figure 2.38

The tasks for self-checking:

1 How can a rope be a model of an electromagnetic

wave?

2 Why is FM radio often less noisy than AM radio?

3 Describe how microwaves cook food?

4 How could you detect ultraviolet radiation in a dark room?

5 How do *X*-ray photographs aid physicians and dentists in their work?

Light is the only visible part of the electromagnetic spectrum. Our eyes are sensitive to a range of wavelengths, which we see as different colors. White light is a mixture of these colors. The colors of the objects we see depend on the color of the light that falls on them and on how they reflect that light into our eyes.

A gamma ray is a packet of electromagnetic energy-γ photon. Gamma photons are the most energetic photons in the electromagnetic spectrum. Gamma rays (gamma photons) are emitted from the nucleus of some unstable (radioactive) atoms.

Alpha Particles. Certain radionuclides of high atomic mass (Ra^{226}, U^{238}, Pu^{239}) decay by the emission of alpha particles. These alpha particles are tightly bound units of two neutrons and two protons each ($_2He^4$ nucleus) and have a positive charge. Emission of an alpha particle from the nucleus results in a decrease of two units of atomic number (Z) and four units of mass number (A). Alpha particles are emitted with discrete energies characteristic of the particular transformation from which they originate. All alpha particles from a particular radionuclide transformation will have identical energies.

Beta Particles. A nucleus with an unstable ratio of neutrons to protons may decay through the emission of a high speed electron called a beta particle. This results in a net change of one unit of atomic number (Z). Beta particles have a negative charge and the beta particles emitted by a specific radionuclide will range in energy from near zero up to a maximum value, which is characteristic of the particular transformation.

2.4.3 Investigation property Light and Matter

You see objects because they reflect light. Some objects reflect more light than others. Dark rough objects reflect little light. Light-colored or white objects reflect much more light. They are more visible in dimly lighted rooms.

The range of wavelengths for electromagnetic waves – from the very long to the very short is called the Electromagnetic Spectrum:

- ***Radio*** and ***TV*** waves are the longest usable waves, having a wavelength of 1 mile (1.5 kilometer) or more.
- ***Microwaves*** are used in telecommunication as well as for cooking food.
- ***Infrared*** waves are barely visible. They are the deep red rays you get from a heat lamp.
- ***Visible light*** waves are the radiation you can see with your eyes. Their wavelengths are in the range of 1/1000 centimeter.
- ***Ultraviolet*** rays are what give you sunburn and are used in «black lights» that make object glow.
- ***X-rays*** go through the body and are used for medical purposes.
- ***Investigation property Gamma rays*** are dangerous rays coming from nuclear reactors and atomic bombs. They have the shortest wavelength in the electromagnetic spectrum of about 1/10,000,000 centimeter.

Electromagnetic waves are transverse waves, similar to water waves in the ocean or the waves seen on a guitar string. This is as opposed to the compression waves of sound. As you learned in Wave Motion, all waves have amplitude, wavelength, velocity and frequency.

The velocity of electromagnetic waves in a vacuum is approximately 300,000 kilometers per second, the same as the speed of light.

When electrons move, they create a magnetic field. When electrons move back and forth or oscillate, their electric and magnetic fields change together, forming an electromagnetic wave. This oscillation can come from atoms being heated and thus moving about rapidly or from alternating current electricity.

Electromagnetic radiation is emitted from all matter with a temperature above absolute zero. Temperature is the measure of the average energy of vibrating atoms and that vibration causes them to give off electromagnetic radiation.

Visible light is emitted from matter hotter than about 700 degrees Celsius. This matter is said to be incandescent. The sun, a fire, and the ordinary light bulb are incandescent sources of light.

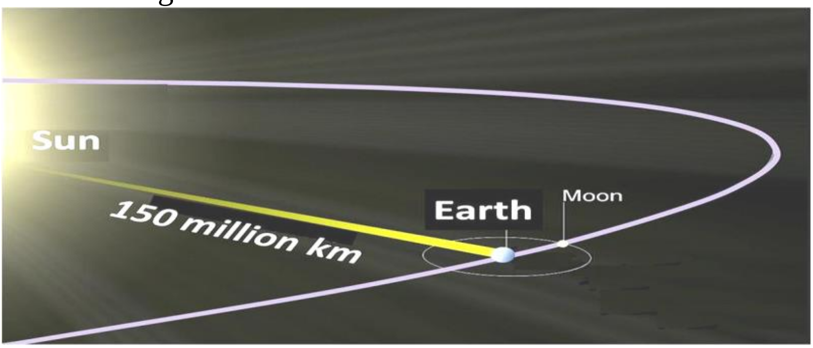


*Figure 2.39 The **speed of light** in vacuum, usually denoted by **c**. Its value is 299,792,458 metres per second*

There are a number of different types of detectors of electromagnetic radiation. We know the common ones for detecting visible light: the eye, camera film, and the detectors on some calculators. Your skin can also detect both visible light and infrared heat rays.

2.4.4 Investigation property THE NATURE OF LIGHT

Energy that is carried through space by waves is called ***radiant energy***. One property of radiant energy is that the higher the frequency of the waves, the greater the energy they have. Frequency is the number of waves produced in a given time. Visible light, the energy to which people's eyes are sensitive, is only one of many kinds of light waves. Each different kind of wave in the spectrum has a different frequency. But they all travel at the same speed and behave in a similar fashion.

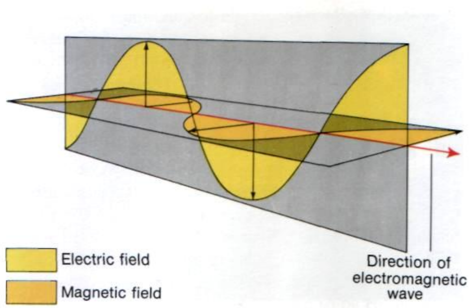


Figure 2.40 Radiant energy (light) is carried through space by electromagnetic waves. These waves move at right angles to electric and magnetic fields [40]

Electromagnetic waves are related to both electricity and magnetism. The energy of the electromagnetic radiation moves at right angles to electric and magnetic ***fields***. These are regions in which the energy may make itself felt, as shown in fig. 2.40. Waves like these are called ***transverse*** (trans-VERS) waves.

Chapter 3
GEOMETRIC OPTICS

3.1 Study of Geometric Optics

In this set of lab exercises, the basic properties geometric optics concerning converging lenses and mirrors will be explored. The goal of the experiment is to be able to analyze ray diagrams so as to determine fundamental properties of image formation. The results determined from the ray diagrams will be compared to the mathematical formulas governing image formation.

General Theory in the previous lab exercise, resection and refraction from at surfaces was explored. In this set of experiments, the resection from a curved mirror and refraction through curved lenses will be explored.

There are two ways to describe the curved objects used in these experiments. The first is by the shape of the object. A lens or mirror that bulges outward from its center is referred to as a *convex* lens or mirror. A lens or mirror that curves inward is a *concave* lens or mirror. In addition to the shape, lenses and mirrors are classied by their response to light rays, that is incident light rays reflect or mirrors and refract through lenses.

As will be seen, light rays incident on a concave mirror are reflected and *converge to a point. For this reason, concave mirrors are also referred to as converging mirrors.*

Remer starts with an order of magnitude demonstration that the speed of light must be so great that it takes much less than one second to travel a distance equal to Earth's diameter, fig. 3.1 [53].

The point ***L*** on the diagram represents the second quadrature of Jupiter, when the angle between Jupiter and the Sun (as seen from Earth) is 90. Romer assumes that an observer could see an emergence of Io at the second quadrature (***L***), and also the emergence which occurs after one orbit of I_o around Jupiter (when the Earth is taken to be at point ***K***, the diagram not being to scale), that is 42½ hours later. During those 42½ hours, the Earth has moved further away from Jupiter by the distance ***LK***: this, according to Romer, is 210 times the Earth's diameter. If light travelled at a speed of one Earth-diameter per second, it would take 3½ minutes to travel the distance ***LK***. And if the period of I_o's orbit around Jupiter were taken as the time difference between the emergence at ***L*** and the emergence at ***K***, the value would be 3½ minutes longer than the true value.

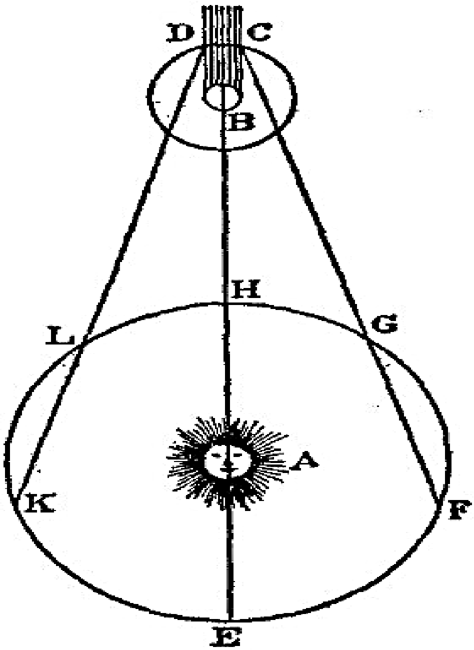


Figure 3.1 Demonstration that the speed of light

Rømer then applies the same logic to observations around the first quadrature (point ***G***), when Earth is moving *towards* Jupiter. The time difference between an immersion seen from point ***F*** and the next immersion seen from point ***G*** should be 3½ minutes *shorter* than the true orbital period of I_o. Hence, there should be a difference of about 7 minutes between the periods of I_o measured at the first quadrature and those measured at the second quadrature. In practice, no difference is observed at all, from which Rømer concludes that the speed of light must be very much greater than one Earth-diameter per second [53].

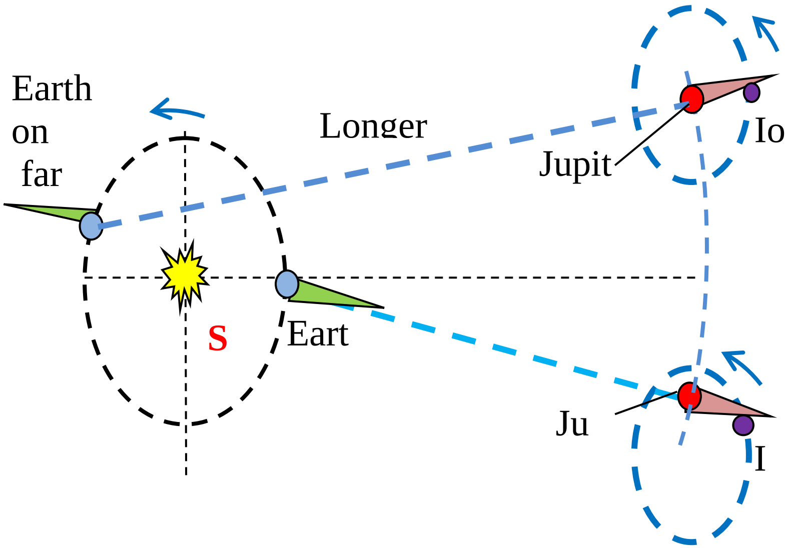


Figure 3.2

Swedish astronomer Pehr Wilhelm Wargentin (1717–83) used Romer's method in the preparation of his ephemerides of Jupiter's moons (1746), as did Giovanni Domenico Maraldi working in Paris.

The remaining irregularities in the orbits of the Galilean moons would not be satisfactorily explained until the work of Joseph Louis Lagrange (1736–1813) and Pierre-Simon Laplace (1749–1827) on orbital resonance.

In 1809, again making use of observations of Io, but this time with the benefit of more than a century of increasingly precise observations, the astronomer Jean

Baptiste Joseph Delambre (1749–1822) reported the time for light to travel from the Sun to the Earth as 8 minutes 12 seconds. Depending on the value assumed for the astronomical unit, this yields the speed of light as just a little more than 300,000 kilometres per second.

The first measurements of the speed of light using completely terrestrial apparatus were published in 1849 by Hippolyte Fizeau (1819–96). Compared to modern values, Fizeau's result (about 313,000 kilometres per second) was too high, and less accurate than those obtained by Rømer's method. It would be another thirty years before A.A.Michelson in the United States published his more precise results (299,910±50 km/s) and Simon Newcomb confirmed the agreement with astronomical measurements, almost exactly two centuries after Rømer's announcement.

A French physicist, Fizeau, shone a light between the teeth of a rapidly rotating toothed wheel [40]. A mirror more than 5 miles away reflected the beam back through the same gap between the teeth of the wheel. There were over a hundred teeth in the wheel. The wheel rotated at hundreds of times a second; therefore a fraction of a second was easy to measure. By varying the speed of the wheel, it was possible to determine at what speed the wheel was spinning too fast for the light to pass through the gap between the teeth, to the remote mirror, and then back through the same gap. He knew how far the light traveled and the time it took. By dividing that distance by the time, he got the speed of light. Fizeau measured the speed of light to be 313,300 Km/s [54].

This table gives some of the best measurements according to Froome and Essen [65].

It has also been suggested that Rømer was measuring a Doppler effect, and this 166 years before Christian Doppler's 1842 discovery [53]. The Doppler effect is the change in observed frequency of an oscillator (in this case, Io orbiting around Jupiter) when the observer (in this case, on Earth's surface) is moving: the frequency is higher when the observer is moving towards the oscillator and lower when the observer is moving away from the oscillator.

Table 3.1

Date	Author	Method	Result (km/s)	Error
1676	Olaus Roemer	Jupiter's satellites	214,000	
1726	James Bradley	Stellar Aberration	301,000	
1849	Armand Fizeau	Toothed Wheel	315,000	
1862	Leon Foucault	Rotating Mirror	298,000	+-500
1879	Albert Michelson	Rotating Mirror	299,910	+-50
1907	Rosa, Dorsay	Electromagnetic constants	299,788	+-30
1926	Albert Michelson	Rotating Mirror	299,796	+-4
1947	Essen, Gorden-Smith	Cavity Resonator	299,792	+-3
1958	K. D. Froome	Radio Interferometer	299,792.5	+-0.1
1973	Evanson et al	Lasers	299,792.4574	+-0.001
1983		Adopted Value	299,792.458	

The Doppler effect is the change in observed frequency of an oscillator (in this case, I_o orbiting around Jupiter) when the observer (in this case, on Earth's surface) is moving: the frequency is higher when the observer is moving towards the oscillator and lower when the observer is moving away from the oscillator. This apparently anachronistic analysis implies that Rømer was measuring the ratio c/ν, where *c* is the speed of light and *v* is the Earth's orbital velocity (strictly, the component of the Earth's orbital velocity parallel to the Earth–Jupiter vector), and indicates that the major inaccuracy of Rømer's calculations was his poor knowledge of the orbit of Jupiter [53].

There is no evidence that Rømer thought that he was measuring c/ν: he gives his result as the time of 22 minutes for light to travel a distance equal to the diameter of Earth's orbit or, equivalently, 11 minutes for light to travel from the Sun to Earth. It can be readily shown that the two measurements are equivalent: if we give τ as the time taken for light to cross the radius of an orbit (e.g. from the Sun to Earth) and *P* as the orbital period (the time for one complete rotation), then $c/\upsilon = P/2\pi$.

Bradley, who *was* measuring c/υ in his studies of aberration in 1729, was well aware of this relation as he converts his results for τ c/υ into a value for τ without any comment [53].

3.2 Experimental study of laws and concepts of geometric optics

We have defined such peculiarities:

1 While conducting the experiments the law of conservation of energy is confirmed. The existing equipment enables to qualitatively and quantitatively eliminate the law of conservation and transformation of energy.

2 It is advisable to introduce the concept of prism, mirror,

lense and combinations of these devices as means of control of light beams

3 To reveal the physical essence and the aperture in the control of the light flux their role in the reception and formation of images on the screen and in the man's eye.

4 There was a problem of clarifying the physical nature of imaginary objects and the role of the eye in this process.

5 To explore the essence of field of view, region of image visibility.

6 To form the notion that geometric optics is based on four laws:

- about the rectilinear distribution of light in a homogeneous environment;
- about the depth of brightness of the image; the independence of the light beams from one from another;
- about the reflection and refraction of the light;
- about conservation and transformation of energy.

7 The border properties of the use of geometrical optics can be broken in the nonlinear phenomena which are supposed to be in a very intense light beams.

Experiment 3.1 Study of the dependence of the refractive index on wavelength

Equipment: Universal projection device (UPD), sliding slot, lens, two physical tripods, cardboard or veneer sheet, a sheet of white paper, a desktop screen, a prism «flint», a pencil, light filters, a screen with a clip for the light filters.

Behind the condenser 1 of the UPD, we fix the sliding slot 2, fig. 2.3, and the lens at the end of the optic bench 3. At the mid-lens height we fix horizontally a cardboard sheet with a sheet of white paper 4, screen 6.

We put the triangular prism «flint» near the lens. 5. Moving the screen, we achieve a clear image of the continuous spectrum. We lead around the position of the prism on a white paper with a pencil and mark the refractive angle.

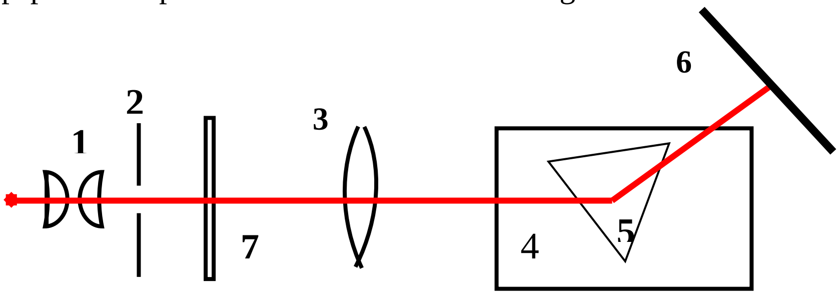


Figure 2.3

We put a screen with a clip for the light filters between a lens and a prism, 7. Alternately, we change the light filters in the clip and mark the position of the refracted rays. For each case, we determine the angle of inclination of the beam and the refractive index n = {sin (A + j) / 2} / {sin (A / 2)}. Since A = 60º, then n = 2sin {(60 + j) / 2}. We build a graph of the dependence of the refractive index on the wavelength.

3.2.1 The nature of reflection. Optics

Your eyes are organs that are sensitive to light. Light passes through the lens of the eye and is focused onto the retina at the back of the eye. Receptors on the retina pick up information and send it to the brain, which interprets the information [40, p. 411].

Frequently, the lens does not properly focus light on the retina. To see clearly, people with this condition need to wear glasses.

Usually, lenses are made by optical mechanics. The lenses must be ground and polished, checked to make certain they conform to the prescription, and put in the eyeglass frames.

Experiment 3.2 The laws of reflection

Equipment: mirror, light, a sheet of cardboard , pencil.

The light that strikes a surface is called **incident,** or incoming, light. Reflected light is the light that bounces off a surface. The light that you see coming from all objects that do not produce light is reflected light. fig. 2.4 shows an incident ray (wave) and its reflected ray (wave). A normal line is a line that is at right angles to another line.

The ***angle*** *i* ***of incidence*** of ray is the angle that the incident ray makes with the normal. The ***angle r of reflection*** of ray is the angle that the reflected ray makes with the normal. How do the angles of incidence and reflection compare in size? They are equal.

The incident ray, the reflected ray and the normal to the reflection surface at the point of the incidence lie in the same plane.

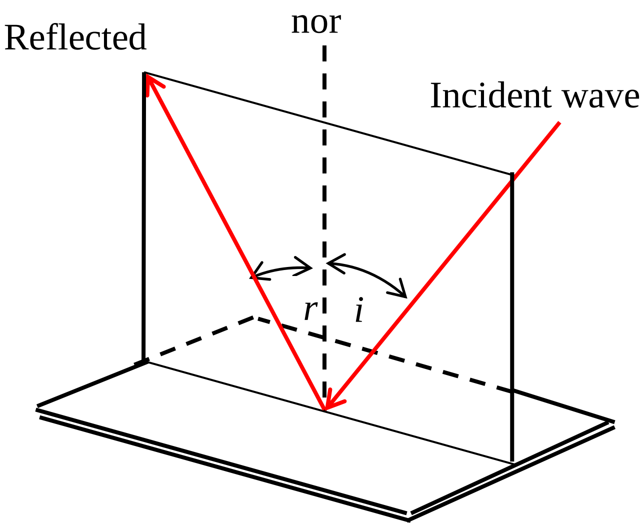


Figure 2.4 The laws of reflection

The angle which the incident ray makes with the normal is equal to the angle which the reflected ray makes to the same normal. Law of reflection: $i=r$, where i is the angle of incidence and r is the reflected angle from the normal. The reflected ray and the incident ray are on the opposite sides of the normal.

3.2.2 Study of Reflected Light

After light has struck a surface and bounced off, it is known as ***reflected*** light. This is the light that is now departing from the surface.

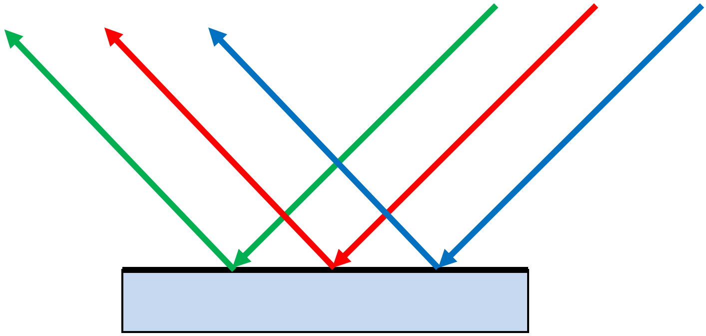


Figure 3.5 Reflected light

When multiple rays of light approach a reflecting surface, each individual ray behaves independently of all the others. Thus, in the fig. 3.5 each of the three incident rays depicted has its own individual angle of incidence, and each reflected ray has its corresponding angle of reflection. If all three angles of incidence are the same and the surface of reflection is perfectly flat as shown, all three angles of reflection will also be the same.

Experiment 3.3 Determination of the angle of incidence and the angle of reflection

Equipment: instrument for geometric optics, mirror.

The ray diagram in fig. 3.6 shows the location of an object's image in a plane mirror. Determine the angle of incidence and the angle of reflection.

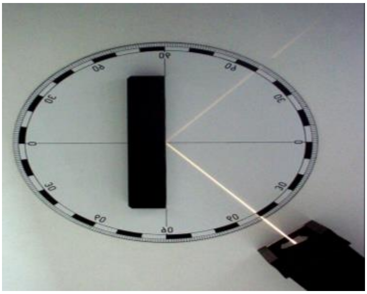


Figure 3.6

We construct an image of an object *h* in plane mirror, fig. 3.7. Notice that the image is «in line» with the object. It seems to be behind the the mirror because reflected rays that strike the eye seem to originate there. You can see this by looking at the dotted-line extensions of the reflected rays.

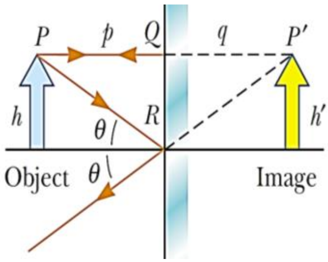


Figure 3.7 [71]

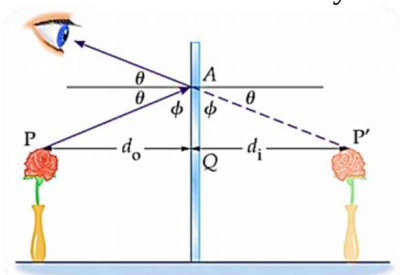


Figure 3.8 [71]

Let's consider the image of the flower in plane mirror, fig. 3.8 and build the image [56].

The exact location of any point on the virtual image is determined by tracing back a number of reflected rays to the point at which they cross behind the mirror [56].

Fig. 3.7 and fig. 3.8 [56] a geometric construction that is used to locate the image of an object placed in front of a flat mirror. Because the triangles *PQR* and *P*/*QR* are congruent, |*p*|=|*q*| and *h*=*h*.

Rays of light from point *P* at the top of the flower appear to originate from point *P*' behind the mirror.

A plane mirror produces a virtual image that appears to be inside the mirror. How does the distance from the object to the mirror relate to the distance of the virtual image «behind» the mirror? The distances are equal [40, p. 400].

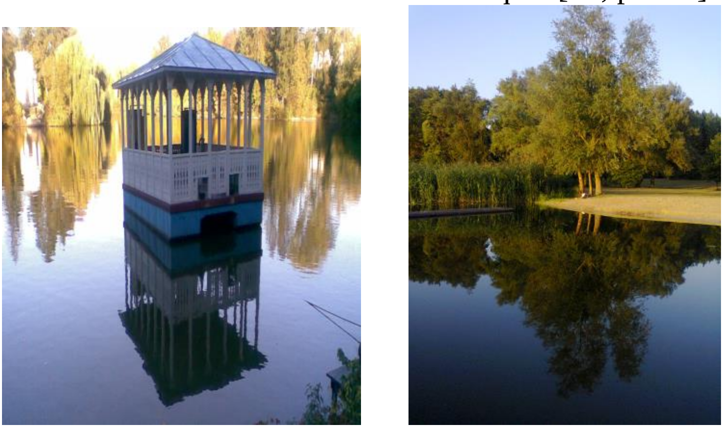


Figure 3.9 The reflection of summer-house in a Sofiy park Uman [55]

3.2.3 Study of Specular reflection

If the reflecting surface is very smooth, the reflection of light that occurs is called ***specular reflection***.

But, that is great for flat surfaces but what about curved surfaces? It works the same way. Simply draw the tangent line to the point of the curve and reflect the light according to the tangent line.

There are actually two types of reflections: specular and diffused.

Specular reflection is reflection from a smooth surface. When light strikes this smooth surface, all the reflected rays are in line with each other.

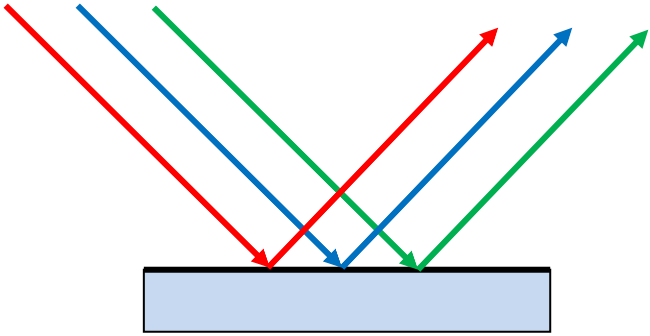


Figure 3.10

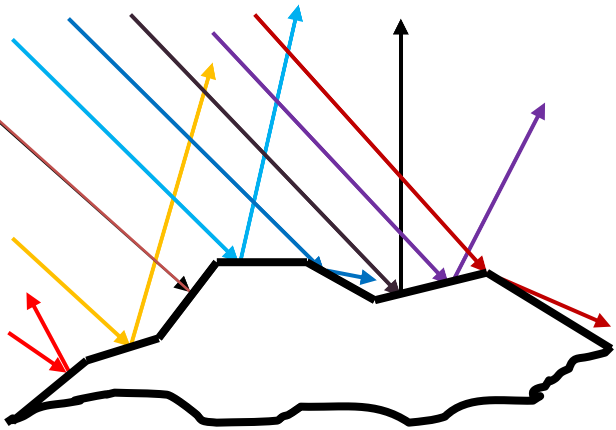


Figure 3.11

Diffused reflection is reflection from a rough surface.

The small bumps and irregularities on a rough surface will cause each of the light rays to reflect in different directions, all following the law of reflection of course.

When the surface is irregular instead of flat, each ray of light still has its angle of incidence and its angle of reflection. However, the angle is measured at the point at which the light strikes the surface. Thus, light striking an irregular surface gets scattered in all directions upon reflection, fig. 3.12.

The Law of Plane Mirrors states that d_i = - d_o. This reflection, like reflections, obeys the Law of Reflection: the angle of incidence equals the angle of reflection. Note that these angles are measured from the normal to either the incident or reflected ray.

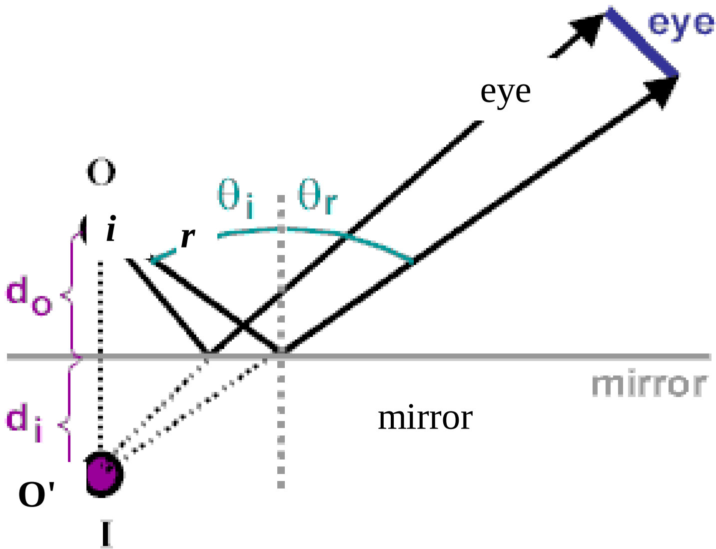


Figure 3.12 Construction of an image in a mirror

Experiment 3.4 Observation of the object in two mutually perpendicular mirrors and the construction of the balloon image

Equipment: two mirrors, located at an angle of 90 degrees, fig. 3.13, a ball *O*.

When an object is placed in front of two mutually perpendicular mirrors as shown, three images are formed. Hang up a ball on a tripod, fig. 3.13. We observe two imaginary images: first in the vertical mirror I_2, and then in the horizontal I_1 [55].

Two flat mirrors are at right angles to each other, as illustrated in fig. 3.13, and an object is placed at point *O*. In this situation, multiple images are formed. Locate the positions of these images.

Solution. The image of the object is at I_1 in mirror 1 and at I_2 in mirror 2. In addition, a third image is formed at I_3. This third image is the image of I_1 in mirror 2 or, equivalently, the image of I_2 in mirror 1. That is, the image at I_1 (or I_2) serves as the object for I_3. Note that to form this image at I_3, the rays reflect twice after leaving the object at *O*.

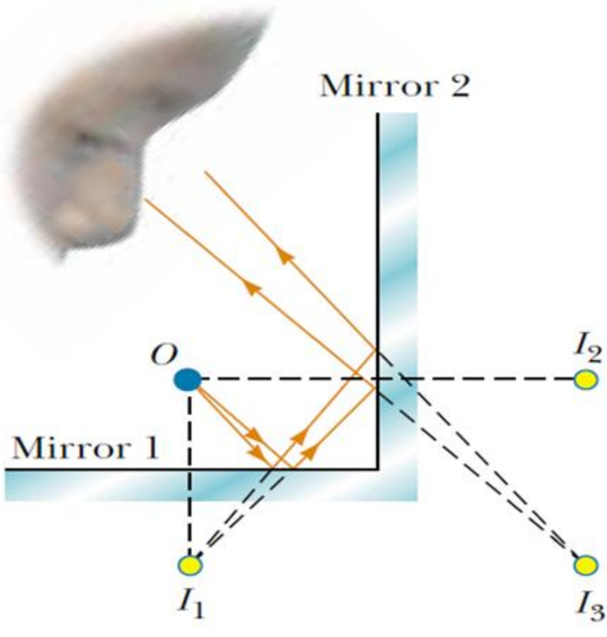


Figure 3.13 Observation of the image in the mirrors [55]

This is the case with ordinary walls and surfaces. Actually, this is all to the good, because it is this scattered reflected light by which we can see such walls and surfaces.

Light always follows the law of reflection, whether the reflection occurs off a curved surface or off a flat surface. The task of determining the direction in which an incident light ray would reflect involves determining the normal to the surface at the point of incidence.

For a concave mirror, the normal at the point of incidence on the mirror surface is a line that extends through the centre of curvature. Once the normal is drawn the angle of incidence can be measured and the reflected ray can be drawn with the same angle. This process is illustrated with two separate incident rays in the diagram.

Studying concave Mirror. A concave mirror, you will recall, curves inward. Its surface is usually a part, or section, of a sphere. An imaginary line called the principal axis passes through the centre of the mirror's surface. All incident rays that are parallel to the principal axis are reflected through the same point. This is called the principal focus, or *F*. Consider reflection from a concave spherical mirror, as shown in fig. 3.14. This mirror is a portion of a sphere of radius *R* whose center is at *C*. *R* is the radius of curvature and is the distance *C* from the mirror.

In this case, the light rays converge after reflecting of the mirror if the object is far enough away from the mirror. This convergence forms an *image*. The distance the object is from the mirror *d*, and the distance of the image from the mirror *f*, are related to the focal *F* length of the mirror by the formula $1/F=1/d+1/f$.

Experiment 3.5 Observation of the image of a candle in a concave mirror

Equipment: spherical mirrors, candles, ruler.

Ray diagrams for spherical convex mirrors, along with corresponding photographs of the images of candles [55].

When the object is located so that the center of curvature lies between the object and a concave mirror surface, the image is real, inverted, and reduced in size.

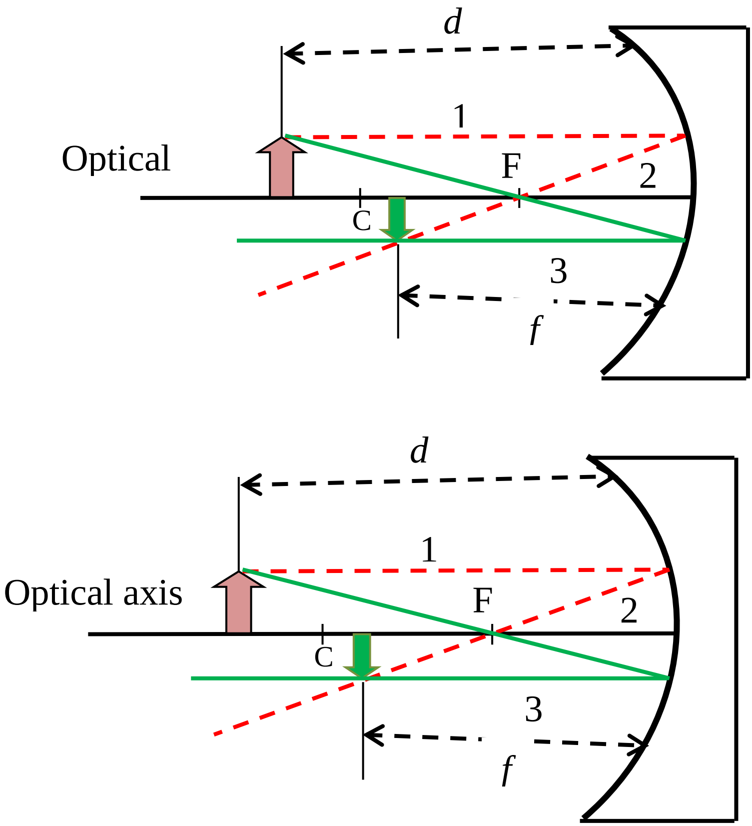


Figure 3.14 Image formations from a curved reflecting surface

Experiment 3.6 Observation of the image of the candle and rose flower in the concave mirror

Equipment: concave mirror, rose flower, dimensional ruler.

We place a concave mirror and a rose flower vertically on the table, fig. 3.18. We change the distance between the flower and the mirror. We observe the image of a rose in the mirror, we make a conclusion.

A concave mirror can make [55] an object appears either smaller or larger. The drawing shows how the reflection of light rays causes a smaller image to be forme.

Figure 3.15 Ray diagram for spherical mirror

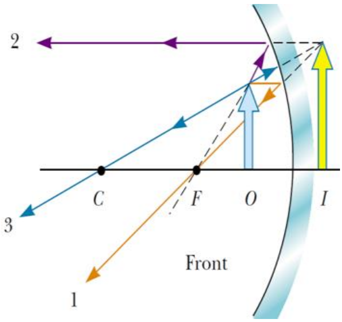


Figure 3.16

Figure 3.17

The image formed by the concave mirror is on the opposite side of the principal axis from the objects. The distance between the image and the principal axis is less than the distance between the object and the principal axis. The image thus appears upside-down, or inverted, and, in this case, is smaller than the object.

Figure 3.18

The image and the object are on the same side of the mirror's surface. Such an image is said to be «real». Light actually passes through a real image and it can be projected onto a screen.

What kind of image do you see when you go to the movies?

Concave reflectors are used for many purposes rather than for mirrors. For example, flashlights and automobile headlights have concave reflectors in them. The bulbs for these lights are located at the principal focus. The rays diverge, or spread out, from there to the mirror. They are then reflected parallel to the principal axis. This produces a beam of very concentrated light rays.

Studying of convex mirror. A convex mirror makes things look smaller. But it has a very large area of reflection. This is why such mirrors are used as outside rear view mirrors on automobiles. They are also used in stores so that security people can see every part of the shopping area. However, convex mirrors give a distorted indication of distance. In such mirrors, things appear to be farther away than they actually are.

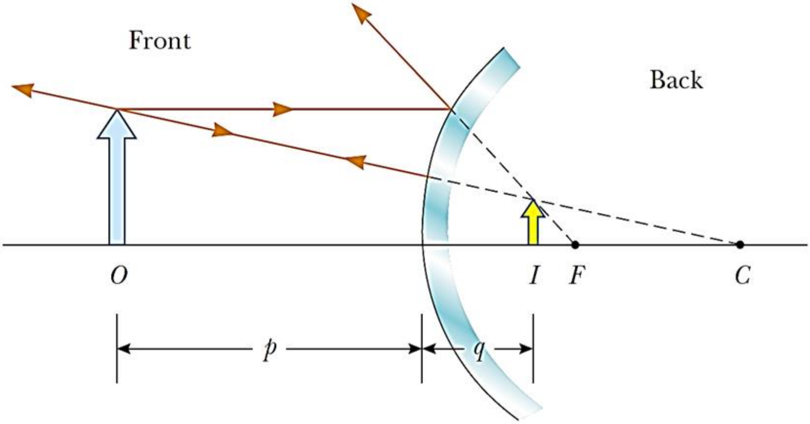


Figure 3.19 Ray diagrams for spherical mirrors, along with corresponding photographs of the images of candles

When the object is located between the focal point and a concave mirror surface, the image is virtual, upright, and enlarged. When the object is in front of a convex mirror, the image is virtual, upright, and reduced in size.

Experiment 3.7 Watching the candle image and building the images in convex mirror and building the image of the subject

Equipment: convex mirrors, candle, measuring ruler.

Place a concave mirror and a candle vertically on the table, fig. 3.20. We change the distance between the candle and the mirror. Watch the candle image and build the image in the mirror, fig. 3.21.

Formation of an image by a spherical convex mirror [55]. The image formed by the real object is virtual and upright.

Study formation of an image by a spherical convex mirror.

Focal length is a parameter particular to a given mirror and therefore can be used to compare one mirror with another. The mirror equation can be expressed in terms of the focal length, fig. 3.19: $1/d+1/f=1/F$.

Figure 3.20

The focal length of a mirror depends only on the curvature of the mirror and not on the material from which the mirror is made. This is because the formation of the image results from rays reflected from the surface of the material [56].

We saw that for an object at infinity, the image is located at the focal point of a concave spherical mirror, where $F = r/2$. But where does the image lie for an object not at infinity? First consider the object shown as an arrow in fig. 3.21, which is placed between *F* and *C* at point *O*.

Example of image formation by a concave mirror [55].

Let us determine where the image will be for a given point *O*' at the top of the object:

a) ray 1 goes out from *O*' parallel to the axis and reflects through *F*;

b) ray 2 goes through *F* and then reflects back parallel to the axis;

c) ray 3 is chosen perpendicular to mirror, and so must reflect back on itself and go through *C* (centre of curvature).

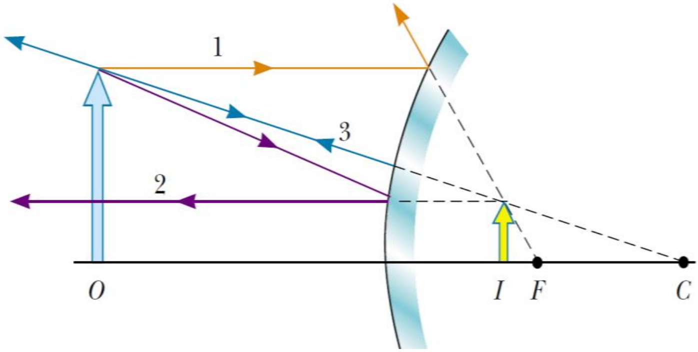


Figure 3.21

To do this we can draw several rays and make sure these reflect from the mirror such that the angle of reflection equals the angle of incidence. Many rays could be drawn leaving any point on an object, but determining the image position is simplified if we deal with three particularly simple rays. These are the rays labelled 1, 2, and 3 in fig. 3.22 and we draw them leaving object point *B′* as follows fig.3.22:

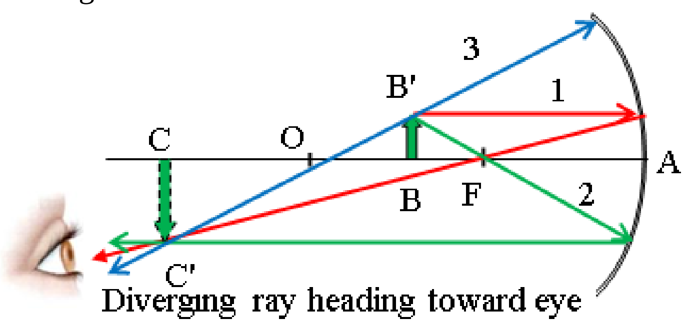


Figure 3.22 [56]

Ray 1 is drawn parallel to the axis; therefore after reflection it must pass along a line through *F* (fig. 3.22). Ray 2 leaves *B*' and is made to pass through *F*; therefore it must reflect so it is parallel to the axis.

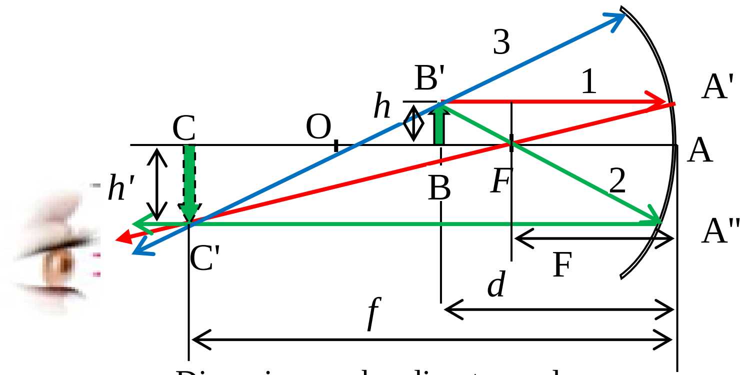
Ray 3 passes through *O* the centre of curvature; it is along a radius of the spherical surface and is perpendicular to the mirror, so it is reflected back on itself. All three rays leave a single point *B′* on the object. After reflection from a (small) mirror, the point at which these rays cross is the image point *C*'. All other rays from the same object point will also pass through this image point. To find the image point for any object point, only these three types of rays need to be drawn. Only two of these rays are needed, but the third serves as a check.

We have shown the image point in fig. 3.22 only for a single point on the object. Other points on the object are imaged nearby, so a complete image of the object is formed, as shown by the dashed arrow in fig. 3.23. Because the light actually passes through the image itself, this is a real image that will appear on a piece of paper or film placed there. This can be compared to the virtual image formed by a plane mirror (the light does not actually pass through that image.

The image in fig. 3.22 can be seen by the eye when the eye is placed to the left of the image, so that some of the rays diverging from each point on the image (as point *C′*) can enter the eye as shown in fig. 3.23.

Image points can be determined, roughly, by drawing the three rays as just described, fig. 3.22. But it is difficult to draw small angles for the «paraxial» rays as we assumed. For more accurate results, we now derive an equation that gives the image distance if the object distance and radius of curvature of the mirror are known.

To do this, we refer to fig. 3.23. The object distance *d* - is the distance of the object (point *B*) from the centre of the mirror. The image distance, *f*, is the distance of the image (point *C*) from the centre of the mirror. The height of the object *BB*' is called *h* and the height of the image, *C'C*, is *h*'.



Diverging ray heading toward eye

Figure 3.23

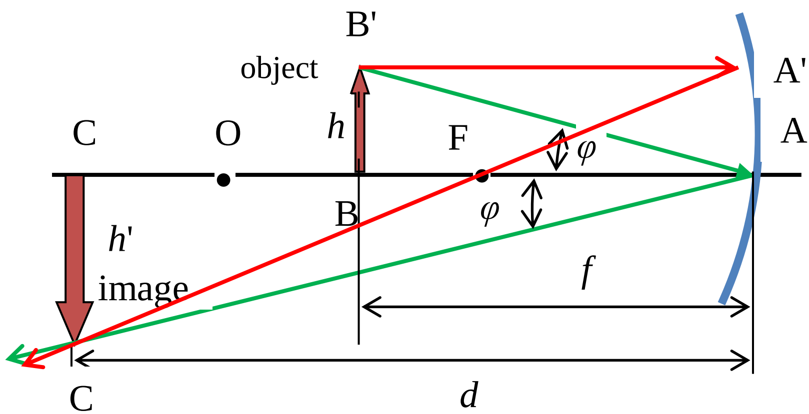


Figure 3.24

Two rays leaving B' are shown: $B'A'C'$ and $B'AC'$. The ray BFA and ray $AFBC$ obeys the law of reflection, so the two right triangles $B'BA$ and $C'CA$ are similar. Therefore, we have $h/h'=d/f$.

The triangles $B'AB$ and ACC' are also similar because the angles are equal and we use the approximation $B'B=h$, (mirror small compared to its radius). Furthermore $FA=F$ the focal length of the mirror, so $h/h'=CF/FA=(d-F)/F$.

The left sides of the two preceding expressions are the same, so we can equate the right sides: $d/f=(d-F)/F$.

We now divide both sides and rearrange to obtain $1/d+1/f=1/F$. This is the equation we were seeking. It is called ***the mirror equation*** and relates the object and image distances to the focal length, where $F = r/2$).

The lateral magnification m of a mirror is defined as the height of the image divided by the height of the object. From our first set of similar triangles above, or the first equation on this page, we can write: $m=h'/h=f/d$.

The minus sign in $m=h'/h=f/d$ is inserted as a convention. Indeed, we must be careful about the signs of all quantities in $1/d+1/f=1/F$ and $d/f=(d-F)/F$. Sign conventions are chosen so as to give the correct locations and orientations of images, as predicted by ray diagrams.

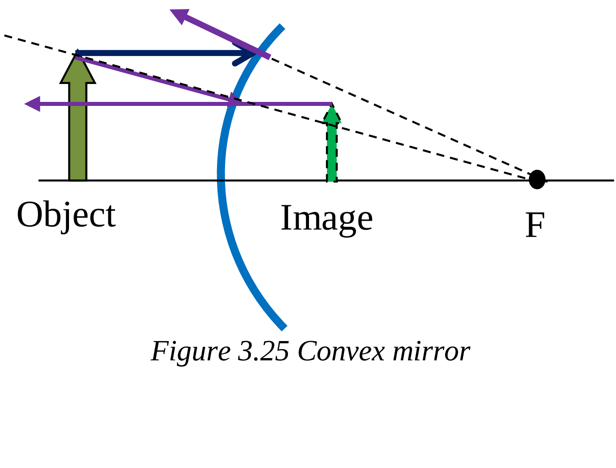


Figure 3.25 Convex mirror

Ray diagram showing image formed by a convex mirror. The three outgoing rays (*P*, *F* and *C*) extend back to a single point at the top of the image [56].

When an object is close to a convex mirror the image is practically the same size and distance from the mirror, fig. 3.25.

Ray diagram showing image formed by a concave mirror

In the limit that the object is very far from the concave mirror the image is small and close to the focal point.

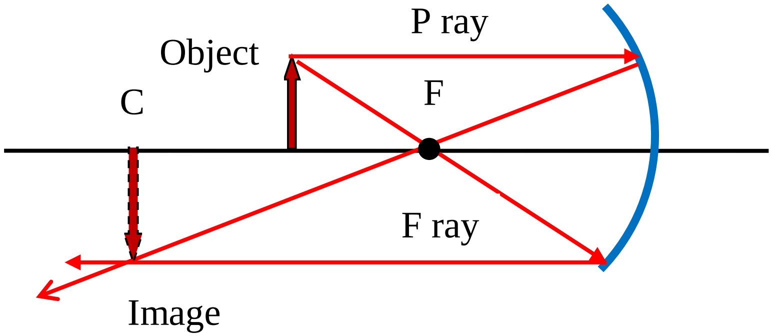


Figure 3.26

Object located outside C: Image is: inverted real reduced (|m|<1).

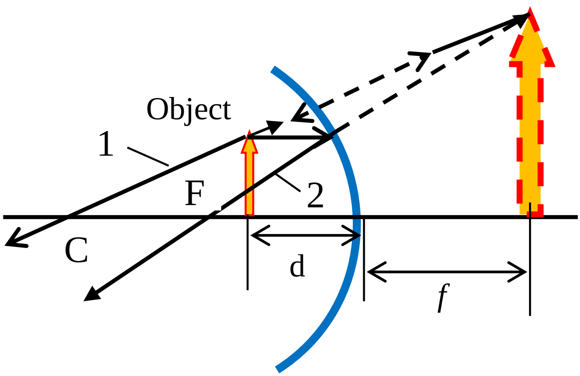


Figure 3.27 d<F. Virtual image, upring, enlarged

Reverse rays: Object located between *C* and *F*: Image is: inverted real magnified (|*m*|>1).

Object located inside F: Image is: Upright (*M* is positive) virtual magnified (|m|>1).

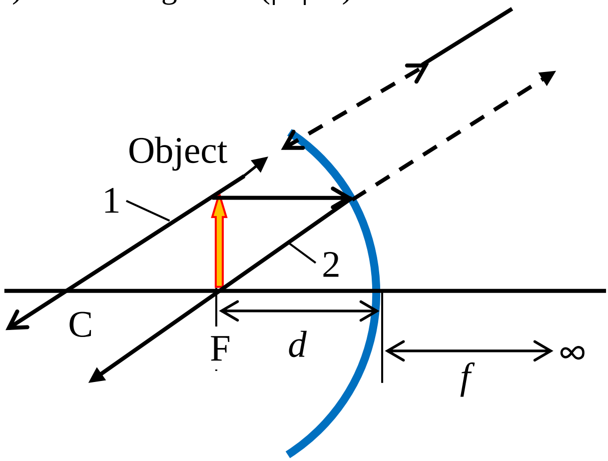


Figure 3.28 Object located the focal point, d=F

Perform a practical task: derive the formula of the mirror.

Use fig. 3.29 and fig. 3.30.

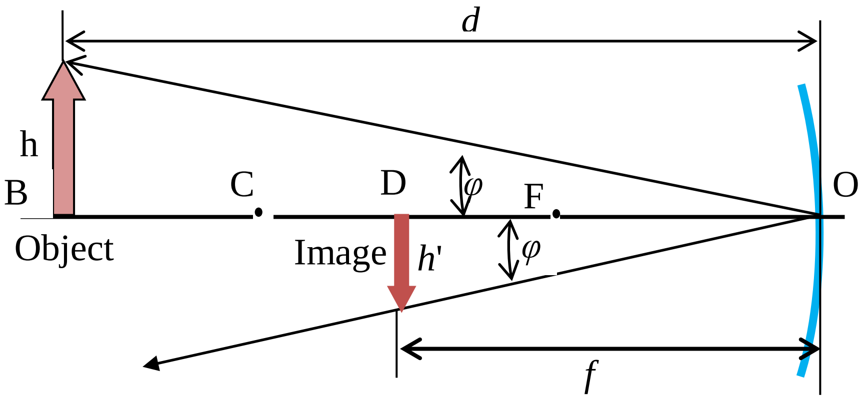


Figure 3.29

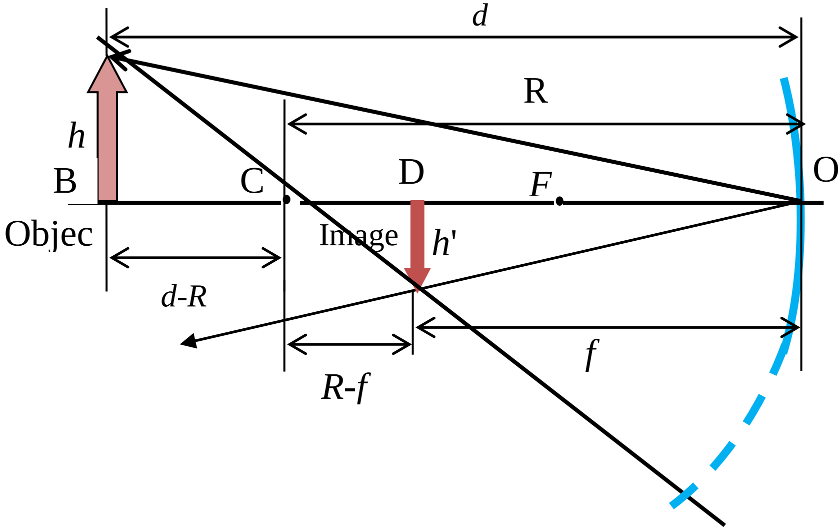


Figure 3.30

Summary of sign conventions:

Object distance *d*, is + if the object is in front of the mirror.

Object distance *d*, is - if the object is behind the mirror.

Image distance *f*, is + if the image is in front of the mirror (real image).

Image distance *f*, is - if the image is behind the mirror (virtual image).

For a concave mirror, focal length *F*, is +

For a convex mirror, focal length *F*, is –

A flat mirror is a curved mirror with *R* = infinity $1/F=1/d+1/f=1/\infty=0$, $1/d=-1/f$, $d=-f$, $m=-f/d= +1$.

Experiment Problem: An object 3 *cm* tall is placed 20 *cm* from the front of a concave mirror with radius of curvature of 30 *cm*. Where is the image formed and how tall is it?

Solution: Always draw a ray diagram (not to scale) to get an overall picture [56].

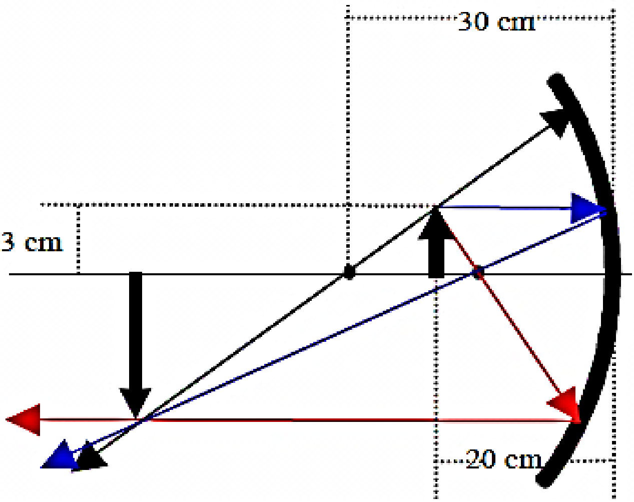


Figure 3.31

From ray diagram, Image is real, inverted and magnified f is positive, m is negative, and $|m|>1$.

Any calculations have to agree with these observations.

$f = Fd/(d-F) = (+15)(+20)/(20 - 15) = +60$ *cm*.

This calculation also agrees with the ray diagram.

$$m = -f/d = -(+60)/(+20) = -3.$$

This calculation also agrees with the ray diagram.

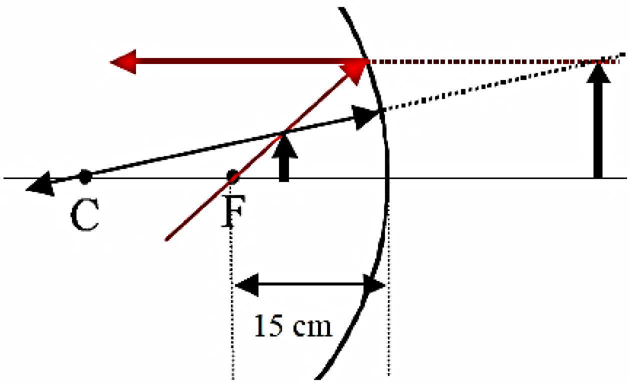


Figure 3.32

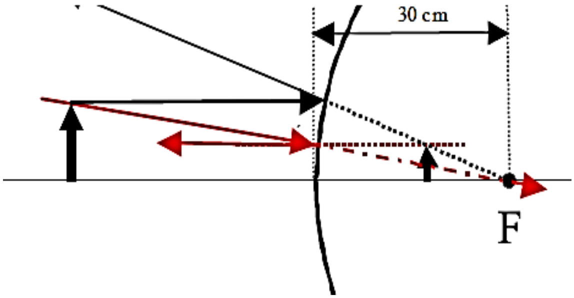


Figure 3.33

Problem: What will the characteristics of the image be if the object is moved to 10 *cm* from the mirror?

Solution: Always draw a ray diagram to get an overall picture (no to scale).

Image is Virtual, Upright and magnified *f* is negative, m is positive, and |m|>1.

Any calculations have to agree with these observations.

$f = Fd/(d-F)$ = (+10)(+20)/(10 – 15) = - 40 *cm*.

This calculation agrees with the ray diagram.

$$m = -f/d = -(-40)/(+10) = +4.$$

This calculation also agrees with the ray diagram.

Problem: An object 2 *cm* tall is placed 24 *cm* in front of a convex mirror whose focal length is 30 *cm*.

1 Where is the image formed?

2 How tall is it?

From the ray diagram below:

Image is virtual, upright reduced *f* is negative, *m* is positive |m| < 1. Any calculations have to agree with these observations.

Mirror is convex so focal length is negative $f=Fd/(d-F)$=(-30)(24)/(24-30)= -13,3 *cm*.

So image is behind the mirror.

This calculation agrees with the ray diagram. m = $-f/d$ = - (- 13,3)/(+24) =+0,55

$h' = mh = 0{,}55x2 = 1{,}11$ *cm*.

Studying of refraction [40, p. 403].

Light is bent, or **refracted,** when it passes from one medium to another.

1 How is the angle of incidence related to the angle of reflection? How are they measured?

2 What are the three types of mirrors? Describe the surface of each.

3How are images described? Describe the image produced by a plane mirror another. You can observe this effect if you look at a straw that has been placed in a glass of water, fig. 3.34 [55].

Experiment 3.7 Study of pencil's refraction in glass of water

The straw appears to be bent or broken. You may have noticed similar examples of refraction if you have reached for an underwater object. The refracted light rays make the underwater object appear closer than it really is.

Figure 3.34 Pencil in glass of water

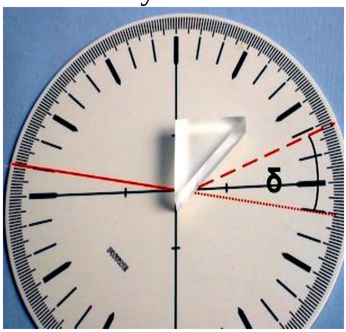


Figure 3.35

Light waves are refracted at the boundary of two different media such as air and water or air and glass. The refraction is the result of a change in the speed of light as it goes from one medium into another. At the point at which the speed of a light ray changes, the light ray bends. The rays bend toward the normal to the surface if they enter a medium in which they slow down. They move away from the normal if they enter a medium in which they speed up.

For example, light travels more quickly through air than through glass. Light passing from air into glass is thus bent toward the normal, as shown in fig. 3.36.

What would happen to light passing from glass into air?

When light passes from one material into a second material where the index of refraction is less ($n_2 < n_1$), the light bends away from the normal, as for rays *SA* and *AA′* in fig. 3.37. At a particular incident angle, the angle of refraction will be 90°, and the refracted ray *D* would skim the surface. The incident angle at which this occurs is called the critical angle.

This effect is called ***total internal reflection***. Total internal reflection can occur only when light strikes a boundary where the medium beyond has a lower index of refraction.

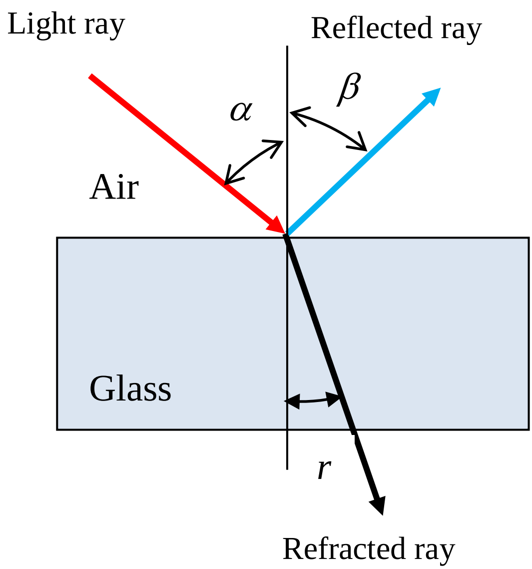


Figure 3.36

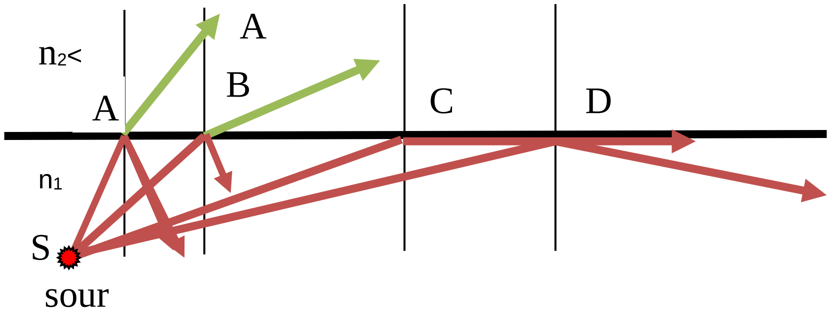


Figure 3.37

Study of refractive Index and Snell's Law. For physicists, it is good to know that waves react, though it is more helpful to know when, and by how much. Refraction can be quantified by relating the angle of incidence (to the boundary between the two media in question) to the angle of refraction. The refractive indexes of the two media can be used to precisely calculate the change in direction of a wave.

The ***refractive index*** of a medium (for a certain wave) is the ratio of the speed of the wave in unrestrained conditions (the absolute fastest speed) to the speed of the wave in that medium. The refractive index has symbol *n*, and, being a ratio, has no unit. In some cases, a single refractive index is given for the two materials involved, but this is simply the combined ratios of their two n's. However, in this unit, we will discuss refractive indexes for individual materials.

The following relates the refractive indices, n_1 and n_2, of two media with two more familiar terms, the angle of incidence *i*, and the angle of refraction, *r*: $\sin i/\sin r = n_2/n_1$.

This is known as **Snell's Law**. However, since *n*, the refractive index is a ratio of the fastest possible speed of the wave to the speed in the medium, we can simplify to get one more equation: $\sin i/\sin r = c_1/c_2$.

If u is the maximum speed of the wave (e.g speed of light in a vacuum), and c_1 and c_2 are the speeds of the wave in their respective media 1 and 2, $n_2=u/c_2$, $n_1=u/c_1$ and $n_2/n_1=c_1/c_2$.

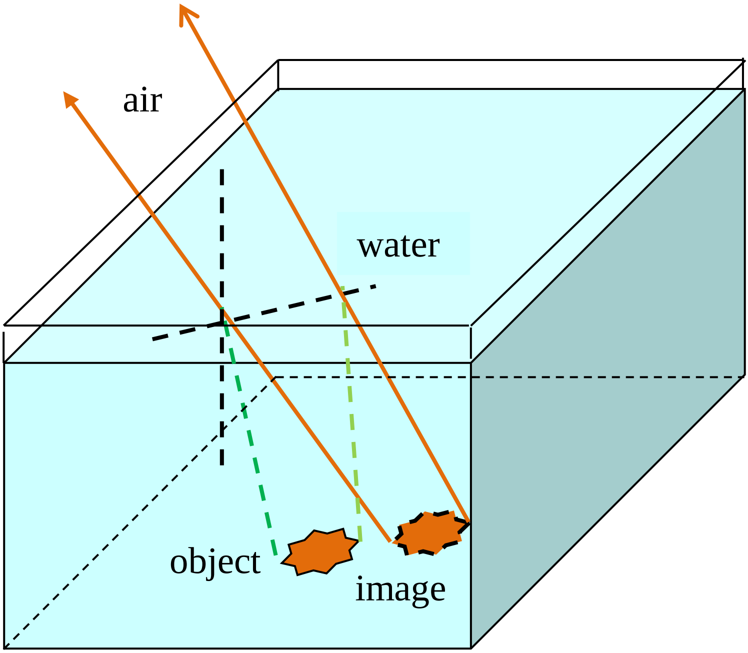


Figure 3.38

3.2.4 Studying wave properties of light

Have you ever tried to dive for a coin you have seen on the bottom of a swimming pool? If you aimed for the spot where the object seemed to be, you probably missed the object. The light ray that was reflected from the coin was bent when it reached the surface of the water and entered the air. This bending of light is one of a number of ways light behaves when it passes from one type of material to another.

Optical fiber. Total internal reflection «pipes» light from one end of an optical fiber to the other. An optical fiber is a thin strand of glass covered by a second layer of glass. Often a protective plastic tube covers the fiber. The inner core has a higher index of refraction than the outer layer. It is said to be more optically dense, fig. 3.39.

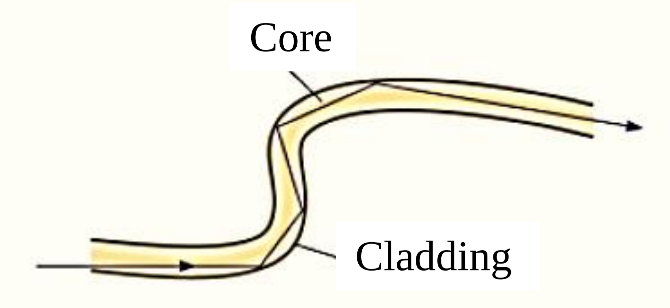


Figure 3.39

Light enters one end of the fiber. When light rays strike the surface between the inner glass core and the outer layer of glass, they undergo total internal reflection. The angle at which the rays are refracted is so great, more than 90°, that they are completely reflected back from the surface. They are trapped in the inner core of the fiber. The rays make many such reflections before leaving the other end. The fiber carries the light from one end to the other with no light escaping. Further, optical fibers are very transparent, so no light is absorbed.

Experiment 3.8 Observation of full internal reflection in a bunch of fishing line

Equipment: source of light, lens, wisp fishing-line.

An optical fiber channels light along its core, fig. 3.40. Reflections between the core and the cladding.

Optical fibers are being used to replace metal wires in communication systems. Crystal lasers are used as light sources because they have very narrow light beams. Electrical telephone signals modulate the brightness of the light. The light can be detected after traveling through up to

14 kilometers of glass fiber.

Figure 3.40

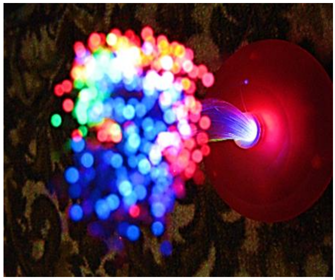


Figure 3.40, a

The detector changes the light back into an electrical signal. Each fiber can carry as many telephone calls as 10 000 wires. Optical fiber telephone cables only 1 centimeter in diameter contain 144 fibers surrounded by a protective covering.

3.2.5 Studying of lenses and their properties

A clear material, e.g. glass, which reflects or refracts light can, for particular curve shapes, cause parallel rays of light to converge at a point. Reflecting surfaces, curved or not, are referred to as mirrors in optics. Mirrors have one focal point to go with their one curved surface. A refracting material with two curved surfaces is called a lens. Since a lens has two curved surfaces, it has two focal points. If the curved surfaces are close enough together that we can neglect the distance between the surfaces, we refer to it as a thin lens. A lens can be one of two types:

- **converging** a lens in which parallel rays of light passing through the lens are brought together at the focal point. Rays of light which come from a point object placed at one of the focal points and which pass through the lens are converted into parallel rays (fig. 3.41).

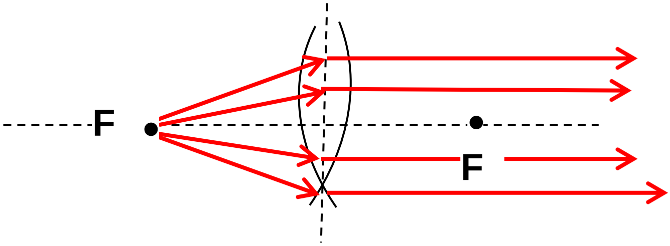


Figure 3.41 First focal points of a converging thin lens

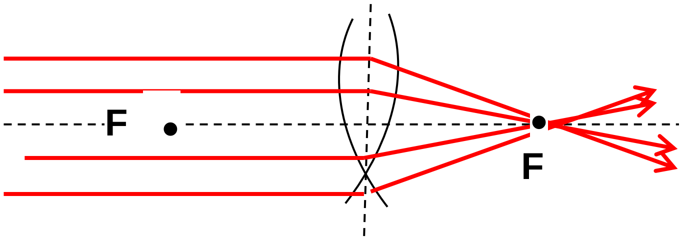


Figure 3.42 Second focal points of a converging thin lens

- **diverging** a lens in which parallel rays of light diverge after passing through the lens. The focal length of a diverging lens is defined as a *negative* quantity (fig. 3.42).

Experiment 3.9 Construction focal points

Equipment: source of light, lens, horizontal screen.

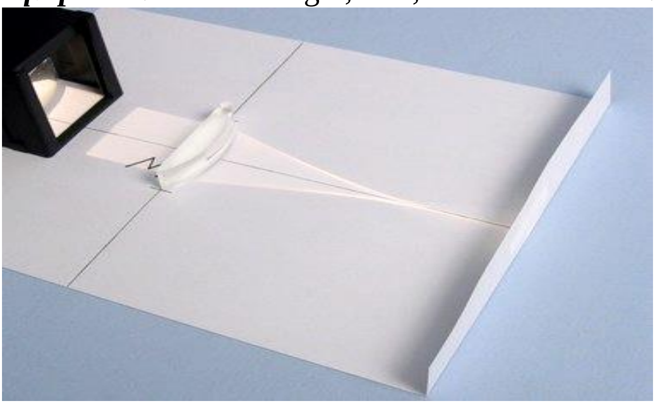


Figure 3.43 First and second focal points of a diverging thin

lens and the negative focal length

We direct a parallel beam of light to the lens, fig. 3.43. Construction of a focal points on the horizontal screen. Drawing motion ray, fig. 3.41 and fig. 3.42.

Experiment 3.10 Studying ray in concave lens

Equipment: source of light, concave lens, horizontal screen.

We direct parallel rays from spring light to concave lens, fig. 3.44.

Drawing of rays motion, fig. 3.45 and fig. 3.46.

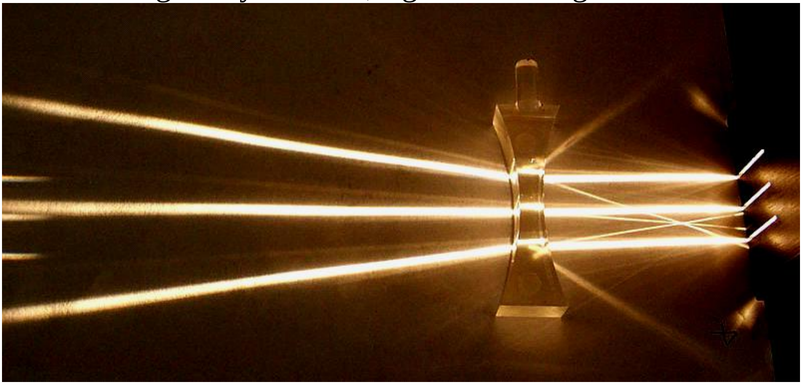


Figure 3.44

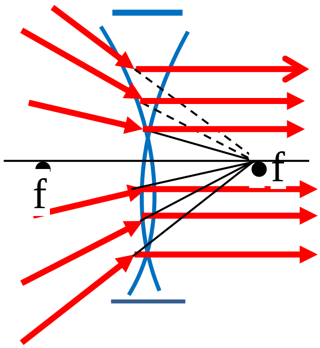


Figure 3.45

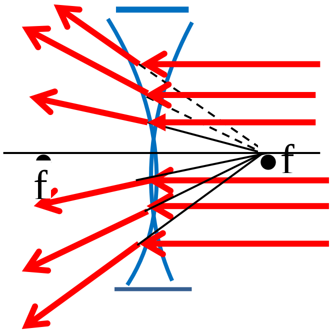


Figure 3.46

3.2.6 Studying of lens

We can use a lens to image an object. In the case of a thin lens, we define the **object distance** *s*, as the distance of the object from the centre of the thin lens. The **image distance** *s*, is the distance of the image formed from the centre of the thin lens, and we usually term the **focal distance**, *f*, as the distance of the focal point from the centre of the thin lens, see fig. 3.47.

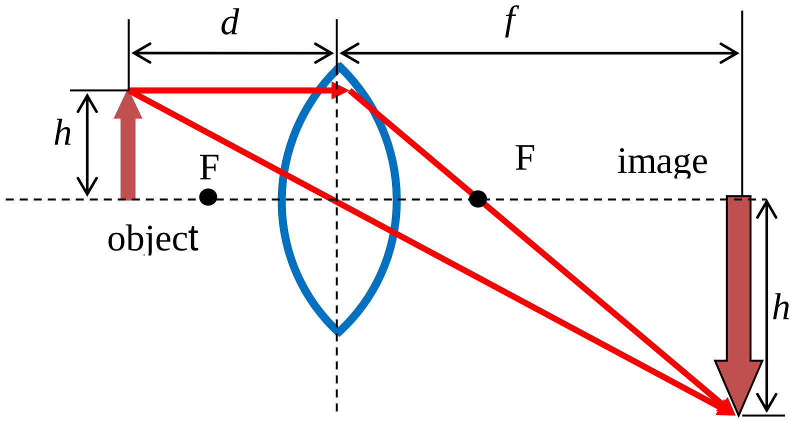


Figure 3.47 Definition of image, object, and focal lengths for a thin lens

The object, image, and focal lengths are related by the formula $1/d+1/f=1/F$.

Furthermore, the size of the image in the plane of the image, object, and lens, which we depict as *h*, is related to the size of the object (call it *y*) by the ***magnification.*** The magnification is $m=h'/h=f/d$.

We define images which are on the same side of a converging lens as the object as *virtual*. Note that in such cases $d<0$ and the magnification is *positive*. For *real* images, the image is inverted compared to the object, i.e. *y* and *h*' have opposite signs. Hence a positive magnification corresponds to an erect, virtual image while a negative magnification corresponds to an inverted, real image.

Let's consider an example.

Problem. A converging lens with a focal length of 7,00 *cm* forms a 1,30 *cm* tall image of a 4,00 *mm* tall real object that is to the left of the lens. The image is erect. Find the locations of the object and the image and determine whether the image is real or virtual.

Solution:

Since we have the sizes of the images, we can find the magnification.

$$m=h'/h=13/4=+3,25$$

Notice that since the image is erect, h>0 and the image is virtual. The magnification also implies $m=f/d$ and f=3,25d.

Since s is positive (the object is real), the image distance is negative so it is located to the left of the lens as the object is. We now find the distances for the object and the image.

So the image is located 15,8 *cm* to the left of the lens and the object is located 4,85 *cm* to the left of the lens.

Experiment 3.11 Laboratory investigation [40, p. 406]

Equipment: source light, convex lens, screen.

Problem. How is the image formed by a convex lens dependent on the distance between the lens and the object?

In this investigation, you will learn how real and virtual images are produced by a thin co convex lens.

Each group of students will need a convex lens, lens holder, screen, meter stick, support stands, and a light source, such as a light bulb.

1 Arrange the apparatus as shown in the illustration. Place the light source at least 2 *m* away from the lens. Then make a table like the one shown below.

2 Focus the light rays of the source of light on the

screen. The image should be bright and clear. For practical purposes, the light rays from such a distant source come in parallel to the principal axis of the lens. Describe and measure the size of the image and of the light source, which serves as the object. Measure and record the focal length, which is the distance between the lens and the focused rays on the screen.

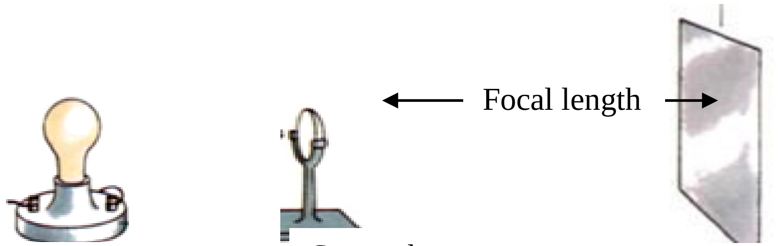


Figure 3.48

Procedure:

3 Move the light source to a position that is greater than twice the focal length of the lens (table 3.2.6.1)

Table 3.2.6.1

Object distance	*Object size*	*Image position (erect or inverted)*	*Image size*	*Focal length*

Align the lens, the source, and the screen so that the image falls in sharp focus on the screen. Record the image size and the distance of the object and screen from the lens in the table. Record the size of the object.

4 Move the light source to a point that is exactly twice the focal length. Adjust the lens and screen to obtain a sharp image. Record the information required in the data table.

5 Try moving the light source to other distances from the lens. What happens to the image size and distance?

Experiment 3.12 Studying of light refraction in a prism

Equipment: source light, prism, screen.

In optics, a ***prism*** is a transparent optical element with flat, polished surfaces that refract light. The exact angles between the surfaces depend on the application. The traditional geometrical shape is that of a triangular prism with a triangular base and rectangular sides, and in colloquial use «prism» usually refers to this type.

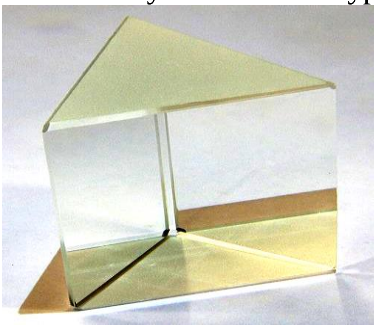


Figure 3.49

Some types of optical prism are not in fact in the shape of geometric prisms. Prisms can be made from any material that is transparent to the wavelengths for which they are designed. Typical materials include glass, plastic and fluorite.

Experiment 3.13 Studying of light refraction in a lens

Equipment: source of light, lens, screen.

Principle. In conjunction with the experiments on the refraction of light, this experiment is of particular importance. Knowledge of the law of refraction is strengthened and transferred to new contexts. At the same time, in this experiment, the students become familiar with the lenses which are most frequently used in optical apparatus.

The main focus of the first part of the experiment concerns the observation of the course of parallel, incident light beams converged by a convex lens and strengthening the concept of focal length.

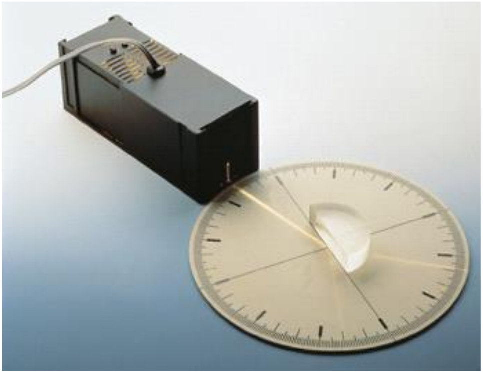


Figure 3.50

In the second part of the experiment, the path of three selected light beams is experimentally investigated and the general prerequisites for the understanding of image formation, to reconsidered later, are laid down.

The second part of the experiment is more demanding in terms of the abilities and experimental skills required of the students. Both experiments can be seen as individual units and can, likewise, be carried out separately. This is to be recommended in the interest of conscientious performance and further strengthening of the student`s experimental skills.

Nevertheless, individual group work can also be recommended (each group investigating the course of different, selected light beams then, at the end of the experiment, the data is collected to give a total result).

Task:

1 How does light pass through a lens?

2 Investigate the passage of light through a plane convex lens.

3 Investigate the passage of selected light rays falling on a plane convex lens.

Principle. In this experiment, the students have the possibility of perfecting their experimental skills and strengthening their understanding of the law of refraction. In conjunction with the observation of incident light at the boundary between air and glass, the path of the light beam is determined and evaluated by using a semigraphical procedure. In this way, the importance of mathematics for the understanding of physics can be demonstrated.

The experiment is demanding in terms of the experimental skills of the students. Only after careful adjustments and a conscientious evaluation can good results be obtained.

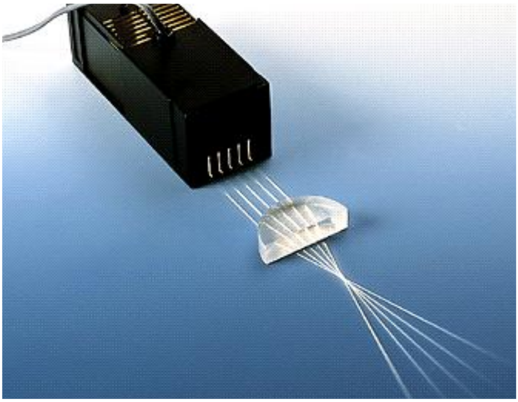


Figure 3.51

Approach. We apply Snell's law at the first surface, where the light enters the glass, and again at the second surface where it leaves the glass and enters the air.

Solution. (a) The incident ray is in air, so n_x = 1,00 and n_2 = 1,50. Applying Snell's law where the light enters the glass α= 60. It gives β = 35,3.

Since the faces of the glass are parallel, the incident angle at the second surface is just β (simple geometry), so $\sin\beta$ = 0,5774. At this second interface, n_1 = 1,50 and n_2 = 1,00.

The direction of a light ray is thus unchanged by passing through a flat piece of glass of uniform thickness.

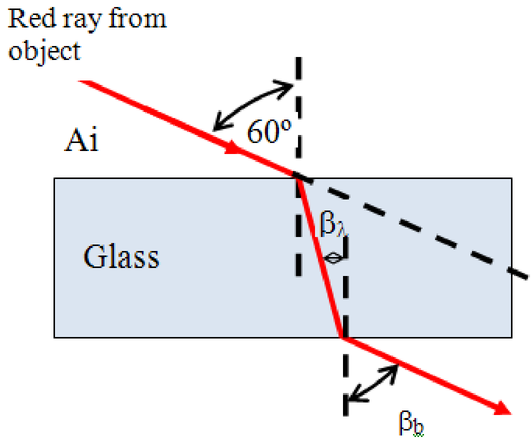


Figure 3.52 Image then viewed through the glass

Experiment 3.14 Determination of apparent depth of a pool

Equipment: ring, water.

A swimmer has dropped her ring to the bottom of a pool at the shallow end, marked as 1,0 *m* deep. But the ring doesn't look that deep. Why? How deep do the ring appears to be when you look straight down into the water?

Approach. We draw a ray diagram showing two rays going upward from a point on the ring at a small angle, and being refracted at the water's (flat) surface, fig. 3.53. The two rays traveling upward from the ring are refracted away from the normal as they exit the water, and so appear to be diverging from a point above the ring (dashed lines), which is why the water seems less deep than it is actually.

Solution. To calculate the apparent depth h' (fig. 3.53), given a real depth h = 1,0 m, we use Snell's law with n_1 = 1,33 for water and n_2 = 1,0 for air: $\sin\alpha = \sin\beta$.

We are considering only small angles, so $\sin\alpha \sim tg\alpha$ with 9 in radians. So Snell's law becomes $\beta \approx n_1\alpha$. From fig. 3.53, we see that $\beta \approx \tan\beta = x/h'$ and $\alpha \approx tg\alpha = x/d$.

Putting these into Snell's law we get $x/h' \approx n_1 x/h$ and $h' \approx h/n_1 = 1,0\ m/1,33 = 0,75\ m$.

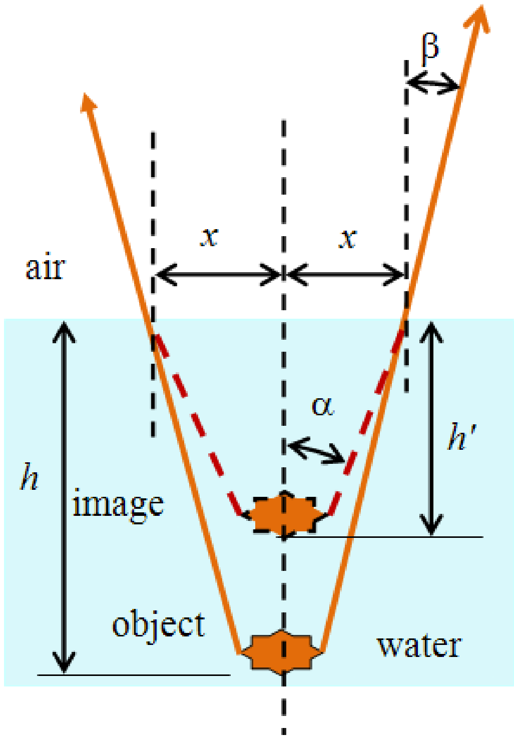


Figure 3.53

The pool seems only three-fourths as deep as it is actually.

Experiment 3.15 Study of notion «Optical illusion» (mirage)

Equipment: *poin B and point C, water.*

Fermat's principle states that the ray path from an observer at A to a point B in space is an extremal of optical length. For example, along a sunbaked road, the temperature of the air is warmest near the road and decreases with height, so that the index of refraction n, increases in the vertical direction.

For an observer at A, the curved path has a smaller optical path than the straight line. Therefore, he sees not only the direct line-of-sight image of the tree top at B, but it also appears to him that the tree top has a mirror image at C. If there is no tree, the observer sees a direct image of the sky and also its mirror image, thereby giving the impression, perhaps sadly, that he is looking at water.

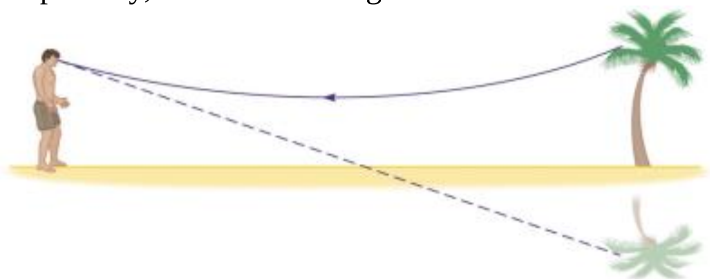


Figure 3.55

Experiment 3.16 Study of the compound microscope

Equipment: objective, two lenses, eyepiece.

A simple magnifier provides only limited assistance in inspecting minute details of an object. Greater magnification can be achieved by combining two lenses in a device called a ***compound microscope***, a schematic diagram of which is shown in fig. 3.55. It consists of one lens, the *objective*, that has a very short focal length f_o<1 cm and a second lens, the eyepiece, that has a focal length f_e of a few centimeters.

The two lenses are separated by a distance L that is much greater than either f_o or f_e. The object, which is placed just outside the focal point of the objective, forms a real, inverted image at I_1, and this image is located at or close to the focal point of the eyepiece. The eyepiece, which serves as a simple magnifier, produces at I_2 a virtual, inverted image of I_1. The lateral magnification M_1 of the first image is q_1/p_1. Note from fig. 3.56. that q_1 is approximately equal to L and that the object is very close to the focal point of the objective: $p_1 \approx f_o$ Thus, the lateral magnification by the objective is $M \approx -L/f_o$. The angular magnification by the eyepiece for an object (corresponding to the image at I_1) placed at the focal point of the eyepiece is, from $m_e = 25/f_e$.

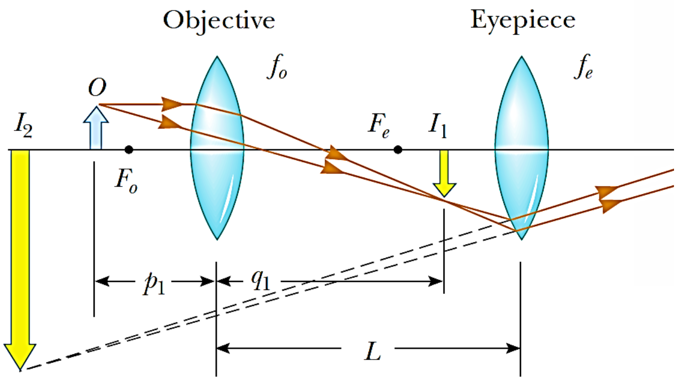


Figure 3.56 Diagram of a compound microscope, which consists of an objective lens and an eyepiece lens

The ability of an optical microscope to view an object depends on the size of the object relative to the wavelength of the light used to observe it. Hence, we can never observe atoms with an optical microscope because their dimensions are small (≈0,1 *nm*) relative to the wavelength of the light (≈500 *nm*).

The three-objective turret allows the user to choose from several powers of magnification. Combinations of eyepieces with different focal lengths [55].

Experiment 3.17 Study of a microscope

Equipment: microscope.

A microscope uses two convex lenses to make magnified images of very small objects. The specimen, or object to be viewed, is placed on a slide.

The slide is placed on a flat part of the microscope called a ***stage.***

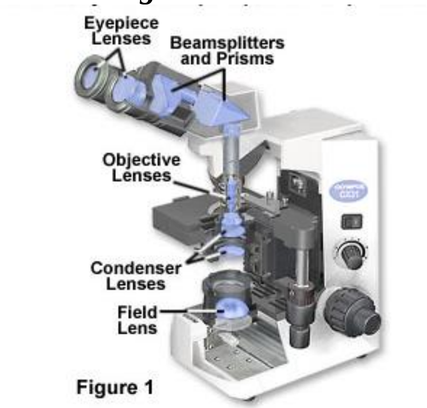


Figure 3.57

Light rays are directed up through a hole in the stage and through the specimen fig. 3.57. A convex lens, the objective lens, produces a magnified real image of the specimen. A second convex lens, the eyepiece lens, magnifies this image again. The total magnification can be 300x or more.

Experiment 3.18 Study of telescope

Equipment: refracting telescope.

Two fundamentally different types of telescopes exist; both are designed to aid in viewing distant objects, such as the planets in our Solar System. The refracting telescope uses a combination of lenses to form an image, and the reflecting telescope uses a curved mirror and a lens.

The lens combination shown in fig. 3.58 is that of a refracting telescope. Like the compound microscope, this telescope has an objective and an eyepiece.

The two lenses are arranged so that the objective forms a real, inverted image of the distant object very near the focal point of the eyepiece. Because the object is essentially at infinity, this point at which I_1 forms is the focal point of the objective. Hence, the two lenses are separated by a distance which corresponds to the length of the telescope tube. The eyepiece then forms, at I_2, an enlarged, inverted image of the image at I_1.

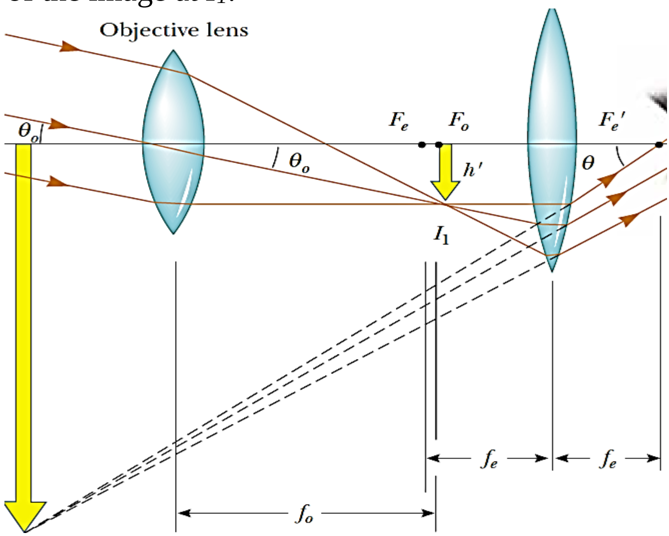


Figure 3.58 Lens arrangement in a refracting telescope, with the object at infinity. A refracting telescope [55]

The angular magnification of the telescope is given by θ_o, where θ_o is the angle subtended by the object at the objective and is the angle subtended by the final image at the viewer's eye. Consider fig. 3.58, in which the object is a very great distance to the left of the figure. The angle θ_0 (to the left of the objective) subtended by the object at the objective is the same as the angle (to the right of the objective) subtended by the first image at the objective. Thus, $tg\theta_o \approx \theta_o \approx -h'/f_o$ where the negative sign indicates that the image is inverted.

The angle θ subtended by the final image at the eye is the same as the angle that a ray coming from the tip of I_1 and traveling parallel to the principal axis makes with the principal axis after it passes through the lens. Thus, $tg\theta \approx \theta \approx h'/f_e$.

We have not used a negative sign in this equation because the final image is not inverted; the object creating this final image I_2 is I_1, and both t and I_2 point in the same direction. To see why the adjacent side of the triangle containing angle θ is f_e and not $2f_e$, note that we must use only the bent length of the refracted ray.

Hence, the angular magnification of the telescope can be expressed as

$$m = \frac{\theta}{\theta_0} = \frac{hf_0}{hf_e} = \frac{f_0}{f_e},$$

and we see that the angular magnification of a telescope equals the ratio of the objective focal length to the eyepiece focal length. The negative sign indicates that the image is inverted.

Fig. 3.59 shows the design for a typical reflecting telescope. Incoming light rays pass down the barrel of the telescope and are reflected by a parabolic mirror at the base. These rays converge toward point A in the figure, where an image would be formed. However, before this image is formed, a small, flat mirror M reflects the light toward an opening in the side of the tube that passes into an eyepiece.

This particular design is said to have a Newtonian focus because Newton developed it. Note that in the reflecting telescope the light never passes through glass (except through the small eyepiece). As a result, problems associated with chromatic aberration are virtually eliminated.

The largest reflecting telescope, with a 6-*m* diameter mirror, is in Zelenchukskaya, Russia. The Multiple Mirror Telescope is on Mount Hopkins, Arizona, has six mirrors, each 1,8 *m* in diameter.

Special electronic devices are used to combine the images from the six mirrors into one. As a result, it can gather as much light as a 4,5 meter mirror, but it costs much less to build.

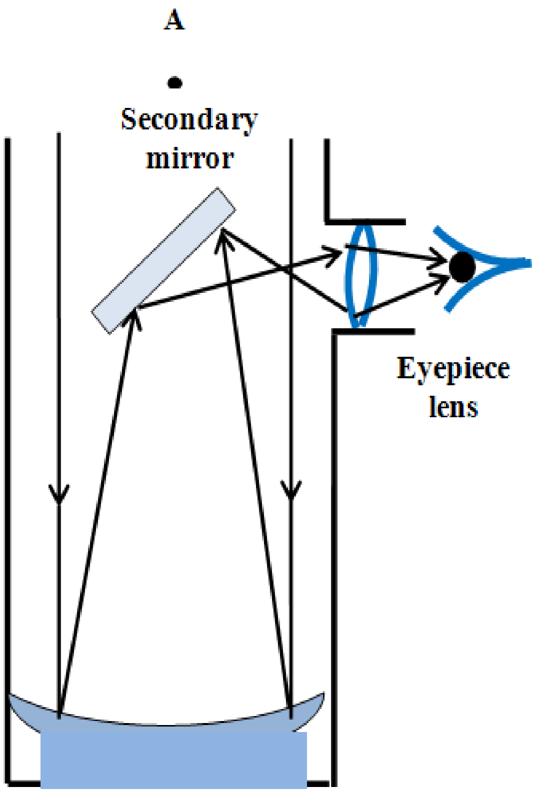


Figure 3.59

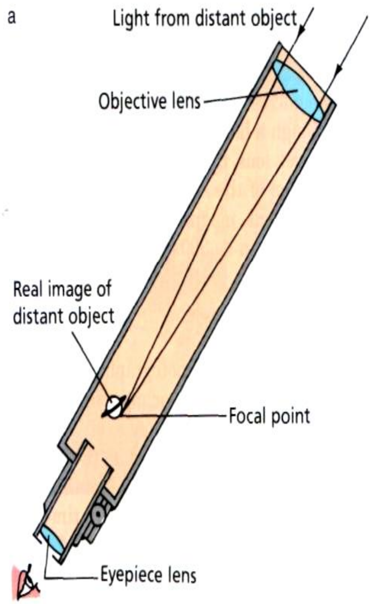


Figure 3.60, a

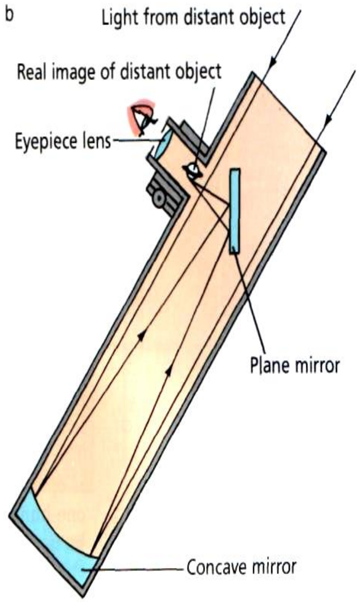


Figure 3.60, b

Experiment 3.19 Study of binoculars

Equipment: binoculars.

Prisms are used to «fold» the light path within a pair of binoculars. This makes the binoculars easier to handle.

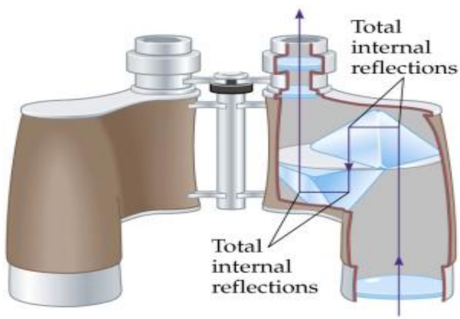


Figure 3.61 Geometrical Optics R.Shankar [58]

Experiment 3.20 Lenses and Vision

Equipment: convex lens, model human eye.

The human eye is filled with a liquid that is mostly water. Light enters through a transparent membrane called ***the cornea*** fig.3.62. It is refracted at this curved surface. It passes through a convex lens and forms an inverted image on the back surface of the eye, the retina. Nerves lead from the retina to the visual area of the brain.

The eye can focus on objects farther away than about 25 *cm*. The lens is made of a flexible transparent material, and muscles control its curvature. To focus an image of a nearby object, the focal length must be made smaller. The muscles tighten, causing the lens to become more convex. To focus images of distant objects, a longer focal length is needed. The muscles relax, allowing the lens to be less convex.

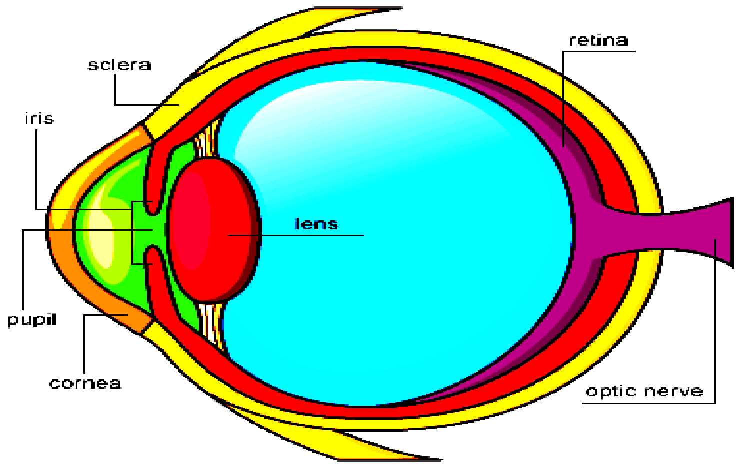


Figure 3.62 [59]

Diagram of the eya

Your eyes have some interesting parts that allow you to see. Light enters the eye through an opening called the ***pupil.*** The amount of light that enters the eye is controlled by the ***iris*.** Muscles adjust the focal length of the lens of the eye by changing the shape of the lens. The light from objects that are not too close to the eye is focused as a real image on the ***retina*.** This part of the eye is at the principal focus of the eye's lens. The retina is made of light-sensitive nerves that transfer the image to the brain fig.3.63.

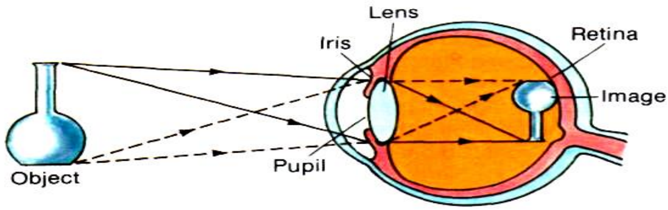


Figure 3.63

The diagrams show how lenses help correct nearsightedness and farsightedness.

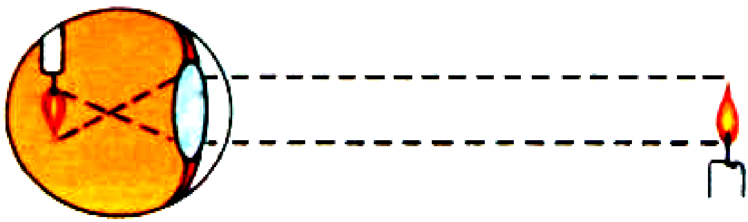


Figure 3.64 Image formed in front of retina. Nearsightedness, eyeball is too long

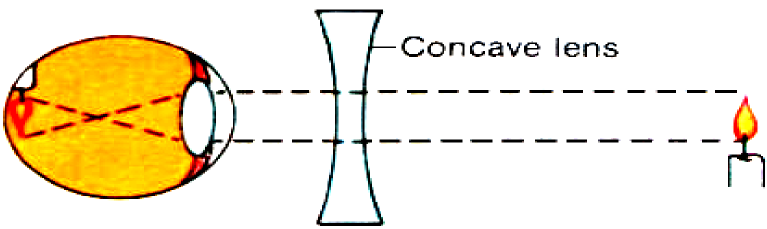


Figure 3.65 Image formed on retina by concave lens (principal focus). Correction

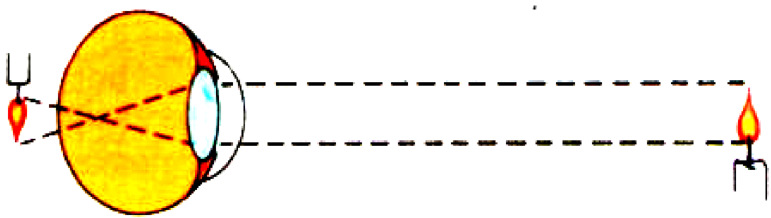


Figure 3.66 Image blurred on retina. Farsightedness (eyeball is too short)

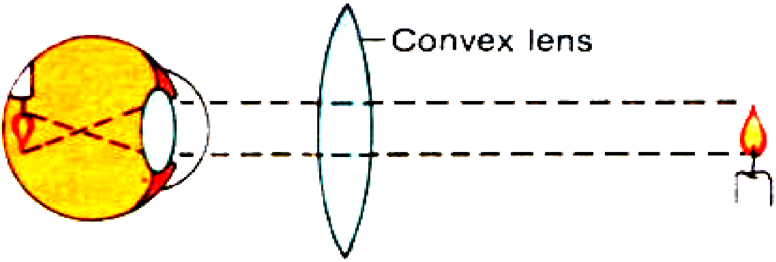


Figure 3.67 Image formed on retina by convex lens (principal focus). Correction

Chapter 4
WAVE PROPERTIES OF LIGHT

4.1 Concept of interference of light

Interference and diffraction experiments make it possible to detect the wide range of phenomena in which the wave properties of light are manifested.

The phenomenon of interference with other fundamental wave phenomena is one of the most important in physics.

The phenomenon of diffraction points to application limits of the rectilinear light propagation law. Diffraction, as a rule, appears due to the interference of waves, which swell in the region of geometrical shadow.

In study of fluctuation, polarization is a fundamental physical concept. This feature of light characterizes the orderliness of light fluctuation orientation, in contrast to the electromagnetic theory of light. During the demonstration of the phenomenon of interference, the following tasks are performed:

1 We justify the wave nature of the phenomenon experimentally.

2 We show that interference is possible only under certain conditions and on this basis we formulate a conclusion on the wave nature of light.

3 We expose the concept of coherence and find the conditions necessary to observe the phenomenon of interference.

4 In experiments we find the patterns of the phenomenon of interference.

5 We establish the nature of the energy distribution in the interference pattern.

6 We find conditions under which the law of independence of light streams is limited.

7 We find that the sharpness of an interference pattern depends on the difference in the amplitudes of overlapping wave oscillations. The difference must be such that it is possible to distinguish the maxima from the minima. Otherwise, the picture will not be clear.

8 We establish the influence of monochromaticity and homogeneity of radiation in the interference of light waves.

9 To obtain wide interference bands, we set the screen at a great distance from Fresnel’s biprism, Jung's double slit, Newton's rings or other device that creates coherent light waves. The initial setup of the installation is carried out at insignificant distances of the screen from the UPD.

10 We conclude that interference is not only a physical phenomenon, but also a method of studying phenomena.

Considering the phenomenon of diffraction of light, we clarify the problem about the nature of the formation of light and fulfill the following tasks:

- we explain the essence of the phenomenon of diffraction;
- we find the conditions under which diffraction of light is manifested;
-we agree two external opposite phenomena: the straightforwardness of light propagation and deviation from it;
- we explain the results of experiments on the basis of the Huygens-Fresnel principle;
- we establish the conditions for the formation of the diffraction maximum from the gap;
- we reveal the identity of the conditions of diffraction and interference bands.

The action of the first diffraction minimum is shown under condition that the difference between the rays is equal to the double half-wave (n = 1) and corresponds to the maximum of light at interference. But the conditions for applying the waves are such that, between the rays of the first upper and second lower parts of the beams, the difference in the ray is half-way,

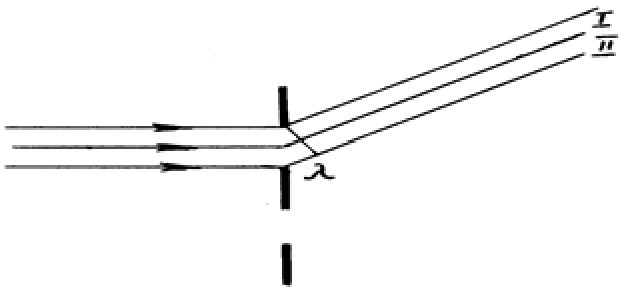


Figure 4.1 Waveguide scheme

At the same time waves extinguish one another. Therefore, in this case, the waves should be divided into three parts:

-in two parts, the difference in stroke will be half an hour and they will extinguish one another, and the remaining third gives a light band;

-show diffraction patterns that arise when increasing the number of slits:

a) the smaller the constant lattice (narrower slit), the wider diffraction bands and the further they are from the middle line;

b) the more slits a grating has, the brighter the diffraction bands. The maxima are formed as a result of the interference of waves, which extend from all the slits;

c) at a constant distance from the slit system of the grating to the screen, the position of the diffraction bands depends on the wavelength and width of the gap. This allows the grating to determine the length of the light wave;

- at a frontal observation we draw attention to the role of distance from the source of light to the obstacle. The use of the lens, through which we monitor, changes the distance from the object of diffraction to the screen or to the observer;

- the origin of colors in thin films, colored interference bands when observed with the Fresnel biprim or with other devices is caused by the dependence of the color of the rays on the wavelength. This dependence also occurs in diffraction processes with gratings and slits;

- there is a diffraction of Fraunhofer and Fresnel. Fraunhofer diffraction occurs from the plane wave front when the source is at a great distance from the obstacle or the lens is set between the source and the obstacle with the specified focal length. Fresnel diffraction diffraction of spherical waves when the light source is relatively close to the obstacle.

In the study of the phenomenon of interference and diffraction, the question of the latitude or longitudinality of light waves remains unnoticed. The problem is solved when the phenomenon of polarization of light is revealed. By performing experiments on the polarization of light, we draw attention to the following features of the phenomenon:

1A polarized wave always has one dominant direction of oscillation, one plane of polarization of the main vector. Such waves will be polarized.

2 In nature, there exist such substances-crystals that pass light waves with a certain orientation of the vector of electric field intensity.

3 An excited electron, when it passes to a normal state, emits a light wave with a certain specific orientation of the electric field strength vector.

4 Different atoms have different polarization plane. The light beam from the not polarized.

Experiment 4.1 Red, blue, and green ray direct on a spherical mirror, fig. 4.2. Two or more waves travelling in the same medium travel independently and can pass through each other. A spherical mirror, as its name implies, has the shape of a section of a sphere. This type of mirror focuses incoming parallel rays to a point, as demonstrated by the colored light rays. Shows a cross-section of a spherical mirror, with its surface represented by the solid, curved black line. (The blue band represents the structural support for the mirrored surface, such as a curved piece of glass on which the silvered surface is deposited.) Such a mirror, in which light is reflected from the inner, concave surface, is called a concave mirror. The mirror has a radius of curvature *R*, and its center of curvature is point *C*. Point *V* is the center of the spherical section, and a line through *C* and *V* is called the principal axis of the mirror.

Experiment 4.2 On fig. 4.3 a demonstration of waves spreading on the surface of water. Each wave spreads independently from one other.

If two waves meet interesting things can happen. Waves are basically collective motion of particles. So when two waves meet they both try to impose their collective motion on the particles. This can have quite

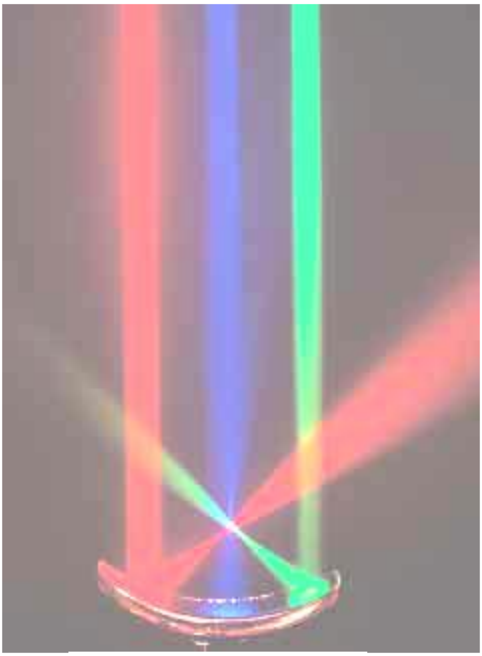


Figure 4.2

different results.

If two identical (same wavelength, amplitude and frequency) waves are both trying to form a peak then they are able to achieve the sum of their efforts. The resulting motion will be a peak which has a height which is the sum of the heights of the two waves. If two waves are both trying to form a trough in the same place then a deeper trough is formed, the depth of which is the sum of the depths of the two waves. Now in this case the two waves have been trying to do the same thing and so add together constructively.

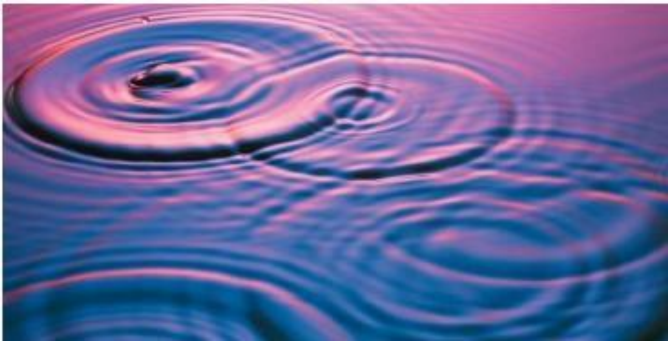


Figure 4.3 Two waves

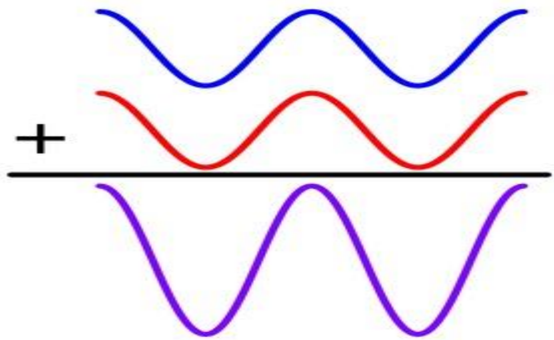


Figure 4.4 Because the waves are aligned with each other, they add up to be twice as big as either one alone

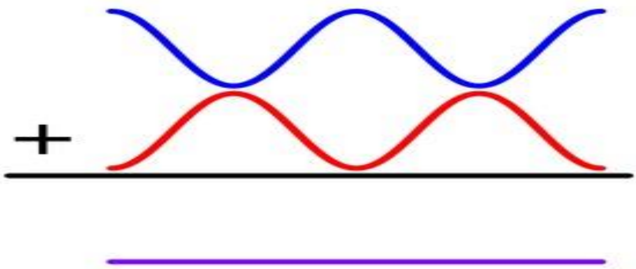


Figure 4.5 Destructive interference. Because the blue and red waves are oppositely aligned, they cancel each other out to give the flat purple line

This is called ***constructive interference.*** If one wave is trying to form a peak and the other is trying to form a trough then they are competing to do different things. In this case they can cancel out. The amplitude of the resulting wave will depend on the amplitudes of the two waves that are interfering. If the depth of the trough is the same as the height of the peak nothing will happen. If the height of the peak is bigger than the depth of the trough a smaller peak will appear and if the trough is deeper then a less deep trough will appear. This is destructive interference.

In regions where they overlap we only observe a single disturbance. This process is called interference. When two or more waves interfere, **the resulting displacement is equal to the vector sum of the individual displacements,** fig.4.6.

If two waves with equal amplitudes overlap ***in phase***, i.e. if crest meets crest and trough meets trough, then we observe a resultant wave with twice the amplitude. We have ***constructive interference***. If the two overlapping waves, however, are completely ***out of phase***, i.e. if crest meets trough, then the two waves cancel each other out completely. We have ***destructive interference***.

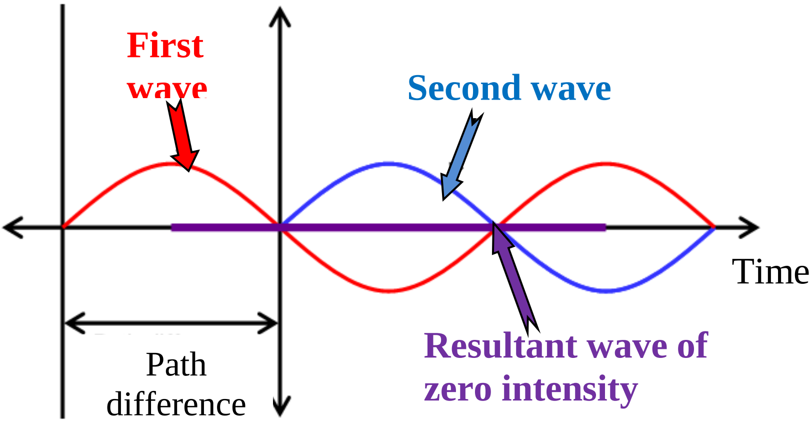


Figure 4.6 Destructive interference of two wave having equal amplitude and frequency

The single slit. When light passes through a single slit whose width w is on the order of the wavelength of the light, then we observe a single slit diffraction pattern. Huygen's principle tells us that each part of the slit can be thought of as an emitter of waves. All these waves interfere to produce the diffraction pattern. Consider a slit of width d as shown in the diagram, fig. 4.7.

For light leaving the slit in a particular direction, we may have destructive interference between the ray at the top edge, ray 1, and the middle ray 5.

If these two rays interfere destructively, so do rays 2 and 6, 3 and 7, and 4 and 8. In effect, light from one half of the opening interferes destructively and cancels out light from the other half. Ray 1 and ray 5 are half a wavelength out of phase if ray 5 must travel 1/2 wavelength further than ray 1. We need $(d/2)\sin\varphi=\lambda/2$ or $d\sin\varphi=\lambda$ for destructive interference to produce the first dark fringe. Other dark fringes in the diffraction pattern produced by a single slit are found at angles φ for which $d\sin\varphi= m\lambda$.

Experiment 4.3 Interference of the tsingle slit. When a monochromatic light source shines through a 0,2 *mm* wide slit onto a screen 3,5 *m* away, the first dark band in the pattern appears 9,1 *mm* from the center of the bright band. What is the wavelength of the light?

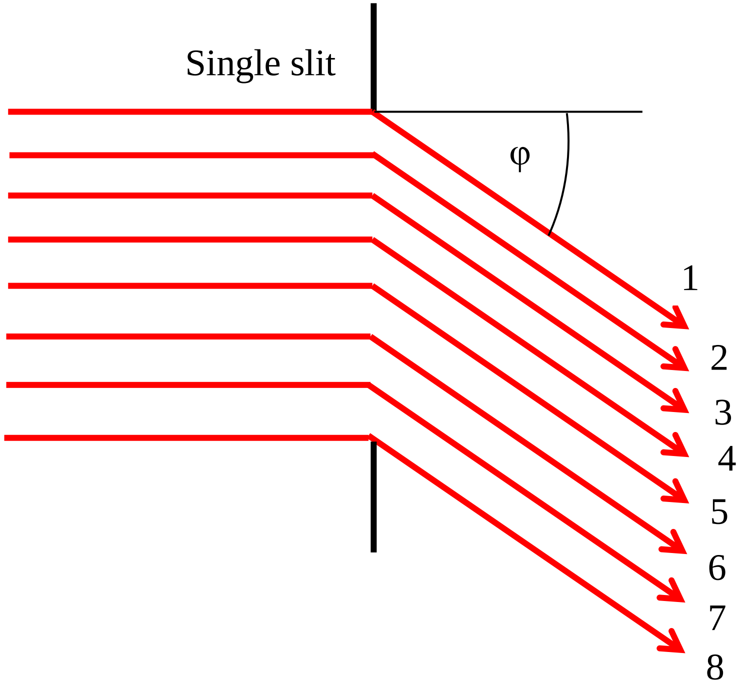


Figure 4.7 Slit width d

Solution. *z*=9,1 *mm*=9,1-3*mL* zw/(*mL*)= (9,1-3*m*)(210-4*m*)/(3,5*m*) = 5,210-7*m* = 520 *nm*.

The first order bright line appears 0,25 *cm* from the center bright line when a double slit grating is used. The distance between the slits is 0,5 *mm* and the screen is 2,7 *m* from the grating. Find the wavelength.

Solution. z= 463 *nm*.

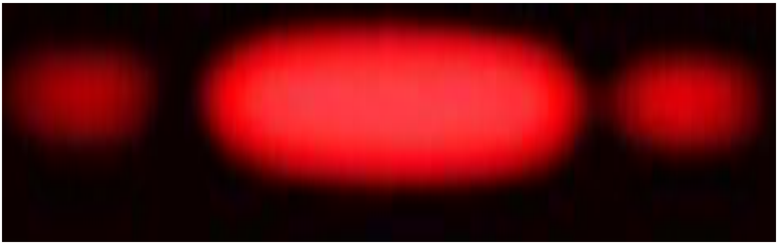


Figure 4.8 Interference of the tsingle slit

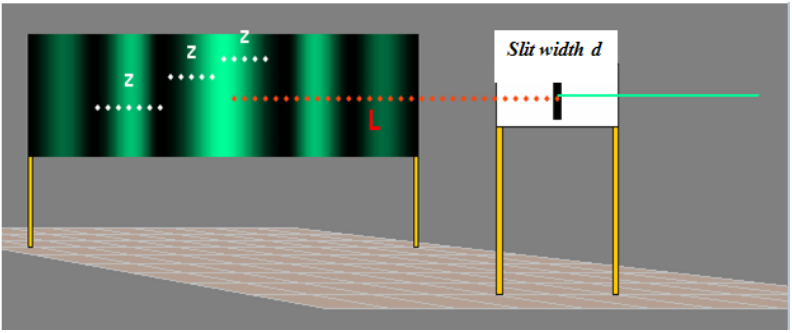


Figure 4.9 Outline nterference of the tsingle slit width d

4.2 Investigation property Fresnel Lens

In physics, the Fresnel Zone method is often used to explain the phenomenon of interference and diffraction of light.

It is a type of lens originally developed by French physicist Augustin-Jean Fresnel for lighthouses. The design enables the construction of lenses of large aperture and short focal length without the weight and volume of material that would be required in conventional lens design. Compared to conventional bulky lenses, the Fresnel lens is much thinner, larger, and flatter, capturing more oblique light from a light source.

Description. Compared to conventional bulky lenses, the Fresnel lens reduces the amount of material required compared to a conventional spherical lens by breaking the lens into a set of concentric annular sections known as «Fresnel zones», which are theoretically limitless. In the first variations of the lens, each zone was actually a different prism.

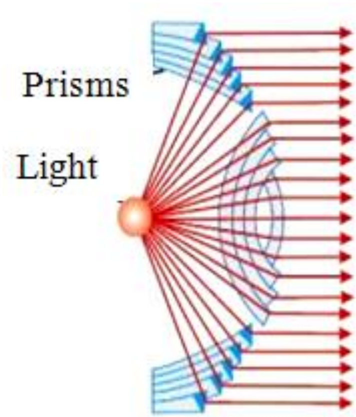


Figure 4.10 Fresnel lens precision graphics

Though a Fresnel lens might look like a single piece of glass, closer examination reveals that it is many small pieces. For each of these zones, the overall thickness of the lens is decreased, effectively chopping the continuous surface of a standard lens into a set of surfaces of the same curvature, with discontinuities in steps between them.

In fact this product can be regarded as an array of prisms positioned in a circular fashion, with steeper prisms on the edges and a near flat convex center. Fresnel lenses are usually made of glass or plastic; their size varies from small to large. Since plastic lenses can be made larger than glass lenses, as well as being much cheaper and lighter, they are used to concentrate sunlight in multiple uses.

4.3 Investigation property Constructive and Destructive Interference

Two waves (with the same amplitude, frequency, and wavelength) are travelling in the same direction on a string, fig.4.11. Using the principle of superposition, the resulting string displacement may be written as: $y(x,t)=y_m sin(kx-\omega t)+y_m sin(kx-\omega t+\varphi)=2y_m cos(\varphi/2)sin(kx-\omega t+\varphi/2)$,

which is a travelling wave whose amplitude depends on the phase (phi). When the two waves are ***in-phase*** (φ=0), they interfere ***constructively*** and the result has twice the amplitude of the individual waves. When the two waves have ***opposite-phase*** (φ=180), they interfere ***destructively*** and cancel each other out.

Constructive interference increases amplitude by combining the amplitude of the two individual waves. Destructive interference decreases the amplitude by combining the waves in such a way that the resulting wave is smaller than the largest original wave.

Let’s consider the production of interference on the surface of water, fig. 4.11.

Wherever a crest coiancides with a trough, the water surface is flattened. Double caests a crest conco with a crest. Flattined region a crest concioss with a trougm.

Interference patterns created by the waves from several fallen drops of water, fig. 4.11.

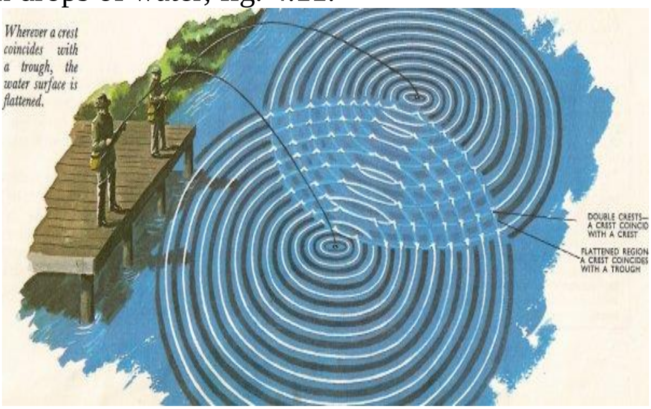


Figure 4.11 Waves overlapping on the water surface

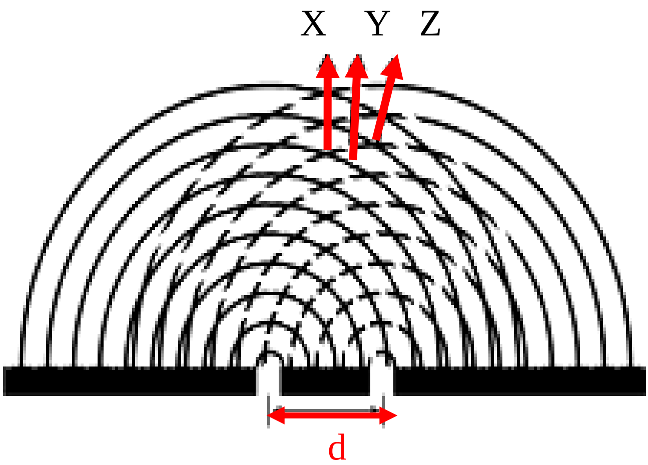


Figure 4.12 Use of Huygen`s principle

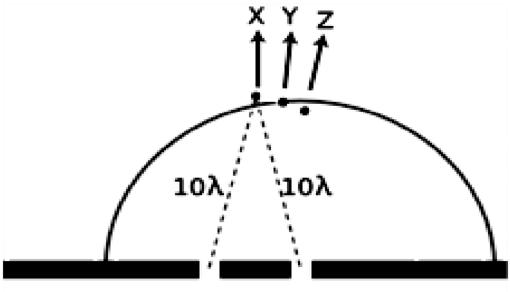


Figure 4.13 Constructive interference along the center-line

Returning to the example of double-slit diffraction, *f*, note the strong visual impression of two overlapping sets of concentric semicircles. This is an example of Huygen`s principle, named after a Dutch physicist and astronomer. Huygens' principle states that any wavefront can be broken down into many small side-by-side wave peaks, *g*, which then spread out as circular ripples, *h*, and by the principle of superposition, the result of adding up these sets of ripples must give the same result as allowing the wave to propagate forward, i. In the case of sound or light waves, which propagate in three dimensions, the «ripples» are actually spherical rather than circular, but we can often imagine things in two dimensions for simplicity.

Experiment 4.4 Young's research system

Equipment: UPD 1-2, a set of double slits 4, a diagonal screen frame, a slit 3, a matte screen 5, screen, a lens (20x) from a micropack.

Interference of light waves creates colorful displays. If light is incident onto an obstacle which contains two very small slits a distance *d* apart, then the wavelets emanating from each slit will constructively interfere behind the obstacle.

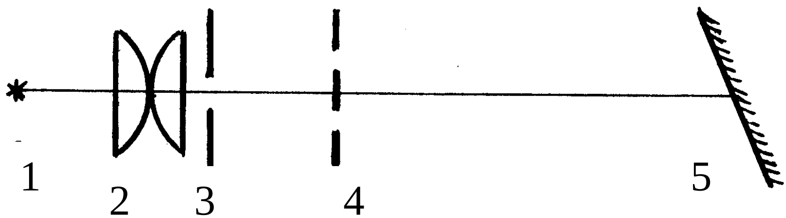


Figure 4.14

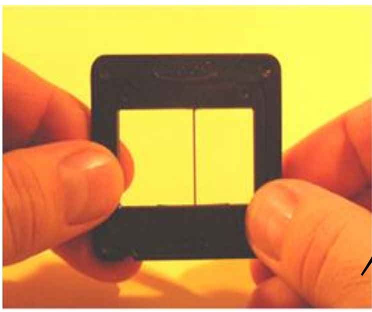


Figure 4.15

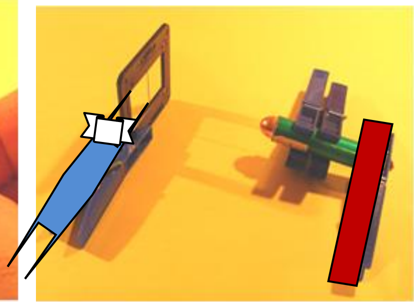


Figure 4.16

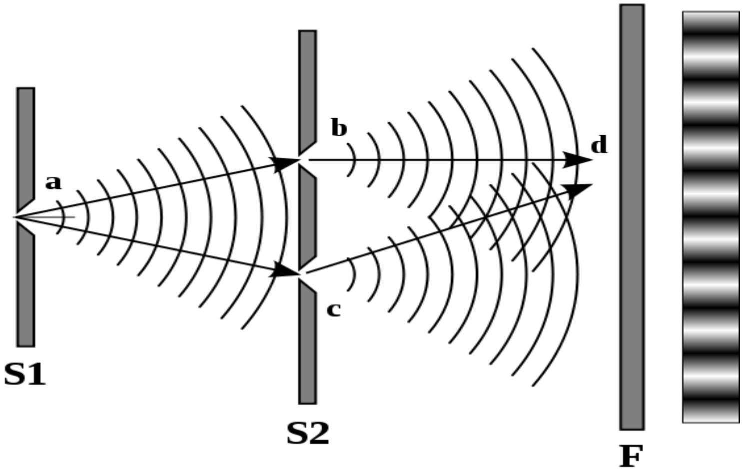


Figure 4.17 Interference of light waves

If we cut a single hole in the barrier, what will happen to the wave at that point? The wave will pass through the single hole and begin to radiate from that point through the medium of the water behind the barrier, like so:

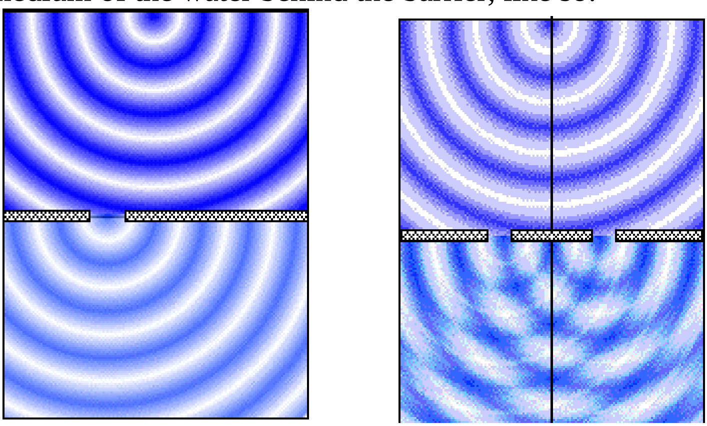


Figure 4.18 Diffraction of one and two stil

The bottom figure is simply a copy of the middle portion of the top one, scaled up by a factor of two. All the angles are the same. Physically, the angular pattern of the diffraction fringes can't be any different if we scale both λ and d by the same factor, leaving λ/d unchanged.

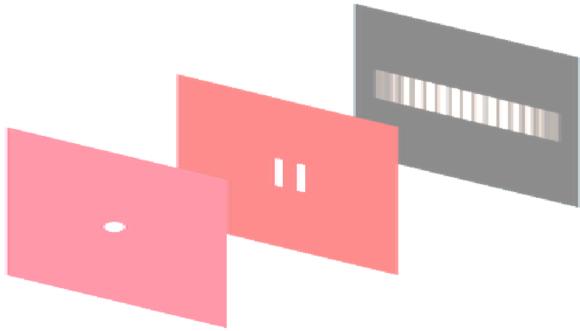


Figure 4.19

If we let the light fall onto a screen behind the obstacle, we will observe a pattern of bright and dark stripes on the screen. This pattern of bright and dark lines is known as a ***fringe pattern***. The bright lines ndicate constructive interference and the dark lines indicate destructive interference.

If we now cut two holes in the barrier, what will happen in the medium of the water behind the barrier? Well, we will now have two waves radiating - one from each hole in the barrier. The radiating waves will be symmetrical, because each is a faithful reproduction of the original wave. The two waves will be overlapping, offset by the distance between the two holes. We saw earlier how two symmetrical and overlapping waves create a pleasing and symmetrical interference pattern. And that is exactly what results from the single wave's passage through two holes in the barrier.

The bright fringe in the middle of the diagram above is caused by constructive interference of the light from the two slits traveling the same distance to the screen. It is known as the ***zero-order fringe***.

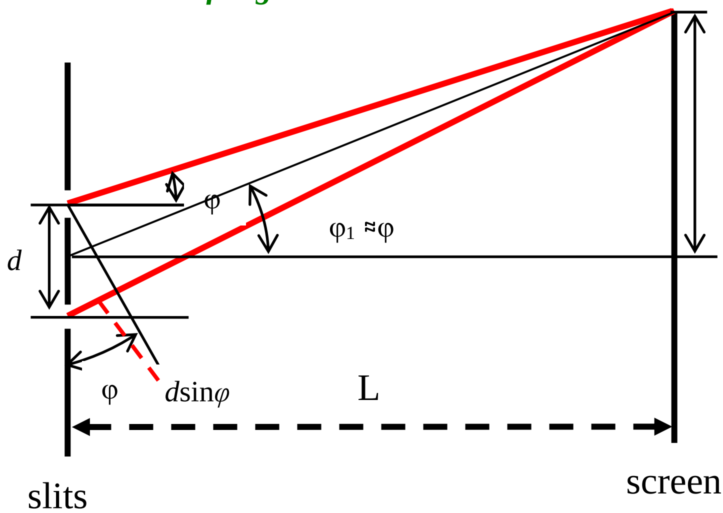


Figure 4.20 Interference of light waves

Crest meets crest and trough meets trough. The dark fringes on either side of the zero-order fringe are caused by destructive interference. Light from one slit travels a distance that is 1/2 wavelength longer than the distance traveled by light from the other slit. Crests meet troughs at these locations. The dark fringes are followed by the first-order fringes, one on each side of the zero-order fringe. Light from one slit travels a distance that is one wavelength longer than the distance traveled by light from the other slit to reach these positions. Crest again meets crest.

Experiment 4.5 The diagram shows the geometry for the fringe pattern. If light with wavelength λ passes through two slits separated by a distance *d*, we will observe constructively interference at certain angles. These angles are found by applying the condition for constructive interference, which is $d\sin\varphi = m\lambda$, $m = 0, 1, 2, \ldots$.

The angles at which dark fringes occur can be found be applying the condition for destructive interference, which is $d\sin\varphi = (m+1/2)\lambda$, $m = 0, 1, 2, \ldots$.

If the interference pattern is viewed on a screen a distance L from the slits, then the wavelength can be found from the spacing of the fringes. We have $\sin\varphi = r/(L^2 + r^2)^{1/2}$ and $\lambda = rd/(m(L^2 + r^2)^{1/2})$, where r is the distance from the center of the interference pattern to the mth bright line in the pattern. If $L >> r$ then $(L^2 + r^2)^{1/2}$ λ L and we can write $\lambda = rd/(mL)$.

Figure 4.21 Interference of light waves

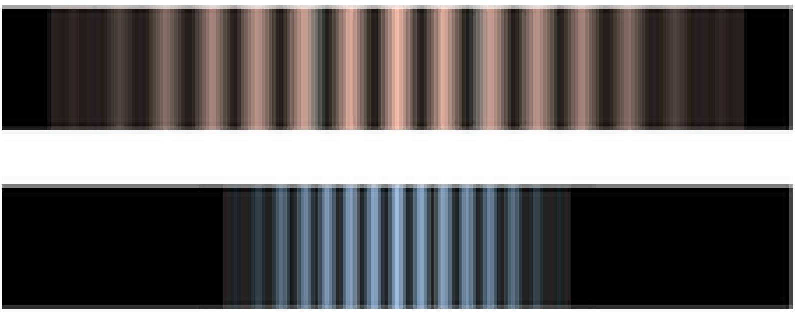


Figure 4.22 Double-slit diffraction patterns of long-wavelength red light (top) and short-wavelength blue light (bottom)

Diffraction can be used to find the structure of an unknown diffracting object: even if the object is too small to study with ordinary imaging, it may be possible to work backward from the diffraction pattern to learn about the object. The structure of a crystal, for example, can be determined from its *X*-ray diffraction pattern.

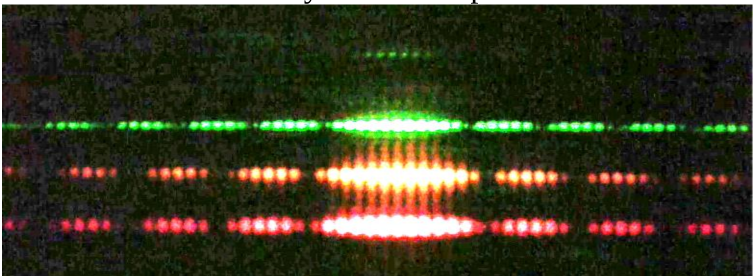


Figure 4.23 Double-slit diffraction patterns of red, orange, green lights

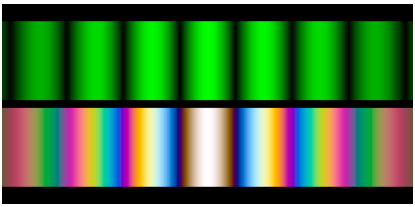


Figure 4.24 Double-slit diffraction patterns of green and natural lights

Figure 4.25 Diffraction at a single slit and double slit system

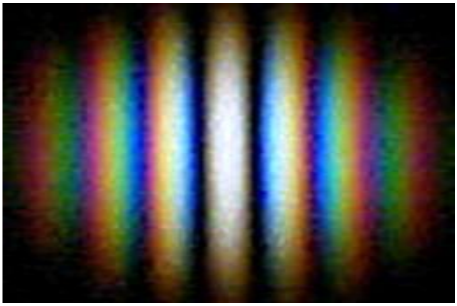


Figure 4.26 Interference pattern at a double slit

Experiment 4.6 However unlike a double slit, the bright fringes are sharper in diffraction grating, fig. 4.27.

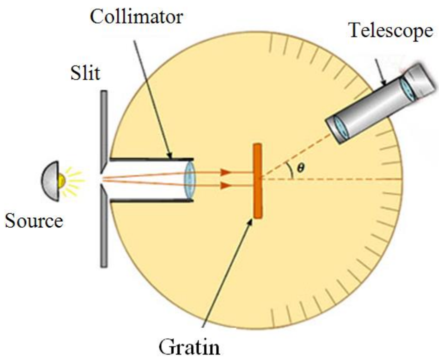


Figure 4.27 The scheme shows a demonstration of interference with diffraction grating

Experiment 4.7 Young's Double Slit Experiment

Equipment: two slits, screen.

This is a classic example of interference effects in light waves. Two light rays pass through two slits, separated by a distance d and strike a screen a distance, L from the slits, as in fig. 4.28.

If $d << L$ then the difference in path length $r_1 - r_2$ travelled by the two rays is approximately: $r_1 - r_2 \approx d\sin\varphi$, where φ is approximately equal to the angle that the rays make relative to a perpendicular line joining the slits to the screen.

If the rays were in phase when they passed through the slits, then the condition for constructive interference at the screen is: $d\sin\varphi = m\lambda$, $m = \pm1, \pm2, ...$ whereas the condition for destructive interference at the screen is: $d\sin\varphi = (m + 1/2)\lambda$, $m = \pm1, \pm2, ...$

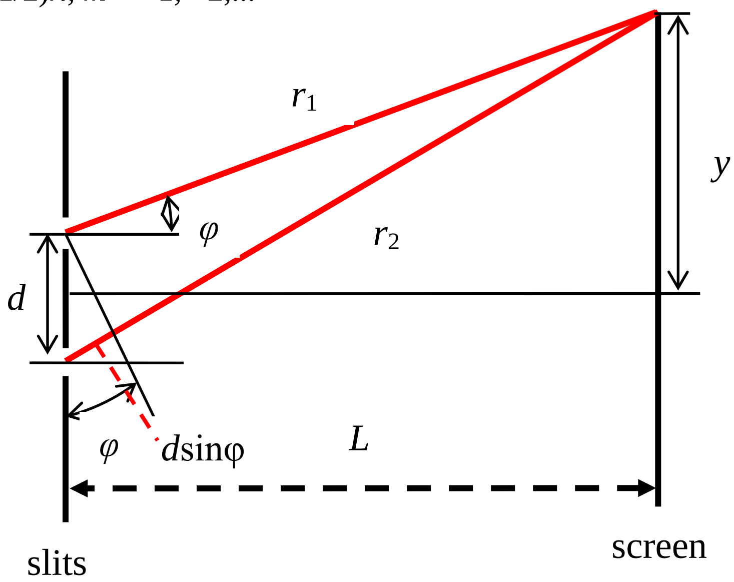


Figure 4.28 Interference of light waves

The points of constructive interference will appear as bright bands on the screen and the points of destructive interference will appear as dark bands. These dark and bright spots are called *interference fringes*. **Note:**

In the case that y, the distance from the interference fringe to the point of the screen opposite the center of the slits (see fig. 4.28) is much less than L ($y << L$), one can use the approximate formula: $\sin\varphi \approx y/L$ so that the formulas specifying the y - coordinates of the bright and dark spots, respectively are: $y_{Bm}=m\lambda L/d$ brightspots $y_{Bm}=(m+1/2)\lambda L/d$ darkspots.

The spacing between the dark spots is $\Delta y=\lambda L/d$.

If $d << L$ then the spacing between the interference can be large even when the wavelength of the light is very small (as in the case of visible light). This give a method for measuring the wavelength of light.

The above formulas assume that the slit width is very small compared to the wavelength of light, so that the slits behave essentially like point sources of light.

1 Using computer programs, you can demonstrate virtual experiments with different sizes of slits and a different distance between them [60].

Virtual experiment of Young's Double Slit can be seen [22]. Condition for a maximum (approximation): $\alpha = 0°$ or $b \sin \alpha = (k + ½) \lambda$, b ... width of slit α ... angle k ... order of).

Experiment 4.8 On the patters we will see a dependence of interference fringes placement from: width, size of the slit, distances between them and from wavelengths.

Discussion Questions

Why is it optically impossible for bacteria to evolve eyes that use visible light to form images?

1 A diffraction pattern formed by a real double slit. The width of each slit is much bigger than the wavelength of the light. This is a real photo.

2This idealized pattern is not likely to occur in real life. To get it, you would need each slit to be comparable in size to the wavelength of the light, but that's not usually possible. This is not a real photo.

A real photo of a single-slit diffraction pattern caused by a slit whose width is the same as the widths of the slits used to make the top pattern.

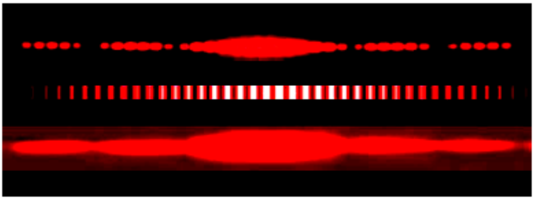


Figure 4.29 Interference of light waves

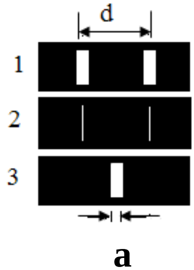


Figure 4.30

Let's consider the intensity of light spreading in the interference patterns from one, two, three and five slits. Double-slit diffraction is easier to understand conceptually than single slit diffraction, but if you do a double-slit diffraction experiment, in real life, you are likely to encounter a complicated pattern like pattern 9 in the figure above, rather than the simpler one, 6, you were expecting. This is because the slits are not narrower than the wavelength of the light being used. We really have two different distances in our pair of slits: *d*, the distance between the slits, and w, the width of each slit. Remember that smaller distances on the object the light diffracts around correspond to larger features of the diffraction pattern. The pattern 9 thus has two spacings in it: a short spacing corresponding to the large distance *d*, and a long spacing that relates to the small dimension *a*.

4.4 Investigation property Interference of light waves of one and two slit

Under the Fraunhofer conditions, the light curve (intensity vs position) is obtained by multiplying the multiple slit interference expression times the single slit diffraction expression. The multiple slit arrangement is presumed to be constructed from a number of identical slits, each of which provides light distributed according to the single slit diffraction expression. The multiple slit interference typically involves smaller spatial dimensions, and therefore produces light and dark bands superimposed upon the single slit diffraction pattern.

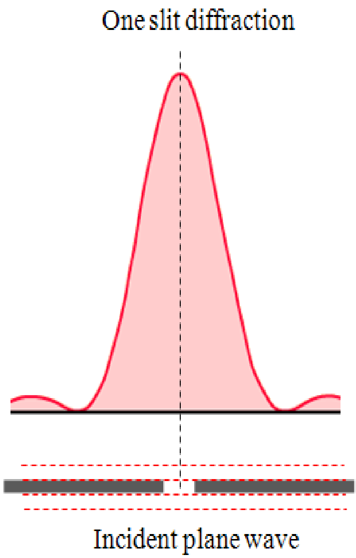


Figure 4.31 Single slit diffraction slit

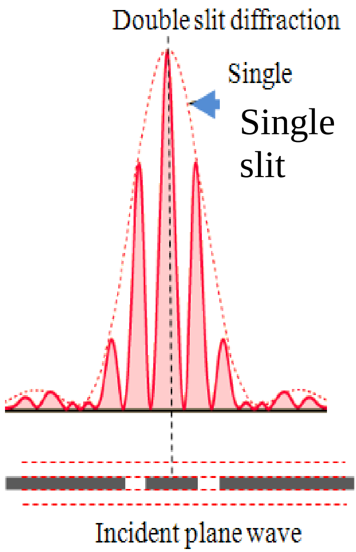


Figure 4.32 Double diffraction

The double-slit experiment, sometimes called ***Young's experiment***, is a demonstration that matter and energy can display characteristics of both waves and particles. In the basic version of the experiment, a coherent light source such as a laser beam illuminates a thin plate pierced by two parallel slits, and the light passing through the slits is observed on a screen behind the plate. The wave nature of light causes the light waves passing through the two slits to interfere, producing bright and dark bands on the screen a result that would not be expected if light consisted strictly of particles.

Table 4.4.1

Index Diffraction concepts Fraunhofer diffraction

	Slit		
1	Single slit	Diffraction and interference	Under the Fraunhofer conditions, a single slit will exhibit a light curve following the single slit diffraction intensity expression. The narrower the slit, the broader the peaks of light. The shape or «envelope» of this light curve will serve to set limiting intensities for multiple slit arrangements, assuming that all the slits are identical.
2	Double slit		
3	Three slits	Interference only	
4	Five slits		

However, at the screen, the light is always found to be absorbed as though it were composed of discrete particles or photons [40; 41]. This establishes the principle known as wave–particle duality.

4.5 Investigation property three and five slit diffraction

The progression to a larger number of slits shows a pattern of narrowing the high intensity peaks and a relative increase in their peak intensity. This progresses toward the diffraction grating, with a large number of extremely narrow slits. This gives very narrow and very high intensity peaks that are separated widely. Since the positions of the peaks depends upon the wavelength of the light, this gives high resolution in the separation of wavelengths.

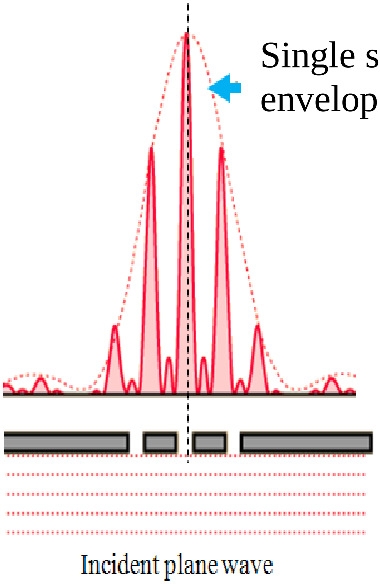


Figure 4.33

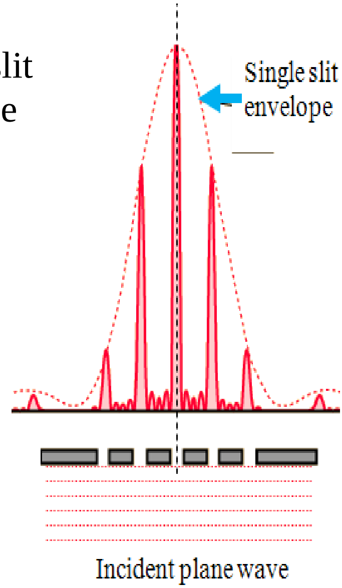


Figure 4.34

Experimetnt 4.9 Interference of light waves on one, two, three, four, five and seven slits, fig. 4.35.

This makes the diffraction grating like a «super prism».

Experiment 4.10 are used in scientific and technical investigations. Manufacturers of wire (and other objects of small dimension) sometimes use a laser to continually monitor the thickness of the product. The wire intercepts the laser beam, producing a diffraction pattern like that of a single slit of the same width as the wire diameter (see the figure below). Suppose a helium-neon laser, of wavelength 632,8 *nm*, illuminates a wire, and the diffraction pattern appears on a screen at distance L =2,65 *m*. If the desired wire diameters 1,19 *mm*, what is the observed distance between the two tenth-order minima (one on each side of the central maximum)? Any help is appreciated!

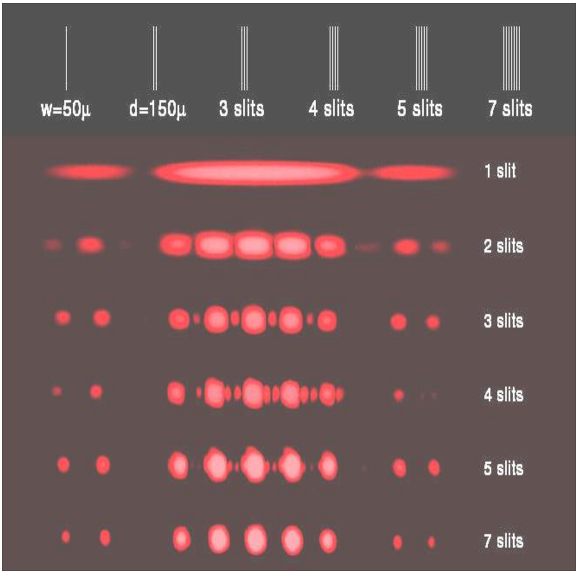


Figure 4.35 Interference of light waves

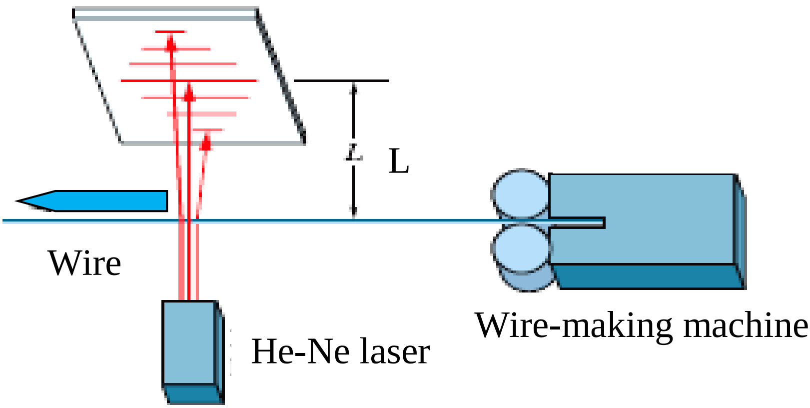


Figure 4.36 Interference of light waves

4.6 Investigation property Standing Waves

When two waves move in opposite directions, through each other, interference takes place. If the two waves have the same frequency and wavelength then a specific type of constructive interference can occur: standing waves can form.

Standing waves are disturbances which don't appear to move, they look like they stay in the same place even though the waves that from them are moving.

Experiment 4.11 The investigation of interference pattern in Young's Double Slit Experiment.

In the double-slit experiment, fig. 3.33, the two slits are illuminated by a single light beam. If the width of the slits is small enough (less than the wavelength of the light), the slits diffract the light into cylindrical waves. These two cylindrical wavefronts are superimposed, and the amplitude, and therefore the intensity, at any point in the combined wavefronts depends on both the magnitude and the phase of the two wave fronts [62]. These fringes are often known as Young's fringes.

The angular spacing of the fringes is given by $d\sin\varphi=m\lambda$, $\varphi=\lambda/d$.

The spacing of the fringes at a distance L from the slits is given by $w_f=L\varphi=L\lambda/d$, where d is the separation of the slits.

The fringes in the picture were obtained using the yellow light from a sodium light (wavelength = 0,589 μm), with slits separated by 0,25 *mm*, and projected directly onto the image plane of a digital camera.

Double slit interference fringes can be observed by cutting two slits in a piece of card, illuminating with a laser pointer, and observing the diffracted light at a distance of 1m. If the slit separation is 0,5 *mm*, and the wavelength of the laser is 0.6 μm the spacing of the fringes viewed at a distance of 1m would be 1,2 *mm*.

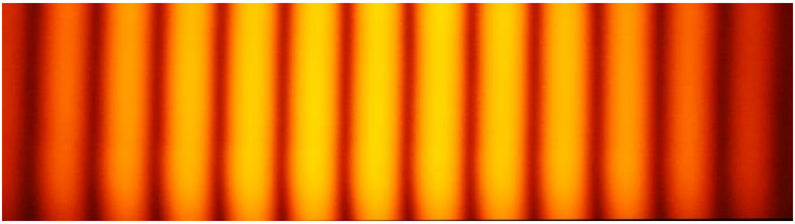


Figure 4.37 Diffraction by a double slit

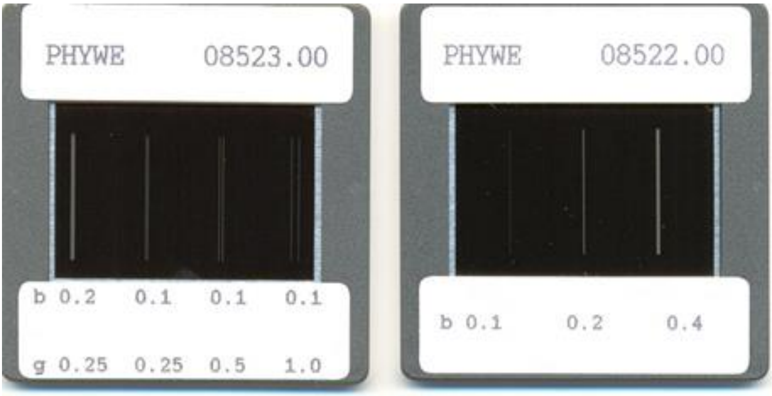


Figure 4.38

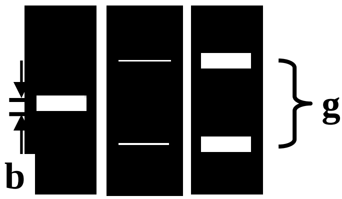


Figure 4.39

In the set of interference and light diffraction, a double slit is included. In the absence of a double slit it is quite easy to make it yourself, fig. 4.40.

1-st way. From the photographic plate we cut the plates in the sizes 4,5x6 *cm*. Glue BF-2 stick to the plate ends stretched along it with a wire diameter of 0.05-0.07 *mm*, fig. 4.40. Then break the blade in half, fig. 4.41, lubricate its ends with glue and stick on both sides (already glued) of the thin wire so that the slits have the same width of 0,03-0,05 *mm*.

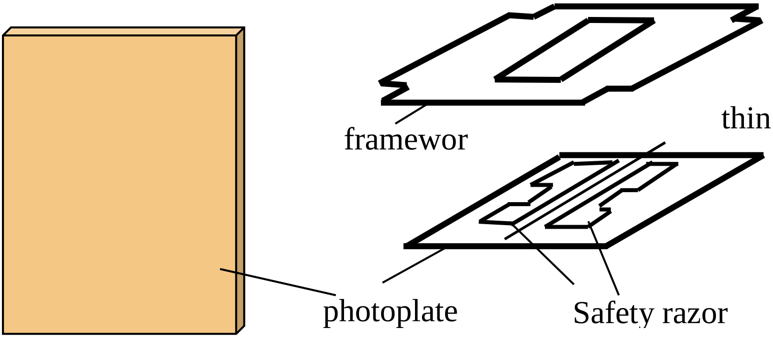


Figure 4.40

When making a double slit, use a microscope or a magnifier. To avoid damaging the slits, after drying the glue, cover the plate with another plate and enclose it with black paper and place it in a frame with a cutout for the slit, fig. 4.40.

2-nd way. One side of the plate removed from the photoemulsion is covered with brush by black ink (better frost-resistant). On the surface of the glass covered with ink, put a metal line in parallel to the side of the plate. Two blades clipped between the thumb and forefinger of the right hand, pass along the edge of the metal ruler, cut two parallel slits at once. The distance between them is equal to the thickness of the razor.

The slits are explored in this way. In the left hand we hold a metal screen with a slit (from the laboratory set). Immediately in front of the eye in the right hand, place a plate with slits. If 5-7 or more interference bands are viewed, then such gaps are suitable for the experiment. In the case when we see three light stripes, we weed the double slit (paint it with ink).

3-rd way. On a sheet of watman we draw two vertical strips of 10 *mm*. wide with the help of black ink. The distance between the strips is 5 *mm*. Take pictures of drawn on a watten strips from a distance of 2-3 *m*. After chemical processing of the film, we cut out the necessary frames and fasten them in the frame of the slides or paste on cardboard plates from the cut out for slits. We have Young's double Slit.

Figure 4.41

Figure 4.42

Let's highlight the main stages and conditions for demonstration.

1 Place the spiral plane of the UPD projection lamp along the direction of light propagation.

2 Directly behind the condenser we attach a sliding slits on a screen vertically with a rod, the blades of which have no mechanical damage.

3 Open the slit to the maximum width. Turn on UPD and watch a light spot on the screen, located at a distance of 60-80 *cm*. There should be no dark stripes or shadows on it. Their presence requires the adjustment of the sliding slit, the cleaning of dust and lining of the condenser lens, or the adjustment of the projection lamp.

4 Place a double slit at a distance of 20 *cm* from the slit in the screen, fig. 4.43.

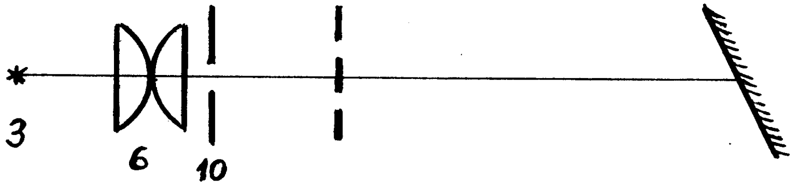


Figure 4.443

Turning the handle of the screen of its clip, we obtain the exact parallel of the slits. Their middles should be on the main optical axis of the condenser. On the screen we observe a vertical light strip with clearly defined edges. We reduce the width of the slit and achieve a clear interference pattern, fig. 4.44.

Then we reduce and increase the distance between the slit and the double slit. The number and width of the interference bands changes on the screen. We set the boundary distances which provide interference.

The above observations are common to all experiments on interference and light diffraction.

Let's replace portable screen on matte. When the distance from the double slit to the screen is 2-2.5 *m*, the width of the interference pattern reaches 15-25 *cm*, and the brightness allows the use of light filters and observe interference in monochromatic light.

Interference pattern is projected onto the screen. To enlarge the picture, turn the screen to a small angle to the incident rays. This setting allows you to set a series of experimental tasks. In particular, with a filter passing a certain wavelength, one can measure the distance between the middle of the neighboring light and dark bands and check the formula $\alpha = t\lambda / L$, where t is the distance between the slits, *L* and the distance from the double slit to the screen.

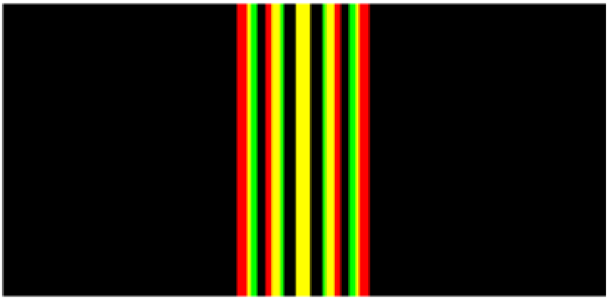


Figure 4.44

In one of the experiments conducted for a wavelength of 550 *nm*, the distance between the strips was 11 *mm* (t = 0.1 *mm*, L = 2 *m*).

Experiment 4.12 Investigation of Fresnel diffraction

In optics, the Fresnel diffraction equation for near-field diffraction, is an approximation of Kirchhoff-Fresnel diffraction that can be applied to the propagation of waves in the near field.

The near field can be specified by the Fresnel number, F of the optical arrangement, which is defined, for a wave incident on an aperture, as: $F=a^2/L\lambda$, where a is the characteristic size of the aperture.

Lis the distance of the observation point from the aperture λ is the wavelength of the wave.

When $F \geq 1$ the diffracted wave is considered to be in the near field, and the Fresnel diffraction equation can be used to calculate its form. The multiple Fresnel diffraction at nearly placed periodical ridges (ridged mirror) causes the specular reflection; this effect can be used for atomic mirrors.

Description. Compared to conventional bulky lenses, the Fresnel lens reduces the amount of material required compared to a conventional spherical lens by breaking the lens into a set of concentric annular sections known as «Fresnel zones», which are theoretically limitless.

In the first variations of the lens, each zone was actually a different prism. Though a Fresnel lens might look like a single piece of glass, closer examination reveals that it is many small pieces. For each of these zones, the overall thickness of the lens is decreased, effectively chopping the continuous surface of a standard lens into a set of surfaces of the same curvature, with discontinuities in steps between them.

In fact this product can be regarded as an array of prisms positioned in a circular fashion, with steeper prisms on the edges and a near flat convex center. Fresnel lenses are usually made of glass or plastic; their size varies from small to large. Since plastic lenses can be made larger than glass lenses, as well as being much cheaper and lighter, they are used to concentrate sunlight in multiple uses.

4.7 Interference of light waves

Experiment 4.13 Investigation of Fresnel biprism

Description: A Fresnel biprism is a glass prism with a very large angle. A 5 *cm* focal length convex lens focuses the laser light on the biprism. The laser beam enters the flat side and exits at the tip of the symmetric triangle with the beam split by the two halves of the prism, which are very nearly parallel. The exiting halves of the beam are refracted so that they overlap and interfere, producing a series of fringes. The 10 *cm* focal length concave lens aids in expanding the fringes so they can be seen on a nearby screen, as seen in the photo above.

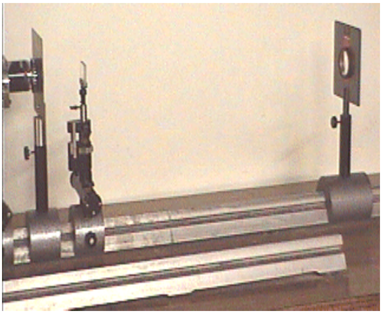
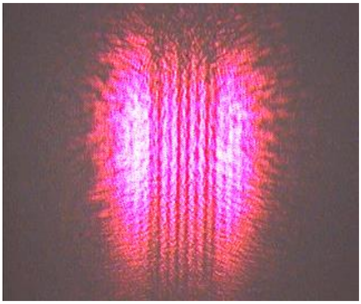
 

Figure 4.45 *Figure 4.46*

Interference from Fresnel's biprism

Equipment: UPD, Fresnel biprism, from the set for interference and diffraction of light, sliding slit, lens number 1 with a focal length of 7.5 *cm*, screen. The scheme of installation is shown on the fig. 4.47.

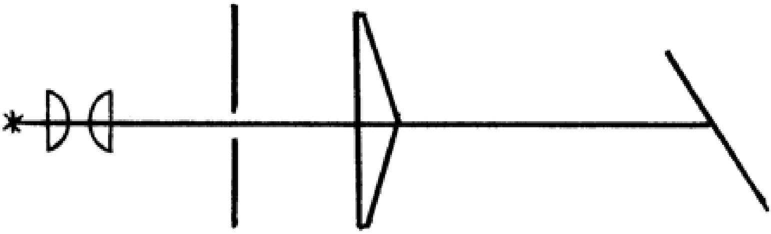


Figure 4.47

The method of performing the experiment is similar to a double-slit experiment.

By changing the mutual position of the slit and the biprism, as well as the width of the crack, we obtain a clear interference pattern on the screen, fig. 4.48, at a distance of 2-2.5 *m* from the biprism. To expand the interference bands, in the path of the rays coming from the biprism, put the lens number 1 (F = 7.5 *cm*).

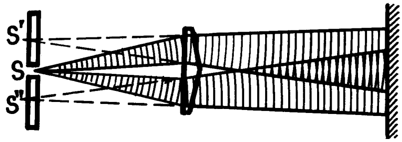


Figure 4.48

Figure 4.49

It is advisable to show students that each of the two coherent beams of light, taken separately, does not give he picture of the interference, but only equally illuminates the screen. To do this, you need to close the non-transparent object in turn first in the right part of the biprism, and then in the left, fig. 4.50.

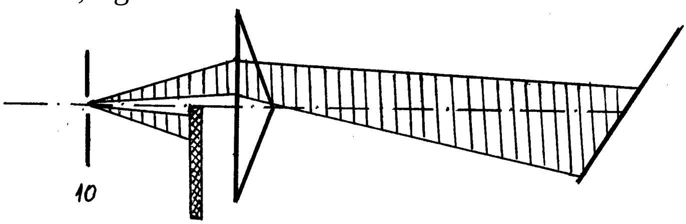


Figure 4.50

Experiment 4.14 On the basis of the experiment with a biprism, a number of experimental tasks can be put in, in particular: Determine the length of the light wave and the magnitude of the refractive angle of the Fresnel's biprism.

In the course of physics, the refractive angle of a biprism is determined by the formula $A = L\lambda / 2da\ (n - 1)$. Hence, the wavelength will be $\lambda = 2Ada\ (n - 1) / L$, where L is the distance from the slit to the screen, d is the distance from the gap to the biprism, and the distance between the two adjacent maxima, n is the refractive index of the glass prism.

Experiment 4.15 Interference of Young's double slit with a laser.

Equipment: laser, double slit, a lens, N_1 (2 *PCs*), matte screen, table screen, rotating mirror, optical bench.

Set up the laser on the optical bench, fig. 4.51. At a distance of 5-7 *cm* from it on the stand fasten the lens N_1, which allows you to get a wider beam. Behind the lens, at a distance of 10-15 *cm* at the screen with the rod put Young's double slit. Have the screen at a distance of 80-120 *cm* from the laser. We obtain the system of vertical dark red bands, fig. 4.52.

Figure 4.51

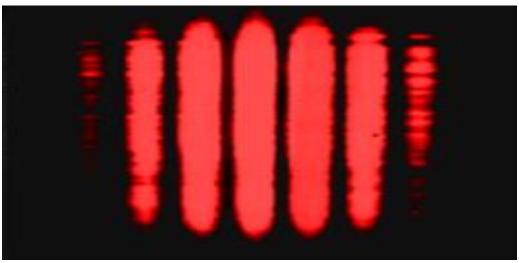


Figure 4.52

For their expansion between the double slit and the screen (in the tripod) have a second lens N_1.

Observe changes on the screen when decreasing or increasing the distance between the double slit and the screen.

Experiment 4.16 Fresnel Mirrors

Thomas Young's 1800 demonstration of interference used two pinholes as sources. To ensure that the signals from each were in phase, they were both illuminated by the same pinhole. The use of two real sources was considered unsatisfactory, and about 1816 Agustin Fresnel (1788-1827) used a pair of mirrors that produced two virtual sources from one real source.

The mirrors are inclined at a slight angle to each other, and illuminated by a monochromatic light source with a beam of light at a small angle to each mirror. The two reflected beams, appearing to come from two closely-spaced virtual sources, interfere with each other and produce maxima and minima.

The apparatus is in the Jack Judson Collection at the Magic Lantern Museum in San Antonio, Texas, and appears to have been home-built.

Experiment 4.17 From two holes

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The apparatus is in the Jack Judson Collection at the Magic Lantern Museum in San Antonio, Texas, and appears to have been home-built.

Figure 4.53

Experiment 4.18 Two plane mirrors that form a dihedral angle a few angular minutes less than 180° used for the observation of the phenomenon of the interference of coherent light beams; proposed by A.J. Fresnel in 1816.

When the mirrors I and II (see fig. 4.55) are illuminated by a source *S*, the beams of rays reflected from them may be considered to have originated from coherent sources S_1, and S_2, which are virtual images of *S*. Interference occurs in the region where the beams cross. If *S* is linear (a slit) and parallel to the edge of the Fresnel mirrors, then upon illumination by monochromatic light the interference picture in the form of parallel slits of evenly spaced dark and light bands or fringes is observed on the screen *M*, which can be set up anywhere in the region where the beams cross. The wavelength of the light can be determined from the distance between the bands. Experiments conducted with Fresnel mirrors were one of the crucial proofs of the wave nature of light.

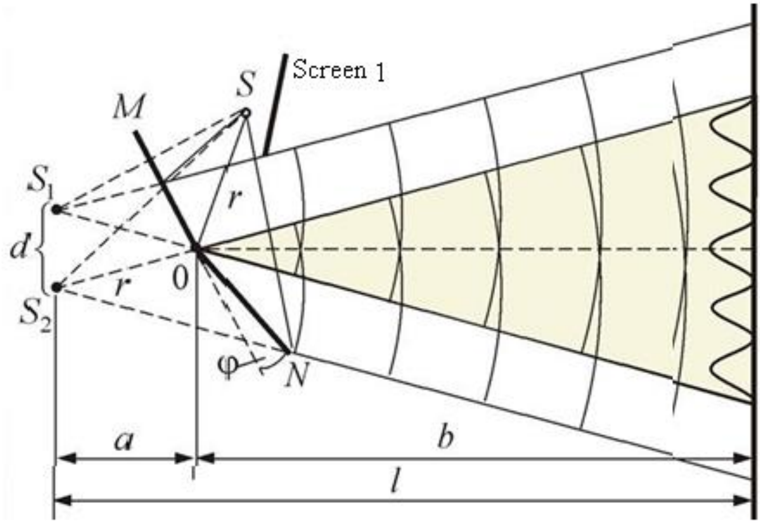


Figure 4.54 Experiments of the Fresnel Mirrors. MO and OM - mirrors, S – light

$\Delta x \approx \lambda l/d = \lambda(a+b)/2a\varphi$, Δx – the distance between adjacent bright bands.

4.8 Investigation property Fresnel Mirrors can be made in several ways

The 1st method. Use two Ioganson's tiles of the same extent. Polished faces serve as the mirrors. Tiles create a dihedral angle close to 180 degrees. A narrow beam of light that falls on the tiles, gives two coherent beams which overlap and interfere with each other. First, on the screen we get two beams reflected from mirrors, and then observe their gradual rapprochement, and finally the overlay with the formation of the interference pattern. The device consists of a rim 2, fig. 4.55, in which we put the cut to size tiles *1* glass plate of good quality (it is better to use glass from photographic plates).

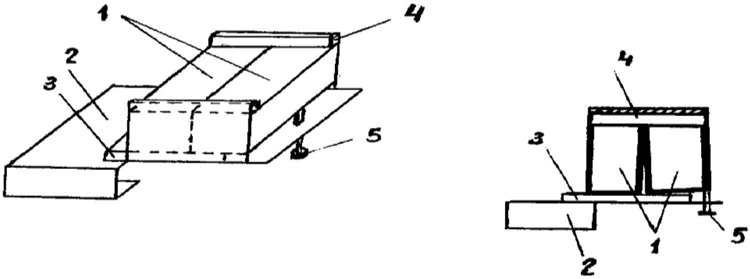


Figure 4.55

On the glass, we place the plates so that one of them goes beyond the edge of the glass. From the top of the tiles between their upper surface and the frame, insert the tough strips of rubber 4, which press the tiles to the glass plates. Under the part of the tile that extends beyond the edge of the table, we have an adjusting screw 5 that changes the two-cornered angle between the tiles. We attach the device to the table from the set to the UPD. The pattern of the setting is shown in fig. 4.56. Its sizes are selected depending on the size of the existing tiles.

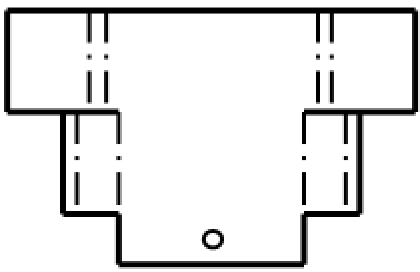


Figure 4.56

2nd way.

Johanson tiles can be replaced with self-made mirrors with an external coating. Mirrors on a plate of glass, treated with a surface up, we place in the frame 2, fig. 4.56.

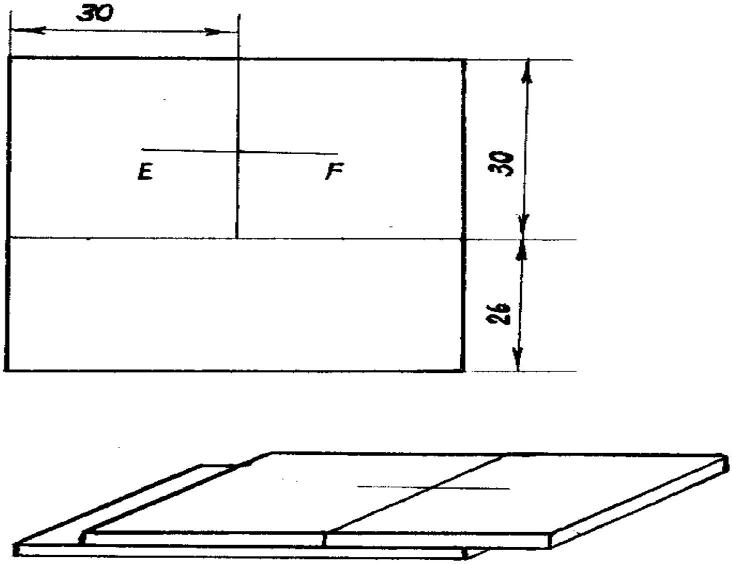


Figure 4.57

To create a double-edged corner, we insert a 0.5 *mm* thick cardboard strip under the outer edge of one of the plates. At the border, ensure that the risks on the plates are coincided. The course of rays is shown on fig. 4.58.

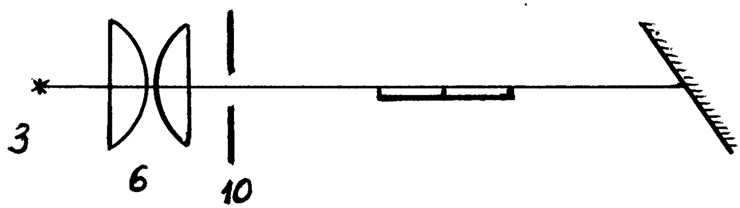


Figure 4.58

Experiment 4.19 Lloyd's Lanes

Equipment: UPD, Lloyd's mirrors, a desktop screen, a matte screen, a rotating mirror. Lloyd's mirror is another device developed during the early part of the 19th century to demonstrate interference. Here, light from a monochromatic slit source reflects from a glass surface and a small angle, appearing to come from a virtual source. The reflected light interferes with the direct light from the source, forming interference fringes. Humphry Lloy *d* published an article about the demonstration in the Proceedings of the Royal Irish Academy of Science in 1837.

This apparatus is part of a large projection lantern system made by E. Leybold's Nachfolger of Cologne. It is normally placed horizontally and attached to the front of the lantern. The slit and reflecting surface can be clearly seen; the beam-blocker perpendicular to the mirrored surface is used to prevent unwanted direct light from flooding the projection screen.

This apparatus is in the Jack Judson Collection at the Magic Lantern Castle Museum in San Antonio, Texas.

Figure 4.59

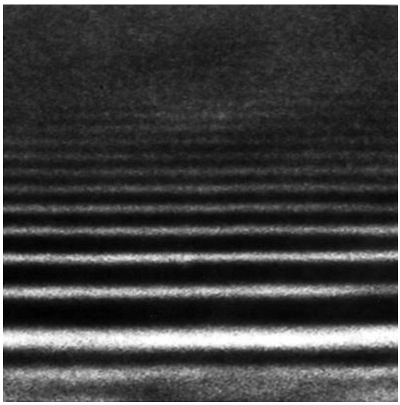


Figure 4.60

In Lloyd's experiment, two beams of light interfere: one is reflected from the mirror at an angle close to 90 degrees, and another straight from the light source, fig. 4.61.

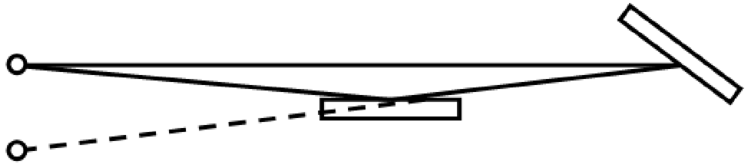


Figure 4.61

The interference picture is different from the others. In the experiments of Jung and Fresnel, we have a symmetrical picture of interference with a light central lane. In Lloyd's experiment, it is not symmetric. In it, the band corresponding to the central lane in the Young's experiment is not light, but dark. This is due to the fact that the reflection of the beam from the mirror surface loses half of a wave, because the glass has a greater refractive index than air.

Lloyd's mirrors are made of mirrors with an outer covering of 12-15 *cm* long and 3-4 *cm* wide. Such a mirror can be made of mirrors from an epideoscope, electric meters with a mirrored scale or from the UPD. The setup for demonstration is shown on fig. 4.62.

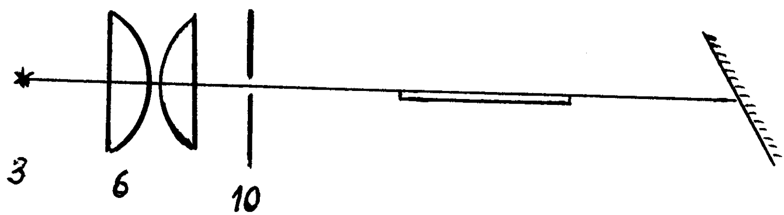


Figure 4.62

At a distance of 10-12 *cm* from the condenser, we have a sliding gap, 0.3-0.5 *mm* wide. Turning the disk slit is brought to a horizontal position. Directly behind the slit on the reiters, which has screws for vertical and lateral displacements, we fix the table on the rods with the mirror of Lloyd. The latter is located at such an altitude, and at such an angle that a part of the rays comes from the crevice slide along its surface, and the other part immediately reaches the portable screen.

On the screen, we observe two horizontal light spots. Turning the mirror around the horizontal axis, and changing the height of the location of the mirrors (along with the table), reduce the angle of the slides of the rays and reduce the bright spots to overlay one on the other. The light and dark interference bands appear on the screen, fig. 4.62.

4.9 Investigation property Acceptance of the wave theory of light

In 1817, the corpuscular theorists at the Academie Francaise which included Simeon Poisson were so confident that they set the subject for the next year's prize as diffraction, being certain that a particle theorist would win it. Augustin-Jean Fresnel submitted a thesis based on wave theory and whose substance consisted of a synthesis of the Huygens' principle and Young's principle of interference.

Poisson studied Fresnel's theory in detail and of course looked for a way to prove it wrong being a supporter of the particle-theory of light. Poisson thought that he had found a flaw when he argued that a consequence of Fresnel’s theory was that there would exist an on-axis bright spot in the shadow of a circular obstacle blocking a point source of light, where there should be complete darkness according to the particle-theory of light.

Fresnel's theory could not be true, Poisson declared: surely this result was absurd. (The Poisson spot is not easily observed in every-day situations, because most everyday sources of light are not good point sources.)

However, the head of the committee, Dominique-Franзois-Jean Arago, and who incidentally later became Prime Minister of France, did not have the hubris of Poisson and decided it was necessary to perform the experiment in more detail. He molded a 2-*mm* metallic disk to a glass plate with wax [64]. To everyone's surprise he succeeded in observing the predicted spot, which convinced most scientists of the wave-nature of light. In the end Fresnel won the competition, much to Poisson's chagrin.

After that, the corpuscular theory of light was vanquished, not to be heard of again till the 20th century. Arago later noted that the phenomenon (which was later to be known as the Arago spot) had already been observed by Joseph-Nicolas Delisle H. [64; 65] and Giacomo F. Maraldi [66] a century earlier.

Experiment 4.20 Interference from an air wedge

Equipment: light source, two translucent plates, a collectible lens of a school set of lenses, narrow thin strips of paper, 4 pins, a physical tripod.

Semi-transparent plates can be made independently of photographic plates, sized 9x12 *cm*. We process them with a solution of sodium and carry out silvering. Methods of silvering are described in the methodical literature, which is now rare.

If one of the glass surfaces is silvered, the other side must be covered with wax or paraffin. The degree of silvering can be determined visually or with the help of a luxmeter for reducing the light flux passing through the fabricated mirror.

After drying the mirrors, put them by mirror surfaces to each other, forming an air wedge, fig. 4.63. To do this, on one side, lay a narrow strip of paper. For one of the legs of the pin, we fix the mirrors in the foot of the physical tripod, sliding the wedge up. At a distance of 70 *cm* from the light source put a lens, fig. 4.63.

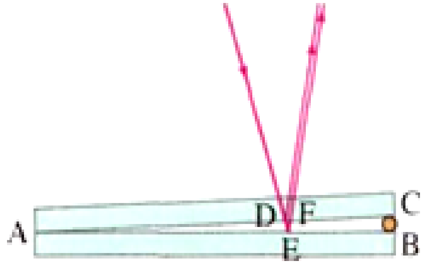


Figure 4.63

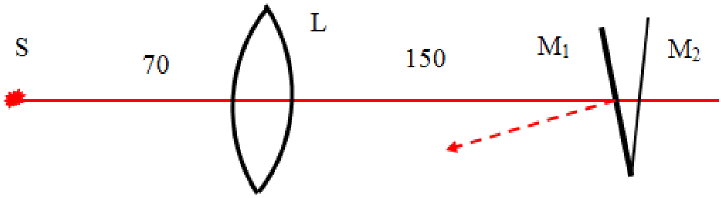


Figure 4.64

We place the wedge 1.5-2 meters from the lens. In the reflected light we see a clear interference image, fig 4.65.

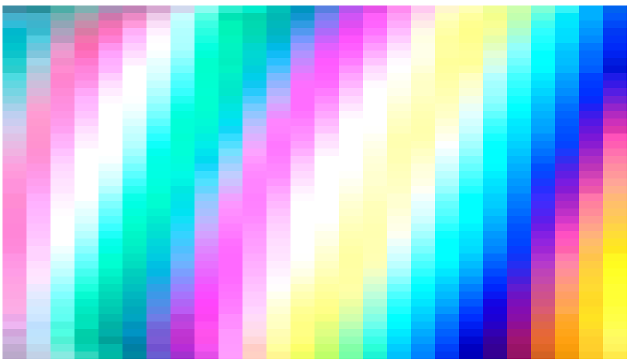


Figure 4.65

The lens in the experiment is used to create a divergent beam of light. With installation, we carry out a number of tasks:

Task 1 Study of the dependence of the width of the interference bands on the environment between the mirrors.

With the pipette, we introduce a few drops of alcohol in a rubber pear and press on it to send steam between the mirrors. Observe the bias of the bands.

Task 2 Study of the dependence of the position of interference bands on the temperature of the medium.

On the spirit-lamp we will heat the end of a copper conductor with a diameter of 0.5 *mm* and a length of 15 *mm* and put it between the mirrors. Interference bands will be displaced, their width will be changed.

Task 3 Study of the dependence of the position of interference bands from the angle of observation.

We change the angle between the direction of observation and the perpendicular to the surface of the mirror (angle of observation). We see that interference bands can be traced within the angle of observation (from 5 to 30 degrees).

Task 4 Study of the dependence of the width of interference bands on the magnitude of the two-cornered angle. Determine the thickness of the strip of paperby the micrometer and place it under one edge of the mirrors. We count the number of light (or dark) interference bands obtained with the wedge. Then we increase the number of paper strips between the mirrors (increase the dihedral angle) and again count the number of stripes. Interference bands become wider, their number decreases.

Task 5 Study of the influence of the mutual location of the light source of the wedge. We place the wedge at a distance of 1 meter from the light source and count the number of received interference bands across the length of the wedge. After that, we increase the distance between the light source and the wedge to 2 meters. Again count the number of bands and their width. We see that with the increasing of distance, their number decreases, and the width increases

Experiment 4.21 Interference in thin films

Equipment: UPD, universal tripod, wire frame, shampoo solution, screen.

From a copper wire with a thickness of 2-3 *mm* we make a frame in the form of an equilateral triangle with a side of 6 *cm*, fig. 4.66.

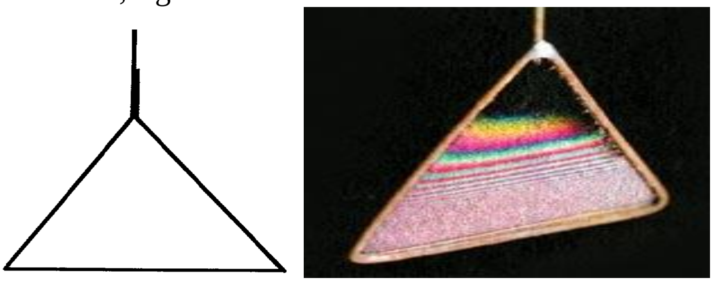


Figure 4.66

Figure 4.67

The oil film phenomenon described earlier is used for filtering light. Precise coatings on optical lenses in binoculars or cameras, astronaut's visors, or even sun glasses cause destructive interference that eliminates certain unwanted colors or stray reflections.

We burn out the place of the conductor connection in one of the corners of the triangle. We attach the carcass in the foot of the physical tripod so that its plane is vertical. Pour two-thirds of shampoo and a third of water iInto the tank. Such solution gives good thin films on the frames. We plunge the skeleton into a tank with a solution of shampoo and remove it from it. The optical installation circuit is shown on fig. 4.68.

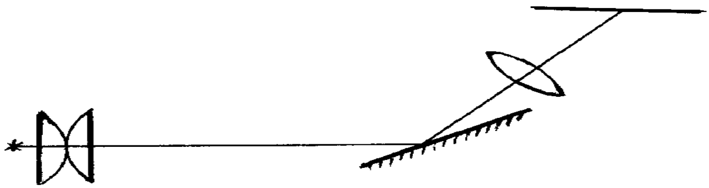


Figure 4.68

We place Frame 2 with a film in a beam of light, which extends from the condenser 1. The film plane forms a 45 degree angle with the main optical axis of the condenser. Reflected from the surface of the film, the ray passes through the lobes 3 to screen 4. Due to the drain of the fluid to the base of the frame, the film takes the form of a wedge. On the screen we observe colored horizontal bands moving upwards. At the same time, we observe the expansion of the strips, indicating a decrease in the angle of the wedge. The use of light filters results in an increase in the number of interference bands. The stripes will be dark and light (according to the color of the light filter).

Experiment 4.22 Interference in a thin air gap with a laser

Equipment: laser LG209, two prisms of the type «flint» or «cron», a device for studying the laws of geometric optics, a concave lens from the laboratory set of optics, a mirror with an outer covering from the set set to UPD.

In the center of the disk screen device for the study of geometric optics clamps, we attach two composite dispersion prisms 1 and 2, fig. 4.69.

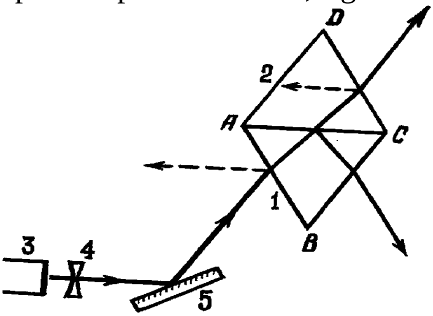


Figure 4.69

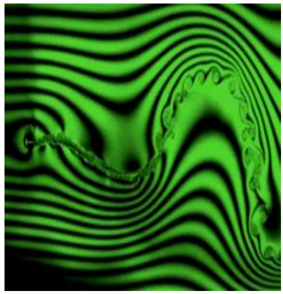


Figure 4.70

The light from laser 3 passes through a concave lens 4, falls on a mirror 5 (with an external coating). The reflected beam passes through the border of the *AB* prism 1, reflects from the lower and upper surfaces of the air gap o *AC* (between prisms 1 and 2) and is divided into two parts: one goes out of prism 1 through the border of the *BC*, and the other through the border of the *DC*. On the screens in the passage and reflected rays we get interference pictures (fig.4.70).

Experiment 4.23 Colored variability

Equipment: UPD, physical tripod, polished steel plate, screen, lens.

Observation of the variability of colors is the result of interference in thin films. The setting for the color variation is similar to that of a soap film. Instead of a triangular frame, we attach vertically the polished steel plate in the foot of the tripod.

Reflected from the plate, the beam falls on the lens and projects onto the screen. Heat the bottom part with spirit-lamp. We observe the colors of variability and their movement. To demonstrate experiments, it is advisable to use a plate as thin as possible, in particular the blade of a safe razor. The heater may be a match. Color bands appear quite fast.

Experiment 4.24 Newton's Rings

A convex test surface on top of a flat reference will give a Newton's rings pattern. If the two surfaces are truly in contact at the center, then the center is always dark in reflection, fig. 4.71. This is because there is a 180 phase change for the reference beam due to the reflection at a boundary from lower index to higher index. Since the test beam has no phase change the two waves destructively interfere.

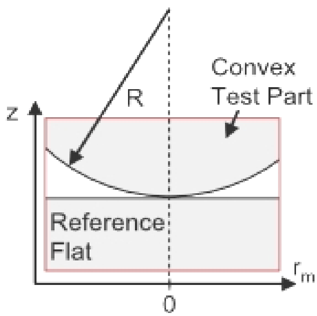


Figure 4.71

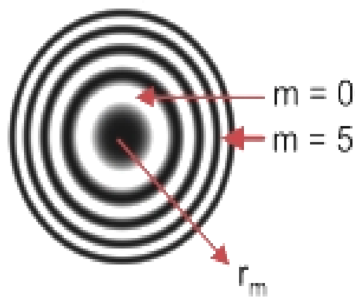


Figure 4.72

The radius of curvature $R=r^2/\lambda(m+1/2)$ is found by counting the number of bright fringes to a radial distance r_m, where the first bright fringe is m=0.

The classic Fizeau interferometer is useful for checking the curvature of a lens surface versus a master surface, as in lens grinding. The surfaces match when only tilt fringes remain.

The device for demonstration of Newton's rings, fig. 4.73, We adjust the interference pattern with the help of the screws so that the picture accures in its center and has a system of concentric circles. At a distance of 10 *cm* from the laser, fig 4.74, place an eyepiece 15x from the microscope. In a screen with a rod at a distance of 10-15 *cm* from the eyepiece, we attach a device for demonstrating the rings of Newton. Turn on the laser.We rotate the device so that its beam plane is 45 degrees. The screen is placed at a distance of 80-120 *cm*. Observe the interference rings in the passed and reflected light through the lens.

Figure 4.73

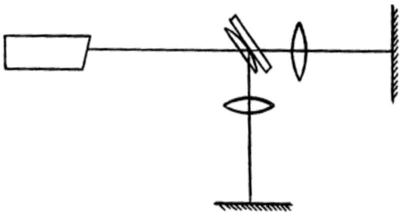


Figure 4.74

It is advisable to place rings in passed and reflected light on one screen. To do this, in the path of reflected light, put a rotary mirror with an outer covering from the *UPD* and direct it to the main screen. We see that the dark places in one picture correspond to the light in the other.

Experiment 4.25 Interference in which two glass surfaces

Equipment: prism, convex lens, a source of light, screen.

This device is related to Newton's Rings, in which two glass surfaces, one flat and one convex, are pressed into close contact, forming a thin film with circular symmetry. In this case, the light is introduced into the system at a large angle of incidence by means of a prism that also forms the plane surface. This avoids the loss of signal by reflection from the upper side of the usual parallel-sided upper plate of glass.

The ray 1 is top interface. Two rays 2 and 5 produce the interference you see in the film. The ray 6 is bottom interface.

When ray 1 strikes the top interface, some of the light is partially reflected, ray 2, and the rest is refracted, ray 3.

When ray 3 strikes the bottom interface, some of it is reflected, ray 4, and the remainder is refracted, ray 6.

When ray 4 strikes the top interface from underneath, some is reflected (not shown) and some is refracted, ray 5.

It is the interference between rays 2 and 5 that produces a thin film's color when the film is viewed from above.
Passing of rays in a flat parallel plate.

The formula used for thin film interference is $EPD = 2t + \Phi$ where t represents the thickness of the thin film Φ is the net phase inversion between rays 2 and 5 (0, λ, $\lambda/2$).

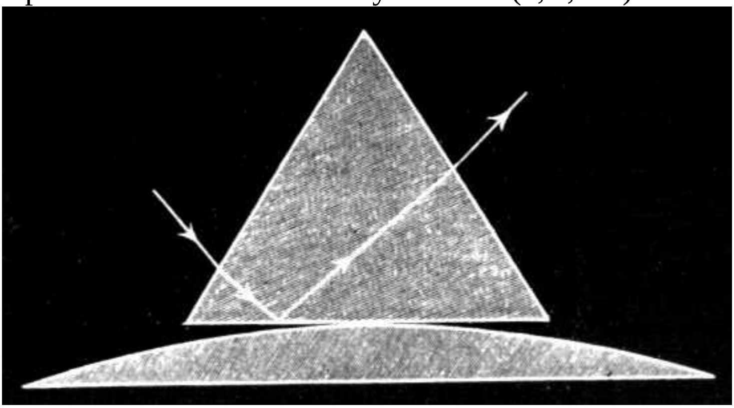


Figure 4.75

EPD represents the extreme path difference - constructive interference: $m\lambda$, where m {0, 1, 2, 3…}; destructive interference: $\frac{1}{2}(2m - 1)\lambda$, where m {1, 2, 3...}.

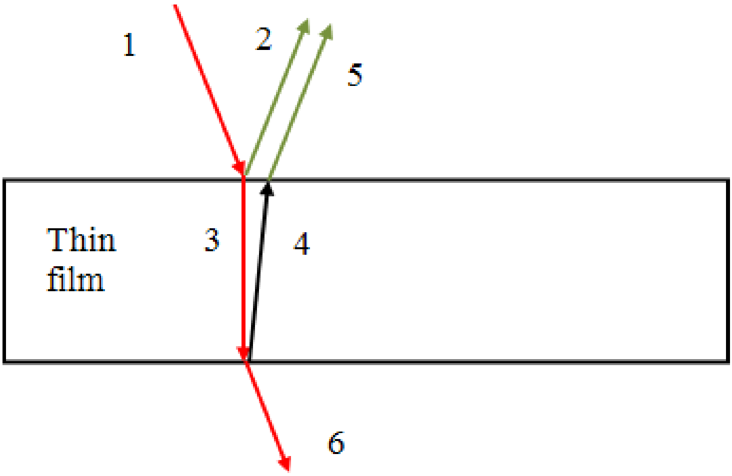


Figure 4.76

Experimemt 4.26 Interference by round disc

In optics, an **Arago spot**, **Fresnel bright spot**, or **Poisson spot** is a bright point that appears at the center of a circular object's shadow due to Fresnel diffraction [40; 41; 42]. This spot played an important role in the discovery of the wave nature of light (see history section below) and is a common way to demonstrate that light behaves as a wave for example in undergraduate physics laboratory exercises. The basic experimental setup is shown in the fig. 4.77.

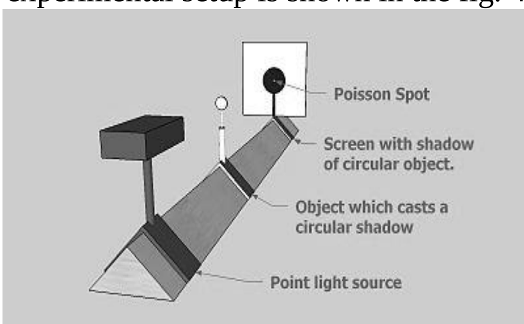


Figure 4.77

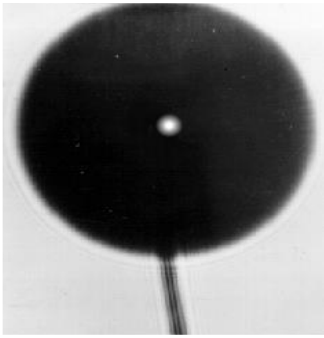


Figure 4.78 Fresnel diffraction showing central Arago spot of laser

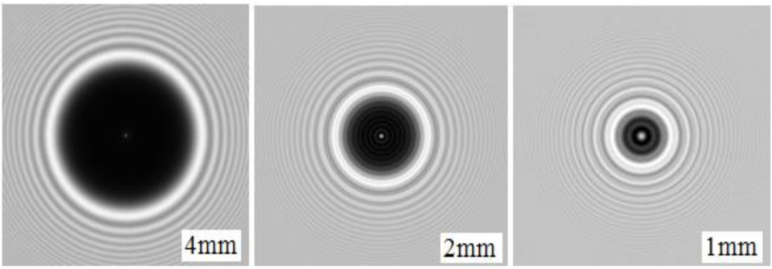


Figure4.79

The images show simulated Arago spots in the shadow of a disc of varying diameter 4 *mm*, 2 *mm*, 1 *mm* at a distance of 1 *m* from the disc. The point source has a wavelength of 633 *nm* e.g. He-Ne Laser. Laser is located 1 *m* from the disc. The image width corresponds to 16 *mm*.

The wave source must be at least smaller in diameter than the circular object casting the shadow and the dimensions of the setup must comply with the requirements for Fresnel diffraction. Namely, the Fresnel number must satisfy

$$F = \frac{d^2}{l\lambda} \geq 1,$$

where d is the diameter of the circular object, l is the distance between the object and the screen, λ the wavelength of the source. The presence of the Arago spot can be easily understood.

When light shines on a circular obstacle, Huygen`s principle says that every point in the plane of the obstacle acts as a new point source of light. The light coming from points on the circumference of the obstacle, and going to the center of the shadow, travels exactly the same distance; so all the light passing close by the object arrives at the screen in phase and constructively interferes. This results in a bright spot at the shadow's center, where geometrical optics and particle theories of light predict that there should be no light at all [67].

Experiment 4.27 Interference on a thin film of oil floatimg on eater

Equipment: a deep bowl, a glass of water, oil.

Pour water into a deep bowl. Come up oil to a pipette. Fall 2-3 drops of oil into water. In some seconds there will be an oil film on water. It is coloured, fig. 4.80.

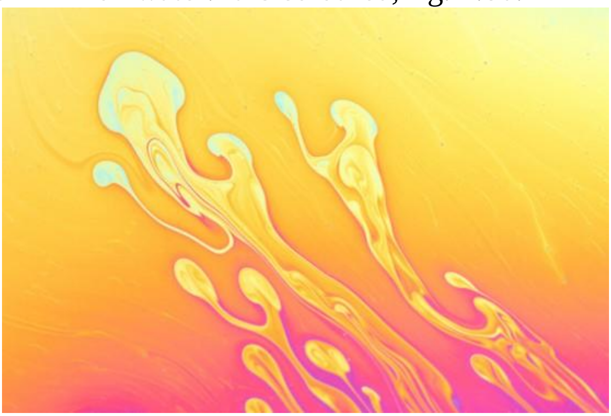


Figure 4.80

Coloured light interference pattern on a thin film of oil floating on water, fig. 4.80. Interference effects commonly arise by reflection in thin films. When the oil film thickness is comparable to the wavelength of light. Light waves reflected from the back of the film may be out of phase with light striking the front of the film, and interference results. Colour arises when the incident light is white, and when variations in thickness of film produce interference in some of the component wavelengths of white light. When such wavelengths are extinguished, the residual light is coloured.

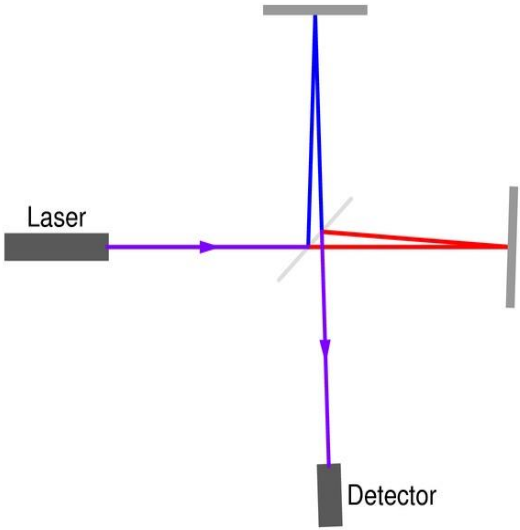


Figure 4.81

The basic layout of a simple interferometer. The laser on the left sends out its beam, which is split in two by a semi-reflective mirror. One half bounces up to the mirror at the top, and is reflected. Half of this returning beam gets through the semi-reflective mirror to the detector at the bottom.

Meanwhile, the other half of the initial beam goes on to the mirror at the right, and is reflected. Half of this returning beam gets reflected by the semi-reflective mirror down to the detector, along the same path as the other beam. At the detector, the two beams can interfere with each other-either constructively or destructively, depending on just how long each path was. If either mirror moves by even a tiny amount, the interference will change dramatically [68].

Chapter 5
PRACTICAL USE OF WAVES PROPERTIES OF THE LIGHT

5.1 Types of interferometers

5.1.1 Michelson Interferometer

The Michelson interferometer is an optical instrument of high precision and versatility. It is generally used in investigations that involve small changes in optical path length. The Michelson interferometer, one can produce circular and straight-line fringes of both monochromatic light and white light. One can use these fringes to make an accurate comparison of wavelengths, measure the refractive index of gases and transparent solids, and determine small changes in length quite precisely. The Michelson interferometer was introduced by Albert Michelson in 1881. It has been used to

1) provide experimental evidence for special relativity,
2) discover the hyperfine structure in the energy levels of atoms,
3) measure tidal effects of the moon on the earth,
4) enable the use of wavelength of light as the international standard for the meter.

The Michelson interferometer operates on the principle of division of amplitude rather than on division of wave front. According to this principle, the incident beam of light falls on a beam splitter, which reflects roughly half of the intensity of the wave front in one direction and transmits the other half of the intensity of the wave front in another direction. The two beams, which travel different optical paths, are subsequently recombined in a common region where interference occurs and fringes are formed. The character of the fringes is directly related to the difference in the optical path lengths for the two beams. It is therefore related to whatever causes a difference in the optical path lengths.

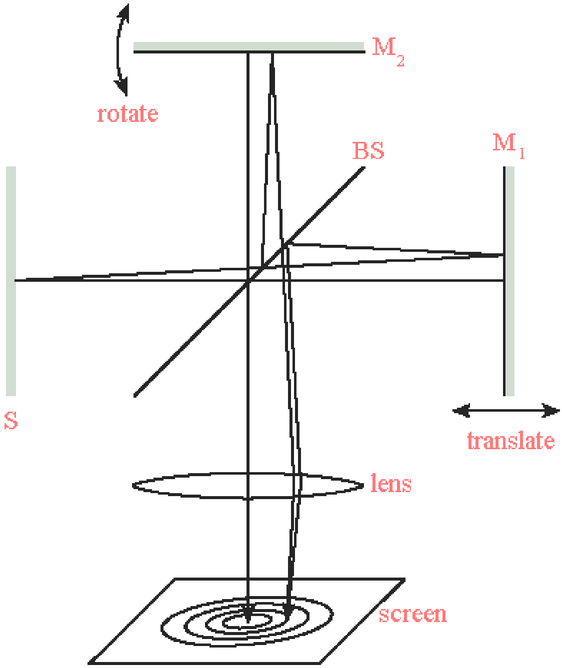


Figure 5.1

In its most common arrangement, a Michelson interferometer is illuminated by an extended source *S* and consists of a 50% beam-splitter *BS* and two mirrors M_1 and M_2 (fig. 5.1). The interference pattern is observed on a screen that is either very far from *BS*, or a lens is placed one focal length in front of the screen. Rotation or translation of one or both mirrors changes the interference pattern.

Interference in a Michelson interferometer can be understood in terms of thin-film interference. Imagine that the arms of the interferometer are rotated, such that there is a single optical axis, as shown in the drawing below (fig.5.2).

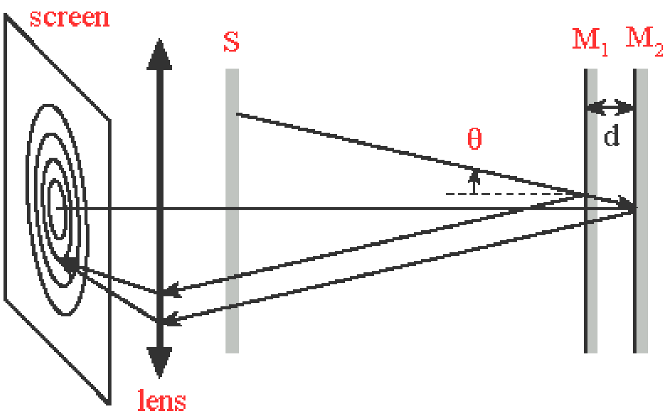


Figure 5.2

Then reflection from the mirrors M_1 and M_2 is analogous to reflection from two surfaces of an air gap of thickness *d*. Since the phase shift upon reflection is the same for both mirrors, we find (fig. 5.3)

$$2d\cos\theta = m\lambda \tag{5.1}$$

for constructive interference.

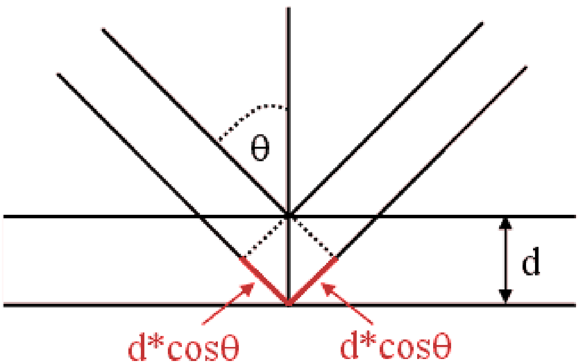


Figure 5.3

If the two mirrors are precisely aligned such that their planes are exactly perpendicular to one another, thus ensuring that path differences over different regions of the mirrors are constant, the fringe pattern will consist of a series of concentric rings. Each ring will correspond to a different angle of view, measured from the normal to the mirror M_1. These fringes are called fringes of equal inclination. They are analogous to fringes of equal inclination that we observe when we shine light from an extended source on a thin film. When the mirror M_1 is moved so as to approach the condition for zero path difference, the fringe pattern appears to collapse, with all fringes moving towards the center, and disappear.

5.1.2 Twyman-Green Interferometer

The Twyman-Green interferometer is a very useful instrument for measuring defects in optical components such as lenses, prisms, plane-parallel windows, laser rods, and plane mirrors. The beam splitter and mirror arrangement of the Twyman-Green interferometer resembles that of a Michelson interferometer. The difference lies in the way the interferometers are illuminated. While the Michelson interferometer is used with an extended light source, the Twyman-Green interferometer is used with a monochromatic point source which is located at the principal focus of a well-corrected lens.

If the mirrors M_1 and M_2 are perpendicular to each other and the beam-splitter *BS* makes an angle of 45° with the normal of each mirrors, then the interference is exactly analogous to thin-film interference at normal incidence (fig. 5.4).

We obtain completely constructive interference when $d = m\lambda/2$, where d is the path length difference between the 2 arms adjusted by translating M_1. We get complete destructive interference when $d=(m+1/2)\lambda/2$. If we rotate M_2, then we see fringes of equal thickness on the screen, since the angle of incidence is constant. This situation is analogous to interference observed with collimated light and a thin film with varying thickness.

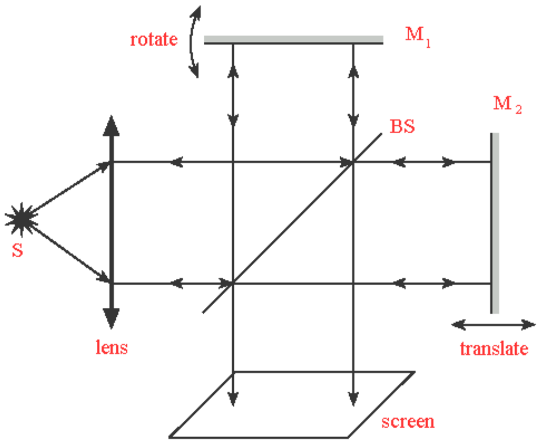


Figure 5.4

When testing optical components, one of the mirrors is intentionally tilted to create fringes. The quality of the component can then be determined from the change in the fringe pattern when the component is placed in the interferometer. Lens testing is particularly important for quantifying aberrations and measuring focal length.

5.1.3 Fabry-Perot Etalon

This Fabry-Perot interferometer or etalon is a folded Michelson interferometer. With a Fabry-Perot etalon we observe the interference pattern formed by light that is transmitted through two partially reflecting mirrors, while with a Michelson interferometer we observe the interference pattern formed by reflected light.

In its simplest configuration, the Fabry-Perot etalon consists of two planes, parallel, highly reflecting surfaces separated by some distance *d*. The reflecting surfaces are formed by a very thin silver or aluminum film, or multi-layer dielectric films on the surface of glass plates. The enclosed air gap generally varies from several millimeters to several centimeters. If the gap can be mechanically varied by moving one of the mirrors, the device is referred to as an interferometer. If the mirrors are held fixed and adjusted for parallelism by screwing down on some kind of spacer, it is said to be an etalon.

A Fabry-Perot etalon operates by multiple beam interference (fig. 5.5). Light which is incident from the left on the first reflection surface is split by reflection into a series of parallel transmitted rays. A ray is partially transmitted at each reflection from the second surface. For simplicity, the figure below does not show the change in direction of propagation of light upon refraction, nor does it show the rays that pass back through the first surface and propagate toward the left.

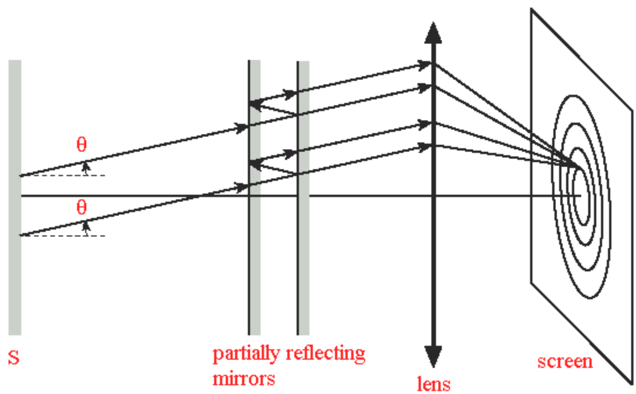


Figure 5.5

The phase difference between successive reflections is

$\delta = 2\pi(2nd\cos\theta / \lambda)$. Constructive interference occurs when $\delta = 2\pi N$, or when $N\lambda = 2nd\cos\theta$, where

λ is the wavelength of the radiation in vacuum,

d is the separation of the reflecting surfaces,

n is the index of refraction of the material between the reflecting surfaces,

θ is the angle of incidence,

N is an integer.

The product *nd* is referred to as the optical thickness to distinguish it from mechanical thickness. Because the wavelength of the light is usually much smaller than the physical separation between the reflecting surfaces, the integer *N* is on the order of 10^4 to 10^5, depending on the mirror separation. The integer *N* is the order of the interference.

The **free spectral range** of the interferometer is defined as the change in wavelength necessary to shift the fringe pattern by one fringe.

$$N\lambda = (N-1)(\lambda + \Delta\lambda_{FSR}), \qquad \Delta\lambda_{FSR} = \lambda/(N-1) \sim \lambda / N,$$

since *N* is very large. Therefore

$$\Delta\lambda_{FSR} = \lambda^2/(2nd\cos\theta) \sim \lambda^2/2nd, \text{ since } \cos\theta \sim 1.$$

If the reflectivity *R* of the mirrors is low, the maxima in the interference pattern will be broad. If the reflectivity is *R* high, the maxima will be very narrow and sharp. This leads to the concept of the **finesse** *F* of the interferometer (fig. 5.6). The finesse is a measure of the interferometer's ability to resolve closely spaced spectral lines. The finesse *F* is defined by the ratio of $\Delta\lambda_{FSR}$ to $\delta\lambda$, the FWHM (full width at half maximum) of the constructive interference maximum for a single wavelength. The finesse increases with *R*.

$$F = \Delta\lambda_{FSR} / \delta\lambda = \pi R^{1/2}(1-R). \qquad (5.2)$$

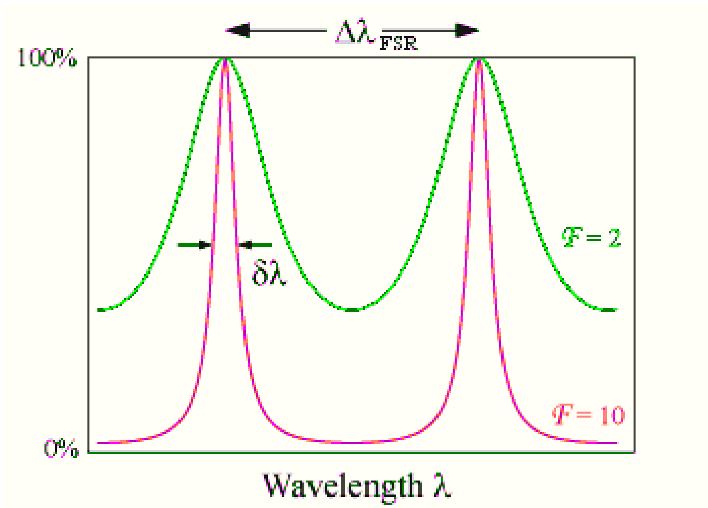


Figure 5.6

The **resolving power** $RP = \lambda / \delta\lambda$ is given by the equation

$$RP = N\lambda / N\delta\lambda = N\Delta\lambda_{FSR} / \delta\lambda = NF \,. \qquad (5.3)$$

5.1.4 Scanning Fabry-Perot Interferometer

This interferometer is simply a folded Twyman-Green interferometer. It is the collimated light version of the Fabry-Perot etalon. Usually the interferometer is used to measure the spectrum of a source by scanning the separation d between the two partially reflecting mirrors (fig. 5.7).

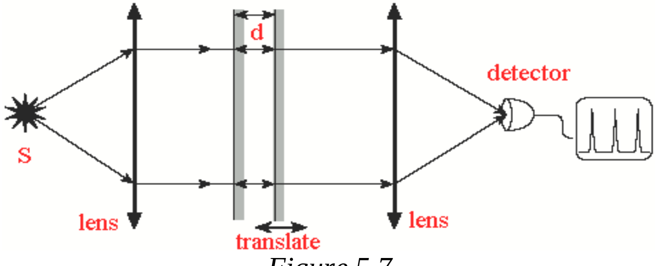


Figure 5.7

5.1.5 Mach-Zehnder Interferometer

This interferometer is a variation of the Michelson/Twyman-Green interferometer. It produces an interference pattern with the light only making a single-pass through a test component. The Mach-Zehnder interferometer is an important diagnostic tool (fig. 5.8). It is most frequently used in the fields of plasma physics, aerodynamics, and heat transfer to measure density, pressure, and temperature changes in gases. Because of its relatively large and freely accessible working space and flexibility of location of the fringes, it is the most suitable interferometer to study the airflow around models of aerodynamic structures.

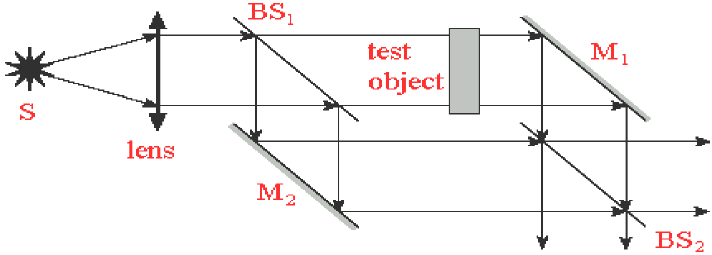


Figure 5.8

An expanded laser beam is divided by a 50% reflecting, 50% transmitting beam splitter into two beams of equal intensity. After reflection at the 100% reflecting plane mirrors M_1 and M_2, the two beams are recombined by a 50% reflecting, 50% transmitting beam splitter.

Assume that the recombined beams are intercepted by a well-corrected positive lens, which brings both beams to a focus.

Two beams of light of equal amplitude and wavelength originating from the same source are brought to a focus at *S*' and *S*", respectively, if the reflecting surfaces are nearly, but not perfectly, parallel to each other. The light from the images *S*' and *S*'' proceeds on, and the beams interfere in much the same way as in Young's double slit experiment (fig. 5.9). In a plane at a right angle to the direction of propagation of the combined beams, an interference fringe pattern will be observed.

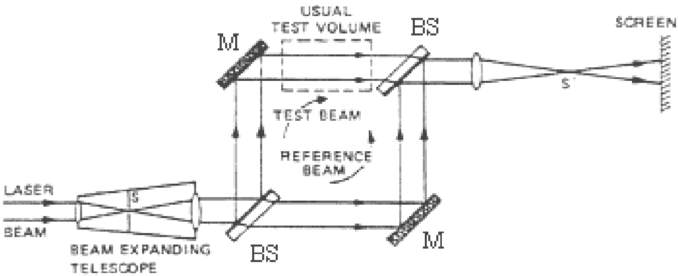


Figure 5.9

If the length of the optical path of one of the beams is changed by inserting a test object into the path of the beam, a new phase shift is introduced between *S*' and *S*'' which causes a shift of the fringes. The extent of the shift is a sensitive measure of the change of the optical path length over the two dimensional fields of view [94].

5.2 Modern equipment for optics stadies and educational experiments on their basis

5.2.1 Optical demonstration and research equipment

Physical experiment on optics is provided by various new sets and devices. Let's consider their features.

Jung Interferometer - intended for conducting frontal demonstration experiments and laboratory works in the study of wave phenomena of light (diffraction, interference) from the section «Optics» in accordance with the school curriculum, as well as on the basis of it, it is expedient to carry out the works of physical workshops at universities.

Young's Interferometer was featured in the manual S.P. Velychko and E.P. Sirik «New Educational Equipment for Spectral Research» [92].

Young Interferometer, fig. 5.10, is a body of profile (1) having a square section, within which an optical circuit is mounted. It consists of two test objects (2), an eyepiece (3), a light source based on light emitting diodes (4), a power source that uses finger batteries (5). Inside the interferometer, an inlet slit of a constant width of 0.1 *mm* is mounted and a measuring grid screen, fig. 5.10 [95].

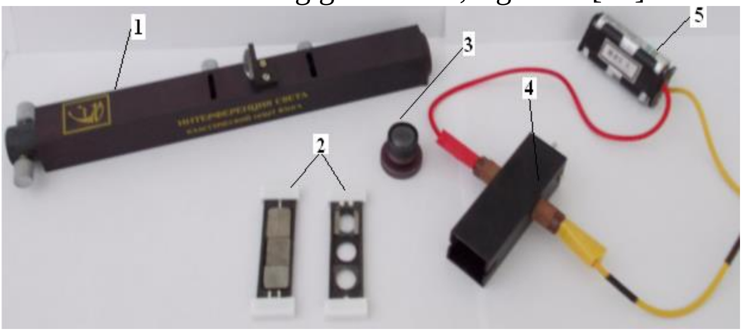


Figure 5.10 Jung Interferometer

With the help of an interferometer, it is possible to repeat on a high technical level a well-known Young experiment, put up by him in 1802. Young's experience was the first of a series of experiments (Fresnel's biprim, Lloyd's mirror), which confirmed the wave nature of light. It is interesting that the crossing (interference) of two wave fronts from two cracks occurs due to another wave phenomenon - diffraction of light.

Combined test-object № 1, in the form of a single and double slit, extends the possibilities of the Young Interferometer (fig. 5.12, *a*). It becomes accessible, in addition to observing the phenomenon of interference on the double Jung gap, observing diffraction on a single slit (analog point hole). Additional test object number 2, (fig. 5.12,b), installed in one of the apertures near the eyepiece, allows you to observe the phenomenon of interference on the fresnel biprim and the phenomenon of diffraction on a thin screen – «threads».

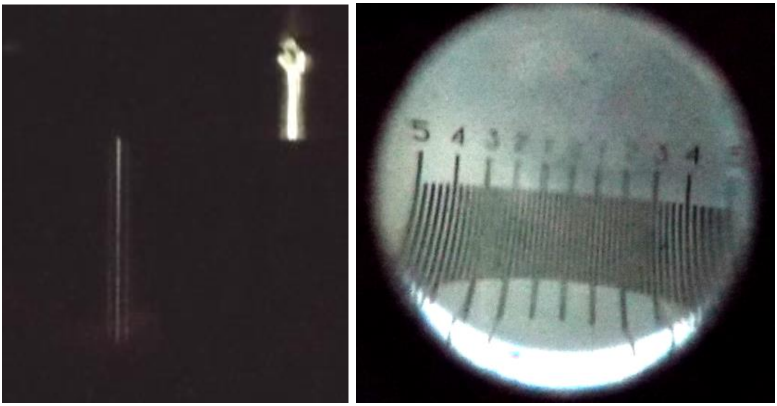


Figure 5.11

When using a light source with LEDs (blue and red), made in the form of a nozzle to the interferometer, it is possible to accurately estimate the wavelength of red and blue light, that is, the visible range of the spectrum (fig.5.13).

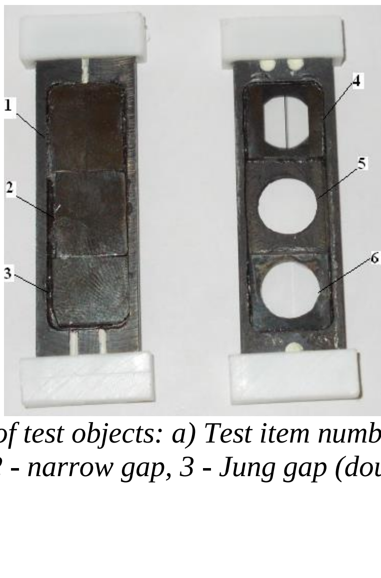


Figure 5.12 A set of test objects: a) Test item number 1 consists of: 1 - wide gap, 2 - narrow gap, 3 - Jung gap (double); b) test

item number 2 consists of: 4 - Fresnel biproses, 5-windows, 6-thin screen («thread»)

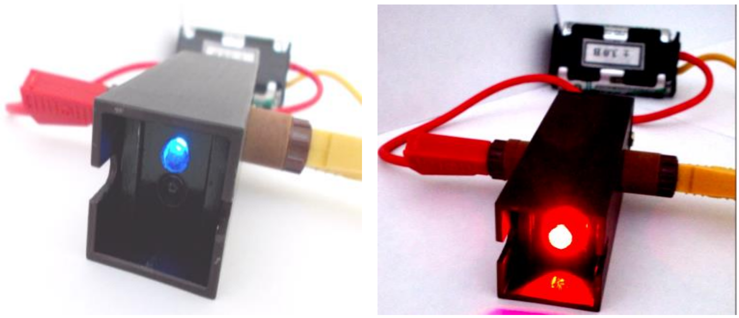


Figure 5.13 Light sources that works on LEDs of different colors

The feasibility of using LEDs for educational purposes is due to a number of parameters and specific characteristics that are especially important and relevant for the learning process, which gives reason to consider these sources of light effective in solving various didactic tasks, as well as in order to improve the system of training physical experiment on optics.

It is necessary to familiarize students who are engaged in institutions with in-depth study of physics, as well as university students, with parameters of LEDs [90]:

1 Semiconductor LEDs emit a fairly bright beam of light enough to perform various types of physical training; while the brightness of the glow of the LED is sufficient for students to perform independent experiments and observations during the frontal laboratory works and the physical workshop, and for performing demonstration experiments by a teacher (teacher).

2 During the implementation of different types of learning experiment LEDs provide qualitative observation of specific features of pictures and experimental results and

the possibility of quantifying the intensity of light radiation through various receivers and recording devices.

3 When operating on a semiconductor basis, LEDs are powered by electric power supplies with a voltage of 1-4 *V*, which makes it possible to recommend them to students to perform independent experimental studies (frontal experiments and observations, physical practice, experiments at home).

4 LEDs are characterized by a rather long service life, are small in size and can be easily transported and stored in the physical office and in laboratories.

5 LEDs do not give monochromatic radiation, but under the conditions of performing experimental research for educational purposes, taking into account the narrow band in which light energy is emitted, with sufficiently reliable results one can obtain quantitative relations, dependencies, values $\Delta\lambda$ of physical quantities, and also to determine a number of physical parameters and constants.

6 LEDs as a light source are quite economical and can therefore be widely used in those installations where high light output is required under low electric power conditions.

In order to perform laboratory research in the physical workshop of the university of geometric and wave optics with the use of semiconductor diodes interesting proposals are the use of combined sources, for example, light sources, in the central part of which there are two light-emitting diodes of different luminescence, which can be switched on simultaneously and alternately.

The use of such a combined light source, for example, in experiments with a diffraction grating, gives convincing results of the difference in wavelengths for different parts of the spectrum, and at the same time makes it possible to calculate the wavelengths of yellow, blue and violet light, at given wavelengths of radiation for a red, blue LED:

- Spectral interval of radiation of a blue LED, 450 ÷ 500 *nm*;

- Spectral radiation interval of a red light-emitting diode, 600 ÷ 650 *nm* [88].

The main technical characteristics of Jung's interferometer are given in table 5.1.

During the laboratory practice of optics it is expedient to use as a light source a laser (fig. 5.14), which is a massive case in which a laser diode is mounted, two 1.5*V* batteries, and a revolver head with integrated optical elements is fixed. The radiation power of the laser diode is less than 10 *mW*, the wavelength of the radiation = 0.650 *nm*, the voltage of the laser diode - 3 *V*.

Figure 5.14

Radiation of a laser diode is formed by means of a revolving head: 1) the spherical expansion of the beam is used to increase the angle of divergence and the formation of the spherical front of the light waves; 2) cylindrical lens increases the difference of the beam in one plane; 3) the laser beam divider allows several beams to be obtained; Prior to this, the rotation of the extreme bunches in relation to the central one is envisaged, which allows to illustrate the cross section of the optical parts in any plane.

Technical characteristics of Jung's interferometer

Table 5.1

№	Name	Characteristics
	Test - object number 1	
1	Width of the wide gap «1»	0,10 *mm*
2	The width of the narrow gap «center»	0,06 *mm*
3	The distance between the cracks in the double Slit Jung is	2t = 0,1 *mm*
4	Width of the cracks in the double slit of Jung	0,025 *mm*
	Test - object number 2	
5	Width of narrow screen «threads»	0,2 *mm*
6	The diameter of the window «center»	10 *mm*
7	Angle of biproses	20 *ang.m.*
8	The distance between the test object number 1 and the scale of the grid	L = 100 *mm*
9	The distance between the test object number 2 and the scale of the grid	L = 50 *mm*
10	The price of the partition of the measuring grid is	e = 0,2 *mm*
11	Enlargement of the eyepiece lens	$\Gamma = 10^x$

Its main parts are two glass or quartz plates with flat surfaces. The inner surfaces of the plates are covered with partially transparent films with high reflectivity. Plates are wedge-shaped to eliminate the harmful effects of light reflected off the external uncovered surfaces. In the first samples of the device, one plate was immobile, and the other was installed on sledges, which allowed moving it with a screw in accordance with the first. However, due to the unreliability of mechanical design, such systems are out of use.

Currently, the plates are separated by a fixed ring of invar or quartz with three protrusions at the ends, to which plates are pressed with springs. The rings are processed with great accuracy, so that the position of the planes, given protrusions, as close as possible to the equilibrium and fine adjustment is carried out by changing the pressure of the springs. An interferometer of this type with a fixed distance between the plates is sometimes referred to as the Fabry-Perot standard.

Multifrequency interference bands created by a plane-parallel plate in normal light are used in the Fabry-Perot interferometer (fig. 5.15).

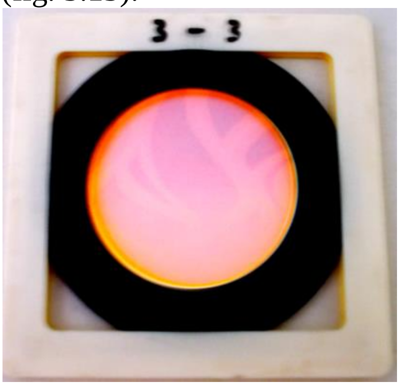


Figure 5.15

The Fabry-Perot interferometer can be used in spectroscopy in combination with a photoelectric detector.

The light of the investigated spectral line, isolated by a pre-monochromator, is sent to an interferometer. The resulting interference pattern is projected onto a ring-shaped hole, concentric to the rings of the picture. This hole passes light from a small part of the order (ring) to a photocell. By changing the optical distance between the plates, you can increase or decrease the size of the rings on the hole and thus explore the structure of the interference pattern. Such a device is of great practical importance because the Fabri-Perot interferometer, as Jacquin [91] showed, misses a larger light flux than a prism or diffraction monochromator with the same force.

The universal and interesting kit for the study of light interference is presented by the German company Phywe, which offers the use of various equipment with different instruments and devices for research and study of optical phenomena [93].

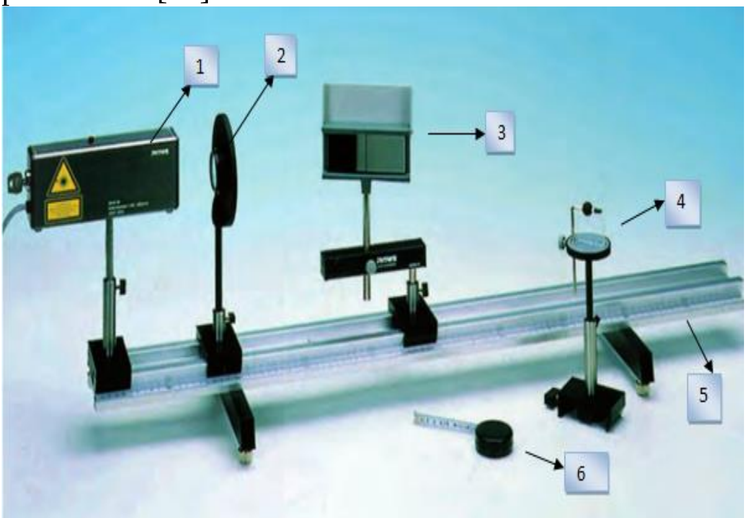


Figure 5.16 Installation for studying the light's integration: 1- laser; 2 - lens; 3 - fresnel biprism; 4 - a pristine table with a holder; 5. Optical profile bench; 6 - measuring tape

Specifications

Table 5.2

№	*Item name*	*Code*	*Number*
1	Brescia Fresnel	08556.00	1
2	Decoration table with holder	08254.00	1
3	Mirror Fresnel	08560.00	1
4	*Lifting lens, f=+20 mm*	08018.01	1
5	Lifting lens, *f=+300 mm, achromatic*	08025.01	1
6	Lens holder	08012.00	2
7	Moving optical profile lava, *h*=30 *mm*	08286.01	2
8	Moving optical profile lava, *h*=80 *mm*	08286.02	2
9	Optical lava, *l* = 1000 *mm*	08282.00	1
10	Adjustable base for optical lava	08284.00	2
11	Laser, He-Ne 1.0 *mW*, 230 V AC	08181.93	1
12	Measuring tape, *l* = 2 *m*	09936.00	1
13	Adjustable holder	08256.00	1

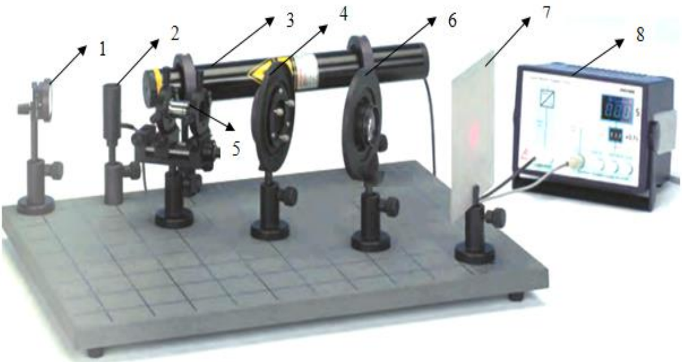


Figure 5.17 Installation for research on Newton's rings: 1-lens; 2 - magnetic stop for optical lava; 3-laser; 4- lens; 5-holder; 6-lens; 7-screen; 8-power source

Specifications

Table 5.3

№	Item name	Code	Number
1	Optical bench with rubber feet	08700.00	1
2	Laser, He-Ne, 5 *mW*	08701.00	1
3	Electric power supply for laser	08702.93	1
4	Holder, 35 × 35 *mm*	08711.00	1
5	External Mirror, 30 × 30 *mm*	08711.01	1
6	Achromatic Object	62174.20	1
7	Small hole, 30 microns	08743.00	1
8	Sliding horizontal device	0817.00	1
9	*xy* device	08714.00	2
10	Ring Device Adapter	08714.01	1
11	Magnetic stop for optical lava	08710.00	5
12	Newtonian lenses for optical lava	08730.02	1
13	Lens holder	08723.00	1
14	Moving lens, $f=+50$ *mm*	08020.01	1
15	Screen transparent with holder	08732.00	1
16	Measuring tape, l = 2 *m*	09936.00	1
17	Laser, He-Ne 0.2/1.0 *mW*, 220 V AC or diode laser 0.2/1.0 *mW*, 635 *nm*	08180.93 08760.99	1 1

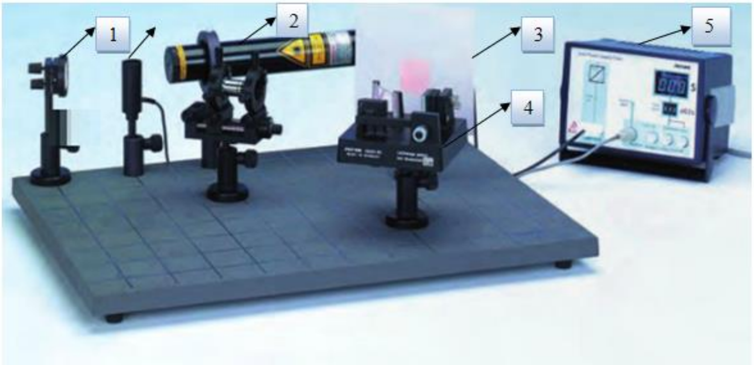


Figure 5.18 Michelson interferometer on the optical base platform: 1- lens; Michelson interferometer; 3- screen; 4- magnetic stop for optical base platform; 5 - power supply

Specifications

Table 5.4

№	Item name	Code	Number
1	Optical base plate with rubber feet	08700.00	1
2	Laser, He-Ne, 5 *mV*	08701.00	1
3	Electric power supply for laser, 5 *mV*	08702.93	1
4	Holder	08711.00	1
5	External Mirror 30×30 *mm*	08711.01	1
6	Magnetic stop for optical base platform	08710.00	4
7	Michelson Interferometer	08557.00	1
8	Acromatic Object 20×N.A. 0.45	62174.20	1
9	Small hole, 30 microns	08743.00	1
10	Sliding horizontal device	08713.00	1
11	*xy* device	08714.00	2
12	Adapter ring device	08714.01	1
13	White screen, 150 × 150 *mm*	09826.00	1
14	Laser, He-Ne 0.2/1.0 *mW*, 220 V AC or diode laser 0.2/1.0 *mW*, 635 *nm*	08180.93 08760.99	1 1

Figure 5.19 Investigation of the coherence of light with spectral lines using the Michelson interferometer

Specifications

Table 5.5

№	Item name	Code	Number
1	Michelson Interferometer	08557.00	1
2	High illumination of mercury lamp	08144.00	1
3	Power supply for Hg-CS / 50 *W*	13661.97	1
4	Optical profile bench	08282.00	1
5	Base for optical profile lava	08284.00	2
6	Moving optical profile lava, *h*=30 *mm*	08286.01	5
7	Lens holder	08012.00	3
8	Lens holder, 50 × 50 *mm*	08041.00	1
9	Adjustable holder	08256.00	1
10	Basis	02006.55	2
11	Stand	02060.00	2
12	Lifting lens, *f=20 mm*	08018.01	1
13	Lifting lens, *f=200 mm*	08024.01	1
14	Diaphragm	08045.00	1
15	Green color filter, 525 *nm*	08414.00	1
16	Glass screen, 50 × 50 *mm*	08136.01	1
17	Moving diaphragm holder	11604.09	1
18	Measuring magnifier	09831.00	1
19	Section adjustable to 1 *mm*	11604.07	1
20	Diaphragm with 4 double cuts	08523.00	1

Figure 5.20 Determination of the CO2 index using the Michelson interferometer

Specifications

Table 5.6

№	Item name	Code	Number
1	Optical base plate with rubber feet	08700.00	1
2	Laser, He-Ne, 5 mW	08701.00	1
3	Power supply for laser, 5 mW	08702.93	1
4	Holder, 35 × 35 mm	08711.00	1
5	External Mirror, 30 × 30 mm	08711.01	1
6	Magnetic stop for optical base platform	08710.00	5
7	Michelson Interferometer	08557.00	1
8	Achromatic Lens 20× N.A. 0.45	62174.20	1
9	Small hole, 30 microns	08743.00	1
10	Horizontal sliding device	08713.00	1
11	*xy* device	08714.00	2
12	Adapter ring device	08714.01	1
13	White screen, 150 mm × 150 mm	09826.00	1
14	Glass material, diameter 21,5 mm	08625.00	1
15	Short gas, CO_2 21 g	41772.06	1
16	Eyedropper, with a rubber tip	64701.00	1
17	Universal clamp with connection	37716.00	1
18	Silicone tubing, d = 5 mm	39297.00	1
19	Laser, He-Ne 0.2/1.0 mW, 220 V AC or diode laser 0.2/1.0 mW, 635 nm	08180.93 08760.99	1 1

Figure 5.21 Determination of air refraction index using Maha-Zhender interferometer

Specifications

Table 5.7

№	Item name	Code	Number
1	Optical base plate with rubber feet	08700.00	1
2	Laser, He-Ne, 5 mW	08701.00	1
3	Power supply for laser, 5 mW	08702.93	1
4	Magnetic stop for optical base plate	08710.00	10
5	External mirror, 30 × 30mm	08711.01	4
6	Holder, 35 × 35 mm	08711.00	4
7	Horizontal sliding device	08713.00	1
8	*xy* device	08714.00	2
9	Ring adapter adapter	08714.01	1
10	Small hole, 30 microns	08743.00	1
11	Achromatic Object 20× N.A. 0.45	62174.20	1
12	Aperture Holder	08719.00	2
13	Radiation separator 1/1	08741.00	2
14	White screen, 150 × 150mm	09826.00	1
15	Glass material, diameter 21,5 mm	08625.00	1
16	Manual vacuum pump with pressure gauge	08745.00	1
17	Universal clamp with connection	37716.00	1
18	Tubing connection, T-	47519.03	1

	shape, ID 8-9 mm		
19	Tube adapter, ID 3-6/7-11 mm	47517.01	1
20	Vacuum hose, *d* = 6 mm	39286.00	1
21	Silicone tubing, *d* = 3 mm	39292.00	1
22	Glass holder	08706.00	1
23	Laser, He-Ne 0.2/1.0 mW, 220 V AC	08180.93	1

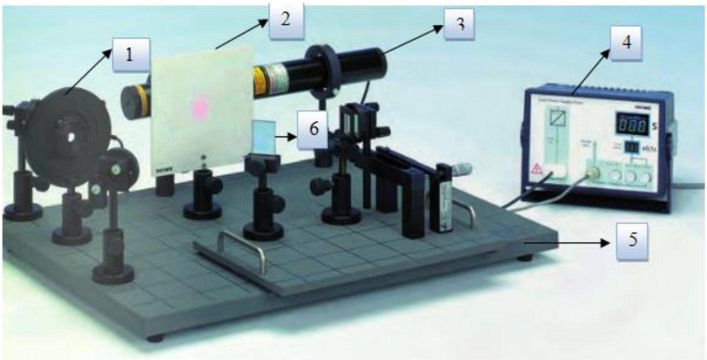


Figure 5.22 Determining the wavelength using the Fabry-Perot interferometer

Specifications

Table 5.8

№	Item name	Code	Number
1	Optical base plate with rubber feet	08700.00	1
2	Laser, He-Ne, 5 *mW*	08701.00	1
3	Power supply for laser, 5 *mW*	08702.93	1
4	Interferometer plate	08715.00	1
5	Holder, 35 × 35 *mm*	08711.00	3
6	External Mirror, 30 × 30 *mm*	08711.01	3
7	Magnetic stop for optical base plate	08710.00	6
8	Aperture Holder	08719.00	2
9	Radiator 1/1	08741.00	1
10	*Radiator* T=30, R=70	08741.01	1
11	Lifting lens, f=*+20 mm*	08018.01	1
12	Lens Stand for Optical Base Plate	08723.00	1
13	White screen, 150 × 150 *mm*	09826.00	1
14	Laser, He-Ne 0.2/1.0 *mW*, 220 V AC	08180.93	1

5.3 Educational experiments on optics using interferometers

5.3.1 Demonstration experiments

Experiment 5.3.1 Observation of the interference and diffraction of light on the Young's gap

Equipment: Young Interferometer.

Set test - object number 2 in neutral position «center».

Plank test - object number 1 set to «2» (the slit of Jung) and send the interferometer to the inlet gap to the source of radiation of the continuous spectrum (Sun, dioprojector, table lamp). Advance the eyepiece on a sharp vision of grid scale strokes. Viewing through the eyepiece grid, to achieve appearance in the field of view of dark and light colorful stripes. This will be an interference pattern (fig. 5.23).

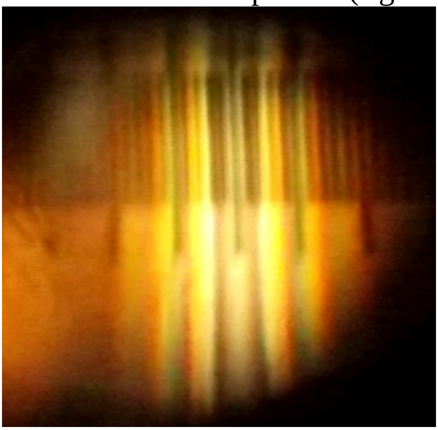
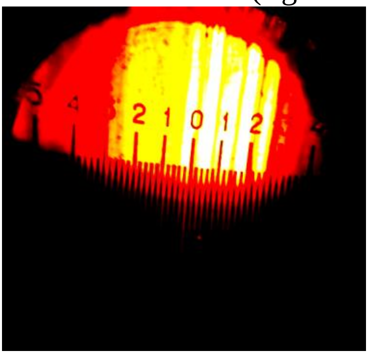
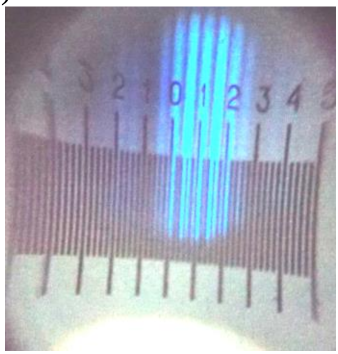


Figure 5.23

Conclusion from the experiment: for the white light, the visible interference pattern is the alternation of colored stripes, both on the edge and in the center. There is no full darkening - the minimum places for one wavelength coincide with the position of the maxima for another.

The second stage of the experiment is as follows. Secure a standard illuminator on the transducer interferometer, made on two LEDs with a stand-alone power supply on the finger batteries. Alternately turn on LEDs with red and blue light. Comparing the interference patterns observed from radiation sources with different spectral composition (the Sun with a solid spectrum and light-emitting diodes with a quasi-monochromatic spectrum of radiation), we arrive at the conclusion that the interference bands became more contrasting and monochromatic, and the size of the interference pattern increased. In addition, a different width of interference bands is formed in images obtained from blue and red LEDs (fig. 5.24).





a) *b)*

Figure 5.24 Image of an interference pattern using the Young interferometer using red (a) and blue (b) LEDs

Conclusions from the experiment: radiation of light emitting diodes by spectral composition is almost monochromatic. As a result, numerous interference bands (maxima and minima) disappearing when using solids of continuous spectrum. The interference pattern becomes monochromatic and contrasting, and the different width of the interference bands is caused by different lengths of light waves in these spectral regions.

Experiment 5.3.2 Observation of diffraction of light

on a single slit

Equipment: Young Interferometer.

Set test - object number 2 in neutral position «center». Guide the eyepiece of the interferometer to the sharp vision of the grid strokes. Set the test object number 1 to the position «center» (the slit is straight narrow) and fix it. Send an interferometer to the inlet slit on the source of radiation (Sun, dioprojector, table lamp). Viewing through the eyepiece grid screen, achieve in the field of view dark and light stripes with a colored border. This will be a diffraction pattern (fig. 5.25).

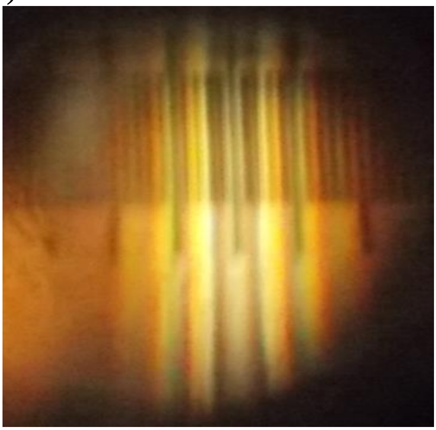


Figure 5.25

Conclusions from the experiment: for a white light, the visible diffraction pattern is the alternation of colored stripes, both at the edge and in the center. There is no full darkening: the minimum places for one wavelength coincide with the position of the maxima for another.

Set the bar with the test objects in the position «1» (the crack is straight narrow) and «center» (the crack is straight broad). Guide the eyepiece to a clear image of the grid divisions. Fix a standard illuminator to the interference in the transducer bush. Alternately, including red and blue

LEDs, observe the diffraction pattern on the scale of the mesh of the interferometer eyepiece. In the field of view, we observe a diffraction pattern «Fresnel diffraction on the crack», with the thin object being a test slot (instead of the classical dot aperture). In the center of the diffraction pattern there is a broad maximum (fig. 5.26).

The width depends on the width of the slit and the length of the light wave. The narrower the slit the wider the maximum, the longer the light wavelength, the greater the diffraction maximum. On both sides of the wide diffraction maximum visible maxima (minima) of the 2-nd, 3-rd, etc. diffraction orders, as well as in the observation of Fresnel zones on the hole.

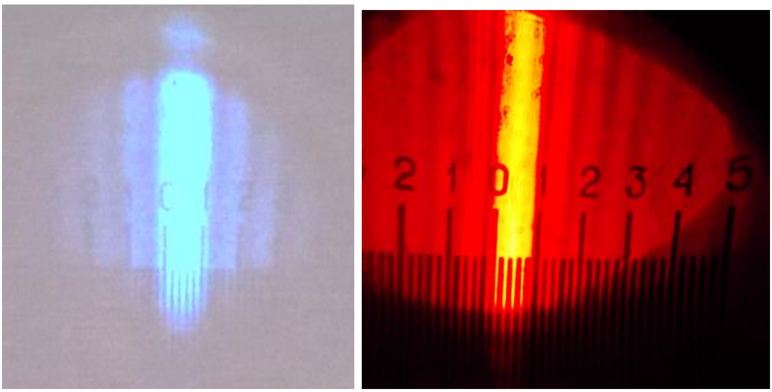


Figure 5.26

Conclusion from the experiment: red and blue LEDs have a narrow spectral radiation interval. As a result, numerous diffraction bands (maxima and minima) disappear in the visible part of the solar spectrum. The picture becomes almost monochromatic and contrasting.

Experiment 5.3.3 Observation of interference on the Fresnel bipromal

Equipment: Young Interferometer.

An interference pattern on a Fresnel biprim is usually observed with a parallel laser beam in passing light. Jung's interferometer allows observing an interference pattern without the use of coherent and monochromatic laser radiation. The role of quasi-monochromatic emitters is performed by ordinary LEDs. «Quasi-coherence» is provided by the first (entrance slit of the interferometer) and the second is a narrow slit of the test-object №. 1. As a result, there is a clear interference pattern on the Fresnel biprim (test-object № 2). In this case, the second narrow slit (test object № 2) performs the role of spatial filtration of the beam, cleans it from the optical «dirt» and provides high quality interference pattern on the fresnel biprism.

Set the first bar with the test objects № 1 to the «center» position (narrow cracks 0.06 *mm*). In the field of vision there is a wide diffraction first maximum, cleared of optical «dirt». Now it is worthwhile to enter the bar of the light window with the test-objects № 2 in the position of «biprim». In the area of the intersection of the wavefront visible contrasting interference bands, parallel to the edge of the biproses. It's easy to see that the strips are not localized in space.

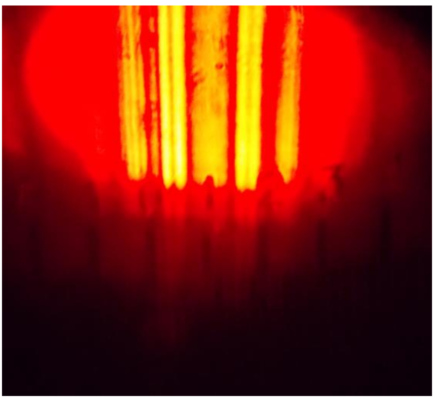


Figure 5.27

To make sure, it is enough to rearrange the test object number 2 along the direction of propagation of the light beam - the contrast of the bands does not change (fig. 5.27).

Experiment 5.3.4 Observing the Poisson Spot

Equipment: Young Interferometer.

Show the Young interferometer in the mode of spatial filtration of the light beam. As already explained above - not only the laser beam can be cleaned from diffraction images and dust. So, we will use the purified diffraction maximum on the «narrow gap» of the test object № 1.

Position test object № 2 in position «2» (narrow screen). In the eyepiece of the interferometer on the background of a wide diffraction maximum from the test-object № 1, diffraction is observed on the «thread» (fig. 5.28).

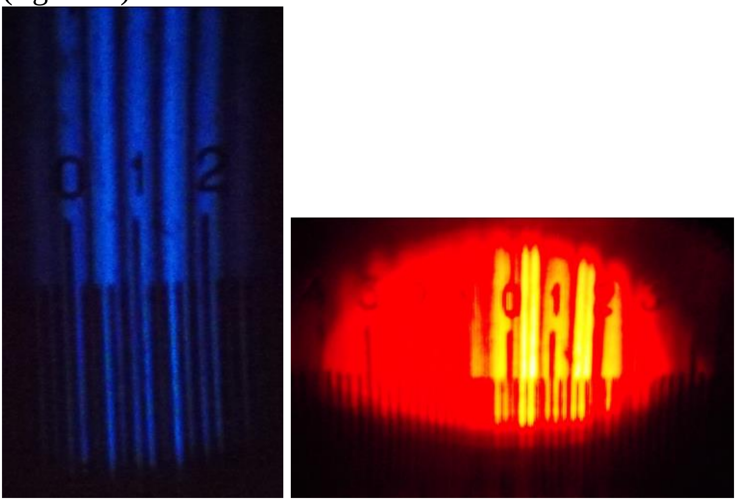


Figure 5.28

The diffraction pattern is a straight black and white strip parallel to the edges of the screen. For any narrow screen (thread) in the center of the geometric shadow is the maximum intensity (Poisson spot).

Experiment 5.3.5 Observation of multi-beam interference using the Fabri-Perot interferometer

Equipment: light source (laser), Fabri-Perot interferometer, screen.

Install the Fabri-Perot interferometer in a parallel laser beam. On the screens installed in the reflected and passing beams of light, a picture of ring-shaped concentric interference bands is observed. In contrast to what was observed earlier on a plane-parallel plate (PPP), ring-shaped bands (maxima and minima) have different widths. In the reflected light, the rings with a minimum illumination are considerably wider (several times) rings related to the maxima and, conversely, passing light (fig. 5.29).

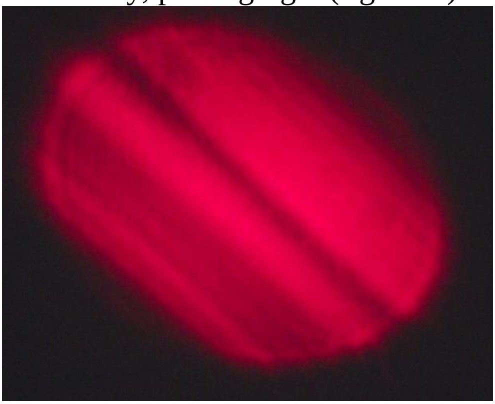


Figure 5.29

On the plane-parallel plate, the interference pattern in passing light was not visible at all. The fact is that there is a two-beam interference on the RFP: two light waves, reflected in parallel sides everywhere in the area where they intersect, gave an interference pattern. The amplitudes of both fronts are approximately equal, and the intensity of each reflected beam is 4-5% of the intensity of the incident wave. Therefore, in the passing light, on the background of 95-96% of the intensity, passed through the plate, the interference pattern is not observed.

On a Fabry interferometer there is a multi-beam interference. The lining of the Fabri-Perot interferometer is a planar-parallel plate (PPP) with surfaces of high quality and minimum wedge-shaped (no more than 5 angle.seconds).

On both sides of the substrate of the substrate, a light-reflecting interference coating is applied: a mirror with a reflection of 96%. Light rays, falling inside the plane-parallel plate (4%), will experience a multiple reflection on its surfaces inside the plate, that is, in the glass.

In this case, on the both sides of the substrate, outwardly, numerous beams are released, weakened by intensity and phase-displaced. The phase difference is determined by the length of the optical path traversed inside the glass.

The result of multidirectional interference is the multiple intensification of the intensity in the maxima and a significant narrowing of their width.

Experiment 5.3.6 The model of interferometers of Jamin, Bashkatova-Ogorodnikova, Brewster

Equipment: interferometers of Jamin, Bashkatova-Ogorodnikova, Brewster

The model of interferometers of Jamin, Bashkatova-Ogorodnikova, Brewster is made using the same details. The bracket is the basis of the devices (fig. 5.30), with which we will enclose all the details of the installation.

We manufacture it from the railway headquarters with a width of 30 and a thickness of 3 *mm*. We adjust the sizes so that the Universal Instrument (UI) table is placed between the ends of the bracket 1 and 2. Detail of the interferometer placed between the surface of the table and the top of the bracket and clamp with two screws with a M_4 cut. The parallelism of the mirrors and glass plates is achieved by cassettes. There are four of them. By the wikipedia, filed on (fig. 5.30, *a*) (folding lines are dotted), with a thickness of 0,3-0,5 *mm* thick, we cut the base for the cassettes.

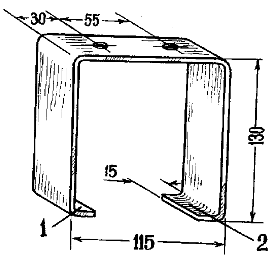


Figure 5.30

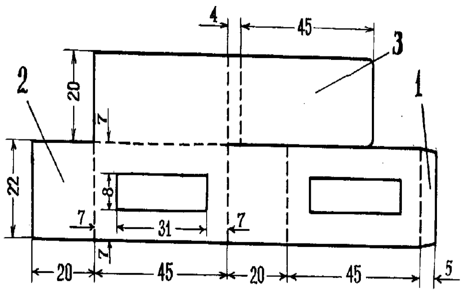


Figure 5.30, a

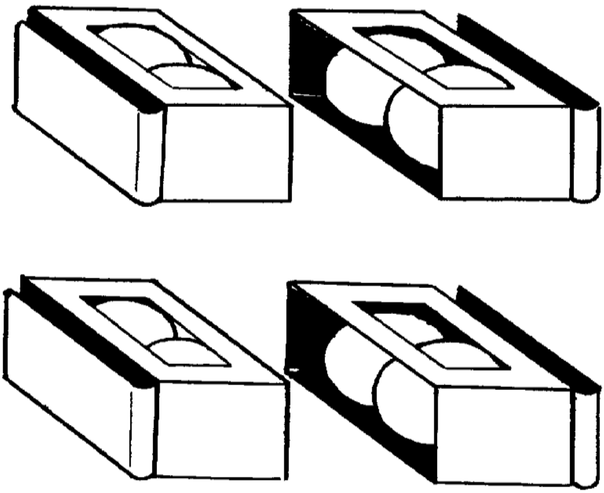


Figure 5.30, b

In the manufactured cassettes we place balls from a ball bearing with a diameter of 22 *mm*. If the other bullet is different, then the dimensions of the cassettes will vary accordingly. I'll try to get it. Plate 3 is slipping over the vertical bar bracket. This ensures reliable adhesion. The general view of the cassette is shown in fig. 5.30, *b*.

In the upper plate, on the back of the 5 *mm* from the cord, we drill 2 openings and set the M_4 thread. In them, screws are usable for grabbing their system. The kit includes two wooden strips of rectangular shape (90x40x40 and 90x40x20 *mm*), rail plates (90x30x4*mm* and two on 30x10x2 *mm*). They serve as support for screws.

Experiment 5.3.7 The model of the Jhamena interferometer

Equipment: jumper interferometer (model), line N_1, UI with diaphragm, physical tripod, cardboard screens, desktop screen.

Elements of the simple optical interferometer circuit are two internal-coated mirrors, which are arranged in parallel. To configure cppoctyty interferometra in a teaching environment, one with internal mirror coating can substituting the mirror with the external surface. This reduces the number of bundles of light coming out of the interferometer and facilitates the setting of an interferometer. Optical mounting scheme is shown in fig. 5.31, *a*, 5.31, *b*, where 1 - UI without condenser 2 - Disc diafrahma with an aperture of 10 *mm*, 3 - lens N_1 of the laboratory set 4 - interferometr Jamin, 5 - cardboard screen for overlapping storonnih beams of light 6 - white screen 7 - Rotary mirror.

The light passes through the diaphragm, focuses on the lens N_1 on the mirror with an outer coating, again falls on the mirror with an internal coating and goes in the direction of the *EF*. In the scheme (for simplicity) the beam of light that is reflected at the point *C* is not shown. The model of the interferometer is in this order: the end of the stack 1 is placed at the table 2, fig. 5.31.

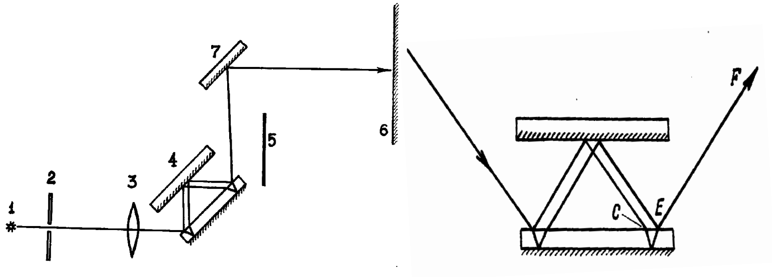


Figure 5.31, a

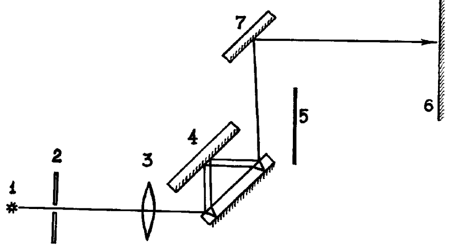


Figure 5.31, b

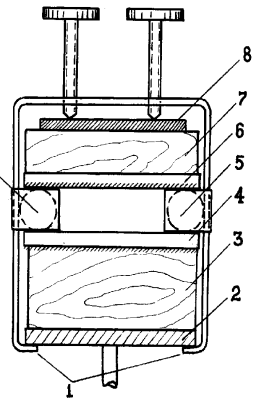


Figure 5.32

On the surface of the table we put a thick wooden gasket 3, it has a mirror with an internal coating 4 (its dimensions 100x50 *mm*). On the edges of the mirror, we put two cassettes 5 and cover them with a mirror with an outer cover 6 (dimensions 100x50 *mm*), and then a thinner wooden bar 7 and a steel gasket 8. Press the screws with screws screwed in the bracket 1 into the holes.

At a distance of 30-32 *cm* from the diaphragm near the optical lobe UI, set up a physical tripod, fig. 5.33.

Using a clutch of a tripod at a height of 20-25 *cm* on a short rod, we press the bar of the table with the details of the interferometer. The bracket is rotated so that the beam of light coming out of the aperture of the diaphragm falls on the lower mirror of the interferometer at an angle close to 40 deg.

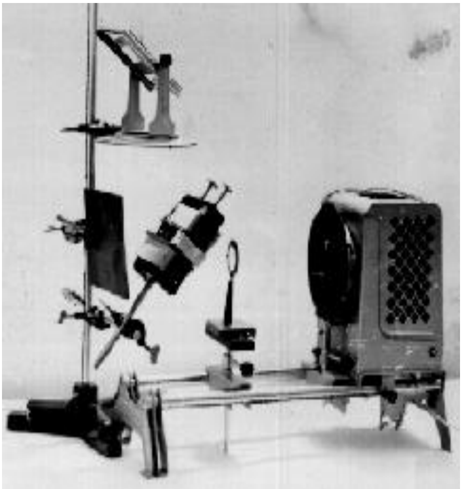


Figure 5.33

To direct the interference pattern on a white screen above the bracket, insert the flat mirror from the UI kit. The cardboard screen closes the other bundles of light that illuminate the interference pattern. To accelerate the setting of the installation, we first achieve a visual vision of the interference pattern in the rays coming from the interferometer from the sun (the interferometer is directed toward the window) or another light source. If necessary, change the pressure of the screws on the mirrors.

Then we put the interferometer in the UI beam. We notice that the ray of the Enlightener fell on the lower mirror with an internal coating, and on the white screen was seen the light strip. Because of this, the interferometer is turned around its axis and we seek the appearance of a small-scale interference pattern on the screen.

If the interference pattern does not appear or it is of poor quality then it is necessary to reduce or increase the pressure of the screws on the mirror, to change the angle of inclination of the mirrors to the incident beam, or to change the other place of the beam of light to the lower mirror. For a significant increase in the angular momentum of the intepferent caption of the line N_1, we move along the main optic axis of the UI (until a clear enhanced interference pattern appears on the screen), fig. 5.34.

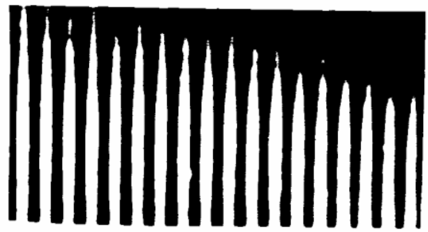


Figure 5.34

If the interference pattern is directed to a wall or large screen, its dimensions will be 2x2 *m*.

Experiment 5.3.8 Intepferometr Bashkatova-Ogorodnikova

Equipment: UI, number on the other, intepfepemetp BashkatovOgopodnikvo line N_1, physical tripod.

Intepferometr Bashkatov-Ogopodnikoe lay down for such a method. The crochet is located at the bottom of the UI, fig. 5.35.

On the surface of the table we put a mirror 1 with an external coating (100x70 *mm*). Two cassettes 2 are applied to the surface of the mirrors, holding the tabs on the side of the bracket. Flat-parallel glass plate 3, cut from a window glass (100x70 *mm*), placed on top of the cassettes.

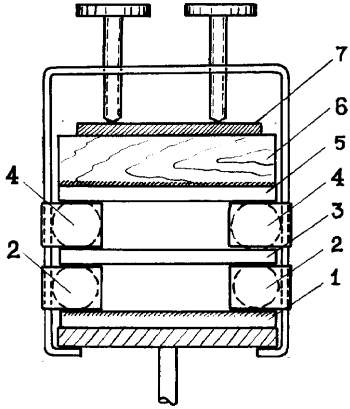


Figure 5.35 *Figure 5.36*

Micrometer pre-checks the thickness of the glass in different places. The thickness difference should not exceed 0.1 *mm*. Then we put another pair of cartridges 4 on a glass plate, which we cover with a mirror (100x50 *m*) with an inner covering 5, a wooden beam 6 and a steel plate 7. Screws fasten all the details of the interferometer. In this case, we have two systems of the Jhamena interferometer. The rod is fixed in a physical stand.

With UPD, remove the handcuff and replace the new one with a diaphragm of 10 *mm*. At the distance of 20 *cm* from the distance line N_1. Univative tripod with interferometer, fig. 5.36 located at 35-40 *cm* from the diaphragm.

The plane of the mirrors of the interferometer should be an angle of 60 degrees with a horizontal plane. A bundle of light is directed to the glass plate 3, fig. 5.35, where it is refracted and falls on the upper mirror, fig. 5.36.

After the reflection and refraction in the plate 3, it hits the screen (the motion of other rays is not considered). The side light is covered with cardboard screens, which are fixed in a physical tripod.

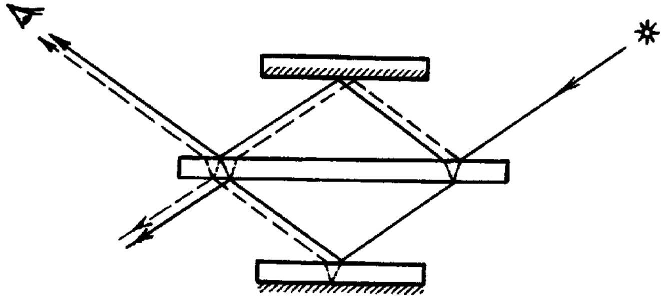


Figure 5.36

Set up the system in such a sequence. Between the diaphragm and the interferometer we put a matt glass from a set of geometric optics. We look through it from the side of the screen, moving the tripod, aiming for a beam of light to fall on that section of the glass plate, which gives the most accurate interference pattern. To achieve this, the angle of inclination of the mirror of the interferometer is also changed by the pressure of the screws.

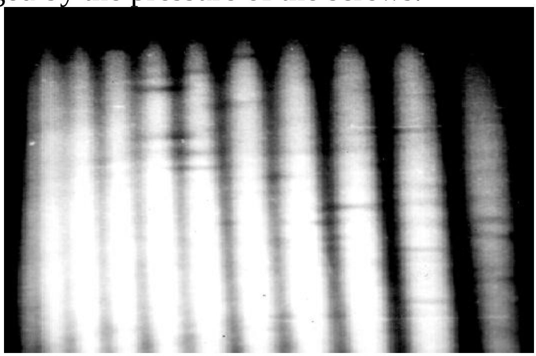


Figure 5.37

Then, instead of a matte glass, put the lens N_1. Moving it along the main optical axis of the UI, we achieve the best interference pattern, fig. 5.37.

With an interferometer, we carry out the following experiments:

1 Observe the interference pattern in white and monochromatic light.

2 Investigate the dependence of the index of air refraction on temperature.

3 We investigate the dependence of the index of refraction of the medium between the mirrors on its composition.

Experiment 5.3.9 Brewster interference pattern model

Equipment: UI, Brewster interferometer, physical tripod, paper screens.

Interferometer, fig. 5.38 a, placed from two glass plates 1 and 3 placed in parallel.

For this there is a glass of plaster 2 between them. Through the plate 1 and 3, a view of the jeep light is observed at a definite slope of the interferometer. We see an interference pattern. Instead of the plate 2, you can remove two cassettes, fig. 5.38. Glasses of plates 1 and 3 are made out of cubes of glass (150 x 100 *mm*). The interferometer consists of the following chains: the ends of the cube 6, fig. 5.38, b, backed by the UI.

On the surface of the table put two wooden bars (thick and thin). Slab bar is covered with a strip of black paper 5. On it, we consistently put the glass plates 1, 2, 3. The upper plate 3 should stand beyond the edge of the black paper 5 by 1.5-2 *cm*. It is applied to a metal plate 7 and is pressed with screws. Instead of a glass plate 2, cassettes can be used (fig. 5.39).

To adjust the interferometer, place the glass plates at an angle close to 45 degrees to the line of sight. The light from the fluorescent lamp or from the window should fall on the protruding part of the plate 3. There are a few drops of light from the sea.

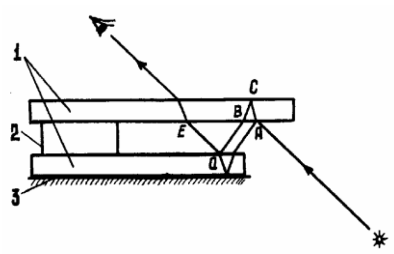


Figure 5.38,a

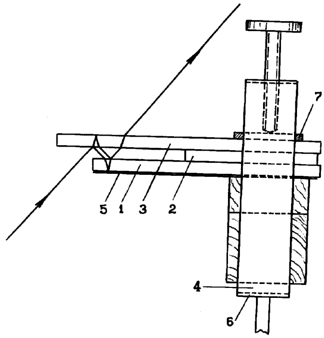


Figure 5.38, b

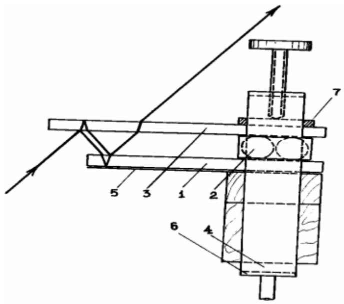


Figure 5.39

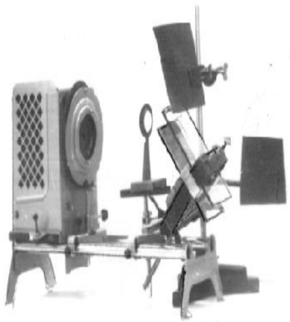


Figure 5.40

On the front of the screen, one should look at the interference pattern. This is achieved by changing the degree of pressure on the plates by screws or by relative changes in the position of plates 1 and 3 (to provide more precise parallelism of the upper and lower plates). In a clutch of a physical tripod horizontally close a short rod, at the end of which at an angle close to 45 degrees to the horizontal line, we attach a rod so many. From the UI condenser we take one lens. At its place place diaphragm (d = 10 *mm*). At a distance of 8-10 *cm* from the diaphragm on the bench, the lens of the lens N_1 is pseudo-light. A universal physical tripod with an interferometer fixed on it is placed at a distance of about 15 *cm* from the diaphragm, fig. 5.40.

Figure 5.41

On a vertical rod stand, fix two paper black screens that overlap the beams of light, which indicate an interference pattern on the screen. After switching on the UI beam of light, passing through the aperture of the diaphragm and lens N_1, it should fall to the protruding end of the upper glass plate. Part of the light is covered by the upper paper screen, which prevents illumination of the interference pattern. The reflected beam of light falls on the lower plate, reflects from it, passes through the top plate, falls to the screen and gives an interference pattern, fig. 5.41. In the absence of a picture, it is necessary to change the pressure of the screws, the inclination angle of the device, the place of falling of the beam on the glass plates or to adjust the parallelism of the glass plates.

5.3.2 Interferometrs for the frontal experiment

We make a working table from the tree, fig. 5.42. It consists of two supporting bars: thick (150x100x150 *mm*) and thinner (150x100x20 *mm*). On the surface of the support bar 1 put the bar 2 (150x70x20 *mm*) and nail it with nails.

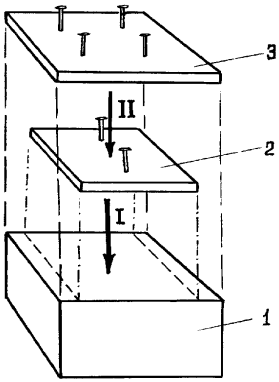


Figure 5.42

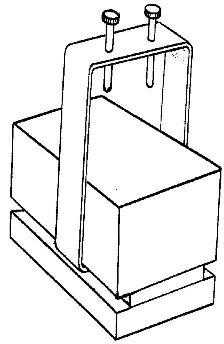


Figure 5.43

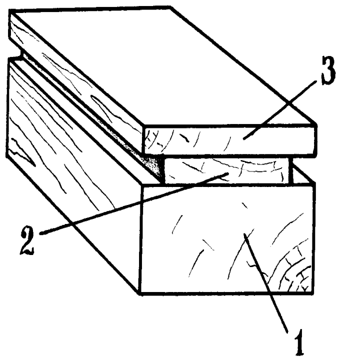


Figure 5.44

On the nailed stick fill the bar 3 and also nail nails. Between the bars on both sides were grooves for fastening the tabs (fig. 5.43, 5.44).

Experiment 5.3.10 Interference scheme of Zhamena

Equipment: a model of the interferometer Jhamena, a light bulb on the stand, a matte screen on a stand from a set for geometric optics, a current source of 4 *V*, a switch, connecting conductors, alcohol, a copper conductor with a length of 15-20 *cm* and a diameter of 12 *mm*, alcohol, a set of filters, combined Light filter, rubber pear.

Make the installation in accordance with fig. 5.45.

Opened ends of the bracket are inserted into the slots of the working table with a thicker supporting bar up. On the surface of the table put a strip of mirror (95x50 *mm*) with an outer covering. On the edges of the mirror put cassettes. At the top of the cassette cover with a mirror with an inner covering. Then on a mirror we put a thinner wooden gasket and an iron plate. The screws fixed on the top of the staples, fasten the folded system. This is how the model of the Jhamena interferometer is made.

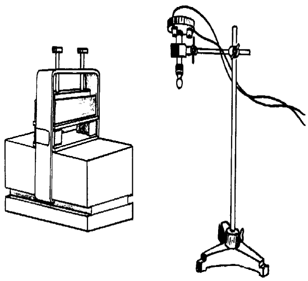


Figure 5.45

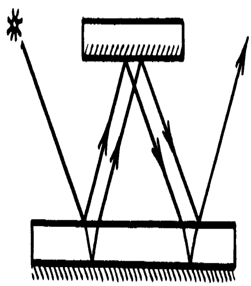


Figure 5.46

On the table we put the model of the interferometer. By device put a universal physical tripod with a light bulb in the paw. Balloon bulbs are located at a height of 20 *cm* above the table. The distance from the bulb to the edge of the lower mirror (horizontally) should be 10-15 *cm*. The ray of light falls on the lower mirror, reflects from it to the upper, is again reflected from the bottom and gets in the eye of the observer, (fig. 5.46).

Initially, the observer sees in the lower mirror image the face of the upper mirror. The interference pattern will look good in the area of the lower mirror from the image of this face to the nearer of the edge of the observer, (fig. 5.47).

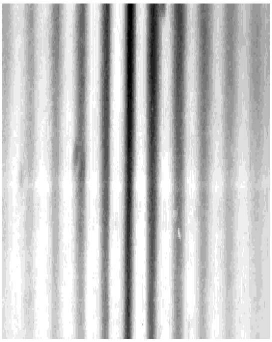


Figure 5.46

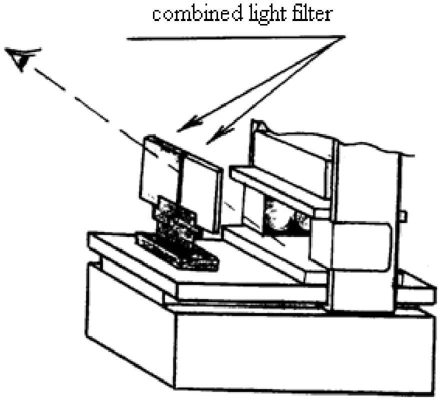


Figure 5.47

After that, we put a frosted display between the bulb and the interferometer. The quality of the picture is greatly improved. If the interference pattern is not visible, then change the pressure of the screws on the system.

With the described interferometer you can perform the following tasks:

1 Observation of interference in monochromatic light.

Continuously examine the interference pattern through a set of filter filters and observe dark on colored stripes.

2 Study of the dependence of the width of interference bands on the wavelength. Interference pattern is viewed through a combination of red-colored light filter, fig. 5.47, from a set for geometric optics. We see wider stripes in red than in blue.

3 Investigation of the dependence of the coefficient of refraction on temperature. The end of a wire of 15-20 *cm* in length and 2 *mm* in diameter is heated on a spatula and introduced into the air gap between the surfaces of the mirrors. We observe the displacement of the interference bands.

4 Comparison of the refractive index of air and alcohol vapor. Put a few drops of alcohol into a rubber bulb with a pipette. Then the pear tip is inserted into the gap between the mirrors and pressed on its surface. We observe the displacement of the stripes (in the opposite direction than in the case of heating).

Experiment 5.3.11 Interference scheme Bashkatov-Ogorodnikova-Popova

Equipment: Interference scheme of Bashatova-Ogorodnikova-Popova, a light-colored light bulb on the stand, a current source of 4 *V*, a matte screen from a set for geometric optics, alcohol, a copper wire with a diameter of 2 *mm*, an alcohol, a rubber pear.

Place the working table with a thin supporting bar up, fig. 5.48.

In the grooves of the table we introduce a bracket and leave it near its end. On the surface of the worktable, place a mirror with an internal coating (dimensions 100x75 *mm*).

On its edges we have cassettes. At the top of the cassette cover a glass plate of 100x150x6 *mm*. Its surface should not have mechanical defects. This check is carried out by a micrometer.

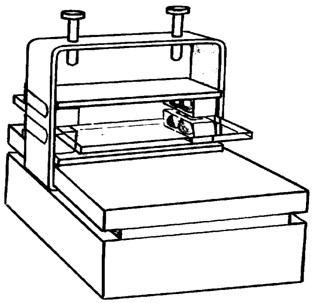


Figure 5.48

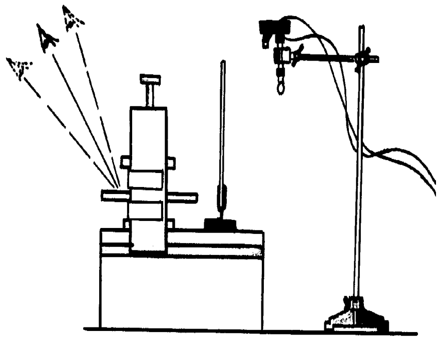


Figure 5.49

The difference in measurements should not exceed 0,1 *mm*. On the glass surface put a second pair of cassettes and cover them with a mirror with an external coating (95x50 *mm*). Then successively apply a wooden gasket, a metal plate and compress the parts with screws staples. On the free part of the table, fig. 5.49, put matte glass on the stand.

Its upper edge should have an image of the upper mirror in it. Moving the head up down, look for an interference pattern, fig. 5.50, should be 1.5 - 2 *cm* higher than the low light bulb, fixed in the foot of the physical tripod. Look at the lower mirror through the surface of the glass plate.

If it is not visible, then the degree of pressure of the screws on the mirror should be changed. With an interferometer you can study: the displacement of the strips, depending on the temperature and composition of the environment between the mirrors, fig. 5.50, *a*, observation of interference in monochromatic and white light, investigation of the quality of the surface of glass, etc.

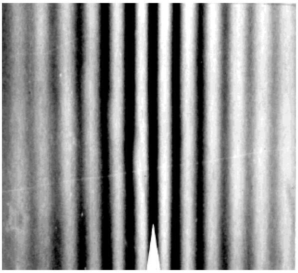


Figure 5.50

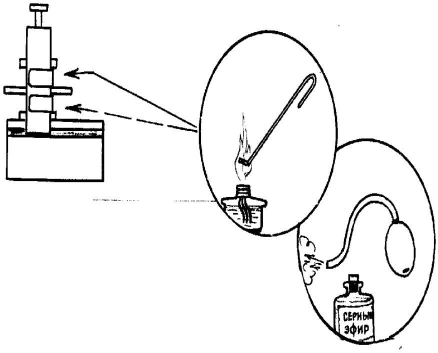


Figure 5.50, *a*

Experiment 5.3.12 Brewster Interference Scheme

Equipment: Brewster interference circuitry, light bulb on the stand, spark plug, switch, connecting conductors, matte screen on the stand, alcohol.

The principal scheme of the interferometer is given in fig. 5.51.

From the plate removed from the emulsion we cut two glass plates 9x3 *cm* and four plates 4x3 *cm*. Put the working table with a larger part up. In the grooves, place the ends of the bracket and bring them to the middle of the table. On the surface of the table we put a thinner wooden gasket. Cover it with a piece of black paper.

Then successively apply: plate 1 (the end of it should coincide with the edge of a sheet of black paper); three to four short plates 2; second longer plate (moves 2 *cm* towards the bottom); wooden gasket and metal plate. The entire system is squeezed by screws. The general view of the installation is shown in fig. 5.52.

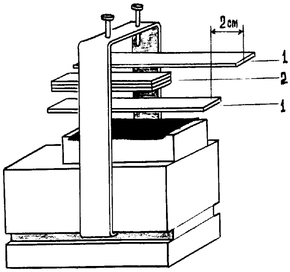


Figure 5.51

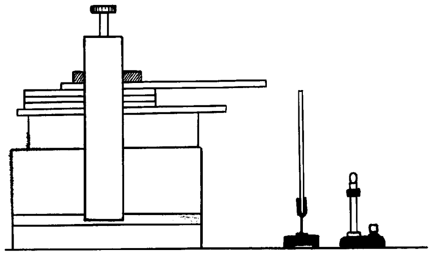


Figure 5.52

Stand with a flashing light bulb located at a distance of 7-8 *cm* from the edge of the work table. Turn on the electric light bulbs and look at it, fig. 5.53, through the top glass plate.

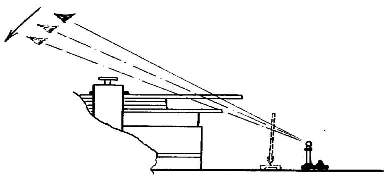


Figure 5.53

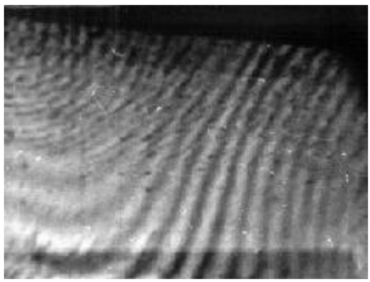


Figure 5.54

Move the eye down so that you can see several bulb images. Then between the light bulb and the table we put a frosted glass.

On the spot of the second or third image of the bulb, we observe an interference pattern, fig. 5.54.

If after the installation of a frosted glass the interference pattern is not observed, then it is necessary to change the degree of pressure of the screws on the plates and the experiment to repeat.

5.4 Interferometers for the work of physical practice

Laboratory work 5.4.1 Measurement of the length of the light wave using the Young interferometer

Purpose*:* to study the phenomenon of light interference; Estimate the range of wavelengths of the visible spectrum; Measure the wavelength of blue and red light; Study Jung's interferometer.

Equipment: Young Interferometer.

Theoretical information

The interference of light is the phenomenon of overlapping two or more coherent light waves, which results in a redistribution of light intensity in space.

Waves are called ***coherent*** if they have the same frequency and at the point of overlap - the constant phase difference.

Consequently, if the waves are coherent, then there is a self-consistent course in the time and space of several wave processes. This condition is satisfied by monochromatic waves - the waves of one strictly determined frequency and constant amplitude. Since one real source does not give a strictly monochromatic light with a constant initial phase, the waves emitted by any independent light sources are always incoherent.

Suppose two coherent monochromatic light waves are superimposed on one another at some point in space. The first wave causes at this point harmonic oscillations

$$\mathring{A}_1 = \mathring{A}_{01}\cos(\omega t + \varphi_1)\,, \tag{1.1}$$

and the second, respectively

$$\mathring{A}_2 = \mathring{A}_{02}\cos(\omega t + \varphi_2) \tag{1.2}$$

Since two harmonic vibrations of the same period are added in the same direction, then the resulting oscillation will also be harmonic with the same period and the same direction, ie

$$\mathring{A} = \mathring{A}_0\cos(\omega t + \varphi) \tag{1.3}$$

The amplitude $\mathring{A}_0$ of this oscillation is:

$$\mathring{A}_0^2 = \mathring{A}_{01}^2 + \mathring{A}_{02}^2 + 2\mathring{A}_{01}\mathring{A}_{02}\cos(\varphi_2 - \varphi_1) \tag{1.4}$$

Since the waves are coherent, then $\cos(\varphi_2 - \varphi_1)$ there is a constant in time value, therefore, the intensity of the resulting wave ($I \approx E_0^2$):

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(\varphi_2 - \varphi_1) \tag{1.5}$$

At points of space, where $\cos(\varphi_2 - \varphi_1) > 0$, $I > I_1 + I_2$, respectively, when $\cos(\varphi_2 - \varphi_1) < 0$, $I < I_1 + I_2$.

Consequently, when two coherent light waves are applied, a spatial redistribution of light intensity occurs, resulting in maxima in some places, and in others, the minima of intensity.

For incoherent waves $\varphi_2 - \varphi_1$, the difference is continuously changing, so the mean value in time is $\cos(\varphi_2 - \varphi_1) = 0$, the intensity of the resulting wave is everywhere the same and is equal $I_1 = I_2$ to $2I_1$ (for incoherent waves under this condition in maxima $I = 4I_1$, in minima $I = 0$).

For reception of light waves the method of division of a wave emitted by one source is applied, which after passing of various optical paths is superimposed on one for one and the interference pattern is observed.

Let the division into two coherent waves take place at a definite point O (fig. 5.55). At the point M where the interference pattern is observed, one wave in an environment with an index of refraction n_1 has passed the path S_1, the second - in an environment with an index of refraction n_2 - the path S_2.

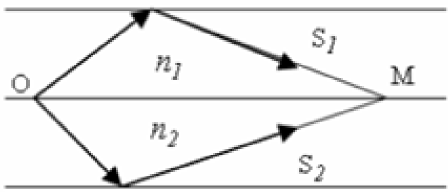


Figure 5.55

If at the point O of the phase of oscillation is equal ωt, then at the point M the first wave will excite oscillations $A_1 \cos\omega(t - \frac{S_1}{\upsilon_1})$, the second wave – oscillations $A_2 \cos\omega(t - \frac{S_2}{\upsilon_2})$, where $\upsilon_1 = \frac{c}{n_1}$, $\upsilon_2 = \frac{c}{n_2}$ - respectively, the phase velocity of the first and second waves. The phase difference of the vibrations excited by the waves at the point M is equal to

$$\delta = \omega\left(\frac{S_2}{\upsilon_2} - \frac{S_1}{\upsilon_1}\right) = \frac{2\pi}{\lambda_0}\left(S_2 n_2 - S_1 n_1\right) = \frac{2\pi}{\lambda_0}\left(L_2 - L_1\right) = \frac{2\pi}{\lambda_0}\Delta, \quad (1.6)$$

where $\frac{\omega}{c} = \frac{2\pi\nu}{c} = \frac{2\pi}{\lambda_0}$, a λ_0 is the wavelength in a vacuum.

The product of the geometrical length of the path S of light-length in this medium on the refractive index n of this medium is called ***the optical path length*** L, and $\Delta = L_2 - L_1$ - the difference between the optical lengths of the waves passing through the paths - is called ***the optical difference of the course***.

If the optical path difference is equal to the whole number of waves in a vacuum

$$\Delta = \pm m\lambda_0 \text{, де } m = 0,1,2,... \tag{1.7}$$

then the oscillations excited at the point in both waves will occur in the same phase. Consequently, (1.7) is the condition of an ***interference maximum***.

If the optical difference is in motion

$$\Delta = \pm(2m+1)\frac{\lambda_0}{2} \text{, де } m = 0,1,2,..., \tag{1.8}$$

then $\delta = \pm(2m+1)\pi$ the fluctuations excited at the point M both waves will occur in the opposite phase. Therefore, equation (1.8) is the condition of an ***interference minimum.***

Description of the laboratory installation

The base of the Young interferometer is the body of the profile having a square section, within which the optical circuit is mounted (fig. 5.56). The device and its elements are described in section 2.1.

At a distance of 100 *mm* from the measuring grid of the eyepiece in the slit of the interferometer body, there is a ***test-object № 1***. It consists of: a single slit (position «1»), a slit (position «center»), a double slit Jung (position «2»). Closer to the eyepiece at a distance is set ***test-object № 2***. It consists of Fresnel biproses (position «1»), thin screen – «threads» (position «2»). In the center of ***test-object № 2*** there is a window that provides the opportunity to observe the ***test-object № 1***.

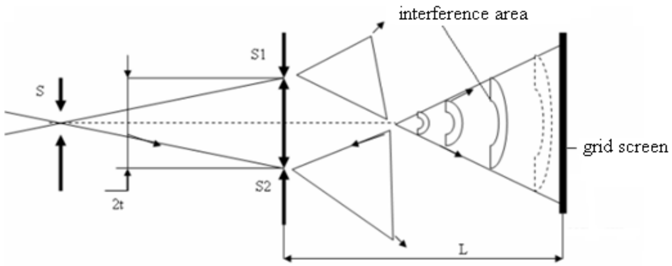


Figure 5.56 Optical scheme of Young's classical experiment: S *- entrance slit,* S_1 *and* S_2 *- Jung double slit,* L *- distance between double slit and grid,* $2t$ *- distance between cracks in the double slit of Jung*

The revolutionary idea in Young's experiment was to use the first incoming slit S. In the absence of such cracks or at a very large width, the spatial coherence of the light beams that illuminate the double slit of Young is not ensured, which inevitably leads to a zero visibility of the interference pattern. When using laser radiation, the need for the first crack disappears, it is not needed, because the laser beam is spatially coherent in its intersection.

Execution of work

1 We set the test object number 2 to the neutral position of the «center».

2 We set the bar with the test object number 1 to the position «2» (double slit).

3 Point the eyepiece on a clear image of the mesh scale distributions. We fix on the transducer interferometer a regular illuminator, made on 2-LEDs.

4 Turn on, in turn, red and blue LEDs, observe the interference pattern and, at the same time, the touches of the scale of the mesh of the interferometer eyepiece.

Note. In order to make the interference pattern more vivid, the inclinations of the interferometer (right-to-left) illuminator within the backlash of the landing sleeve are allowed.

5 On the scale of the grid, we measure the number of dark (light) bands N corresponding to the corresponding number n of grid distributions. Then the distance between the diffraction minima (maxima) will be calculated by the formula:

$$d = \frac{en}{N} \tag{1.9}$$

Given that the price of the minimum distribution of the measuring grid in the field of view of the eyepiece mm, we obtain:

$$d = \frac{0{,}2n}{N} \ (mm) \tag{1.10}$$

Measurement is carried out 3 times.

6 Measure the distance between the maxima of interference bands for blue and red LEDs. We will receive: $d_{\text{red.,}}$ d_{blue}. We substitute the value in the formula for determining the wavelength of light: $d\sin\varphi = k\lambda$.

7 For the first order of the interference pattern $k = 1$, and

for the small angle φ to the first order $\sin\varphi \approx tg\varphi \approx \dfrac{2t}{L}$.

Under these conditions we get:

$$\lambda = d_{\text{red}}.(\text{blue}) \quad \frac{2t}{L}, \text{ або } \lambda_{\text{red.}}.(\text{blue}) = \frac{0{,}2n}{N}\frac{2t}{L}, \qquad (1.11)$$

where $2t$ - the distance between the cracks in the double slit of Jung ($2t = 0{,}1\,\text{mm}$), and L - the distance between the double slit of Young and the scale of the grid ($L = 100\,\text{mm}$).

8 Calculate the wavelength for red and blue LEDs according to formula (1.12):

$$\lambda_{\text{red.}}(\text{blue}) = \frac{0{,}2n}{N}0{,}001 \ (mm) \qquad (1.12)$$

9 We calculate absolute and relative errors and draw up a work report.

Control questions

1 Do you define the interference of light?

2 How do coherent waves get?

3 Record the maximum and minimum conditions for interference.

4 Tell us about the device and the principle of the interferometer Jung.

5 What types of interferometers do you know?

Laboratory work 5.4.2 Determination of the refractive index of liquids and the concentration of non-colored solutions using the interferometer ITR-1

Purpose: to get acquainted with one of the types of modern high-sensitivity laboratory interferometers and to master the interference method of determining the refractive index and the concentration of non-painted liquid solutions.

Equipment: 1) interferometer laboratory, model ITP-1; 2) reducing transformer T4-220 B / 8 B; 3) a holder with a two-chamber glass dish 10 mm long for liquids; 4) wooden frame - stand for storage of the cuvette in a non-operating condition; 5) flasks with reference liquids (distilled water, ethyl alcohol, 2%, 5%, 7% and *x*% ethyl alcohol in water).

Theoretical information

The main optical property of substances is the refractive index of light. There are ***absolute*** *n* and ***relative refractive*** index *N*.

Consider two coherent rays that coincide on the screen at point *A*, passing from the sources S_1 and S_2 of the distance d_1 and d_2 in optically different environments n_1 and n_2 (fig. 5.57).

Assume that the wave front of the light beams is flat and we write the equation of the plane wave at the point *A* for each beam. For the first beam $\tilde{o} = A\sin 2\pi\left(\frac{t}{T} - \frac{d_1}{\lambda_1}\right)$, for the second beam $\tilde{o} = A\sin 2\pi\left(\frac{t}{T} - \frac{d_2}{\lambda_2}\right)$.

Calculate the phase difference of these beams at point *A*:

$$\varphi_1 = 2\pi\left(\frac{t}{T} - \frac{d_1}{\lambda_1}\right) \qquad (2.1)$$

$$\varphi_2 = 2\pi\left(\frac{t}{T} - \frac{d_2}{\lambda_2}\right) \qquad (2.2)$$

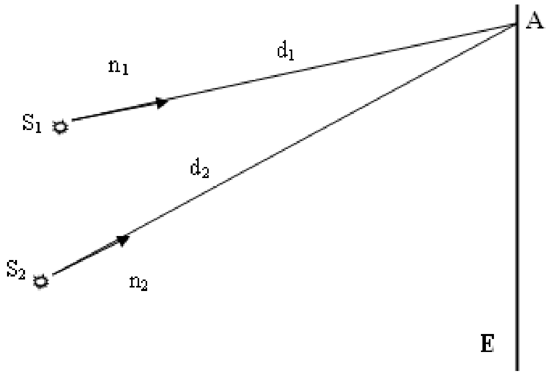


Figure 5.57 Determination of the optical path length and the phase difference of two coherent beams

Then the phase difference $\Delta\varphi = \varphi_1 - \varphi_2$, or $\Delta\varphi = 2\pi\left(\frac{d_2}{\lambda_2} - \frac{d_1}{\lambda_1}\right)$. Because $\lambda_1 = \frac{\lambda_0}{n_1}$, $\lambda_2 = \frac{\lambda_0}{n_2}$, then $\Delta\varphi = \frac{2\pi}{\lambda_0}(n_2 d_2 - n_1 d_1)$. Expression $\frac{2\pi}{\lambda_0}$ - ***the value has become.***

Therefore, the phase difference of two coherent beams, erected at any point in the screen, depends on the geometric length of the path and on the absolute refractive index of the media in which these rays are propagated. If the rays pass, for example, in the air geometrically equal paths, then the phase difference can be formed by introducing a transparent plate or cuvette in a path of one of the rays, which has an absolute refractive index different from the main medium (air). It is precisely this way of creating the phase difference of two coherent rays used in an interferometer of type

ITR 1.

The product of the absolute index of refraction of the medium on the geometric length of the path of the ray in this medium is called the ***optical path length*** $D = nd$. The formula $\Delta\varphi = \frac{2\pi}{\lambda_0}\Delta D$ establishes the relationship between the difference in the course of two beams collected at this point of the screen, with the corresponding phase difference.

Coherent rays, collected in one point of the screen, interfere if the rays have the same phases ($\Delta\varphi = 0,\ 2\pi,....,2k\pi$), then they amplify each other; If the rays come to the A point of the screen in the antiphases ($\Delta\varphi = \pi,\ 3\pi,...,(2k+1)\pi$), they weaken. Accordingly, the illumination of the screen changes: in the places of amplification of rays the illumination increases, in places weakening decreases. Such uneven illumination of the screen, which is the consequence of the interference of the coherent rays, is called ***an interference pattern***. In the interferometer ITR-1, the ***interference pattern*** has the form of vertical light (painted) and dark bands.

It should be noted that when propagating interfering rays in the same medium ($n_1 = n_2 = n$), the difference in stroke arises as a result of uneven geometric distances from sources of rays to different points of the screen (fig.5.58).

For the center point of the screen, the paths SO_1 and SO_2 are the same. Since n = const, then $\Delta\varphi = 0$. Therefore, the central part of the screen in this case will be brightly lit, regardless of the environment in which the rays are propagated. Symmetrically on both sides of the central light strip, the first dark strips will be placed, followed by light bands, etc.

In order to predict the result of the interference of the rays at point A, we express the difference in the course ΔD

of the distance L, l, H, which is easy to measure in the experiment. From the rectangular triangles S_1BA and $S_2B`A$ we have,

$$d_1^2 = L^2 + (H - l)^2; \; d_2^2 = L^2 + (H + l)^2. \qquad (2.2.3)$$

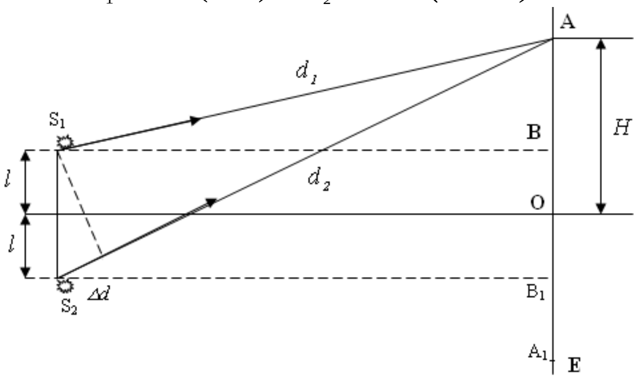


Figure 5.58 Calculating the difference between the rays for different points on the screen

We calculate the difference between the squares of distances d_1 and d_2:

$$d_2^2 - d_1^2 = (L^2 + 2Hl + l^2)(L^2 + H^2 - 2Hl + l^2) = 4Hl. \qquad (2.2.4)$$

Consider the difference in the squares of two numbers:

$$d_2^2 - d_1^2 = (d_2 - d_1)(d_2 + d_1). \qquad (2.2.5)$$

Because always $L >> 2l$, then $d_1 + d_2 \approx 2l$. From here

$$2L(d_2 - d_1) \approx 4Hl; \; d_2 - d_1 \approx \frac{2Hl}{L}. \qquad (2.2.6)$$

The difference in the course of rays $\Delta D = n(d_2 - d_1)$ in this case is equal $\Delta D = \frac{2nHl}{L}$. Accordingly, the difference between the phases of interfering rays can be calculated by the formula $\Delta\varphi = \frac{2\pi nH2l}{\lambda_0 L}$, where $2l$ - the distance between coherent light sources (in the case of an interferometer ITR-1 is the distance between the cracks, from which two parallel light streams are formed); L -distance from the light source to the screen (length of the interferometer); H -distance from the center of the screen to the considered point on the screen; λ_0 - the wavelength of light used in the interferometer.

The intensification of light (maximum) occurs when the interfering rays «come» into the considered point of the screen in identical phases. In the case of phase defects, the illumination is weakened (minimum). Consequently, the following equality can be considered as a condition for a maximum and a minimum:

$$\Delta\varphi_{\max} = 0,\ 2\pi,\ 4\pi,...,2k\pi, \text{ where } k = 0, 1, 2, 3. \qquad (2.2.7)$$

$$\Delta\varphi_{\min} = 0,\ 2\pi,\ 4\pi,...,2k\pi, \text{ where } k = 0, 1, 2, 3. \qquad (2.2.8)$$

Or $\frac{2\pi nH2l}{\lambda_0 L} = 2k\pi$, $\frac{2nH2l}{\lambda_0 L} = 2k\frac{\lambda_0}{2}$ – the condition of the maximum. (2.2.9)

$\frac{2\pi nH2l}{\lambda_0 L} = (2k+)\pi$, $\frac{2nH2l}{\lambda_0 L} = (2k+1)\frac{\lambda_0}{2}$ – minimum condition. (2.2.10)

The last formulas show that, at constant values l, L, λ_0, k, the value of H varies (the interference pattern is shifted by changing the index of refraction of the medium. The magnitude of the displacement of the interference pattern along the screen is associated with the magnitude of the change in the refractive index of the medium along the path of one of the rays.

This connection is used in the work of the ITR-1, in which the displacement of the upper (moving) interference pattern relative to the lower (stationary), determines the difference in the refractive index of the liquids in the dishes of the device.

From the condition of the maximum $\frac{2nH2l}{\lambda_0 L} = 2k\frac{\lambda_0}{2}$

also it follows that various values λ_0 correspond to different values of H for unchanged values l, L, n, k. This means that in the illumination of the slits of the interferometer with nonmonochromatic light (a bulb of ignition without a light filter), a spectrum should be created as a result of interference. Each interference peak observed in the ITR-1 interferometer is a continuous spectrum that is turned by the short-wave (violet) part to the central luminous band. This band is a maximum of zero order ($k = 0$). At zero maximum, the light of all wavelengths is amplified at the same point of the screen. Therefore, the central maximum is uncolored, which makes it easy to determine it and avoid a possible error when combining moving interference pattern with stationary. At zero maximum, the light of all wavelengths is amplified at the same point of the screen. Therefore, the central maximum is uncolored, which makes it easy to determine it and avoid a possible error when combining moving interference pattern with stationary. For example, stained maximums of the 1st and 2nd order can hardly be distinguished. Therefore, when moving a moving interference pattern into the original position, it is possible to mistakenly combine the maximum of the 1st order of the moving picture with the maximum of the 2nd order of the stationary interference pattern and assume an error in one band (30 to 40 divisions of the scale of the compensator). Consequently, the combination of interference pictures should be controlled by the central uncolored maximum.

Description of the laboratory installation

Interferometer ITR-1 - a universal laboratory device, by means of which it is possible to measure the difference in absolute values of refraction of liquids, gases and gas mixtures. To measure the difference between the refractive index of liquids and their solutions, the interferometer ITR-1 is equipped with a set of glass cuvettes of various sizes.

The fundamental optical scheme of the interferometer ITR-1 coincides with the scheme of the Rayleigh interferometer (fig. 5.59).

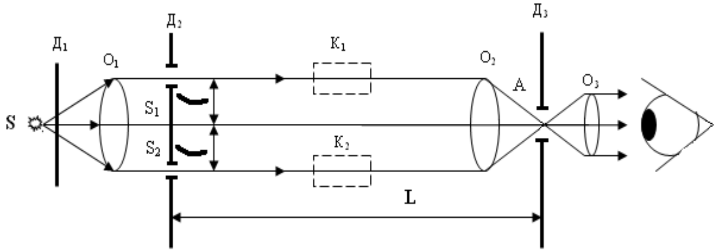


Figure 5.59 Optical circuit of an interferometer

A divergent beam of light from the incandescent bulb *S* (8 *V*; 0.4 *A*) passes through a narrow slit D_1 and enters the lens O_1, with the help of which a parallel beam of a width is formed $2l$. This beam illuminates the diaphragm D_2 with two narrow vertical slits, resulting in the formation of two parallel beams, which extend in the body of the interferometer at a distance $2l$ from each other.

Thus, the slit of the diaphragm D_2 can be considered as two sources of plane waves S_1 and S_2. On the path of these rays, a holder with a cuvette having two identical chambers filled with the test (K_1) and reference (K_2) fluids is installed in the device housing. After passing through the cuvette, the rays are collected by an objective O_2 into one point *A*, which lies in the plane of the diaphragm D_3 with a vertical gap. On the other hand, the point *A* lies in the focal plane of the cylindrical eyepiece O_3, from which the beams reach the eye of the observer in parallel beam and after the refraction in the crystal form an interference pattern on the retina.

As a result of the passage of rays through the cuvettes K_1 and K_2, filled with liquids with different refractive indices, an additional difference of motion (phase difference) is formed. These results in the displacement of the interference pattern observed through the cylindrical eyepiece O_3, in the left or right side, depending on the ratio of the refractive index of the liquids in the left and right chambers of the cell. In order to determine the magnitude of the displacement of the interference pattern, the cuvette is installed in the housing of the interferometer so that it crosses only the upper half of the rays. The lower half of the rays do not obstruct the cuvette, so they propagate in the air and form a lower fixed interference pattern in comparison with which the displacement of the upper interference pattern is determined.

In order to return the moving (upper) interference pattern to the original position, that is, to combine it with the lower (stationary) system of interference bands, an interferometer provides a compensator consisting of two glass plates of the same thickness. One of the plates of the compensator (left relative to the observer looking into the eyepiece) is set on the path of the left beam motionless. The second plate of the compensator, which is installed in the path of the beam, passed through the right cell, is mobile. With the help of a lever and a drum, a moving plate in the frame can be tilted and, to change the optical length of the path of the right beam in this plate. By increasing the angle of inclination of the moving plate to the horizon, the length of the path of light in it decreases (fig. 5.60). This makes it possible, with the help of the right plate, to reduce the difference in stroke by an amount equal to the difference created by the filling of cuvettes with liquid with different refractive indices, that is, to compensate for it.

Choosing the angle of inclination of a moving plate, in which the additional difference in the course, introduced by fluids with different refractive indices, will be compensated by the difference in motion, formed by changing the slope of the moving plate. Then the upper interference pattern is aligned with the lower one. The maximum change in the angle of inclination of the movable plate of the compensator is about 8^0.

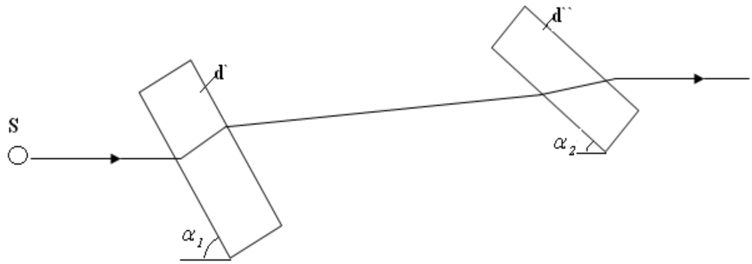


Figure 5.60 Increasing the optical path length by reducing the angle between the plate and the beam

The calibration of the scale of the compensator is carried out in relative dimensionless units $[c] = \frac{1}{division}$.
Circularscale drum has 100 divisions, vertical scale - 30. So, the compensator is designed for divisions $100 \times 30 = 3000$. According to the passport data of the device it is known that when using a cuvette of 8 *cm* in length, the maximum difference of absolute refractive index, which can be measured on the device, is $\Delta n = 0{,}00063$. Obviously, the compensator drum will be installed at the end of the scale, that is, at the 3000th division. Therefore, the price of the division will be equal $c = \frac{0{,}00063}{3000} = 2{,}1 \cdot 10^{-7} \frac{1}{div.}$.

The magnitude of the displacement of the upper interference pattern depends on the difference in the refractive index of the liquids in the cuvettes. The additional difference required for compensation is proportional to the inclination of the movable plate of the compensator or the indications of the scale of the reel of the micrometer screw, through which the slope of the plate changes through the lever. This linear dependence between the distributions of the scale of the compensator and the measuring physical quantity (the difference between the refractive index of reference fluids, the reference liquid and the solution of a certain concentration) was used to construct a gauge graph.

Execution of work

1 Remove the top cover 1 (fig. 5.61) of the housing 5 interferometer, remove the holder with the dish.

2 We install the cover 2 on the housing and turn on the power of the interferometer (the cord from the interferometer - to the socket on the transformer panel T - 4, the «Brightness» knob is set to the middle position).

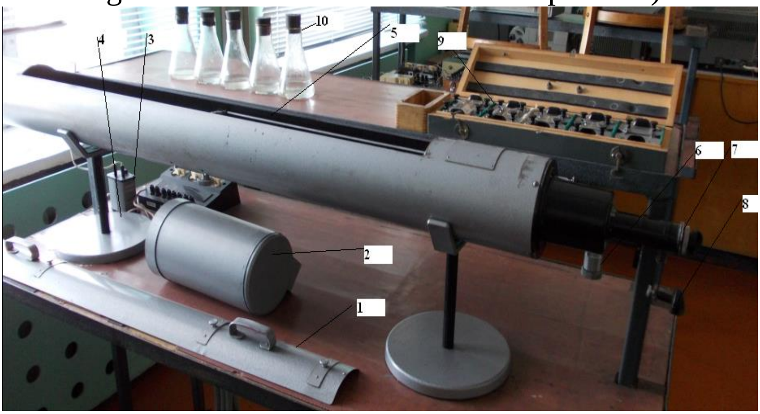


Figure 5.61 General view of the interferometer ITR - 1: 1 - upper cover; 2 - protective cap; 3 - transformer T-4; 4 - stands; 5 - thermostat; 6 - a drum with a scale; 7-line pipe; 8 - magnifier; 9 - set of ditch; 10 - solutions for the experiment

3 We observe in the optic tube 7, we obtain the clearest picture of the interference pattern (rotation of the aluminum washer with a knitting near the eyepiece lens 7); Using the «Brightness» knob on the transformer, we set the brightness of the interference pattern (fig. 5.62).

4 We install a holder with a clean, empty cuvette, 1^0 *cm* in length to the thermostat, close the lid of the

interferometer body, and combine the zero (unpainted) maxima of the upper and lower interference patterns, rotating the reel of the compensator. Take off the countdown N_0 on the scale of the compensator, which will be used for the zero count of the device.

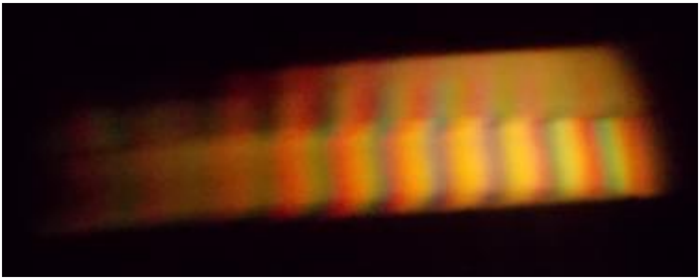


Figure 5.62 Image of an interference pattern in an IGT interferometer – 1

5 Take a cuvette from the thermostat, set it to a wooden stand and a burette for distilled water, fill both chambers with water at their depths, cover with glass lids.

6 We set the cuvette to the thermostat (the camera with the letter «P» to the right of the observer near the visual tube). The upper interference pattern is practically not shifted if the cameras are clean cues. When shifting this picture, again install the compensator so that the pictures coincide and this value is set to zero.

7 The price of the divisions of the scale of the compensator is found on the passport data of the device: for a cuvette 1 *cm* the maximum difference of the absolute refractive index, which can be measured on the device, is $\Delta n = 0{,}005$, while the compensator drum will be installed at the end of the scale, that is, at the 3000th division $c = \dfrac{0{,}005}{3000}$.

8 Find absolute refractive indices of four solutions of

various concentrations of ethyl alcohol in water. Water from the right (*P*) cuvétes pour out, dry and pour 2% solution of ethyl alcohol, in water (using a separate burette). After compensating the optical difference of the run, we take the countdown on the scale of the compensator and insert it into the table 5.4.2.1.

Table 5.4.2.1

Substances in a cuvette		Impressions of the scale		Indicator difference refraction $\Delta n = cN$	Absolute indicator Refraction of water (t =20^0C)	Absolute refractive index Solution $n = n_v + \Delta n$
Camera «L»	Camera «P»	Scale N\`	Count from the prime zero N= N\`-N_0			
Water	2 %				1,33299	
Water	5 %					
Water	7 %					
Water	*x* %					

The performed experiment is repeated with other three solutions (5%, 7% and unknown concentration *x*%). In the previously determined price of the dividers of the scale of the drum of the compensator C and on the reference scale N = N\`-N_0, we calculate the difference between the refractive indices of the four solutions and water ($\Delta n = cN$). Water is used as a reference liquid, and therefore the refractive index of each solution is determined as follows: $n = n_v + \Delta n$.

9 Based on the three reference solutions (2%, 5%, 7%), we construct a calibration graph, with the horizontal axis postpone the concentration of solutions, and on the vertical - the absolute index of refraction of the solution. Using the graph, determine the concentration of the unknown solution.

10 After the measurements are completed, always wash the cuvette and dry.

Control questions

1 Why are the interference peaks observed in the ITR-1 device turned upside-down? Repeat your answer with the appropriate formulas.

2 Why in the interferometer ITR-1 do not use monochromatic light, which is very easy to get through the light filter?

3 What is the purpose of the compensator? What should his plates be?

4 What conclusions can be drawn from the following examples:

a) the conditional zero, determined without a cuvette, and when the cuvettes with intermediate chambers are installed, do not coincide?

b) the conditional zero, determined when installing cuvettes with intermediate chambers and when installing both chambers with distilled water, are different?

5 What is the physical content of the absolute index of refraction of the medium? Relative refractive index of two media? How are these values correlated?

Laboratory work 5.4.3 Investigation of the dependence of the index of refraction of air against pressure by the interferometer Zhamena

Purpose: to study the structure and application of the jumper interferometer; Determine the dependence of the index of air refraction on pressure.

Equipment: Jhamena interferometer; Vacuum vessel; Water pressure gauge; Gas cuvettes; Vacuum pump.

Theoretical information

The refractive index n of a substance depends on its density ρ for other unchanged conditions. This dependence can be expressed by the ratio:

$$\frac{n^2 - 1}{n^2 + 2} \quad \frac{1}{\rho} = const. \qquad (3.1)$$

For gases that are at low pressures, the relation (3.1) can be simplified. Given that in the case under consideration $n \approx 1$, we can write:

$$\frac{n^2-1}{n^2+2}\frac{1}{\rho} \approx \frac{2(n-1)}{3\rho} = const, \qquad (3.2)$$

Or

$$\frac{n-1}{\rho} = const. \qquad (3.3)$$

On the other hand, because the temperature of the gas density ρ is proportional to its pressure P, then we write:

$$\frac{n-1}{P} = const \quad, \text{або } n-1 = kP, \qquad (3.4)$$

where k - some coefficient of proportionality.

From (3.4) it is seen that at constant temperature, the change in the refractive index Δn and the change in pressure ΔP are interconnected by the following formula:

$$\Delta n = k\Delta P \qquad (3.5)$$

In this paper, you need to check this relationship. They are measured ΔP with a water pressure gauge, Δn - with the help of a jumper interferometer.

Description of the laboratory installation

The main part of the Jhamena interferometer are two identical, thick, flat parallel glass plates P_1 and P_2, silver plated on one side. Of course, these plates are arranged so that their planes were a small angle. The course of rays in the jhamen interferometer is shown in fig. 5.63.

The light from the source focuses on the slot with a condenser and falls on the plate P_1 with a parallel beam.

Let's consider one of the rays of this beam. As a result of the reflection from the plate P1, the ray is split. Each of the two parallel rays I and II falling on the plate P_2, when repulsed from its surfaces, is split again, so that at the output of the device four rays 1, 2, 3 and 4 are formed which are parallel to each other.

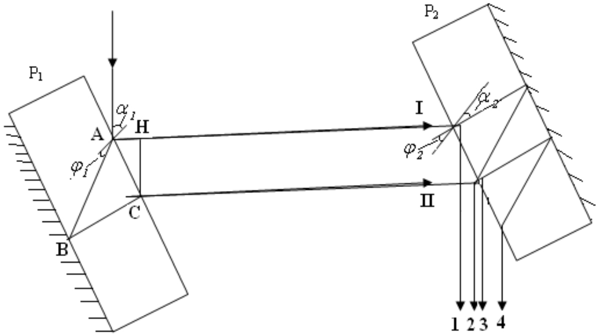


Figure 5.63

Between any pair of rays, except for the rays 2 and 3, there is a significant difference in the course due to different number of passages through the thickness of the plates P_1 and P_2. This difference in stroke is several centimeters, and because of the use of white light interference is not observed between rays 1-2, 3-4, 1-4. Interference phenomena arise only with the superposition of rays 2 and 3.

Let's calculate the difference between the paths between these rays. Difference between the rays I and II, reflected from the front and back surfaces of the plate P_1,

$$\Delta_1 = \ddot{i}\,(\grave{A}\hat{A} + \hat{A}\tilde{N}) - (\grave{A}\acute{I}\ \ ) = 2hn\cos\varphi_1, \qquad (3.6)$$

where n - coefficient of refraction of the substance of the plate; h - thickness of the plate; φ_1 - the refractive angle in the plate P_1.

After the reflection from the surfaces of the plate P_2, the rays 2 and 3 acquire an additional difference in stroke

$$\Delta_2 = -2hn\cos\varphi_2, \qquad (3.7)$$

where φ_2 is the refractive angle in the plate P_2. The complete difference between the races between rays 2 and 3

$$\Delta = \Delta_1 + \Delta_2 = 2hn(\cos\varphi_1 - \cos\varphi_2) \qquad (3.8)$$

The formulas (3.6) and (3.7) did not take into account the difference in the reflection from the front and back surfaces of the plates. This is justified by the fact that each of rays 2 and 3 was formed as a result of one reflection from the front and one - from the rear surfaces.

As can be seen from fig. 4.65, the rays 2 and 3 are parallel with each other, so the interference can be observed with the help of a visual tube inserted into infinity, or simply an eye impromptu to infinity. The maxima of illumination are located at those points of the focal plane of the optic tube, where the rays converging with the difference of course

$$\Delta = m\lambda, \text{ where } (m = 0, \pm 1, \pm 2, ...) \qquad (3.9)$$

Difference of course

$$\Delta = (2m+1)\frac{\lambda}{2} \qquad (3.10)$$

meets the minimum luminance. Therefore, in the field of view of the pipe there is a system of horizontal interference bands.

If observations are made in white light, the central band is achromatic (white), it is surrounded by two deep minima. Next is a system of painted bands, the clarity of which gradually deteriorates. The achromatic or zero band is located at those points of the field of view, where the path difference is zero for all wavelengths.

Observing the described interference pattern, it is easy to determine the refractive index of a substance introduced into one of the light beams I or II. According to this, the refractive index of the medium through which the second light beam passes must be known.

Let in the beam I the body is brought into length L (for example, a cuvette with gas) with an index of refraction n_1. The ray of ray II continues to pass in the air with an index of refraction n_2. Then there is a difference between the rays I and II additional to that which is defined by the expression (3.8).

$$(n_2 - n_1)L = Y, \tag{3.11}$$

If $Y = m\lambda$, where m - is an integer, then obviously the interference pattern in the monochromatic light that is observed in the pipe undergoes a shift in the bands m. This means that in the place of the zero band will be a strip with the number m, in the first place - the strip with the number $(m+1)$, etc.

Now we can write $L(n_2 - n_1) = m\lambda$ down where

$$n_1 = n_2 - \frac{m\lambda}{L} = n_2 - \frac{Y}{L}. \tag{3.12}$$

If quantities are known n_2, $Y = m\lambda$, L then by formula (3.12) we define an unknown value n_1.

But it is more convenient to apply a method of compensating measurements. The method of compensation, or the zero method, will be to increase the optical path of beam II, to make the interference pattern return to its original position and again to combine the achromatic band with the thread of the tube eyepiece. Having determined how much we had to increase the optical path of ray II, we will know the value Y included in the formula (3.12).

In the Jhamena interferometer, this is achieved by using a calibrated gap difference compensator, which is implemented as follows. In light beams I and II, in addition to the measuring cuvet, two flat, parallel glass plates of the same thickness are introduced (fig. 5.64).

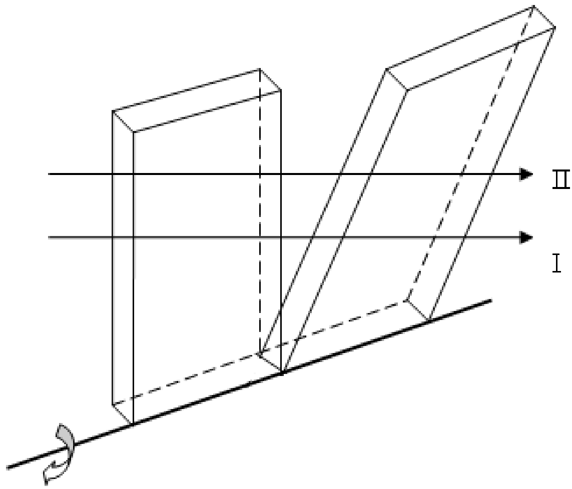


Figure 5.64

Plates are fixed on their common horizontal axis so that they form a small corner (about 10`).

The rotation of the plates around the common horizontal axis changes their effective thickness, which intersects the beams of the rays I and II, that is, they add an additional difference in the course of those light rays passing through them. This difference in stroke will change due to the rotation of the plates around the horizontal axis.

This is based on the principle of the compensator in the interferometer Jhamena. To restore the initial position of the interference pattern, the compensator must make between the rays I and II the difference between the course of the opposite sign compared to the difference in motion that was caused by the displacement of the interference pattern.

For a measuring purpose, it is necessary to connect the angle of rotation of the compensator with the difference of course, which it introduces in the light rays for each of its orientation. In this work, the number of strips m on which the interference pattern is shifted is related to the angle of rotation α of the compensator by the following relation:

$$m = C\alpha \, , \tag{3.13}$$

where m from formula (3.12).

Gas cubes inserted into the interfering rays I and II are metallic tubes closed at the ends by identical flat-parallel glass disks.

Execution of work

1 At atmospheric pressure of air in both cubes with the help of a compensator combine an achromatic band with a thread of an eye-catching eye-tube.

2 Decrease air pressure in one of the ditch step by step on a $\Delta P = 20, 18, 16, ..., 2, 0$ cm of water column, using a compensator, combine the zero band with the thread of the eyepiece. We fix the value of the angle of rotation of the compensator for each change in air pressure. We write the values in the table.

3 Determine the number of bands m for each case by the formula (3.13).

4 Determine the change of refractive index $\Delta n = n_2 - n_1$ of dilute air for each value ΔP by the formula (3.12).

5 Measurement is repeated at least 10 times.

6 For each value, find the mean value and enter all the data in table 5.4.3.1.

7 Construct a dependency graph $\Delta n_{mid.} = f(\Delta P)$.

Note!

1 Length of gas cuvette $L = 25\, \tilde{n}m$.

2 Gauge constant $\tilde{N} = \frac{1}{3} \deg rees^{-1}$.

3 Absolute refractive index of air at atmospheric pressure $n_2 = 1{,}000292$.

4 Before the slit of the interferometer, an orange filter is installed, so you need to take the length of the light wave $\lambda = 600$ $\hat{\imath}\hat{\imath}$ (1 nm = 10^{-9} m).

Table 5.4.3.1

ΔP cm water column	α_1	Δn_1	α_2	Δn_2	... α_{10}	Δn_{10}	$\Delta n_{mid.}$
20							
18							
16							
14							
12							
10							
8							
6							
4							
2							
0							

Control questions

1 Defining an interferometer?

2 Name what interferometers you know?

3 What is the structure and principle of the Jhamena interferometer?

4 What is the optical diagram of the Jhamena interferometer?

5 Where interferometers are used?

6 By what formula is the change in the refractive index of dilute air?

Laboratory work 5.4.4 Experimental verification of the Einstein equation for a photoelectric effect, determination of Planck's constant and electron output operation

Equipment: 1) monochromator Um - 2; 2) power sources; 3) electric bulb; 4) electronic bridge on the lamp 6Н1П; 5) photocell; STS - 3; 6) microampermeter; 7) voltmeter.

Theoretical information

Photoelectric effect is a phenomenon in which the corpuscular nature of light clearly manifests itself. The collision of electrons with photons results in the electrons being pulled out of a photocathode. This interaction is described by the laws of conservation of energy and momentum, which simultaneously describe other processes: absorption and radiation by atoms of light, scattering of quanta by particles. We will write these laws in the following way:

$$E_F + E = E_F` + E`, \qquad (4.1)$$

where E_f, E, $E`_f$, E'is the energy of the photon and the electron before and after the interaction.

$$\overrightarrow{Đ_F} + \vec{Đ} = \overrightarrow{Đ_F}` + \vec{Đ}`, \qquad (4.2)$$

where $\overrightarrow{P_F}$, $\overrightarrow{P}$, $\overrightarrow{P`_F}$, $\vec{P}`$, - are the corresponding impulses.

The process of the photoelectric effect on free electrons in a crystal is characterized by the fact that the photons are completely absorbed by the electrons in the process, and therefore

$$Å_F` = 0, \text{ then } \overrightarrow{P`_F} = 0. \qquad (4.3)$$

Then

$$E_F + E = E` \qquad (4.4)$$

$$\overrightarrow{Đ_F} + \vec{Đ} = \vec{Đ}` \qquad (4.5)$$

But when we assume that the electrons in the conduction band of the metal move at low speeds, then $\overrightarrow{Đ_F} = \vec{Đ}`$ ($\overrightarrow{P} = 0$).

But the electron, taking off from the crystal, receives only part of this pulse, and the main part takes away the entire crystal. Therefore, for the calculation of the electron energy, the law of conservation of momentum can not be taken into account.

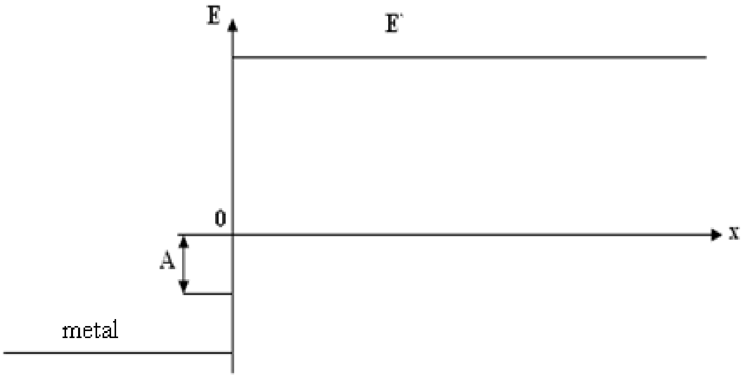


Figure 5.65

In addition, it must be taken into account that the electron in the conduction band of the metal is not completely free. To extract it from the metal it is necessary for him to provide energy equal to the amount of work out of the metal. In other words, for an electron $\mathring{A} = -\grave{A}$.

So,

$$h\nu - A = \frac{m\upsilon^2}{2} \tag{4.6}$$

Even with monochromatic illumination, the energy of electrons flowing from the photocathode is different. The electrons in the conduction band have different energies, being at different energy levels of the conduction band.

At work $\grave{A}$, the energy that needs to be expended in order to rip out an electron from deeper energy levels needs to spend more energy, and therefore their kinetic energy will be less after the departure of the crystal. In addition, the electrons may lose some of their energy along the path to the photocathode's surface. Hence, the relation (4.6) determines the kinetic energy of not all, but only the fastest electrons.

We will also define such a feature of the process. If we have a completely free electron (in a vacuum), then the photoelectric effect is not possible in this case. In this case, the conservation laws have the form (the electron will be considered as immovable):

$$h\nu + mc^2 = \frac{mc^2}{\sqrt{1 - \frac{\upsilon^2}{c^2}}} \qquad (4.7)$$

$$\frac{h\nu}{c} = \frac{m\upsilon^2}{\sqrt{1 - \frac{\upsilon^2}{c^2}}} \qquad (4.8)$$

Solving this system shows that it is incompatible. And this means that absorption by a completely free electron of the entire photon is impossible.

To test the relation (4.6), the Einstein equation is often used by the delaying potential. To do this near the photocathode place the second electrode - anode. This electrode imposes a negative potential relative to the cathode U. As we have said above, the electrons that have escaped from the cathode have different kinetic energies.

Those electrons whose energy satisfies $\frac{m\upsilon^2}{2} = eU$, where e - the electron charge, can not reach the anode. Therefore, when the U anode current increases at constant intensity and the frequency of incident light will decrease if the delayed potential increases U. For some value $U = U_l$ (the locking potential), even the fastest electrons do not reach the anode, and therefore the anode current is stopped.

Therefore, the maximum kinetic energy of photoelectrons $E_{\max} = \frac{m\upsilon_{\max}^2}{2}$ is related to the locking potential of the relation:

$$E_{\max} = \frac{m\upsilon_{\max}^2}{2} = eU_z \qquad (4.9)$$

In the experiment, as a rule, the dependence of the electron anode current in the cell element on the value is studied U .

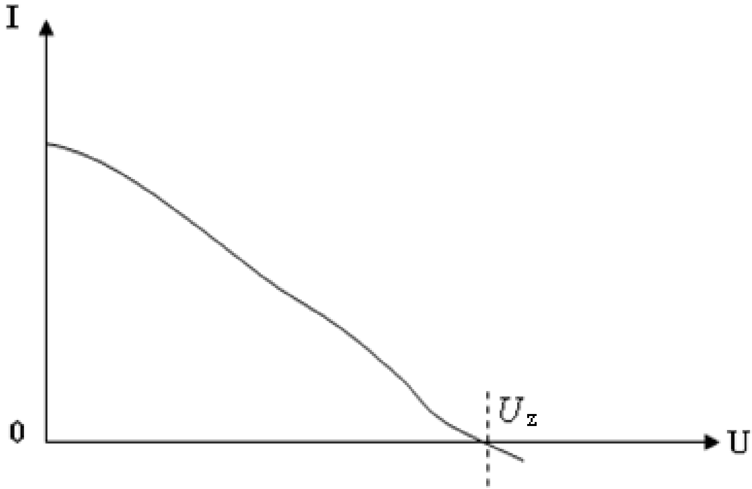


Figure 5.66

As follows from the above, the form of dependence $^2 = {}^2(U)$ is determined by the material and the thickness of the photo layer, from the shape of the electrodes and the lighting conditions. Interesting is not the curve itself, but only the point of intersection of the curve with the axis of stress ($^2 = 0$), which determines the locking potential U_z (fig. 5.66).

If the relation (4.9) is substituted in equation (4.6), then we obtain:

$$h\nu = eU_l + A, \qquad (4.10)$$

Or

$$U_l = \frac{h}{e}\nu - \frac{A}{e} \qquad (4.11)$$

Verifying experimentally the Einstein equation must be convinced that U_l it depends only on the frequency of light ν, and this dependence is linear (fig. 5.67).

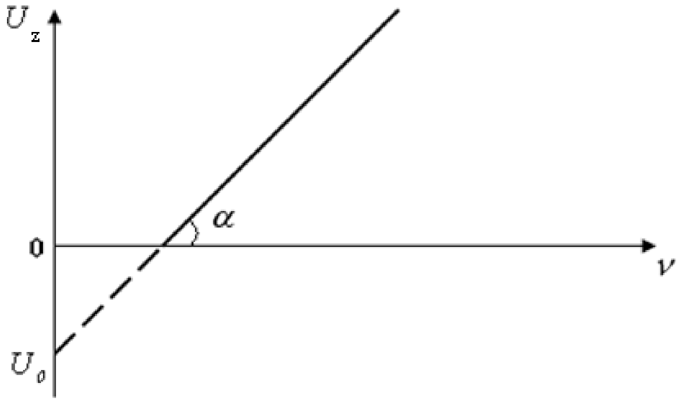


Figure 5.67

Then determining the tangent of the angle of inclination α of the straight line $U_l(\nu)$ to the frequency axis, determine the constant Planck:

$$tg\alpha = \frac{dU_l}{d\nu} = \frac{h}{e}. \text{ Means } h = e \cdot tg\alpha \qquad (4.12)$$

Description of the laboratory installation

Scheme of the experimental installation is shown in fig. 5.68.

To increase the sensitivity of the measuring system and the accuracy of the measurements, the so-called electronic bridge of resistance is used. The shoulders of the bridge in this case are the supports R_1, R_2 and those internal supports of the lamp (triple triode 6H1P). Electronic bulbs are capable of changing their internal resistance, depending on the potential of the control grid.

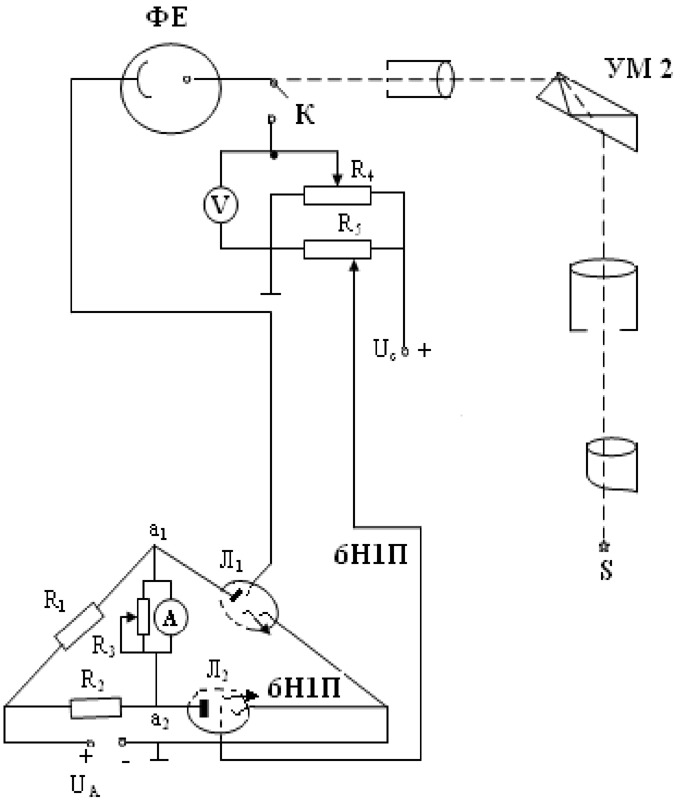


Figure 5.68

Small changes in the potential of the control grid greatly change the internal resistance of the lamp, then such a circuit has a high sensitivity. In our case, the change in the potential of the grid in one half of the dual 6H1P triode is carried out with the help of a photocell. The equilibrium of the bridge is fixed by a micrometer $\mu \grave{A}$. To determine the stable Planck, use is made of an anion-cesium photocell STS-3. Support R_1 and R_2 order of 1000 Ω.

The electronic bridge scheme works like this. When the photocell is dimmed, its internal resistance is very large. But because the photocell is included in the circle of the control grid of the triode L_1, then when the photocell is darkened, the electrons flying from the cathode to the anode will accumulate on the grid of this triode. These electrons will charge the grid to some negative potential. Through the circle: triode L_1 and resistance R_1, a weak current flows. On the grid of the triode L_2 at this time, the electrons will not accumulate, because this grid through the resistance R_5 is connected to the battery of the grid U_e. Therefore, the current flowing through R_2 and the lamp L_2 will not be equal to the current flowing through R_1 and the lamp L_2. Then the points a_1 and a_2 will be at different potentials ($R_1 = R_2$), so some current flows through the microampermeter.

By controlling the potentiometer R_5 that is plugged into a grid power supply, we install on the control grid of the triode such a potential, in which through the triode L_2 flows the same current, as well as through L_1 the darkened cell. The bridge is balanced, the current through the microamper meter does not flow when the voltage of the galvanometer U_0`.

Direction to the photocell light frequency ν from the monochromator. Photons tear out electrons from the cathode of the photocell, circulating current and the potential of the grid L_1 will increase. The equilibrium of the bridge will be broken. From balancing the bridge, applying to the photocell with a potentiometer R_4 delaying the difference in potentials, at which the photocell will shut down and the net of the lamp L_1 will set the previous potential. The bridge again comes to equilibrium: voltmeter U_1 displays (the lagging potential difference is measured by the difference in voltmeter displays $U = U_1 - U_0$`).

As noted, the measurement is reduced to determining the dependence of the locking potential on the frequency of light falling on the photocell. But the exact measurement of this potential causes a number of difficulties. As the experiments show, $I(U)$ it approaches the abscissa axis at a small angle, in some cases it enters the negative region I, as shown in fig. 5.69.

The value of locking capacity under these conditions is somewhat undetected. This course of the curve, in addition to the above-mentioned reasons, is associated with the presence of a reverse photoelectric effect (photoelectric effect from the anode), as well as with ion currents in the cell. In this case, not the curve itself, but the tangent to the curve taken on a straight line plot $I = I(U)$ (fig. 5.69), is used to determine the locking potential.

The accuracy of the experiment as a result is low and is 10-15%.

Monochromator UM-2 (fig. 5.70) is fixed on a bench *P*, where light source and condenser are also located, which are fixed on tripods. The lenses of the collimator, the system of dispersing prisms, as well as the lens of the optic tube are contained inside the device housing. Inlet slit is regulated by the width of the micrometer screw.

The lens of the collimator must be set so that the slit is in the focus of the lens. On the side of the instrument case there is a scale 4 with a nonius indicating the position of the lens of the collimator. The scale is illuminated by a light bulb.

In the focal plane of the lens of the visual tube there is an outlet slit. To establish the position of the spectral line in the plane of the output slit, there is an index in the form of a triangle. The index is observed through an eyepiece. The output of the spectral line to the index is made by turning the dispersing prisms through the drum. The index is lit by a light bulb.

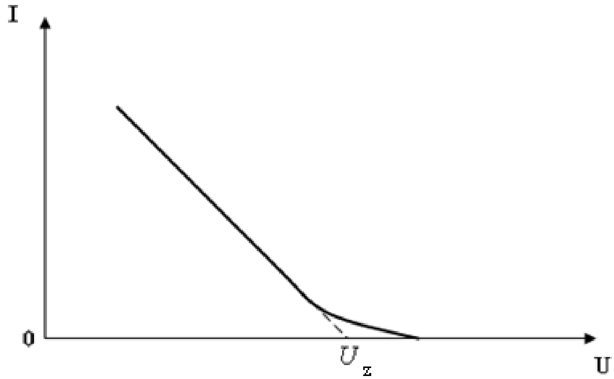


Figure 5.69

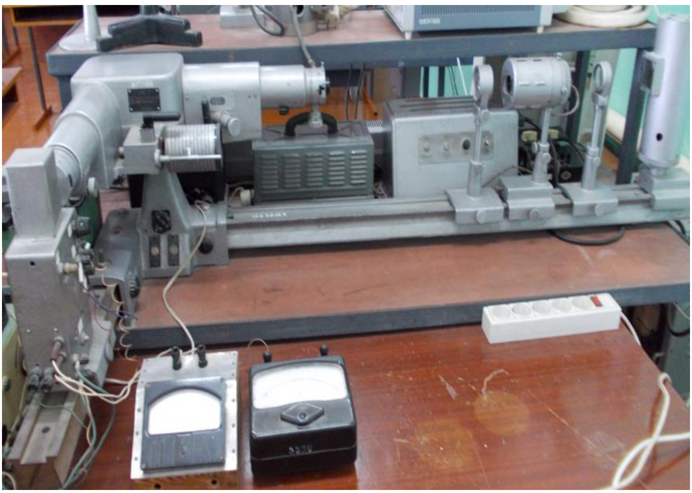


Figure 5.70 General view of the installation

Directly above the light bulb is a disk with a set of filters. Turning the disc can illuminate the index with yellow, red or green light. The oculus of rotation can be set for the eye of the observer on a clear image of the index and spectral lines.

The counting device of the device is a drum that is connected to the system of dispersing prisms. When turning a drum into a single division 2^0, the prism system returns to 20``. Monochromator UM-2 is a symmetric system: the focal distance of its collimator lens is equal to the focal length of the lens of the optic tube F = 280 *mm*.

Execution of work

1 Fill the scheme and balance the bridge. The bridge's equilibrium starts when the minimum resistance R_3 shunting the microamper meter to prevent it from being damaged. Then we increase R_3 and balance the bridge with greater sensitivity of the microamper meter (up to maximum sensitivity).

2 Turn on the light source S and select the frequency of the monochromator, using the calibration graph, in the yellow-green area of the spectrum, warm the monochromator and the bridge scheme.

3 Turn on the key K and illuminate the photocell with a beam of light ν_1 from the monochromator. By changing the voltage on the grid with a potentiometer R_4, we change the dependence $I = f(U) = f(U_1 - U_0`)$, putting the results obtained into the table.

4 Based on these results, we construct a curve $I = f(U_1 - U_0`)$ by which we determine U_l the frequency ν_1.

5 Turning the drum of the monochromator, we pass to another (higher) frequency and carry out the same measurements, determine the delay potential for higher frequencies $\nu_2, \nu_3, \nu_4, \nu_5$.

6 Based on the defined values U_l and ν build a dependency graph $U_l = \varphi(\nu)$. Recall that in the degree table of the monochromator is given not the frequency ν, but the wavelength λ. Frequency is calculated by the formula:

$$\nu = \frac{2\pi \tilde{n}}{\alpha} \qquad (4.13)$$

7 From the schedule $U_l = \varphi(\nu)$ we determine $tg\alpha = \frac{U_{l2} - U_{l1}}{\nu_2 - \nu_1}$ and count

$$h = e \cdot tg\alpha = e\frac{U_{l2} - U_{l1}}{\nu_2 - \nu_1} \ (J \cdot s) \qquad (4.14)$$

8 We check the independence of the locking potential from the intensity of light falling on the photocathode, determining U_l when the different width of the input gap of the monochromator.

Control questions

1 What is the phenomenon of photoelectric effect?

2 How is the electron output from the metal determined?

3 Can I explain the phenomenon of photoelectric effect on the basis of classical electrodynamics?

4 Why is there a saturation current in vacuum photocells? Is the saturation current in gas-filled photocells possible?

5 Explain how the electronic resistance bridge works.

6 How to determine the output of the output $\grave{A}$, if the known delay is the potential difference for different frequencies?

Laboratory work 5.4.5 Measurement of curvature of surfaces by an interference method

Purpose: to study the features of light interference under the scheme of Newton; to experiment experimentally with the image of Newton's rings, to investigate their quantitative characteristics and the wavelength of light.

Equipment: microscope, illuminator, red and green light filters, glass plate, flat-convex lens.

Theoretical information

One of the methods for obtaining coherent light beams is to split one wave into several at refraction and refraction on the surfaces of a partition of two media. This method is called the ***amplitude division method***. Interference received by this method is called ***Newton's interference***.

Falling on a thin transparent plate or film, the light wave from the distant source is partially reflected from its upper surface, and partly passes inside and is reflected from the lower surface (fig. 5.71).

As a result, in the direction of the reflected rays 1 and 2, two coherent waves propagate.

The optical difference between the rays 1 and 2 is

$$\Delta D = n(AB + BC) - (AD + \frac{\lambda}{2}) \qquad (5.1)$$

An additional path difference occurs $\frac{\lambda}{2}$ due to the change in the phase of the oscillations of the light vector on the reflection of the beam 1 from the upper surface of the plate at point *A*, that is, from an optically thicker medium. At point *B*, where light is reflected from an optically less dense medium (air), there is no additional phase difference. From fig. 5.71 it is clear that

$$AB = BC = \frac{d}{\cos r}, \quad AD = AC\sin i = 2d\ tgr \sin i, \qquad (5.2)$$

where i and r, is the angle of incidence and refraction. So, that's why $\sin i = n \sin r$ then

$$\Delta D = 2n\frac{d}{\cos r} - 2dn\ tgr \sin i \quad \frac{\lambda}{2} = \frac{2dn}{\cos r}(1 - \sin^2 r) - \frac{\lambda}{2} = 2dn\cos r - \frac{\lambda}{2}, \qquad (5.3)$$

or

$$\Delta D = 2d\sqrt{n^2 - \sin^2 i} - \frac{\lambda}{2}. \qquad (5.4)$$

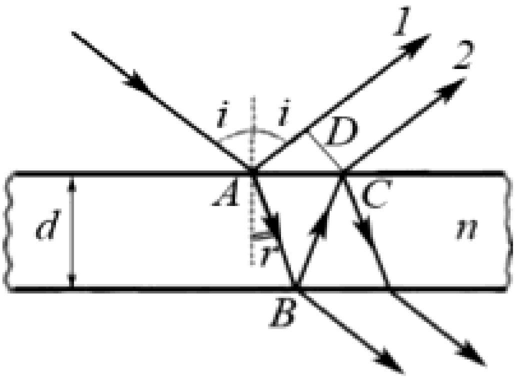


Figure 5.71 Determination of the path difference during reflection in thin films

The condition for the maximum of intensity is reflected in the formula:

$$2d\sqrt{n^2 - \sin^2 i} - \frac{\lambda}{2} = k\lambda, \qquad (5.5)$$

where $k = 1,2,...$. To have a minimum of intensity we have

$$2d\sqrt{n^2 - \sin^2 i} - \frac{\lambda}{2} = (2k+1)\frac{\lambda}{2}, \qquad (5.6)$$

Optical difference in the course of rays 3 and 4, which passed through the plate,

$$\Delta D` = 2dn\cos r, \qquad (5.7)$$

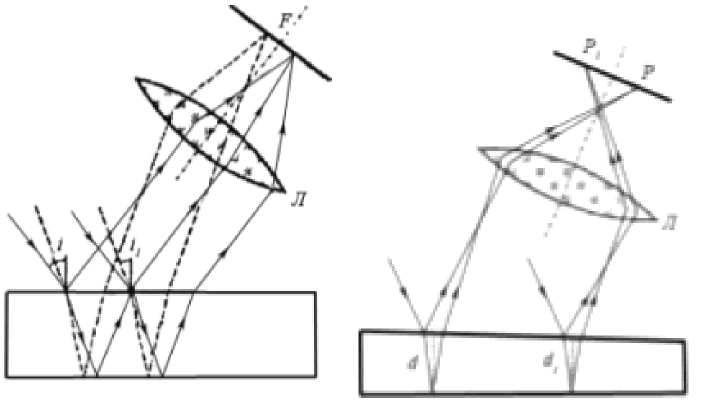
smaller ΔD than reflected light on $\frac{\lambda}{2}$. Therefore, the maxima of light that passed through the plate correspond to the minima in the reflected light.

It follows from formula (5.4) that the difference in the course of rays in a plane parallel plate depends on the angle

i of incidence of these rays on the outer surface of the plate. That is, to each value is i the other difference of course.

Rays with the same inclination, reflected from the upper and lower surfaces of the plate, propagate in parallel, and therefore the interference bands are localized on infinity. For their observation it is necessary to collect rays with the help of a lens (fig. 5.72, *a*). On the screen located in the focal plane of the lens *A*, we observe interference bands with a common center at point *F* on the main optical axis of the lens. They are called ***strips of the same inclination***.

If a thin transparent plate with variable thickness is illuminated by a parallel beam, then we observe an interference pattern, each band of which is formed by the reflection of the rays in the places of the plate with the same thickness (fig. 5.72, *b*).



a) *b)*

Figure 5.72 a) interference in a flat parallel plate; b) interference in a wedge-shaped plate

To monitor strips of the same thickness, it is convenient to use a cleaning lens. It gives an image of the top surface of the plate, since strips of the same thickness are placed exactly there. If the angle between the surfaces of the plate is small, then the difference in the velocity of the rays with high accuracy can be determined by the formula (5.4) for each value of thickness d_i at the point of falling of this beam on the surface.

In the case of thick plates with non-constant thickness, interference bands can be observed only in monochromatic light. The deviation from the parallelism of the surfaces of the plate should be relatively small, because otherwise the strips of the same thickness will be located close. In thin plates interference can be observed in white light, then there are colored stripes.

Streams of the same thickness can be observed when a flat-convex lens with a large radius of curvature touches a flat glass surface. Between the lens and the plate an air layer, whose width rises from the point of contact to the edges, is formed (fig. 5.72). If a luminaire normally falls on a monochromatic light beam, then the light waves reflected from the upper and lower boundaries of the layer interfere, forming strips of the same thickness. Plots of the same thickness are concentric circles with center at the point of contact of the lens and plate, then the strips of the same thickness are concentric rings, called ***the ring of Newton***.

Consider the reason for the appearance of the rings of Newton (fig. 5.73). Under observation, in reflected light, the rays at the point *C* interfere with the difference in the velocity of the rays 1 reflected at the boundary of the upper surface of the air layer and with the beam 2 reflected from the lower surface of the stratum at the point *B*. Let d - the thickness of the air layer for the point *C*.

Then the difference ΔD between the rays 1 and 2 is calculated by the formula:

$$\Delta D = 2nd + \frac{\lambda}{2}, \tag{5.8}$$

where *n* is the refractive index of the medium between the lens and the plane parallel plate (n = 1). From fig.4.75 it is clear that

$$r^2 = R^2 - (R-d)^2 = 2Rd - d^2, \qquad (5.9)$$

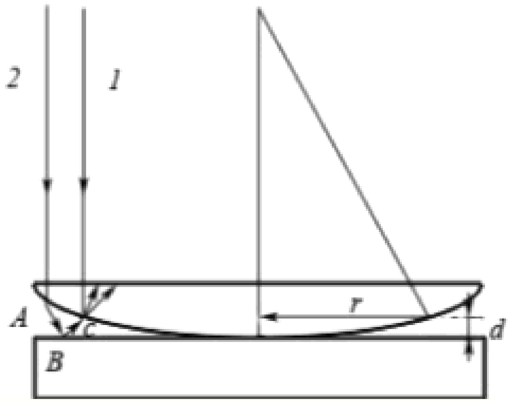


Figure 5.73 Newton rings creation

where r is the radius of the interference ring, R -the radius of curvature of the lens.

If $R >> d$ you have one

$$r^2 = 2Rd\,. \qquad (5.10)$$

The terms of the maximum (light rings) and minima (dark rings) are:

$$\Delta D = 2dn + \frac{\lambda}{2} = k\lambda, \qquad (5.11)$$

$$\Delta D = 2dn + \frac{\lambda}{2} = (2k+1)\frac{\lambda}{2}, \qquad (5.12)$$

where k is an integer. Using the formula (5.9), we find that the radius of a light ring is calculated by the formula:

$$r = \sqrt{(2k-1)R\frac{\lambda}{2}}, \qquad (5.13)$$

And the radius of the dark ring is calculated by the formula:

$$r = \sqrt{kR\lambda}\ . \qquad (5.14)$$

From formulas (5.13) and (5.14) one can determine either R, λ. Due to the elastic deformation of the glass it is difficult to achieve the perfect contact of the spherical lens and the plane plate at the point of contact. The more precise result we obtain, if we calculate the radius of curvature of the lens or the wavelength by the difference between the radii of the two rings.

Consequently, the final formula has the form

$$\lambda = \frac{(r_k - r_n)(r_k + r_n)}{(k - n)R}, \qquad (5.15)$$

where k and n - numbers of rings ($k >> n$).

Description of the laboratory installation

The bulk of the instrument for studying Newton's rings is a microscope (fig. 5.74), On whose subject table there is a lens-plate system, through which we receive Newton's rings. The microscope microscope has a diopter-driven mechanism. The focal plane of the eyepiece has a scale that can be used instead of a mesh.

Scale and grid - these are flat-parallel round glass plates. One of them is a scale with a price of 0,01 *mm*, and on the other - a grid with the price of the side of the square of 1,0 *mm*.

For approximate estimation of linear sizes or areas of objects in one of the eyepiece tubes of the device, it is necessary to insert an eyepiece 8^x with a scale. The mechanism of the dioptric eyepiece must achieve a clear image of the scale or grid. Then the turning of the flywheels of the focusing mechanism achieves a clear image of the subject.

Table 5.1 for translation specifies the size of the object corresponding to one section of the scale or grid for all magnifications of the microscope. To determine the approximate dimensions of an object (its linear dimensions or area), it is enough to calculate the number of divisions of the scale, which are enclosed in the measuring section of the object, and multiply it by the number indicated in the table given in table 5.4.5.1 to increase the microscope during which the measurements are made.

Table 5.4.5.1

Converting a scale or grid to the size of an object for different magnifications of a microscope

Rounded magnification values applied to the flywheel of the drum	One price of the scale divisions is 0.1 *mm*	Side of the square is 1 *mm*
	Correspondence to the size of the subject	
0,6	0,17	1,7
1	0,1	1
2	0,05	0,5
4	0,025	0,25
7	0,014	0,14

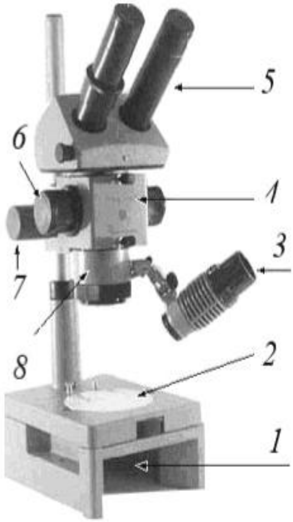


Figure 5.74 Microscope structure: 1 - table and mirror for working in direct light; 2 - a table for work in reflected light; 3 - illuminator; 4 - case with drum; 5 - eyepiece; 6 - switch

magnitude; 7 - the flywheel of the focusing mechanism; 8 – lens

Execution of work

1 We install a lens with a light filter and a plate in the frame on the microscope slide.

2 Toggle the magnification of the lens of the microscope by 0.6^x and shifting the lens with the plate, turning the microscope until an interference pattern of Newton's rings appears in its eyepiece.

3 Gradually changing the magnification of the microscope in the direction of growth move the microscope to fill the entire field of the eyepiece with interference rings.

4 Measure the radii of Newton's rings using a scale or mesh eye for multiplicity of 8^x.

5 Calculate the radius of curvature of the lens by the formula

$$R = \frac{(r_k - r_n)(r_k + r_n)}{(k - n)\lambda} \qquad (5.16)$$

6 We install another light filter and determine the radii of Newton's rings by the formula (5.15) we find the effective length of the light wavelength of the passage of the filter.

7 Submit the results in table 5.4.5.2. and table 5.4.5.3.

8 Calculate the absolute and relative errors for the radius of curvature of the lens and the wavelength.

9 We draw a conclusion and write the final result in the following way:

$$R = (R_{av} \pm \Delta R), m \text{ at } E,\%$$

$$\lambda = (\lambda_{av} \pm \Delta\lambda), m \text{ at } E,\%.$$

Table 5.4.5.2

Results of determining the radius of curvature of a lens by Newton's rings

№	λ,	k	r_k	r_n	n	R	ΔR	$E,\%$

	nm							
1.								
2.								
Average value								

Table 5.4.5.3

Results of the determination of the light wavelength along Newton's rings

№ п/п	λ, nm	k	r_k	r_n	n	λ	$\Delta\lambda$	$E,\%$
1.								
2.								
Average value								

Control questions

1 Describe Newtonian Rings.

2 What is the physical nature of Newton's rings?

3 Why are the radii of light and dark rings equal?

4 How do we experimentally determine the wavelength of light using a device for receiving Newton's rings?

5 Output the working formula used in this work.

Chapter 6
SPECIAL APPLICATIONS OF LIGHT

6.1 Diffraction

The laser is one of the most spectacular inventions of the past 50 years. Perhaps you have seen the pencil-thin beams cross the sky in a laser light show. Or you might have noticed the spiderweb-like pattern of laser beams in an automated supermarket checkout cash register. Lasers are another optical tool that will be important in the years to come.

Light is a transverse electromagnetic wave. Reflection, refraction, diffraction, and interference are phenomena observed with all waves.

Experiment 6.1 Diffraction from the hole One of the most interesting, and also very useful, properties of waves is diffraction. When a wave strikes a barrier with a hole only part of the wave can move through the hole, fig. 6.1,b.

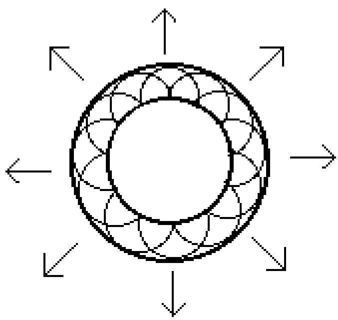


Figure 6.1,a

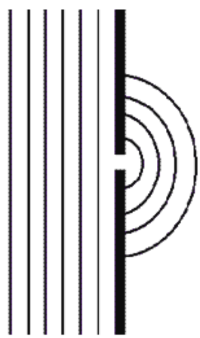


Figure 6.1,b

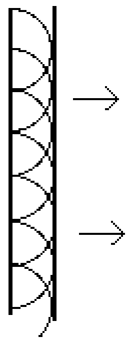


Figure 6.1,c

If the hole is similar in size to the wavelength of the wave diffractions occurs. The waves that comes through the hole no longer looks like a straight wave front. It bends around the edges of the hole. If the hole is small enough it acts like a point source of circular waves. This bending around the edges of the hole is called ***diffraction***. To illustrate this behavior we start by with Huygen's principle, fig. 6.1,c.

Fig. 6.2 shows the shape of the wave front on the surface of the water from the plane exciter, from the wide gap and from the narrow slit.

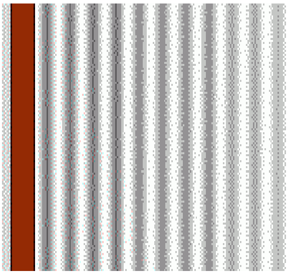
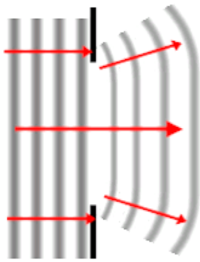
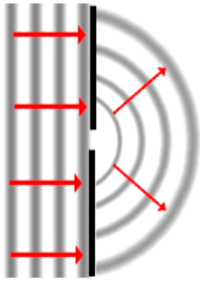




Figure 6.2a *Figure 6.2b* *Figure 6.2c*

Image of plane waves [69].

Experiment 6.2 Water waves in a ripple tank

Diffraction diffraction in a circular ripple tank. Observation of the front of the wave from different openings on the water surface fig. 6.3, fig.6.4.

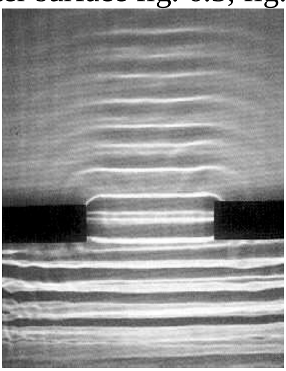


Figure 6.3 A single large slit [70]

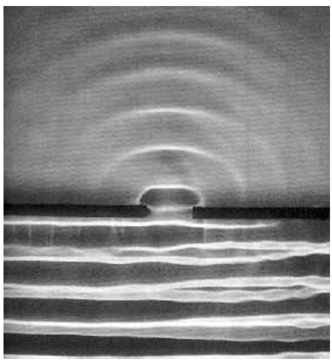


Figure 6.4 A single small slit

Huygen's principle states that each point on a wave front acts like a point source or circular waves. The waves emitted from each point interfere to form another wave front on which each point forms a point source. A long straight line of points emitting waves of the same frequency leads to a straight wave front moving away.

Christian Huygens, a contemporary of Newton's, thought light was a wave and proposed a theory or principle that is still useful in understanding the propagation of waves.

When light passes through a small opening, comparable in size to the wavelength l of the light, in an otherwise opaque obstacle, the wavefront on the other side of the opening resembles the wavefront shown below.

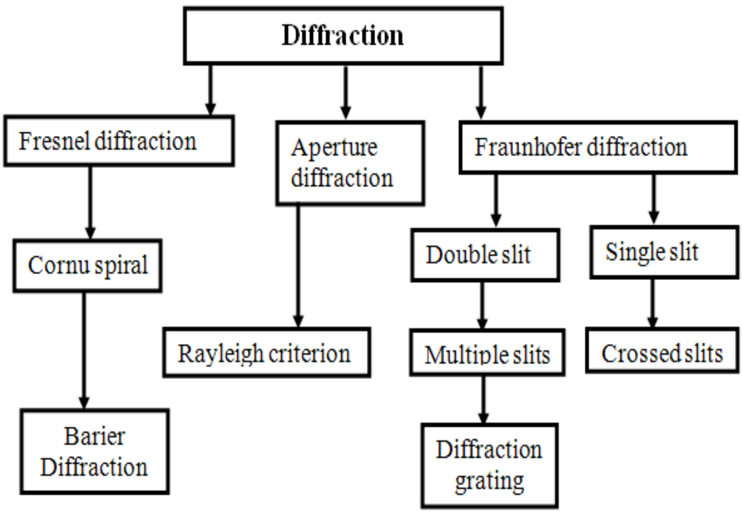


Figure 6.5 Structure diffraction

The light spreads around the edges of the obstacle. This is the phenomenon of ***diffraction***. Diffraction is a wave phenomenon and is also observed with water waves in a ripple tank [41].

Different types of diffraction are shown on the fig. 6.5.

Diffraction occurs either when waves pass through an opening or around an object that blocks their path. The effects of diffraction are visible mainly when the size of the opening or the blocking object is close to the wavelength of the wave.

When water waves strike a narrow opening, diffraction occurs fig. 6.6. reinforce to produce light and dark areas (a). [71].

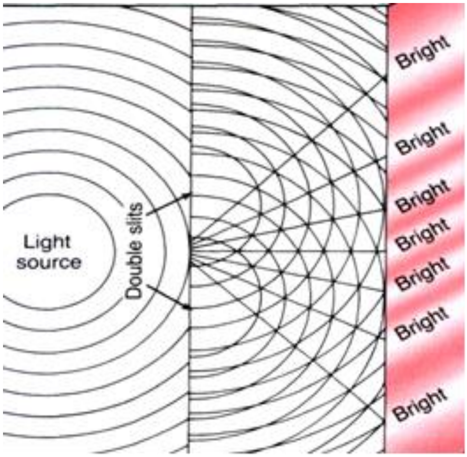


Figure 6.6 After passing through the double slits, the light waves

Wave interference can be demonstrated with water waves (b) of large amplitude and regions of small amplitude. In 1801 Thomas Young, an English scientist, showed that light can show interference effects. He first passed light through a narrow slit. That light was then passed through a pair of closely-spaced slits. The two slits acted like two separate sources of light of the same wavelength. The light from these slits fell on a screen. Look at fig. 6.6. Young observed a series of dark bands where a crest from one wave crossed a trough from the other, and light bands where two crests or two troughs added together.

His observations of the interference patterns showed clearly that light had the characteristics of a wave [40].

6.2 Experimental study of diffraction of light

We have developed a series of experiments on the diffraction of light. The general scheme of their staging is shown in fig. 6.7. It consists of a light source, a condenser, an aperture, a subject body and a screen.

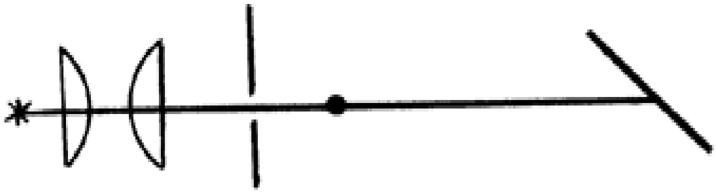


Figure 6.7

Experiment 6.3 Diffraction from point apertures

Equipment: laser, plate with an aperture, screen.

For operative setup of the demonstration we define a sighting circle in the center of which there is an invisible diffraction aperture, fig. 6.8

Adjust the revolving head to a spherical lens. Place a plate with an aperture on the path of the laser beam, fig. 6.8. On the screen we observe an interference pattern, in the center of which we observe a dark spot.

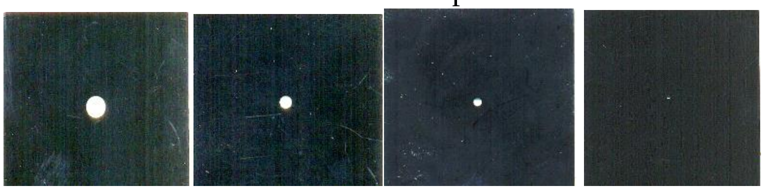


Figure 6.8 Plates with apertures

We turn to the observation of the diffraction pattern from round apertures of various sizes. In a light beam, we place plates sequentially with apertures, the diameter of which increases, fig. 6.9.

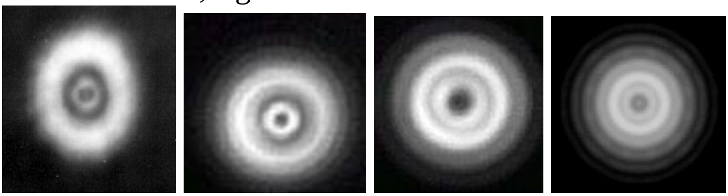


Figure 6.9 Diffraction of the apertures

Experiment 6.4 Investigation pass light through a circular hole

The behavior of the light rays falling on the hole determines the relationship between the length of the light waves and the diameter of the aperture. The diffraction occurs when the size of the obstacle in the wave path is comparable to its length or less. The origin of diffraction is determined by the ratio between the diameter of the obstacle - *d*, the distance between the obstacle and the diffraction point of observation - *L*, the wavelength:

$p = \dfrac{d^2}{L\lambda}$: $p << 1$- Fraunhofer diffraction; $p \approx 1$ - Fresnel diffraction; $p>>1$ there is no diffraction on the other side. Fig. 6.6 shows a case where $p>>1$, and when $p<<1$, fig. 6.7. The number *p* is the diffraction criterion.

Physical analysis of the phenomenon consists in the fact that the hole is conventionally replaced by fictitious sources of light, which excite secondary spherical waves. They spread toward the observer. Depending on the distance *L* wave, the screen comes in a different phase. Accordingly, they either intensify or weaken. Such a system has axial symmetry. The falling cylindrical beam of light becomes conical. On the screen there is an asemic diffraction pattern. Alternating bright and dark rings are called maxima and minima of illumination.

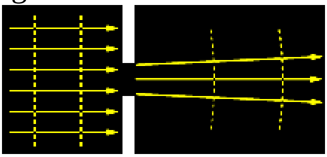


Figure 6.10 Large Aperture

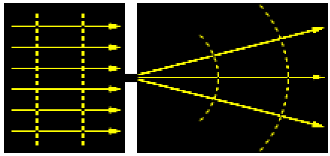


Figure 6.11 Small Aperture

Experiment 6.5 Diffraction from point beads glued on a glass plate

Equipment: laser, plates with an beads (diameter 1-2 *mm*) glued on a glass plate (one, two and three), screen, fig. 6.8, fig.6.9, fig. 6.10.

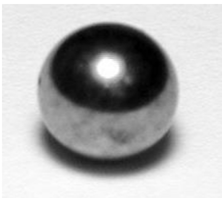


Figure 6.12

Figure 6.13

Figure 6.14

For operative setup of the demonstration we define a sighting circle in the center of which there is an invisible diffraction beads, fig. 6.7.

Adjust the revolving head to a spherical lens. Place a plate with an aperture on the path of the laser beam. On the screen we observe an interference pattern, in the center of which we observe one a dark spot.

We turn to the observation of the diffraction pattern from round beads. In a light beam, we place plates sequentially successively with one, two and three beads the identical diameter, fig. 6.12, 6.13, 6.14.

Figures 6.15, 6.16, 6.17 depict diffraction patterns from one, two, three small balls.

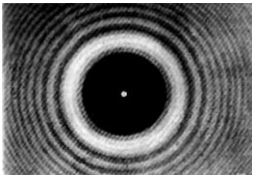
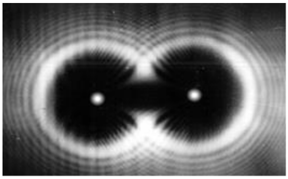
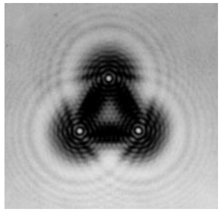




Figure 6.15 *Figure 6.16* *Figure 6.17*

So, we see that in all distances from the screen to the diffraction element in the center of the diffraction pattern, in all cases, we observe a dark spot (Poisson-Arago's spot). When the distance from the screen to the diffraction element increases, the intensity of the dark spot in the middle of the diffraction pattern increases

We project interference pattern onto the screen. If necessary, with the help of a mirror, it can be projected on the ceiling of the classroom or on the side wall.

Experiment 6.6 Diffraction from a thin droplet water

Equipment: laser, eyepiece 15 x, sliding slit, pipette with diameter 2-0,5 *mm*, matte screen, desktop screen, rotary mirror, lens 1.

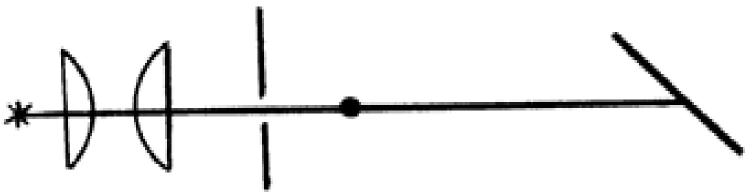


Figure 6.18

Install the assembly in accordance with fig. 6.18. The laser will expand the laser beam. Attach the vertical pipette to the tripod. The crane will adjust the slow growth of the drop volume in the pipette. Put a drop in the laser beam at a distance of 20 *cm* from the eyepiece. Around the drop we observe a system of diffraction bands, fig. 6.19, 6.20.

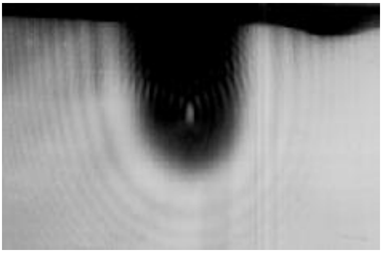
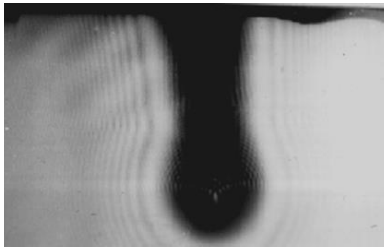
 

Figure 6.19 *Figure 6.20*

Diffraction from a thin droplet

Experiment 6.7 Diffraction from a thin dart

Equipment: UPD, sliding slit, frame with a stretched wire with diameter 0,2-0,3 *mm*, matte screen, desktop screen, rotary mirror, lens 1.

Figure 6.21

The UPD burning lamp will set the plane of the spiral along the main optic axis of the condenser. Directly behind the condenser, fig. 6.21, in the screen, we attach a sliding slit, the blades of which are adjusted to the maximum width.

Turning on the UPD and on the screen, which is at 60-80 *cm*, we see the light of the spot. On the latter, there should not be any dark dark stripes. At the distance of 20 *cm* from the slit in the screen, we place a frame with a stretched dart with a diameter of 0.05-0.1 *mm*, fig. 6.22. We achieve the parallels of the slab and the wires by turning the rails on the rods. the screen is 60 *cm* away from the condenser. On it we see a light band with clear edges. Only under these two conditions, we change the width of the gap to the appearance in the center of the light strip fig. 6.23, fig. 6.24.

First we see a system of narrow light and dark bands, which then merge into one light spot. Extend the picture by turning the screen at a certain angle to the optical axis of the condenser. The matte screen allows you to watch a better image of diffraction. You can also use a rotary mirror.

The clarity of the lines of diffraction depends on the width of the slit UPD, but at the same time the brightness of the picture decreases. So we seek optimal correlations in the installation. For comparison of diffraction patterns, we take a larger diameter wire (0.2-0.3 *mm*). Under these conditions light can not get into the center of the geometric shadow, if it is distributed in a strictly straightforward manner.

Figure 6.22

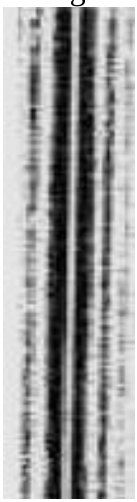


Figure 6.23

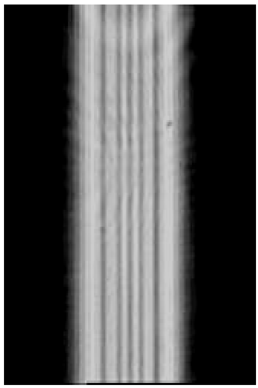


Figure 6.24

This diameter of the wire is preferable, since it initially causes the appearance of two sharp dark bands in the region of the geometric shadow that limit the central maximum, fig. 6.24, against which it is noticeable. The appearance of dark and light bands in the region of the geometric shadow is explained by the interference of the waves, which bend the wire from one side and the other. The distance between the middle of adjacent dark bands in the geometric shadow region is calculated using the formula $x=\lambda L/d$, where λ the effective wavelength is 550 *nm*, *L* is the distance from the wire to the screen, *d* is the diameter of the wire.

Experiment 6.8 The diffraction of light from the slit

Equipment: UPD, two sliding slots, a matte screen, a desktop screen, slit.

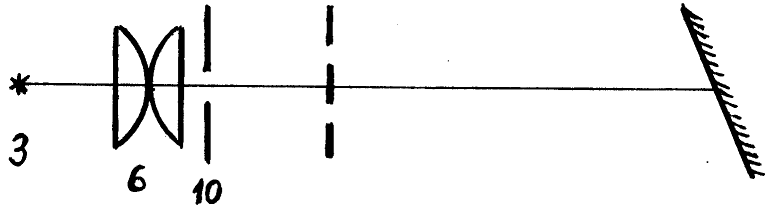


Figure 6.25

The UPD's optical lava is located along the demonstration table. The plane of the spiral of the projection lamp is oriented along the main optic axis of the condenser. First, sliding slit 10 with the greatest possible width of the gap is fixed directly behind the condenser, fig. 6.25.

In an previous experiment, replace the warp thread with a thin slit, drawing fig. 6.24. The method of his statement is similar to the previous one. At the distance of 20 *cm* from the slit in the screen, we place a frame with a stretched dart with a diameter of 0.05-0.1 *mm* on slit.

Turn on UPD. The screen should have a light strip with no extraneous eclipses. At a distance of 30 *cm* from the first slit, put a the second. Turning the disk of the screen, we reach the parallels of the slits. On the screen (at a distance of 60 *cm* from the second slit) we see a light band with clearly defined edges. Under this condition, we reduce the width of the second slit until a system of narrow dark and light bands appears on the screen. As the width of the sliding slit decreases, the narrow dark strips merge into one dark central band (two Fresnel zones are inserted in the slit).

On fig. 6.24 in the center there is a dark strip that is limited to the bright. Further, the reduction of the width of the second slit leads to a one-to-one expansion of the clear band and a decrease in its brightness. Lightening is associated with a decrease in the width of the slit, and the loss of the bright strip indicates improve diffraction.

If the illuminating beam does not illuminate the whole length of the slit, the spacing of the vertical fringes is determined by the dimensions of the illuminating beam. Close examination of the diffraction pattern below shows that there are very fine horizontal diffraction fringes above and below the main spot, as well as the more obvious horizontal fringes.

Experiment 6.9 Checking for diffraction conditions

Equipment: UPD, two sliding slits, a frame with a wire rod, a matte screen, a desktop portable screen.

In school practice, in the study of diffraction, it is often considered that the dimensionality of the slit width or screen with wavelength is a condition for the absence of diffraction and the implementation of the laws of geometric optics. However, the conditions for the occurrence of diffraction depend on the ratio of three values: the size of the obstacle *D*, the distance from its observation point *R* and the wavelength. λ: a) $D << \sqrt{\lambda R}$, the diffraction pattern occupies a small, narrow area in front of the obstacle or slit; b) $D = \sqrt{\lambda R}$, the differential picture occupies the entire spectrum on the screen of the slit; c) $D >> \sqrt{\lambda R}$, the diffraction pattern takes not only the surface opposite the gap, but also enters the region of the geometric shadow. To test these correlations measure distances, table 6.2.1.

Table 6.2.1

Value correlation for diffraction

R, м	0,03	0,07	0,15	0,3	0,75
$\sqrt{\lambda R}$ x 0,001	0,1	0,19	0,29	0,4	0,62

The value of the obstacle is D = 0,6x0,001 *m*, the average wavelength of the wave is 550 *nm*. Comparisons of the obtained data and the results of experiments give the opportunity to conclude: after the specified sizes of the slit, the diffraction pattern is narrowed. At 15 *cm* from the screen to the obstacle, it is small, at 7 *cm* it is almost not visible, and at 3 *cm* it disappears.

Experiment 6.9 A simple quantitative description

Multiple-slit arrangements can be mathematically considered as multiple simple wave sources, if the slits are narrow enough. For light, a slit is an opening that is infinitely extended in one dimension, and this has the effect of reducing a wave problem in 3D-space to a simpler problem in 2D-space. The simplest case is that of two narrow slits, spaced a distance *a* apart.

To determine the maxima and minima in the amplitude we must determine the path difference to the first slit and to the second one. In the Fraunhofer approximation, with the observer far away from the slits, the difference in path length to the two slits can be seen from the image to be $\Delta S = a \sin \theta$.

Diagram of a two slit diffraction problem, showing the angle to the first minimum, where a path length difference of a half wavelength causes destructive interference.

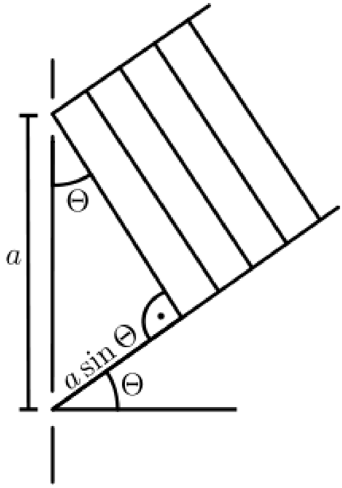


Figure 6.26

Maxima in the intensity occur if this path length difference is an integer number of wavelengths, $a \sin\theta = n\lambda$, where *n* is an integer that labels the *order* of each maximum, λ is the wavelength, *a* is the distance between the slits and θ is the angle at which constructive interference occurs.

The corresponding minima are at path differences of an integer number plus one half of the wavelength: $a \sin\theta = \lambda(n + 1/2)$.

For an array of slits, positions of the minima and maxima are not changed, the *fringes* visible on a screen however do become sharper, as can be seen in the image.

Experiment 6.10 Diffraction by a slit of infinite depth

The width of the slit is *W*. The Fraunhofer diffraction pattern is shown in the image together with a plot of the intensity vs. angle θ. The pattern has maximum intensity at $\theta=0$, and a series of peaks of decreasing intensity. Most of the diffracted light falls between the first minima. The angle, α, subtended by these two minima is given by: $\alpha \approx 2\lambda/W$.

Thus, the smaller the aperture, the larger the angle, α subtended by the diffraction bands. The size of the central band at a distance z is given by $d_f = 2\lambda_z/W$. For example, when a slit of width 0.5*mm* is illuminated by light of wavelength 0.6 *nm*, and viewed at a distance of 1000 *mm*, the width of the central band in the diffraction pattern is 2,4 *mm*.

The fringes extend to infinity in the *y* direction since the slit and illumination also extend to infinity.

If W < λ, the intensity of the diffracted light does not fall to zero, and if D << λ, the diffracted wave is cylindrical.

Experiment 6.11 Mathematical description

The mathematical representation of a radial wave is given by

$$E(r) = A\cos(kr - \omega t + \varphi)/r\,,$$

where $k = \dfrac{2\pi}{\lambda}$, λ is the wavelength, ω is frequency of the wave and φ is the phase of the wave at the slits. The wave at a screen some distance away from the plane of the slits is given by the sum of the waves emanating from each of the slits. To make this problem a little easier, we introduce the complex wave Ψ, the real part of which is equal to E

$$\psi(r) = Ae^{i(kr-\omega t+\varphi)}/r\,,$$

$$E(r) = \mathrm{Re}(\psi(r))\,.$$

Numerical approximation of diffraction pattern from a slit of width four wavelengths with an incident plane wave. The main central beam, nulls, and phase reversals are apparent.

Experiment 6.12 Study the Fraunhofer diffraction equation

When a beam of light is partly blocked by an obstacle, some of the light is scattered around the object, and light and dark bands are often seen at the edge of the shadow - this effect is known as diffraction. These effects can be modelled using the Huygens–Fresnel principle. Fresnel developed an equation using the Huygens wavelets together with the principle of superposition of waves, which models these diffraction effects quite well.

The Fraunhofer diffraction equation is a simplified version of the Kirchhoff's diffraction formula and it can be used to model the light diffracted when both the light source and the viewing plane are effectively at infinity with respect to the diffracting aperture. In this case, the incident light is a plane wave so that the phase of the light at each point in the aperture is the same. The phase of the contributions of the individual wavelets in the aperture varies linearly with position in the aperture, making the calculation of the sum of the contributions relatively straightforward in many cases.

Strictly speaking, the Fraunhofer approximation only applies when the diffracted pattern is viewed at infinity, but in practice it can be applied in the far field, and also in the focal plane of a positive lens.

Experiment 6.13 Study Fresnel diffraction

Fresnel diffraction occurs when: $F = a^2 / L\lambda \geq 1$, a - aperture or slit size, λ - wavelength, L - distance from the aperture.

When the distance between the aperture and the plane in which the pattern is observed is large enough that the difference in phase between the light from the extremes of the aperture is much less than the wavelength, then individual contributions can be treated as though they are parallel.

For example, if a 0,5 *mm* diameter circular hole is illuminated by a laser with 0,6 μm wavelength, the Fraunhofer diffraction equation can be employed if the viewing distance is greater than 100 *mm*.

Experiment 6.14 Using Lens in the diffraction study

A plane wave incident on a positive lens is focused at a point by the lens; all the rays have the same phase at the point of focus, so that this is equivalent to viewing the plane wave at infinity. Thus, if the diffracted light is focused with a lens, the observed diffraction pattern can be modelled using Fraunhofer diffraction, fig. 6.27. The diffracted light can be considered to be made up of a set of plane waves of varying orientation. When a lens is located in front of the diffracting aperture, each plane wave is brought to a focus at a different point in the focal plane with the point of focus being proportional to the *x*- and *y*-direction cosines, so that the variation in intensity as a function of direction is mapped into a positional varation in intensity.

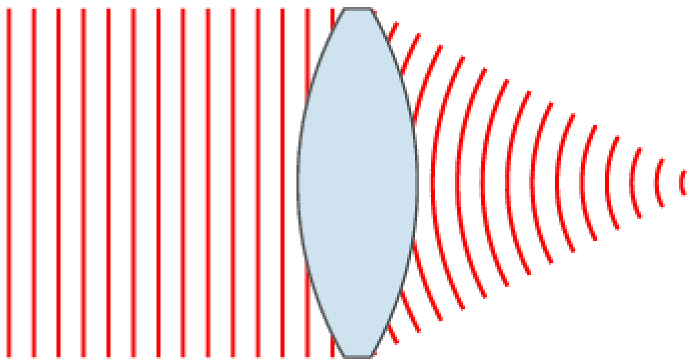


Figure 6.27

Parallel light rays which pass through a small aperture begin to diverge and interfere with one another. This becomes more significant as the size of the aperture decreases relative to the wavelength of light passing through, but occurs to some extent for any size of aperture or concentrated light source.

Experiment 6.15 Investigation of the intensity of light in a diffraction pattern

We will analyze the fig. 6.28. On the axis of the hole on the screen, select the point *P*. It corresponds to the main maximum of illumination. At the point *Q*, the first secondary maximum is formed. Its intensity is less than main. For subsequent highs, the intensity gradually decreases as the distance from the diffraction center increases. The angle of diffraction is determined from the equation $sin\theta=\lambda/d$, where d is the angle between the direction on the center of the diffraction pattern and the direction on its first minimum, λ - the length of the light wave.

Fig. 6.29 shows how the intensity of the diffraction peaks changes, depending on their order. The greater the distance from the center, the intensity decreases. The minima between the secondary maxima are arranged in points of multiple magnitudes λ/d.

With the decreasing of the size of the slit d, the angle θ, on which the diffracted light deviates, increases $sin\theta =\lambda/d$. In the central part there is a maximum of illumination, then there are other maxima of the second - $\lambda/d; -\lambda/d$, the third one is $-2\lambda/ d; 2\lambda/d$. The diffraction angle will be increased with a change in the wavelengths from violet to red. The distances between the central and other maximum from violet to red light will be diminished.

Since the divergent rays now travel different distances, some move out of phase and begin to interfere with each other - adding in some places and partially or completely canceling out in others. This interference produces a diffraction pattern with peak light intensities where the amplitude of the light waves add, and less light where they cancel out, fig. 6.29.

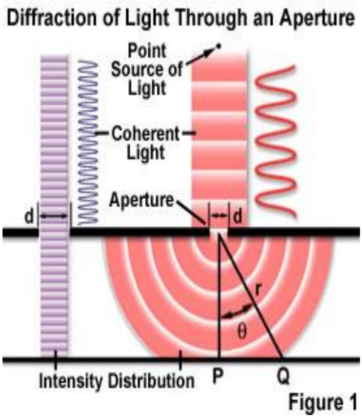


Figure 6.28

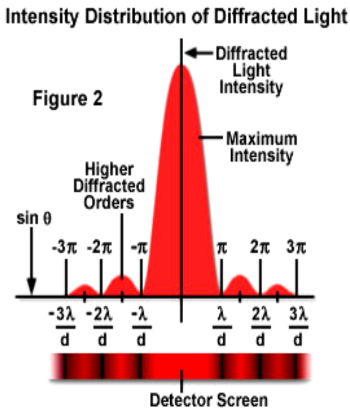


Figure 6.29 [72]

If one were to measure the intensity of light reaching each position on a line, the data would appear as bands similar to those shown below. For an ideal circular aperture, the 2-D diffraction pattern is called an «airy disk», after its discoverer George Airy. The width of the airy disk is used to define the theoretical maximum resolution for an optical system (defined as the diameter of the first dark circle).

Experiment 6.16 Diffraction of light from different screens

Equipment: Bulb of 3.5-V., lens, N_1, combined screen, physical tripod.

We make a combined screen. We attach: a needle with a ring, a needle with a tip, a ring on a leg made of copper conductor with a diameter of 0.05 *mm* to a cardboard plate of 3x4 *cm* by plasticine (fig. 6.30).

We hold the plate vertically in the foot of the physical tripod. The filament light is set along the direction of light propagation. Look at the bulb from a distance of 1.5 *m* through the lens. Change the distance between the eye and the lens. We achieve full illumination of the field. Without changing the position of the eye, between the lens and the light source, put the screens. We find such a distance between them, which shows a clear diffraction pattern in the form of dark and light interference bands along the screens, fig. 6.30.

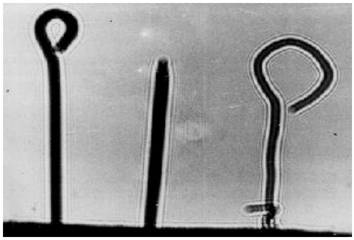


Figure 6.30

Experiment 6.17 Diffraction from the wire wedge

Equipment: light bulb on 3,5 V, on a stand, a current source of 4 V, a switch, a wedge-shaped slit, a lens N_1, a cardboard with a wedge.

Cut the rectangular plate from the cardboard in the size of 3x4 *cm*. We attach two pieces of conductor (diameter of conductors 0.6-0.7 *mm*) in the length of 4 *cm* to it. The angle between them is 15-20 degrees. We place the third conductor with a diameter of 0.04-0.06 *mm* on the bisector of the corner (fig. 6.31, 6.32).

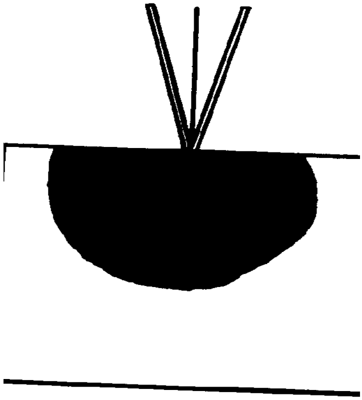


Figure 6.31

Figure 6. 32

We fasten a cardboard plate on a feet of a physical tripod at a distance of 1.5 *m* from the bulb. Look at the bulb through the lens and the wedge, fig. 6.31. We see a diffraction pattern, fig. 6.32. We draw attention to the width of the diffraction bands from the wires of different diameters. We will remove the middle wire and observe its influence on the diffraction pattern.

Experiment 6.18 Diffraction from wedge-shaped slits

Equipment: a set of wedge-shaped slits, a physical tripod, a 3.5-volt bulb on the stand, a current source of 4 volts.

We cut square sheets of black paper in the sizes 5x5 *cm*. and make wedges in them in 12 degrees almost to the middle of the square: two wedges at an angle of 90 degrees between their bisectors, fig. 6.34; two wedges with parallel bisectors; one wedge in the middle of the square. We fix wedge-shaped slits in a physical stand at a distance of 1.2-1.5 *m* from the bulb. Through the lens number 1 and wedges consistently watch light sources. We observe a diffraction pattern, fig.6.35, from two wedges, which are at an angle of

90 degrees, fig. 6.36, from two parallel wedges, fig.6.37, from one wedge.

Figure 6.33

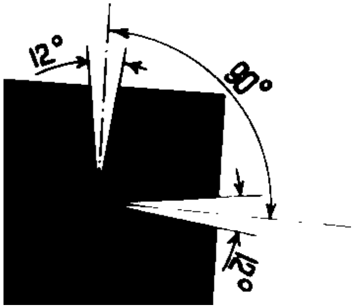


Figure 6.34

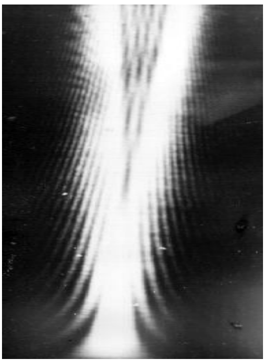


Figure 6.35

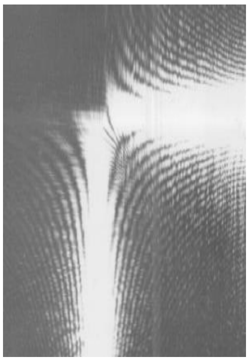


Figure 6.36

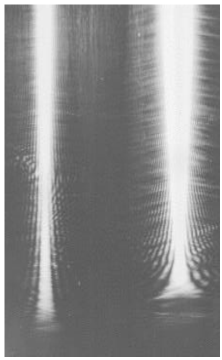


Figure 6.37

Experiment 6.19 Diffraction from the darkened corner

Equipment: glass plate with darkened angle, physical tripod, bulb of 3.5V, lens 1, current source of 4V.

Cover a glass plate (4x5 *cm*) with ink. When the ink is dry, cut two lines through the plate with the help of blade of a safe razor under the metal ruler, forming an acute angle between them, fig. 6.33.

Hold the plate in the foot of the physical tripod and place it at a distance of 1.5*m*. from the light bulb on the stand. Through the lens 1 and the wedge we consider the light source. We observe a diffraction pattern.

Experiment 6.20 Diffraction from the wedge-shaped slit

Equipment: lens 1, bulb of 3.5V, current source of 4V, wedge-shaped slit, physical tripod.

In a corky or rubber stopple we make a hole with a diameter of 1-2 *mm*. We insert two identical feathers from the pupil's hand in it so that the angle between them will be minimal, fig. 6.38. We set the filament lamp bulb along the direction of light propagation. It serves as a point source of light. We look at the bulb through the lens and the wedge-shaped slit. We see a clear silhouette of the wedge. We remove the wedge from the lens. Visible slit is expanding.

At the peak of the wedge fig. 6.39, at some distance there a light spot appears that has a stretched cone shape.

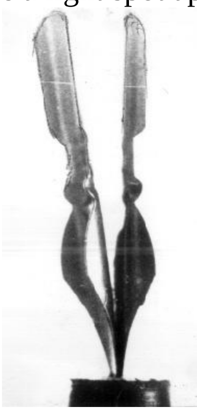


Figure 6.38

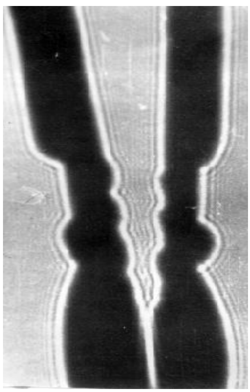


Figure 6.39

Figure 6. 40

In the area of the shadow on both sides of the central light strip, we see a system of dark and light diffraction bands, fig. 6.39, 6.40.

Experiment 6.21 Comparison of diffraction from the slit and obstacles of the same width

Equipment: laser, direct linear obstacle**s** of the same width 0,6 *mm*.

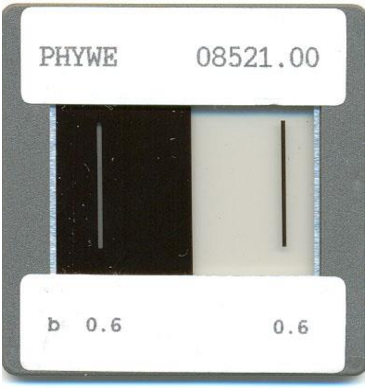


Figure 6.41 Slit and obstacle equal width

At the demonstration table we exhibit a laser. Put the revolver head in the position of «cylindrical lens». Place the plaque with direct obstacles on the stand and place it on the demonstration table in the focal plane of the cylindrical lens.

We direct the light beam on a linear obstacle-thread of 0.6 *mm* wide and observe a diffraction pattern.

Then we will watch the diffraction pattern from the slit, the size of which is equal to the obstacle-thread.

The diffraction pattern is a direct interference band parallel to the edges of the obstacle. Interference bands are observed both in the shadow region and in the area of free light propagation.

We draw conclusions: in the center of the diffraction pattern, in the case of a thread, we observe a light band maximum, and in the case of a slit in the center we have a dark band. The intensity of the light will be greater when the screens are narrower.

Experiment 6.22 Formation of regularities the Diffraction grating

We have seen that diffraction patterns can be produced by a single slit or by two slits. When light encounters an entire array of identical, equally-spaced slits, called a ***diffraction grating***, the bright fringes, which come from constructive interference of the light waves from different slits, are found at the same angles they are found if there are only two slits. But the pattern is much sharper [73].

The figure below shows the interference pattern for various numbers of slits. The width of all slits is 50 micrometers and the spacing between all slits is 150 micrometers. The location of the maxima for two slits is also the location of the maxima for multiple slits. The single slit pattern acts as an envelop for the multiple slit patterns.

Comparing diffraction patterns consistently from one slit to seven cracks, the following patterns are noticeable:

- the width of the colored strips decreases;
- the number of central spectra starting from the case of two cracks is 5;
- the size of the central highs is decreasing, and the sharpness increases.

For two slits, there is one single position between bright peaks, where the interference is totally destructive. Between the zero-order and first-order fringes, there is one position which requires that one of the waves travels exactly 1/2 wavelength further than the other to reach it. For three slits, however, there are two positions where destructive interference takes place.

One is located at the point where the path lengths differ by 1/3 of a wavelength, while the other is located where the path lengths differ by 2/3 of a wavelength. For 4 slits, there are three positions, for 5 slits there are four positions, etc. For a diffraction grating with a large number of slits, the pattern is sharp because of the many positions of completely destructive interference between the bright, constructive-interference fringes [73].

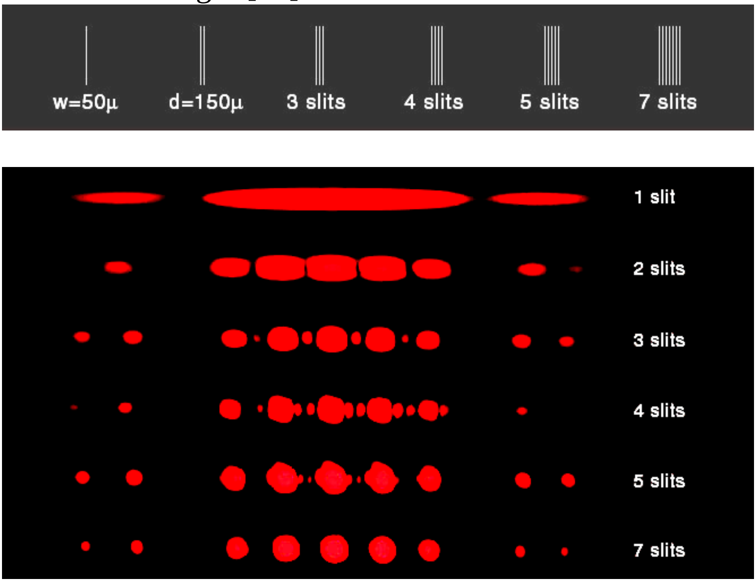
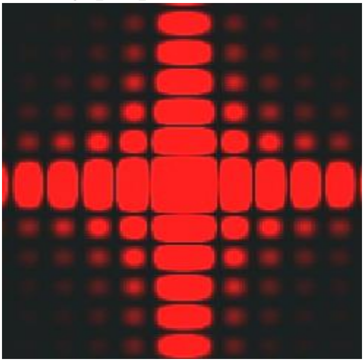


Figure 6.42 The bright fringes, which come from constructive interference of the light waves from different slits, are found at the same angles they are found if there are only two slits [73]

If the distance between slits is *d*, and the angle to a bright fringe of a particular color is λ, the wavelength of the light can be calculated.

Experiment 6.23 Diffraction by a rectangular aperture

The form of the diffraction pattern given by a rectangular aperture is shown in the figure on the fig. 6.43. There is a central semi-rectangular peak, with a series of horizontal and vertical fringes. The dimensions of the central band are related to the dimensions of the slit by the same relationship as for a single slit so that the larger dimension in the diffracted image corresponds to the smaller dimension in the slit. The spacing of the fringes is also inversely proportional to the slit dimension.



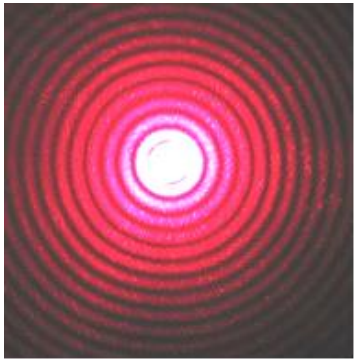
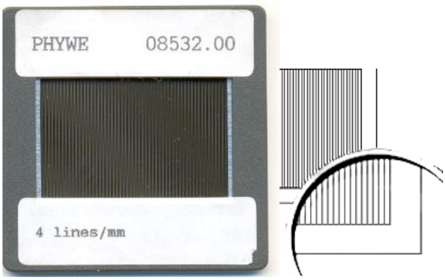


Figure 6.43 *Figure 6.44* [74]

Computer generated intensity pattern formed on a screen by diffraction from a square aperture, fig. 6.43.

Diffraction of red laser beam on the hole, fig. 6.44.

Experiment 6.24 Diffraction grating



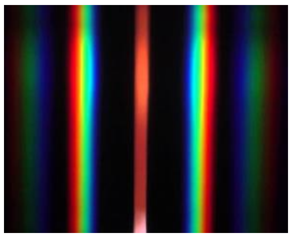


Figure 6.45 *Figure 6.46*

A spectrum is formed as light from a narrow source passes through a diffraction grating, fig. 6.45. A diffraction grating allows light to pass through many parallel slits to form a spectrum, fig. 6.46.

Interference can also occur when there are many sources of light. A ***diffraction grating*** is a piece of glass or plastic containing many parallel lines or slits, fig. 6.46.

Some diffraction gratings have 10 000 slits per centimeter.

When light of a single color passes through a diffraction grating onto a screen, an interference pattern of bright and dark bands appears. The separation between the bands depends on the color and is greatest for red light. White light forms rainbow-like colored spectra. Thus, diffraction gratings can be used in the same way prisms are used to separate white light into colors.

Experiment 6.25 Observation of the spectrum from the reflecting diffraction grating

A phonograph record or compact disk has closely spaced grooves that can act like a diffraction grating. Look at the reflection of a distant lamp in a record. Note the separation of colors.

Figure 6.47 The laser shines through the «back» of a compact disk. The grooves in the disk act as a diffraction grating, producing a spectrum

Ordinary pressed CD and DVD media are every-day examples of diffraction gratings and can be used to demonstrate the effect by reflecting sunlight off them onto a white wall. This is a side effect of their manufacture, as one surface of a CD has many small pits in the plastic, arranged in a spiral; that surface has a thin layer of metal applied to make the pits more visible. The structure of a DVD is optically similar, although it may have more than one pitted surface, and all pitted surfaces are inside the disc.

Experiment 6.26 Observation of the diffraction pattern from plastic

The school plastic protractor is directed at an angle to the source of diffused light, and changing the angle we consider the diffraction pattern and the order of the spectrum colors.

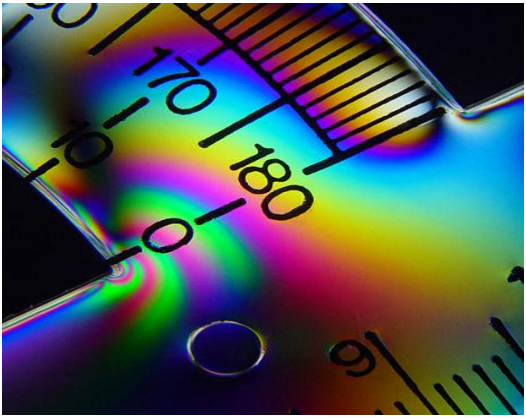


Figura 6.48 Diffraction grating on a piece of plastic

Review

1 Light moves into glass from water at an angle. Is the light refracted toward or away from the normal when it enters the glass?

2 Light moves from water into air. Is the light refracted toward or away from the normal when it enters the air?

3 The corner of a fish tank can serve as a water-filled prism. Would the red or violet light be bent more?

4 If you view white light in a diffraction grating, which light is seen at a larger angle, red or violet?

5 Is orange or blue light refracted more by glass? Support your answer.

Diffraction gratings are often used in monochromators, spectrometers, lasers, wavelength division multiplexing devices, optical pulse compressing devices, and many other optical instruments.

Experiment 6.27 Research of the Bragg's law

Following Bragg's law, each dot (or *reflection*), in this diffraction pattern forms from the constructive interference of *X*-rays passing through a crystal, fig. 6.49. The data can be used to determine the crystal's atomic structure.

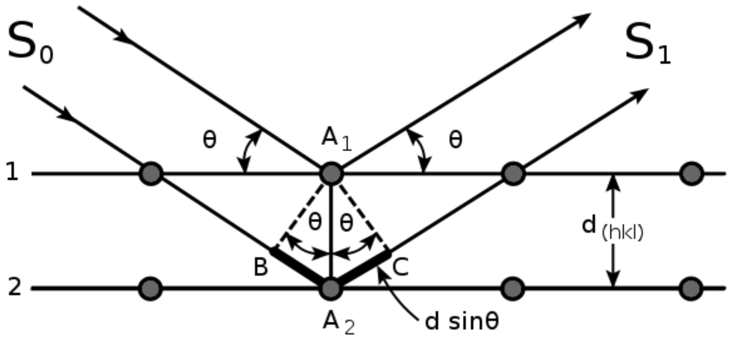


Figure 6.49

Two beams with identical wavelength and phase approach a crystalline solid and are scattered off two different atoms within it, fig. 6.49. The lower beam traverses an extra length of $2d\sin\theta$. Constructive interference occurs when this length is equal to an integer multiple of the wavelength of the radiation.

For a crystalline olid, the waves are scattered from lattice planes separated by the interplanar distance *d*. Where the scattered waves interfere constructively, they remain in phase since the path length of each wave is equal to an integer multiple of the wavelength. The path difference between two waves undergoing constructive interference is given by $2d\sin\theta$, where θ is the scattering angle.

This leads to **Bragg's law**, which describes the condition for constructive interference from successive crystallographic planes (h, k, and l, as given in Miller Notation) of the crystalline lattice: $2d\sin\theta = n\lambda$, where n is an integer determined by the order given, and λ is the wavelength.

A diffraction pattern is obtained by measuring the intensity of scattered waves as a function of scattering angle. Very strong intensities known as Bragg peaks are obtained in the diffraction pattern when scattered waves satisfy the Bragg condition.

The model of diffraction of particles on a crystal lattice can be demonstrated with the help of the following experiment. We make two identical diffraction gratings perpendicular to the lines of the hole and direct the light beam to such a system. on the screen we get a diffraction pattern, fig. 6.50.

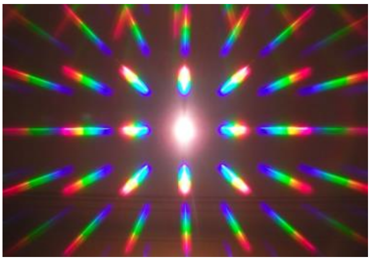


Figure 6.50

Experiment 6.28 Pattern of Rings

Equipment: UPD, diaphragm with round aperture, glass plate 4.7x5 *cm* in size, lycopods, Vaseline, 8x optical microscope, screen, rotary mirror.

Schematic diagram is shown in fig. 6.51.

Figure 6.51

Take a clean glass plate and lubricate with vaseline. We rub it with a piece of wool so that a rather thin layer of vaseline, remains on the glass. After this, sprinkle the glass with a lycopods. Put the plate vertically and shake the larva of the licopods from the glass hitting easy.

Before the demonstration of the pattern of rings, it is expedient to show students the spore of the licopods by means of microprojection using a lens 8x from the microscope. We locate the optical bench along the demonstration desk. Optical bench is located along the demonstration table. Then we put diagram 10 with a round hole of 8-10 *mm* in diameter in UPD instead of a condenser. At a distance of 2 *m* from the ophthalmic luminaire, we put up the glass vertically, covered with licopods.

Clip the glass in the foot of physical tripod. On the way to the rays we put the rotary mirror and, turning it back, we show a picture to the students. Demonstration does not require good eclipse [77].

Experiment 6.29 Patterns of the rings

When light travels through thin clouds made up of nearly uniform sized water or aerosol droplets or ice crystals, diffraction or bending of light occurs as the light is diffracted by the edges of the particles. This degree of bending of light depends on the frequency (color) of light. The result is a pattern of rings, which seem to emanate from the sun, moon, planet or other astronomical object. The most distinct part of this pattern is a central, nearly white disk. This is an atmospheric airy disc. It is distinct from rainbows and halos, which are mainly caused by refraction [77].

Figure 6.52 Solar glory, Spectre of the Brocken

Figure 6.53 Cloud iridescence

Experiment 6.30 Cloud iridescence is the occurrence of colors in a cloud similar to those seen in oil films on puddles, and is similar to irisation. It is a fairly uncommon phenomenon, most often observed in altocumulus, cirrocumulus and lenticular clouds, and very rarely in Cirrus clouds. The colors are usually pastel, but can be very vivid. Iridescence is generally produced near the sun, with the sun's glare masking it, so it is more easily seen by hiding the sun behind a tree or building. Other aids are dark glasses, or observing the sky reflected in a convex mirror or in a pool of water.

Iridescent clouds are a diffraction phenomenon cause by small water droplets or small ice crystals individually scattering light. Larger ice crystals produce halos, which are a refraction phenomena rather than iridescence. Iridescence should similarly be distinguished from the refraction in larger raindrops that makes a rainbow, fig. 6.54.

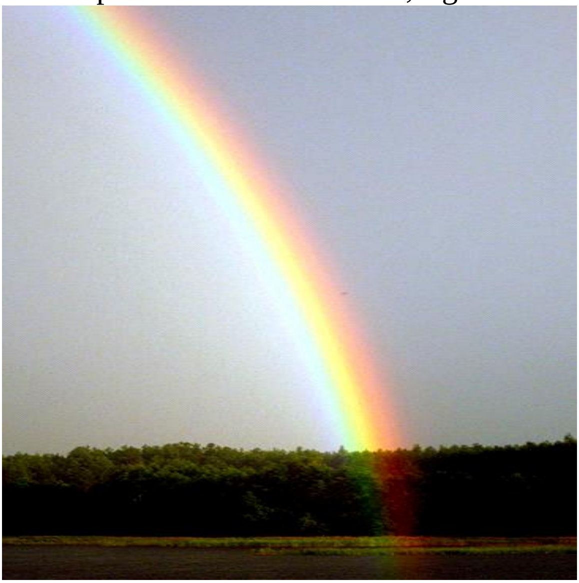


Figure 6.54

If parts of clouds have small droplets or crystals of similar size, their cumulative effect is seen as colors. The cloud must be optically thin, so that most rays encounter only a single droplet. Iridescence is therefore mostly seen at cloud edges or in semi-transparent clouds, and newly forming clouds produce the brightest and most colorful iridescence. When a thin cloud has droplets of similar size over a large extent, the iridescence takes on the structured form of a ***corona***, a central bright disk around the sun or moon surrounded by one or more colored rings.

Experiment 6.31 Airy Disk

Airee's rings (or Airee's figures) - in optics, this is the image of the most focused beam of light created by an ideal lens with a circular aperture, limited by diffraction of light.

The diffraction pattern, created as a result of a uniformly illuminated circular aperture, has a bright central aperture, known as the Airee disc, which, together with light concentric rings around, is called Airey's picture. Named after George Biddle Avery. The phenomenon of the formation of a disk and rings was known before Airy; John Herschel described the appearance of the image of a light star through a telescope with a large increase in the article about light for Encyclopedia Metropolitana in 1828 [76].

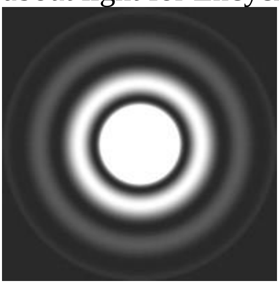


Figure 6.55 [77]

Matching

Match each description with the correct vocabulary word from the list above. Some words will not be used.

1 radiation with wavelengths just longer than light

2 radiation with wavelengths slightly shorter than radio waves

3 the bending of waves around barriers

4 material that absorbs, reflects, or transmits certain colors

5 material that blocks all light

6 the bending of a wave because of change in velocity

7 can be used to separate white light into its component colors

8 radiation used to picture the bones in the body

9 to change radio waves so they can be used for communication

10 arrangement of electromagnetic waves by wavelengths

The concept of diffraction

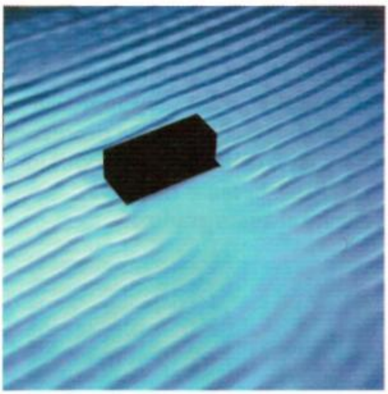


Figure 6.56

Waves spread as they travel. When they encounter an obstacle, they bend around it somewhat and pass into the region behind it, as shown in fig. 6.56 for water waves. This phenomenon is called diffraction.

The amount of diffraction depends on the wavelength of the wave and on the size of the obstacle, as shown in fig. 6.56. If the wavelength is much larger than the object, as with the grass blades of fig. 6.57,*a*, the wave bends around them almost as if they are not there. For larger objects, parts (b) and (c), there is more of a «shadow» region behind the obstacle where we might not expect the waves to penetrate - but they do, at least a little. Then notice in part (d), where the obstacle is the same as in part (c) but the wavelength is longer, that there is more diffraction into the shadow region. As a rule of thumb, only if the wavelength is smaller than the size of the object will there be a significant shadow region. This rule applies to reflection from an obstacle as well. Very little of a wave is reflected unless the wavelength is smaller than the size of the obstacle.

Figure 6.57,a

Figure 6.57,b

Figure 6.57,c

Experiment 6.32 Poisson

In 1819, Augustin Fresnel (1788-1827) presented to the French Academy a wave theory of light that predicted and explained interference and diffraction effects. Almost immediately Simeon Poisson (1781-1840) pointed out a counter-intuitive inference: according to Fresnel's wave theory, if light from apoint source were to fall on a solid disk, part of the incident light would be diffracted around the edges and would constructively interfere at the center of the shadow (fig. 6.57, *a*). That prediction seemed very unlikely. But when the experiment was actually carried out by Francois Arago, the bright spot was seen at the very center of the shadow (fig. 6.57,*a*). This was strong evidence for the wave theory.

Fig. 6.57,*a* is a photograph of the shadow cast by a coin using a coherent point source of light, a laser in this case.

The bright spot is clearly present at the center. Note also the bright and dark fringes beyond the shadow. These resemble the interference fringes of a double slit. Indeed, they are due to interference of waves diffracted around the disk, and the whole is referred to as a diffraction pattern. A diffraction pattern exists around any sharp-edged object illuminated by a point source, as shown in fig. 6.57, *b* and *c*.

We are not always aware of diffraction because most sources of light in everyday life are not points, so light from different parts of the source washes out the pattern. Suppose the light striking a diffraction grating is not monochromatic, but consists of two or more distinct wavelengths.

Then for all orders other than $m = 0$, each wave length will produce a maximum at a different angle (fig. 6.57, *a*), just as for a double slit. If white light strikes a grating, the central ($m = 0$) maximum will be a sharp white peak. But for all other orders, there will be a distinct spectrum of colors spread out over a certain angular width, fig. 6.57, b. Because a diffraction grating spreads out light into its component wavelengths, the resulting pattern is called a spectrum.

Figure 6.58

Solve tasks

Task 1

Determine the angular positions of the first- and second-order maxima for light of wavelength 400 *nm* and 700 *nm* incident on a grating containing 10,000 lines/*cm*.

Apprpach. First we find the distance *d* between grating lines: if the grating has *N* lines in 1 *m*, then the distance between lines must be *d* = 1/*W* meters. Then we use Eq., sinθ=*mX*/*d*, to find the angles for the two wavelengths for *m* = 1 and 2.

Solution. The grating contains 1.00 X 104 lines/*cm* = 1.00 X 106 lines/*m*, which means the distance between lines is *d*=(l/l.OO X 106) *m* = 1.00 X 10"6*m* = 1.00 /*am*. In first order (*m* = 1), the angles are

$$\sin\theta_{400} = \frac{m\lambda}{d} = \frac{(1)(4.00\times10^{-7}m)}{1.00\times10^{-6}m} = 0.400$$

$$\sin\theta_{700} = \frac{m\lambda}{d} = \frac{(1)(7.00\times10^{-7}m)}{1.00\times10^{-6}m} = 0.700$$

So $\theta_{400} = 23.6^0$ and $\theta_{700} = 44.4^0$. In second order,

$$\sin\theta_{400} = \frac{2\lambda}{d} = \frac{(2)(4.00\times10^{-7}m)}{1.00\times10^{-6}m} = 0.800$$

$$\sin\theta_{700} = \frac{2\lambda}{d} = \frac{(2)(7.00\times10^{-7}m)}{1.00\times10^{-6}m} = 1.400$$

so θ_m = 53.1°. But the second order does not exist for *A* = 700 *nm* because sinθ cannot exceed 1. No higher orders will appear.

Task 2

Spectra overlap. White light containing wavelengths from 400 *nm* to 750 *nm* strikes a grating containing 4000 lines/*cm*. Show that the blue at *A* = 450 *nm* of the third-order spectrum overlaps the red at 700 *nm* of the second order.

Apprpach. We use sinθ= *mX/d* to calculate the angular positions of the *m*=3 blue maximum and the *m*=2 red one.

Solution. The grating spacing is *d* = (1/4000) *cm*. The blue of the third order occurs at an angle 6 given by

$$\sin\theta = \frac{m\lambda}{d} = \frac{(3)(7.00\times10^{-7}m)}{2.50\times10^{-6}m} = 0.540$$

Red in second order occurs at

$$\sin\theta = \frac{(2)(7.00\times10^{-7}m)}{2.50\times10^{-6}m} = 0.560\,,$$

which is a greater angle; so the second order overlaps into the beginning of the third-order spectrum.

Chapter 7
POLARIZED LIGHT

7.1 Polarized Light

Light is a transverse wave, like a wave on a rope. You can form a wave on a rope by moving the rope up and down, or by moving it side to side, or in any plane in between. The waves in light can also vibrate in any plane. Most light consists of waves vibrating in many planes. ***Polarized light,*** however, consists of waves vibrating only in one plane. A filter can polarize light, fig. 7.1.

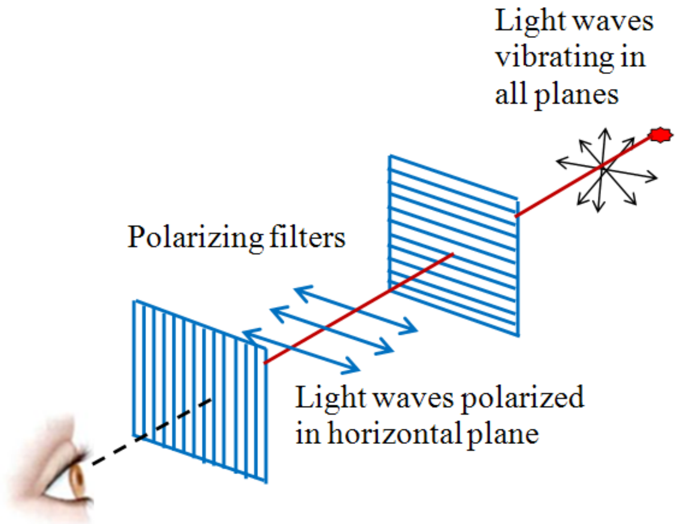


Figure 7.1

The filter has long, thin molecules that are all lined up in parallel rows. Light vibrating parallel to the molecules is absorbed, while light vibrating at right angles to the rows passes through. Polarizing sunglasses contain such filters.

Polarizing sunglasses are useful because light coming from the sky is polarized as it is scattered by the atmosphere, fig. 7.2.

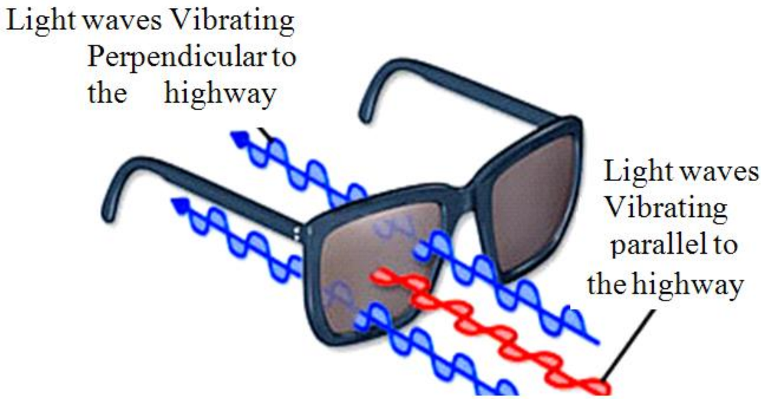


Figure 7.2

The filters in the sunglasses are rotated so they absorb this polarized light, reducing the glare. Similar filters are used in cameras to make the sky appear darker. Light reflected at an angle from shiny surfaces is also polarized. Sunglasses reduce the glare of light reflected off the road or windows of other cars.

Experiment 7.1 Investigation of the phenomenon of polarization

Equipment: light source 3, condenser 6, diaphragm 7, first polarizer P_1, lens 7, second polarizer P_2, screen.

If two polarizers are set up in series so that their optical axes are parallel, light passes through both, fig. 7.3. However, if the axes are set up 90 degrees apart, the polarized light from the first is extinguished by the second. As the angle rotates from 0 to 90 degrees, the amount of light that is transmitted decreases. This effect is demonstrated in the following diagram. The polarizers are parallel at the top and crossed at the bottom.

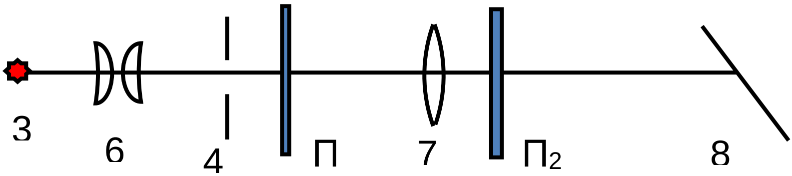


Figure 7.3 Polarization study scheme

Experiment 7.2 Polarization of two mirrors

Equipment: UPD, two black mirrors, sliding slot, lens.

We make black mirrors from glass photocells in the sizes of 4.7x5 *cm*. Cover one side of the plates with black ink.

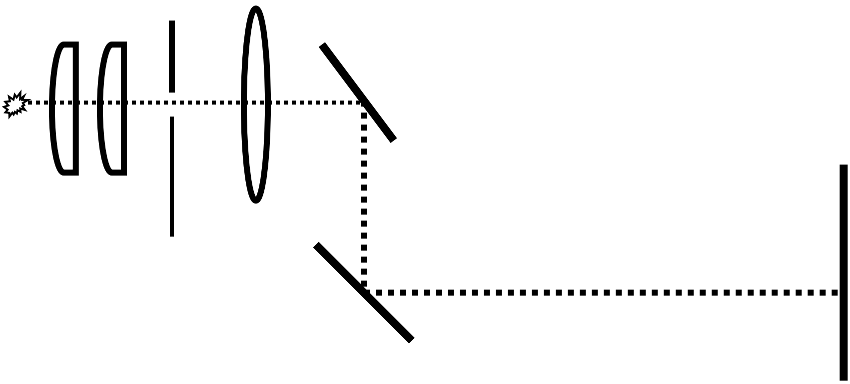


Figure 7.4

We have two black mirrors: one will serve as a polarizer, and the second as analyzer. The scheme of installation is shown on fig. 7.4.

We put the diaphragm behind the condenser. With the help of objective we direct a beam of light on the first black mirror fixed in the screen with a rod. The angle of incidence of a beam should be equal to 57 degrees (the angle of maximum polarization). After reflection the light falls on the second black mirror fixed in a physical tripod. On the screen we see a bright spot. Slowly we turn the second mirror. We observe a change in the brightness of the light spot on the screen. If the planes of polarization of mirrors' rays are parallel, then we have maximum illumination, and if perpendicular - the minimum.

Experiment 7.3 Investigation glass tension when heated

Equipment: UPD, two polarizers, a piece of glass, alcohol, a nail in diameter of 3-4 *mm*, a physical tripod, a screen.

The installation scheme is given in fig. 7.5

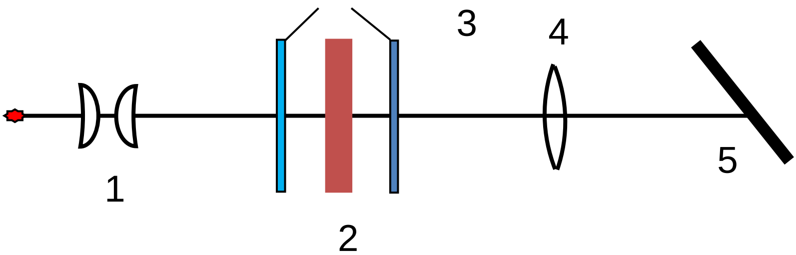


Figure 7.5

In the middle of the optical bench in a physical tripod, we attach a piece of window glass vertically 2. From both sides of it we put the Polaroid 3. With the help of objective 4 we project the plate to the screen 5.

First, the Polaroid is oriented so that the intensity of light passing through them is maximal. Then we turn one Polaroid (by the handle of the screen) 90 degrees. There is no spot on the screen. We heat a nail or other metal object on alcoholic lamp and touch it to the glass. On the screen we observe the appearance of light and dark spots. They arise due to the formation of tension in the glass with its heterogeneous heating.

Experiment 7.4 Interference of polarized light

Equipment: UPD without condenser, lens with focal length of 80 *cm*, device for monitoring interference of polarized light, physical tripod.

In cardboard of 20x20 *cm* in the center we cut a double slit (fig. 7.6).

The width of each slit is 2 *mm*, the distance between them is 4 *mm*. One of the slits is closed by polarizing film from a set for polarization, having determined the orientation of the plane of polarization in advance. We close the second half of the slit with a piece of polarized film. Where, the plane of polarization is oriented in the same way as in the film that closes the first slit. Close the other half of the slit with a polarized film, where the polarization plane will be perpendicular to the previous one. At a distance of 10-15 *cm* from the UPD without a condenser, we have a sliding slit. We set a lens (F = 80 *cm*) at a distance of 80 *cm* from the slit. The manufactured device is fixed in a paw of a physical tripod and placed at a distance of 10 *m* from the UPD. The observer is 30-70 *cm* away from the polarization device.

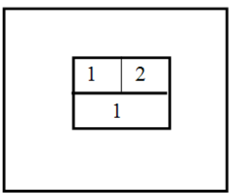


Figure 7.6

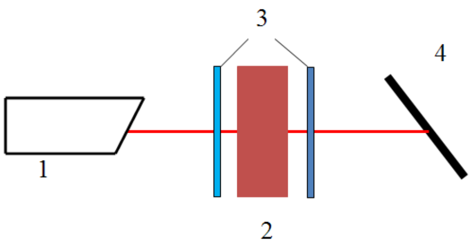


Figure 7.7

In the field of view of the observer you need to get two light spots from the double slit. Without changing the position of the eyes, in the field of view, we introduce the combined lens N_1 or the other one. In the case where the plane of polarization coincides, we see a clear interference pattern, in the case of their perpendicularity, we have a bright spot.

The distance of 6 *m* from the device to the UPD is minimal, in which there is still an interference. Increasing this distance to 10-12 *m* leads to improved brightness and clarity of the picture.

Natural sunlight and almost every other form of artificial illumination transmits light waves whose electric field vectors vibrate in all perpendicular planes with respect to the direction of propagation. When the electric field vectors are restricted to a single plane by filtration, then the light is said to be ***polarized*** with respect to the direction of propagation and all waves vibrate in the same plane.

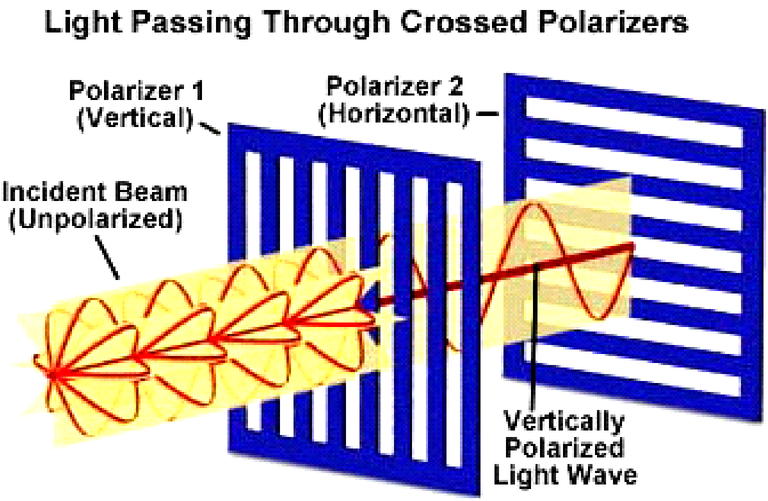


Figure 7.8

The lenses of the sunglasses have polarizing filters that are oriented vertically with respect to the frames. In the fig. 7.8 above, the blue light waves have their electric field vectors oriented in the same direction as the polarizing lenses and, thus, are passed through. In contrast, the red light wave is perpendicular to the filters and is blocked by the lenses. Polarizing sunglasses are very useful when driving in the sun or at the beach where sunlight is reflected from the surface of the road or water leading to glare that can be almost blinding.

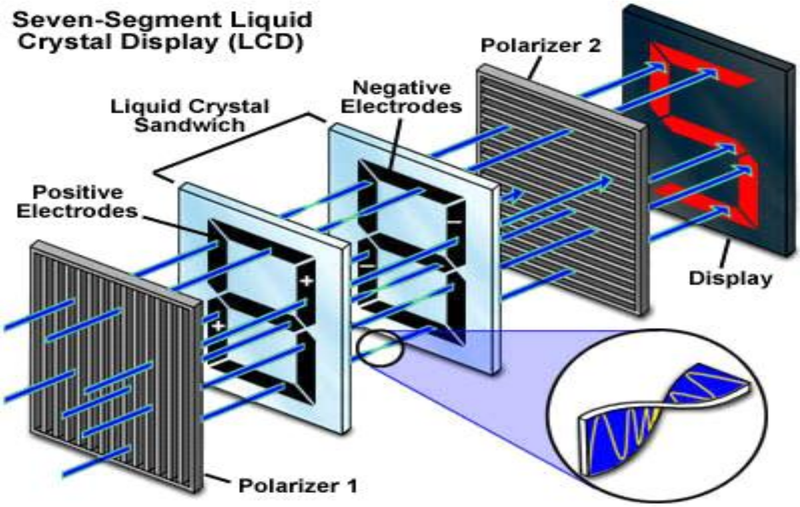


Figure 7.9

An excellent example of the basic application of liquid crystals to display devices can be found in the seven-segment LCD numerical display, fig. 7.9. Here, the liquid crystalline phase is sandwiched between two glass plates that have electrodes attached similar to those depicted in the illustration below.

In fig. 7.9, the glass plates are drawn with seven black electrodes that can be individually charged. Light passing through polarizer 1 is polarized in the vertical direction and, when no current is applied to the electrodes, the liquid crystalline phase induces a 90 degree «twist» of the light and it can pass through polarizer 2, which is polarized horizontally and is perpendicular to polarizer 1. This light can then form one of the seven segments on the display.

When current is applied to the electrodes, the liquid crystalline phase aligns with the current and loses the cholesteric spiral pattern. Light passing through a charged electrode is not twisted and is blocked by polarizer 2. By coordinating the voltage on the seven positive and negative electrodes, the display is capable of rendering the numbers 0 through 9. In this example the upper right and lower left electrodes are charged and block light passing through them, allowing formation of the number «2».

Polarization of light is very useful in many aspects of optical microscopy.

Figure 7.10

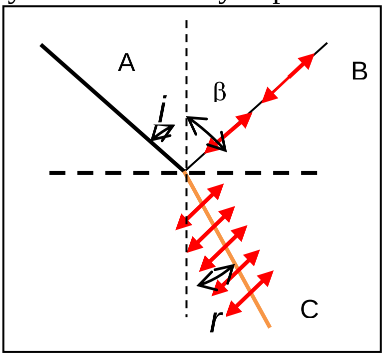


Figure 7.11

Brewster's Law: In 1811 Brewster's proposed it. When *Un-polarized* light is incident at the angle called Brewster's angle or angle of polarization, the light that is reflected from the surface is therefore perfectly polarized.

He was able to prove that the tangent of the angle of polarization is numerically equal to the refractive index of the medium. On fig. 7.11 *i* is refractive index of the medium and *r* is the polarization angle.

Suppose, un-polarized light is incident at an angle equal to the polarizing angle on the glass surface. It is reflected along PB and refracted along PC, fig. 7.11.

The polarized light microscope is designed to observe and photograph specimens that are visible primarily due to their optically anisotropic character. In order to accomplish this task, the microscope must be equipped with both a ***polarizer***, positioned in the light path somewhere before the specimen, and an ***analyzer*** (a second polarizer), placed in the optical pathway between the objective rear aperture and the observation tubes or camera port.

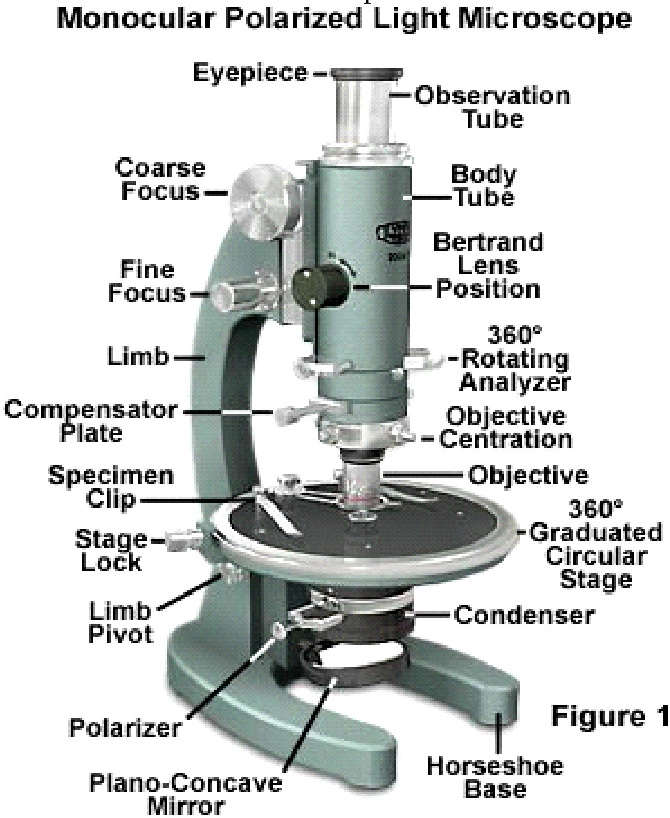


Figure 7.12

From Snell's Law $\mu - \dfrac{\sin i}{\sin r}$. From Brewster's Law $\mu = tgi = \dfrac{\sin i}{\cos i}$. Comparing $\cos i = \sin r = \cos(\dfrac{\pi}{2} - r)$, then $i = \dfrac{\pi}{2} - r$, or $i + r = \dfrac{\pi}{2}$. As $i + r = \dfrac{\pi}{2} \langle ABC$ is also equal to $\dfrac{\pi}{2}$ therefore, the reflected and the refracted rays are at right angles to each other.

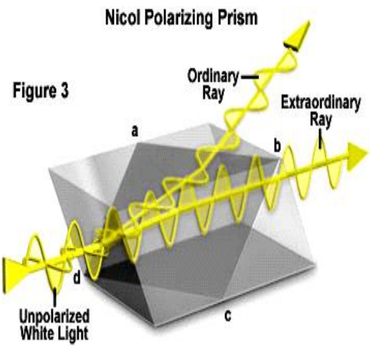


Figure 7.13

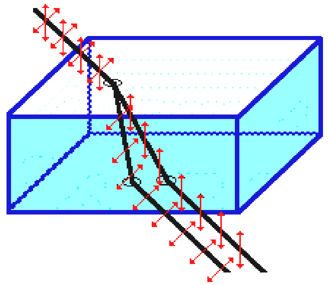


Figure 7.14

Presented in fig. 7.13 is an illustration of the construction of a typical Nicol prism. A crystal of doubly refracting material, usually calcite, is cut along the plane labeled ***a-b-c-d*** and the two halves are then cemented together to reproduce the original crystal shape. A beam of unpolarized white light enters the crystal from the left and is split into two components that are polarized in mutually perpendicular directions. One of these beams (labeled the ordinary ray) is refracted to a greater degree and impacts the cemented boundary at an angle that results in its total reflection out of the prism through the uppermost crystal face. The other beam (extraordinary ray) is refracted to a lesser degree and passes through the prism to exit as a plane-polarized beam of light.

Polarization can also occur by the refraction of light. Refraction occurs when a beam of light passes from one material into another material. At the surface of the two materials, the path of the beam changes its direction.

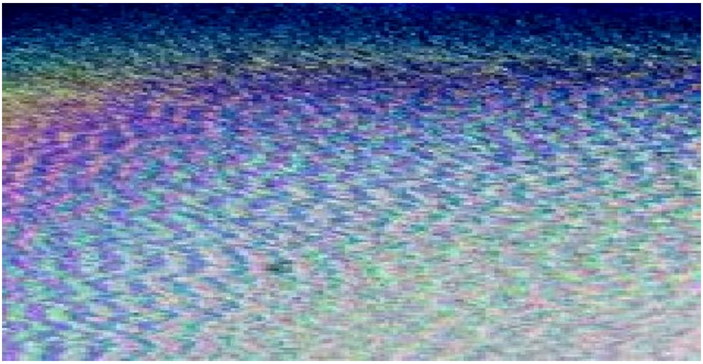


Figure 7.15

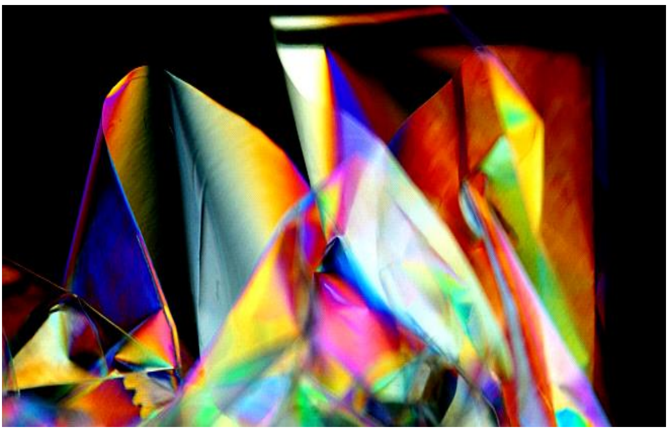


Figure 7.16

Figure 7.17

7.2 Light and Polarization

Light can be represented as a transverse electromagnetic wave made up of mutually perpendicular, fluctuating electric and magnetic fields. Fig. 7.18 shows the electric field in the *xy* plane, the magnetic field in the *xz* plane and the propagation of the wave in the *x* direction. The right half of the figure shows a line tracing out the electric field vector as it propagates. Traditionally, only the electric field vector is dealt with because the magnetic field component is essentially the same.

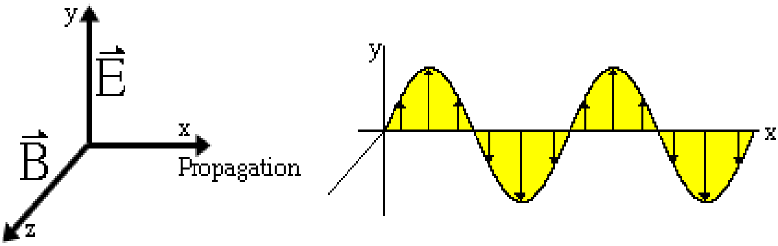


Figure 7.18

This sinusoidally varying electric field can be thought of as a length of rope held by two children at opposite ends. The children begin to displace the ends in such a way that the rope moves in a plane, either up and down, left and right, or at any angle in between.

Ordinary white light is made up of waves that fluctuate at all possible angles. Light is considered to be «linearly polarized» when it contains waves that only fluctuate in one specific plane. It is as if the rope is strung through a picket fence-the wave can move up and down, but motion is blocked in any other direction. A polarizer is a material that allows only light with a specific angle of vibration to pass through. The direction of fluctuation passed by the polarizer is called the «easy» axis.

Chapter 8
QUANTUM PROPERTIES OF LIGHT

8.1 Quantum properties of light

Quantum properties of the light have features of the physics of the microworld and are described by a quantum mechanism. Their essence is the following.

1The dominant influx of wave or quantum properties in the ippo-mation depends on the time of radiation or absorption of energy. The larger the chatter of the oscillating system, the more likely it is to exhibit quantum volctivocity.

2 Separate acts of photon radiation are random. The total of their number varies with chaos, exhibiting fluctuations. Photon manifests itself both in wave and particle properties. During its motion, the photon behaves like a particle that constantly fluctuates and therefore displays duality at the same time.

3 Human eye has a special status that is sensitive to the sensory feeling and, when studying quantum physics, becomes part of the observation toolkit.

4 It should be noted that, after the expiration of time, the fact is that it determines the predominant effect of the wave or quantum properties of the light.

5 In the visible and ultraviolet parts of the spectrum, in the processes of radiation and absorption, electrons play a major role in infrared ions.

6 In the quantum physics, the systematic and visible manifestation of conservation laws, symmetries is essential.

Experiment 8.1 Construction of the graph of the dependence of the intensity of radiation, on the temperature of the emitter and frequency

Equipment: UPD, shotgun, prism of direct vision, LAT, selenium photocell, galvanometer M 1032, desktop screen.

Selenium photocell has a selective property, and the prism of direct vision does not give a uniform expansion over the frequencies of light falling on it. Therefore, in the experiment, we deal with the simulation of the dependence of the intensity of the tungsten filament temperature on temperature and frequency.

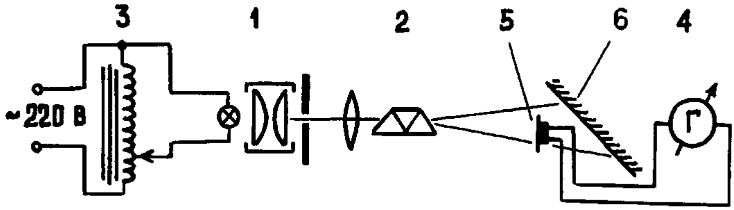


Figure 8.1

From the modeling of this dependence to the real experimental expansion of light, a holographic diffraction grating and a bolometer, instead of prisms and selenium photocell, should be used, or specially selected photodiodes should be used. The difficulty of staging such an experiment is, first of all, in the absence of a sensitive bolometer.

In the case of simulation, we make the installation for fig. 8.1. UPD incorporating the LATS 3. Light beam with limited gaps. The objective concentrates bright light on the effects of direct vision 2. On the spectrum, we observe a spectrum. Selenium phototoelement 5 is connected with a galvanometer 4. Beforehand, we make a slit with a width of 5 *mm t*o the photoelectric cell. The cleft should be parallel to the spectral bands. The average width of the colors of the spectrum should be equal to the width of the crack of the photocell.

At a voltage of 220 V, the photocell is introduced into each strip of spectrum. The displays of the galvanometer are fixed in the table. LATAM change the voltage on the incandescent lamp, that is, change the temperature of light radiation with tungsten. The experiment is repeated for different voltage values. We construct a graph of the dependence of the intensity of radiation (in relative units) on the temperature of the radiator fig. 8.2. and from the frequency of fig. 8.3.

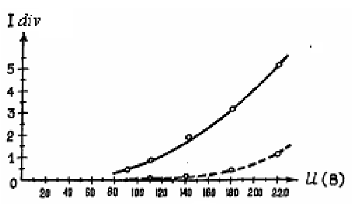


Figure 8.2

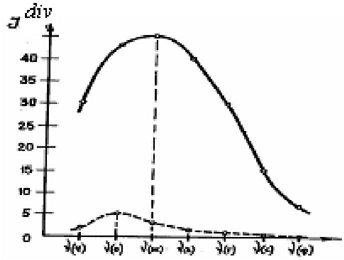


Figure 8.3

After analyzing the obtained results, we plot the dependence of the intensity of the radiation of the tungsten filament on the temperature of the emitter and the emitted frequency fig. 8.4.

The resulting graphs are compared with the real ones, which are given in the textbooks and manuals, and we draw the appropriate conclusions, evaluate the resulted modeling method.

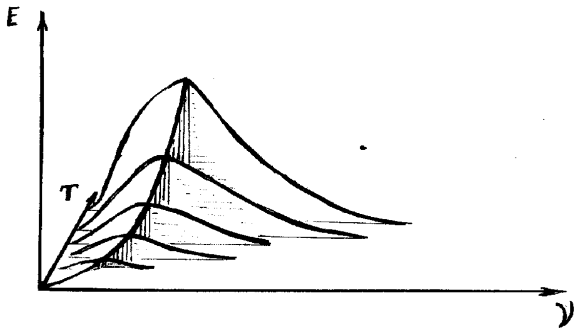


Figure 8.4

Experiment 8.2 Demonstration of the phenomenon of photoelectric effect

Equipment: an amp on the field transistor, a brass net, a zinc disc, two stands from a set of electrostatics, a demonstration galvanometer from an ammeter, a source of constant stabilized current IEPP1, VUP2, an ultraviolet emitter.

An ultraviolet emitter can be a cosmetic device «Photon» or a self-made source. Cut the zinc disc in a diameter of 12 *cm*. We cut another disc from the brass mesh (cell density 2 *mm*) (fig. 8.5).

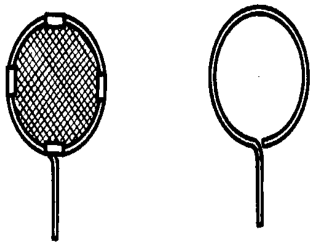


Figure 8.5

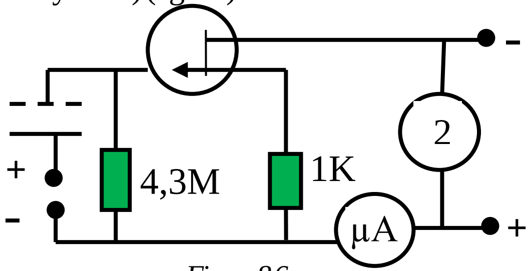


Figure 8.6

From the disks make a capacitor located on the ebonite supports. Fold the circle according to the scheme (fig. 8.6).

The indicator of the current is a demonstration galvanometer from the ammeter. In the circle of drainage flow we supply a voltage of 1.5 V from IEPP-1. In the circle of the condenser, activate the VU-2 and supply a voltage of 250 V. The condenser is illuminated with ultraviolet rays. The arrow is deviating into 3 divisions (scale of 5 divisions). We cover the light flux, the current disappears. Immediately before each experiment, zinc drive must be cleaned with sandpaper. In the circuit, as a voltage amplifier, the field transistor KP103I was used.

Experiment 8.3 Detection of «dark» current

Equipment: from a previous experiment.

In the diagram, fig. 6.6, the VUP-2 switch is switched on, and the damping switch is replaced by a digital numerical immersion microprocessor. The battery in the box is supplied in 2.5 volts. The oven is supplied with a brass plate with ultra-violet shade. The microampermeter indicates a change in the volume of 2 μA.

Experiment 8.4 Removal of the volt-ampere characteristics of the photoelectric effect

Equipment: self-made current amplifier at the transistor type KT312, KT315, current source IET-1, photocell TG-4 or other, illuminator for shadow projection, physical tripod.

The quantitative effects of the photoelectric effect can be obtained by copying the type of CT-312, KT315. Field transistors act better than voltage amplifiers. To know the current-voltage characteristic it is necessary to amplify the current strength. Collect the scheme, fig. 8.7.

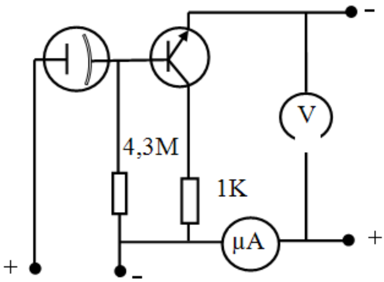


Figure 8.7

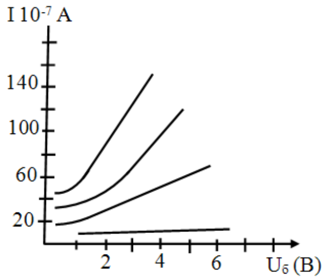


Figure 8.8

The source of current is IER-1 or battery. Inside the base, turn on a TG4 cell or other photocell. Between the emitter and the collector, set the voltage to 5 V.

The heater is located at a distance of 1.3 *m* from the foethelet. The light bulb of the light bulb is absorbed in the light and the focus is on the bright spot on the photodetector's catheter. Particularly the meaning of the light of the light changes in the midst of the anode and the catheter of the cell. Fixing the lower value of the video output. The estimated value of the photocurrent with the correction of the value of the correction factor of the tpanzicton. The structure of the building depends on U = f (I), fig. 8.8.

With the help of the proposed in the experiments 8.2-8.4 the equipment should be explored.

Depending on the size of the photocurrent from the magnitude of the brightness, fig. 8.10 and the dependence of the function depend on $F = f(I)$, fig. 8.9.

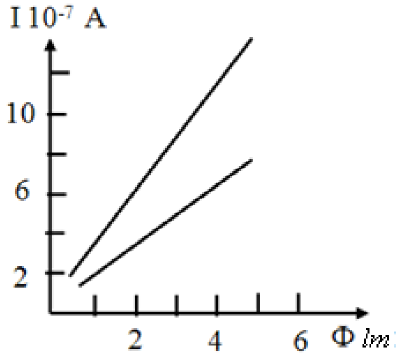


Figure 8.9

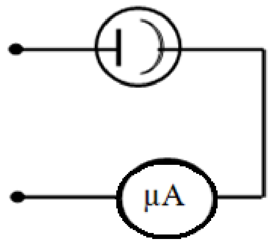


Figure 8.10

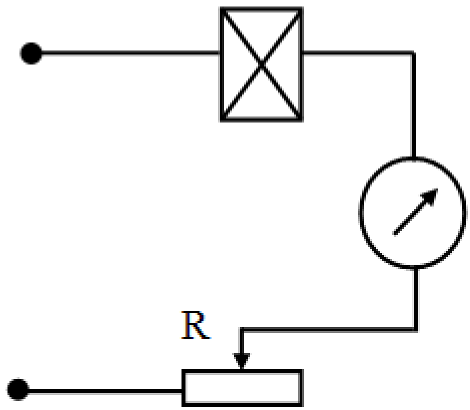


Figure 8.11

In this scheme, instead of a digital microamper meter, you can use the arrowhead, and in the extreme case, the galvanometer from the ammeter:

- to investigate the red limit of the photoelectric effect;
- to investigate the state of the photocurrent of saturation;
- we study the laws of the photoelectric effect according to the scheme, fig. 8.11.

Experiment 8.6 Detection of the red boundary of the photochemical process

Equipment: darkened room, three photoshop, developer, fixer, water, a set of filters, a shade projector illuminator, a physical tripod, a gloss.

We place a sheet of photo paper on the crop frame. Then, in photographic paper (15x10 *cm*) in two rows, place the filters in the following order: red, orange, yellow (first row), green, blue, purple (second row), fig. 8.12.

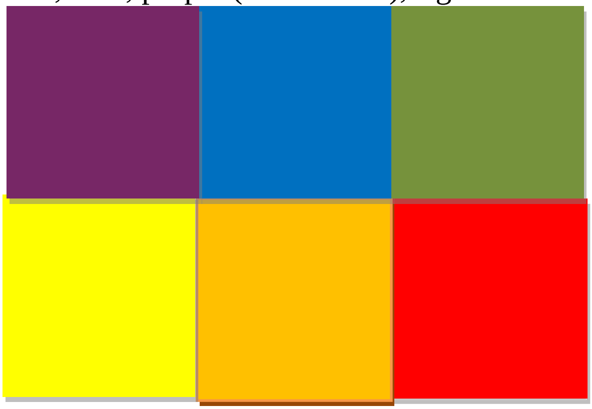


Figure 8.12

Turn on the luminaire for a shadow projection for 3-5 seconds, display, fix and wash photopaper and dry it on the gloss. We conduct an analysis of the photo, fig. 8.13, and draw a conclusion on the red boundary of the photochemical process. The boundary of photochemical reaction for photographic paper lies between the frequencies of orange and yellow light filters.

Experiments 8.7 Investigation of photochemical regularities

Equipment: from experiment 8.6.

Preparation for the experiment is similar to the experiment 8.6. In front of the opening in the box of the drawer on the bridge of the poisonous cadaver with a 5x5 *cm* clearance. In the illuminator for a shadow projection place a yellow filter. Cover the lid with a red glass.

Through armpit we move hands with an envelope with photo paper into the drawer. Expand the envelope we remove from it a strip of photo paper 5x15 *cm* and place it on the cadre frame. The field for illuminating paper is 5x5 *cm*. Turn on the illuminator for the shadow projection, remove the red glass from the cover and light up with a red glass and move the photographic paper in length by 5 *cm*.

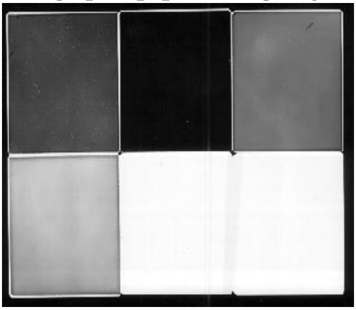


Figure 8.13

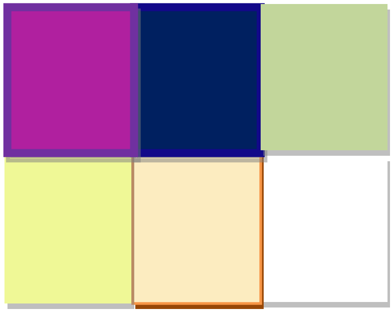


Figure 8.14

Illuminate the photographic paper for 4 seconds. The third part of the photo paper is exposed for 8 seconds. After that, turn on the red lantern, process photographic paper with reagents and gloss it.

Attentive eye-catching eyes are visible, fig. 8.15.

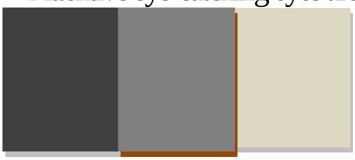


Figure 8.15

Figure 8.16

Compare the degree of blackening of the photo paper and its exposure time for yellow and blue light filters. We conclude that the mass of contacting with light substances is proportional to the exposure time.

Experiment 8.8 Determination of Planck's constant in the photoelectric method

Equipment: self-made current amplifier, photomultiplier FEU-2, illuminator for shadow projection, a set of filters.

Stable Plank can be detected by a photoelectric method for known latency potential. To do this, we make homemade bridge amplifier of voltage, rice. Current source at 6 A, voltmeter at 100 V, potentiometer 30-50 Ω, potentiometer on 500-1000 Ω.

The job is performed in the following order:

1) Close the photocell from the light.

2) We set the potentiometer knobs to the extreme right position.

3) We set to zero the indications of the microamper meter at the output and no more regulate it.

4) Open the photocell.

5) With the potentiometer hand, we deduce the delaying potential to zero.

6) We work with the use of filters.

The shoulders of the bridge are the supports *R*, *r* and the internal supports of the double triode 6H1P. Electronic bulbs are capable of changing their internal resistance, depending on the potential of the grid. In the proposed scheme, the change in the potential of the grid of the triode is carried out by the photocell FEU-2 (turn on the photocell as a photocell without the use of an emitter). The equilibrium of the bridge is fixed by a microamper meter. When the photocell is dimmed, its internal resistance is large. On the grid of the L_a lamp, electrons emanating from the cathode are accumulated. The net will have a disproportionate potential. A weak current flows through the circle of the L_R (fig.8.17).

There will be no such electron capture on the mesh of the lamp L_b, because it is connected through the resistance *q* with the current source U_c. The strings flowing through the shoulders of r_{Lb} and R_{La} will not be equal. Some microcurrent flows through the microamper meter. Potentiometer *q* level them at voltage U_v.

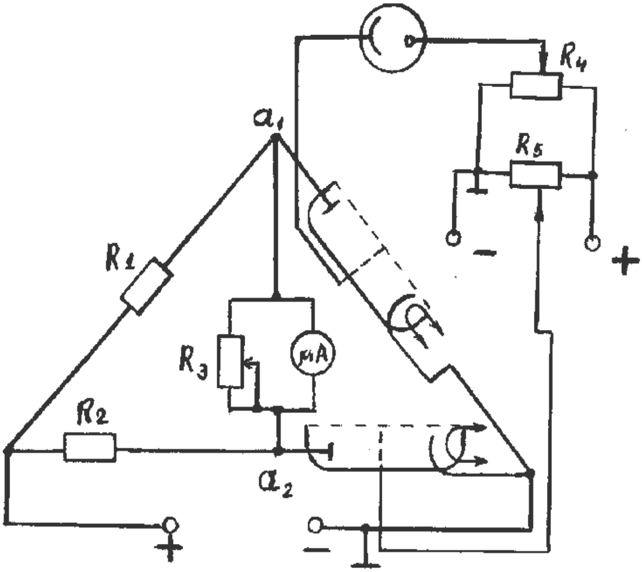


Figure 8.17

We direct the monochromatic light on the photocell. Bridge equilibrium is disturbed, because the potential of the L_a bulb is increasing. We offset the bridge by feeding the retaining voltage to the photocell with the potentiometer *Q*. The delaying potential is determined by $U = U_z - U_v$. The state of the experiment is carried out in the following sequence:

1 The sampler device from photocell FEU-2 put on a bar stands.

2 At a distance of 50-80 *cm* from the photocell, place the illuminator from the shadow projection.

3 In the clip of the illuminator, successively place filters from the school set.

4 Potentiometer *Q* changes the voltage on the grid lamp. Each time we determine the size of the lagging potential.

We construct the dependency graph $U = f(I)$.

So $tg\ \alpha = (U_2 - U_1)/(\nu_2 - \nu_1)$. The value of the table of the Planck is determined by the formula $h = l$ tg $\alpha = l(U_2 - U_1)/(\nu_2 - \nu_1)$. In this experiment, we can use other schemes of investigation of the laws of the photoelectric effect. On fig. 8.18 shows the scheme of the device on the parametric amplifier.

It uses a B_a source of 4 V DC, a DC source of 100 V (VUP-2), milliamemer M 82 with a scale of 500-600 μV, an R resistance of 300 MΩ, a voltmeter U_a at 6 V, an U-volt meter of 100.

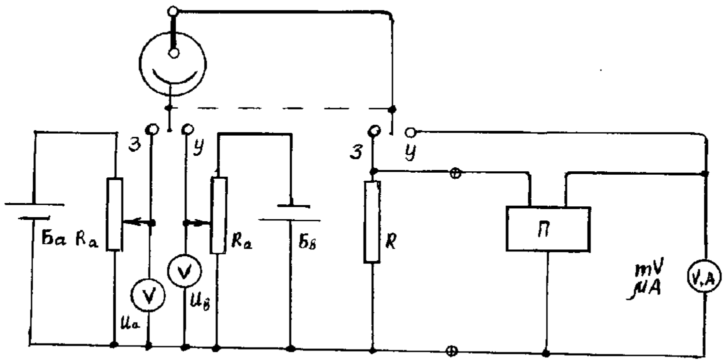


Figure 8.18

In, the potentiometer R_a is 30-50 Ω, the potentiometer R_v is 500-1000 Ω. The job is performed in the following order:

1 Close the photolence from the light.

2 We set the potentiometer handles to the extreme right position.

3 We set to zero the indications of the microamper meter at the output and no longer regulate it.

4 Open the photocell.

5 With the potentiometer hand, we deduce the delaying potential to zero.

7 We perform the work using light filters.

Experiment 8.9 Simulation of Bot Experiment

Equipment: 1V light bulb, 4V current source, 16 Ω rheostat, switch, two SG2S lamps, self-made indicator, VUP-2, two low frequency school amplifiers.

A photon source is a light bulb coupled to a current source via a switch and a rheostat. As photon indicators, we use SL2S type dimmers, fig. 8.19.

The amplification of current pulses is achieved with the help of two low frequency pedestal amplifiers. Stabilites are sensitive to cosmic rays and other sources of elemental particles. To reduce the side effect both indicators place in a lead tube with a thickness of walls 2-3 *mm*. Such a pipe is made from a piece of armored telephone cable with a diameter of 4-5 *cm* and a length of 20-30 *cm*.

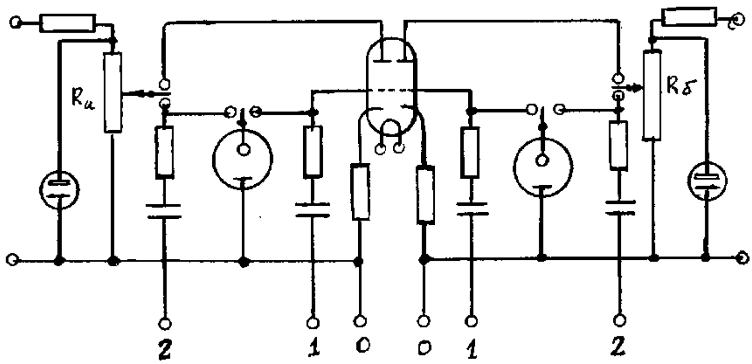


Figure 8.19

Also, the pipe can be made of several tubes of a smaller diameter: we cut them along the length, expand to the desired diameter, fold one to another and wrap with an insulating strand, in the middle part of the pipe we drill a revolver behind the chuck for a low light bulb. On the contrary, we make another breakthrough to observe the degree of incandescence of the bulb. The pipe is placed in two small metal clamps, with which we clamp in the lapps of the physical tripod.

With resistors R_a, R_b and at the incandescent light bulbs, we choose such a mode of operation of the installation, so that each of her shoulders gives 20-30 consecutive per minute. Loudspeakers are separated from each other at a distance of 1.5-2 *m*. This allows you to distinguish the impulses of each stabilizer. Regulators of the tone of the amplifiers adjust different tones of sound impulses.

To improve the sensitivity of the device using the double triode type 6N1P or 6N23P. For this switch, fig. 8.19, we are converted to position 2 (electric bulbs have plenty of nomepacs).

Experiments are conducted in the following sequence:

1 To UPUP-2, we connect the power conductors of the circuit and supply it to a voltage circle of 200 V.

2 Low frequency amplifiers are combined with the output of the registration device.

3 Resistors R_v and R_g ensure that each shoulder of the installation gives 20-30 deductions per minute.

4 Then turn on the bulb of incandescence.

5 With the rheostat, we change the degree of inflammation of the bulb and hear the change in the pulse frequency. This is confirmed by the effect of the light flux on the work of the meter.

6 Then set the bulb constantly and count the number of pulses per minute for each shoulder.

7 Compare the data obtained with the case when the light bulb is turned off. We have a difference of about 30-40 impulses per minute. We draw attention that the amplifiers are running at the same time. This indicates that the radiation of light has a photonic character.

Experiment 8.10 Simulation of the Bot Test on the Thyratrons

Equipment: homemade appliance, lead tube.

The scheme of a self-made device for the indexing of photons is shown in fig. 8.20.

The indicators of the photons are stabilized by SG2S. A variation of the resistance of R_a on the thyratrons reaches a voltage of about 120 V. The method for manufacturing a lead tube with an electric light bulb is described in the test

8.20. According to the wave theory, the wave front of the light wave from the source extends to the two counterparts practically the same.

Therefore, both counters should work synchronously. If the radiation passes in the form of individual photons, which have a certain direction of distribution in space, then between the acts of operation of both meters there should be no connections. In reality, they do not work synchronously, which confirms the photonic nature of the radiation of light.

The device turns on 220V. If you use a meter of type SI1G, you can fix the gamma radiation.

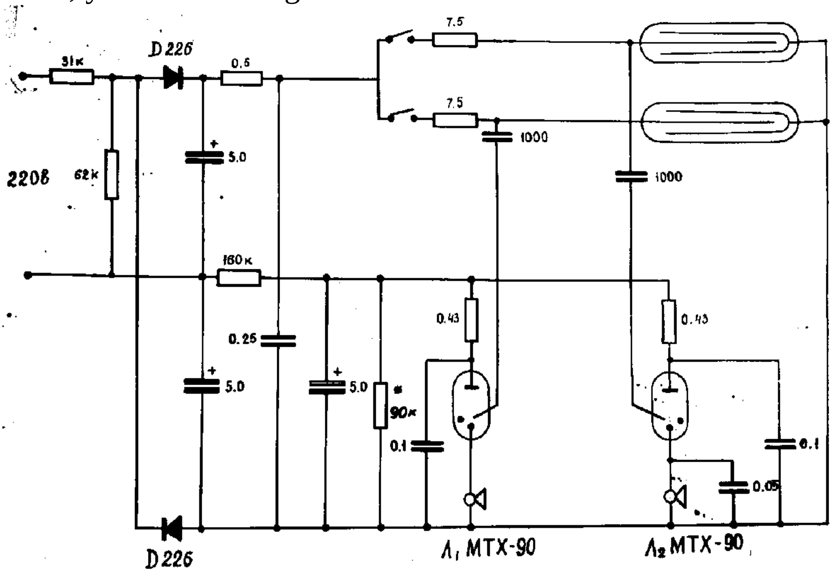


Figure 8.20

8.2 Radioactivity and Nuclear Reactions

A block of wood on the roof of a building has potential energy in many forms. If it is dropped off the roof, its gravitational potential energy is converted into kinetic energy. If it is burned, its chemical potential energy is converted to thermal energy and light. The nucleus of every atom in the wood has a large amount of potential energy. In this century, humans have learned to convert the potential energy of the nucleus to other forms. The uses that humankind makes of this tremendous energy will determine the future of Earth (conversion of energy).

8.2.1 Radioactivity

Radioactivity was discovered by a French scientist, Henri Becquerel, in 1896. He left some uranium ore lying on a photographic plate in a dark desk drawer. When he developed the plate, Becquerel was surprised to find an outline of the uranium sample. Uranium had released invisible radiation that exposed the plate. He had discovered that uranium is a radioactive element.

All elements are made of atoms. In the nucleus of an atom are the protons and neutrons. The strong nuclear force between the particles holds them together. However, the nuclei of some elements are not held together strongly enough. These nuclei are unstable. To be unstable means that a nucleus emits a particle or radiation. The particle or radiation is emitted with a large amount of kinetic energy. This process is called **radioactive decay.** The new nucleus that results from the decay may be unstable and decay again, or it may be stable.

In 1898, Marie and Pierre Curie discovered **two** new radioactive elements, polonium and radium, in uranium ore. Both polonium an radium are more radioactive than uranium. Since that time, many more radioactive elements have been discovered. Recall that isotopes are atoms of the same element with different numbers of neutrons.

All of the isotopes of elements with atomic numbers greater than that of bismuth are radioactive. However, some natural isotopes of lighter elements are also radioactive. For example, potassium, carbon, and oxygen all have naturallyoccurring radioactive isotopes.

Periodic system

Group	1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	I	II												III	IV	V	VI	VII	VIII
Period																			
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca		21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr		39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

Figure 8.21 Although technicium, element 43, does not occur naturally on Earth, it has been detected in the spectrum of the sun and other stars

Synthetic elements are those that have been produced in the laboratory or in nuclear reactors. They do not occur naturally. Elements with atomic numbers between 93 and

118 are synthetic elements. All isotopes of the synthetic elements are radioactive.

8.2.2 Nuclides

The study of radioactivity and nuclear reactions involves the study of the atomic nucleus. Thus, it is necessary to label different isotopes of the same element. A **nuclide** is the nucleus of an isotope that has a specific atomic number and atomic mass. The symbol used to show a particular nuclide includes the atomic number, mass number, and element symbol. The element carbon has several different nuclides. One carbon nuclide has the following symbol. Mass number, Element name, Atomic number. This nuclide is called carbon-12.

The stability of a nuclide depends upon the ratio of protons to neutrons in the nucleus. Look at the distribution of nuclides in fig. 8.22. The lighter nuclides that are stable have almost equal numbers of protons and neutrons. The stable nuclides of heavier elements have more neutrons than protons. Stable nuclides like carbon-12 do not decay. Carbon-12 has six protons and six neutrons.

If there are too many or too few neutrons compared with the number of protons in a atom, that nuclide may be radioactive. Carbon-14 has six protons and eight neutrons and is radioactive. Many of the common elements have radioactive nuclides. Radioactive nuclides have many practical uses. They are used to trace a substance through a living system. For instance, radioactive phosphorus-32 placed in the soil around a plant will be absorbed into the plant.

The movement of the phosphorus-32 through the plant can be followed with a Geiger counter, an instrument used to detect radiation. By tracking the movement of the element, scientists may learn how it is used in the plant.

Some radioactive nuclides, such as cobalt-60, emit high energy radiation that can be used to kill cancer cells. Radioactive nuclides are also used to detect tumors and other diseases in organs.

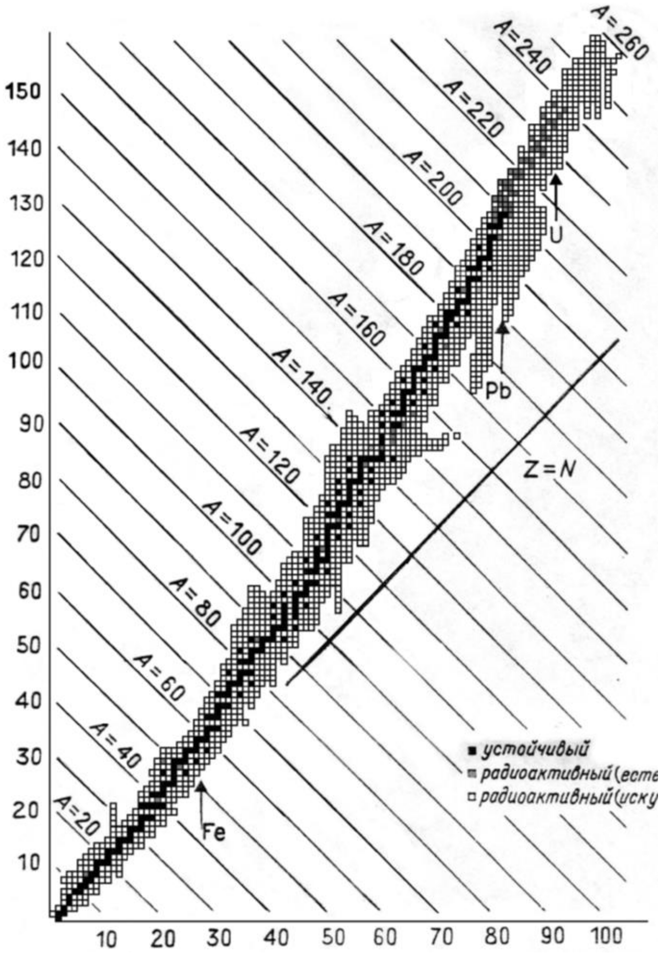


Figure 8.22

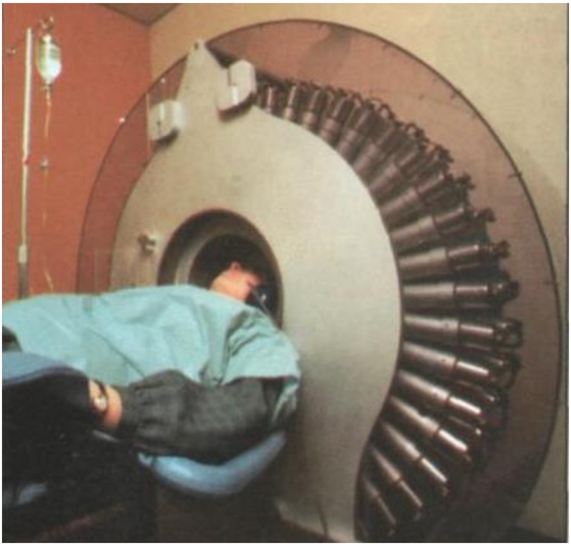


Figure 8.23 Radioactive elements are used as tracers in modern diagnostic procedures such as PET scans

Table 8.2.2.1

	Radioactive N		Nuclides of Some Elements	
Element	Nuclide	**Atomic mass**	**Protons**	**Neutrons**
Hydrogen en	H	3	1	2
Helium	**He**	5	2	3
Lithium	Li	8	3	5
Carbon	C	14	6	8
Nitrogen	**N**	16	7	9
Potassium	**40**	40	19	21

Experiment 8.11 with Wilson's camera

Equipment: Material list, Variable transformer, 25 VAC/ 20 VDC, 12 A 13531-93, Housing for experiment lamp, Cloud chamber,w/o source Ra, H-base PHYWE, with

5 fixing points, Single condenser, *f* 100 *mm* 08, Holder G 6.35 f.50/100W halo.lamp , Support rod PHYWE, square l 400 *mm*, Right angle clamp.

Figure 8.24 Detection of radioactive radiation with the Wilson cloud chamber

Figure 8.25

Principle. At higher temperatures, there is sufficient infrared radiation that we can feel heat if we are close to the object. At still higher temperatures (on the order of 1000 K), objects actually glow, such as a red-hot electric stove burner or the heating element in a toaster. At temperatures above 2000 K, objects glow with a yellow or whitish color, such as white-hot iron and the filament of a light bulb. The light emitted is of a continuous range of wavelengths or frequencies, and the spectrum is a plot of intensity vs. wavelength or frequency. As the temperature increases, the electromagnetic radiation emitted by objects not only increases in total intensity but reaches a peak at higher and higher frequencies.

The spectrum of light emitted by a hot dense object is shown in fig. 6.25 for an idealized blackbody. A blackbody is a body that would absorb all the radiation falling on it (and so would appear black under reflection when illuminated by other sources). The radiation such an idealized blackbody would emit when hot and luminous, called blackbody radiation (though not. necessarily black in color), approximates $\lambda_p T$=2,9010^{-3} *mK*. This is known as Wien's law.

8.2.3 The Sun's surface temperature

Estimate the temperature of the surface of our Sun, given that the Sun emits light whose peak intensity occurs in the visible spectrum at around 500 *nm*.

Approach. We assume the Sun acts as a blackbody, and use λ_p=500 nm in Wien's law. SOLUTION Wien's law gives T=2,9010^{-3} *mK*/λ_p≈6000 K.

Star color.

Suppose a star has a surface temperature of 32,500 *K*. What color would this star appear?

Approach. We assume the star emits radiation as a blackbody, and solve for in Wien's law1.

Solution. From Wien's law we have $\lambda_p = 2.9010^3 mK/T = 2{,}9010^{-3}\ mK/3{,}25\ 10\ K = 89{,}2\ nm$.

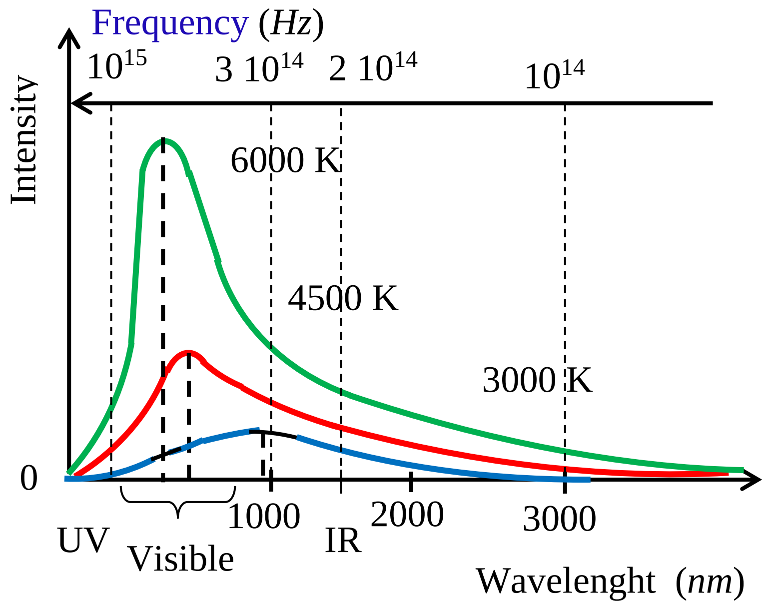


Figure 8.26

The peak is in the UV range of the spectrum, and will be way to the left in fig. 8.26. In the visible region, the curve will be descending, so the shortest visible wavelengths will be strongest. Hence the star will appear bluish (or blue-white).

NOTE This example helps us to understand why stars have different colors (reddish for the coolest stars, orangish, yellow, white, bluish for «hotter» stars.)

8.3 Planck's Quantum Hypothesis

A major problem facing scientists in the 1890s was to explain blackbody radiation. Maxwell's electromagnetic theory had predicted that oscillating electric charges produce electromagnetic waves, and the radiation emitted by a hot object could be due to the oscillations of electric charges in the molecules of the material.

Although this would explain where the radiation came from, it did not correctly predict the observed spectrum of emitted light. Two important theoretical curves based on classical ideas were those proposed by W Wien (in 1896) and by Lord Rayleigh (in 1900).

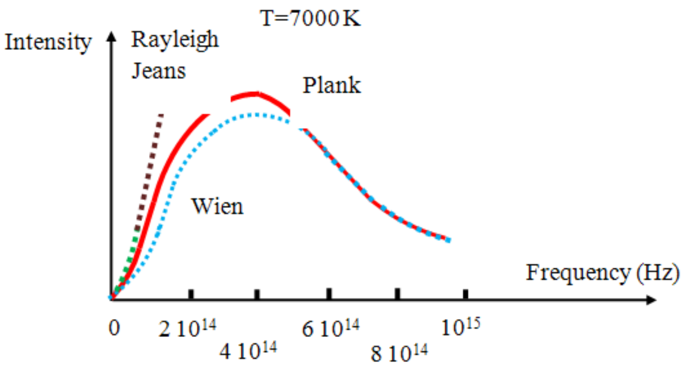


Figure 8.27

The latter was modified later by J. Jeans and since then has been known as the Rayleigh-Jeans theory. As experimental data came in. it became clear that neither Wien's nor the Rayleigh-Jeans formulations were in accord with experiment (fig. 8.27).

In the year 1900 Max Planck (1858-1947) proposed an empirical formula that nicely fit the data (now often called Planck's radiation formula): Planck's formula $I(\lambda, T)$ is the radiation intensity as a function of wavelength A at the temperature T; k is Boltzman's constant, c is the speed of light, and h is a new constant, now called Planck's constant. The value of h was estimated by Planck by fitting his formula for the blackbody radiation curve to experiment. The value accepted today is h=6,62 10^{34} *Dz c*.

To provide a theoretical basis for his formula, Planck made a new and radical assumption: that the energy of the oscillations of atoms within molecules cannot have just any value; instead each has energy which is a multiple of a minimum value related to the frequency of oscillation by Planck's assumption suggests that the energy of any molecular vibration could be only a whole number multiple of the minimum energy *h*.

Where *n* is called a ***quantum number*** («quantum» means «discrete amount» as opposed to «continuous»). This idea is often called Planck's quantum hypothesis, although little attention was brought to this point at the time. In fact, it appears that Planck considered it more as a mathematical device to get the «right answer» rather than as an important discovery in its own right. Planck himself continued to seek a classical explanation for the introduction of *h*. The recognition that this was an important and radical innovation did not come until later, after about 1905 when others, particularly Einstein, entered the field.

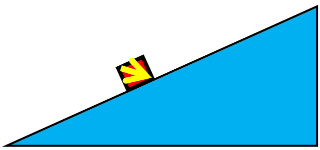


Figure 8.28

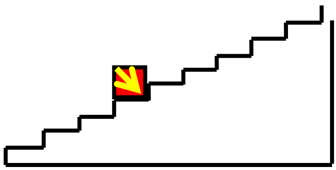


Figure 8.29

Photon Theory of Light and the Photoelectric Effect

The quantum hypothesis, fig. 8.29, states that the energy of an oscillator can be $E = hf$, or $2hf$, or $3hf$, and so on, but there cannot be vibrations with energies between these values. That is, energy would not be a continuous quantity as had been believed for centuries; rather it is quantized-it exists only in discrete amounts. The smallest amount of energy possible (hf) is called ***the quantum of energy.***

Another way of expressing the quantum hypothesis is that not just any amplitude of vibration is possible.

A simple analogy may help. Compare a ramp, on which a box can be placed at any height, to a flight of stairs on which the box can have only certain discrete amounts of potential energy, as shown in fig. 8.28.

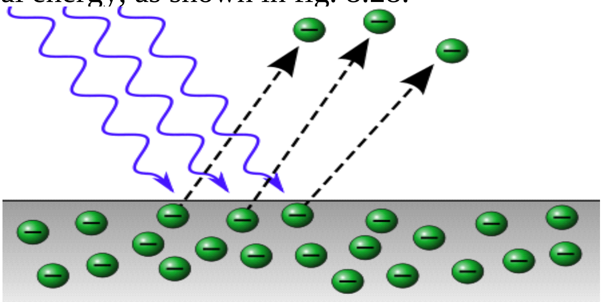


Figure 8.29 Photoelectric effect

In 1905, the same year that he introduced the special theory of relativity, Einstein made a bold extension of the quantum idea by proposing a new theory of light. Planck's work had suggested that the vibrational energy of molecules in a radiating object is quantized with energy $E = nhf$, where n is an integer and f is the frequency of molecular vibration. Einstein argued that when light is emitted by a molecular oscillator, the molecule's vibrational energy of nhf must decrease by an amount hf (or by $2hf$, etc.) to another integer times hf, such as $(n - 1)hf$. Then to conserve energy, the light ought to be emitted in packets, or quanta, each with energy.

Again h is Planck's constant. Since all light ultimately comes from a radiating source, this suggests that perhaps light is transmitted as tiny particles, or photons, as they are now called, as well as via waves predicted by Maxwell's electromagnetic theory. The photon theory of light was a radical departure from classical ideas. Einstein proposed a test of the quantum theory of light: quantitative measurements on the photoelectric effect. When light shines on a metal surface, electrons are found to be emitted from the surface.

This effect is called the photoelectric effect and it occurs in many materials, but is most easily observed with metals. It can be observed using the apparatus shown in fig. 8.29.

Figure 8.30

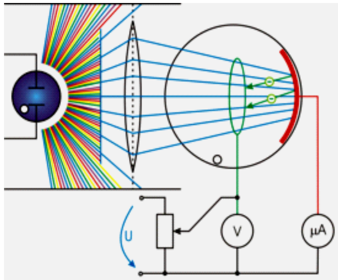


Figure 8.31

A metal plate *P* and a smaller electrode *C* are placed inside an evacuated glass tube, called a photocell. When the photocell is in the dark, the ammeter reads zero. But when light of sufficiently high frequency illuminates the plate, the ammeter indicates a current flowing in the circuit. We explain completion of the circuit by imagining that electrons, ejected from the plate by the impinging radiation, flow across the tube from the plate to the «collector» *C* as indicated in fig. 8.31.

Equipment: high voltage supply unit, 0-10 kV, power supply for spectral lamps, spectral lamp *Hg* 100, pico 9 base, electroscope, kolbe type, lamp holder, pico 9, f.spectr, lamps, high-value resistor, 10 MΩ, screen, metal, 300 x 300 *mm*, conductor ball, *d* = 40 *mm*, danger sign - high-voltage, zinc plate f.photoelectric effect, plexiglas plate, 200x200x4 *mm*, socket adapter for safety tubing, 10 pcs., supporting blocks,set of 4, felt, natural hair, 10 x 10 *cm*, emery paper, medium, 5 sheets, conn. cord, safety, 32 *A*, 100 *cm*, blue; conn. cord, safety, 32 *A*,100 *cm*, grye; conn. cord, safety, 32 *A*, 25 *cm*, grye.

Extension unit for safety connecting cables. The results were fully in agreement with Einstein's Stand tube.

A brightly polished Zinc plate on an electroscope is negatively charged. When lit with the *Hg* vapour lamp, the electroscope discharges again. The plate is not discharged if a glass sheet is held between the lamp and zinc plate or the electroscope is positively charged. That electrons should be emitted when light shines on a metal. It is consistent with the electromagnetic (EM) wave theory of light.

Einstein pointed out, however, that the wave theory and the photon theory of light give very different predictions on the details of the photoelectric effect.

For example, one thing that can be measured with the apparatus of fig. 8.31 is the maximum kinetic energy of the emitted electrons. This can be done by using a variable voltage source and reversing the terminals so that electrode *C* is negative and *P* is positive. The electrons emitted from *P* will be repelled by the negative electrode, but if this reverse voltage is small enough, the fastest electrons will still reach *C* and there will be a current in the circuit. If the reversed voltage is increased, a point is reached where the current reaches zero-no electrons have sufficient kinetic energy to reach *C*. This is called the stopping potential, or stopping voltage, V_0, and from its measurement, $K_{\max}$ can be determined using conservation of energy (loss of kinetic energy = gain in potential energy): $K_{max}=eV_o$.

Now let us examine the details of the photoelectric effect from the point of view of the wave theory versus Einstein's particle theory.

First the wave theory, assuming monochromatic light. The two important properties of a light wave are its intensity and its frequency (or wavelength). When these two quantities are varied, the wave theory makes the following predictions:

1 If the light intensity is increased, the number of electrons ejected and their maximum kinetic energy should be increased because the higher intensity means greater electric field amplitude, and the greater electric field should eject electrons with higher speed.

2 The frequency of the light should not affect the kinetic energy of the ejected electrons. Only the intensity should affect K_{max}.

The photon theory makes completely different predictions. First we note that in a monochromatic beam, all photons have the same energy ($E=hf$). Increasing the intensity of the light beam means increasing the number of photons in the beam, but does not affect the energy of each photon as long as the frequency is not changed. According to Einstein's theory, an electron is ejected from the metal by a collision with a single photon. In the process, all the photon energy is transferred to the electron and the photon ceases to exist. Since electrons are held in the metal by attractive forces, some minimum energy W_0 is required just to get an electron out through the surface. W_0 is called the ***work function***, and is a few electron volts (l eV = 1.6 10^{-19} J) for most metals. If the frequency f of the incoming light is so low that hf is less than W_0, then the photons will not have enough energy to eject any electrons at all. If $hf > W_o$, then electrons will be ejected and energy will be conserved in the process. That is, the input energy (of the photon), hf, will equal the outgoing kinetic energy K of the electron plus the energy required to get it out of the metal, $hf=K+W$.

The least tightly held electrons will be emitted with the most kinetic energy (K_{max}), in which case W in this equation becomes the work function W_0, and K becomes K_{max}: $hf=K_{max}+W_o$.

Many electrons will require more energy than the bare minimum (W_o) to get out of the metal, and thus the kinetic energy of such electrons will be less than the maximum. From these considerations, the photon theory makes the following predictions:

1An increase in intensity of the light beam means more photons are incident, so more electrons will be ejected; but since the energy of each photon is not changed, the maximum kinetic energy of electrons is not changed by an increase in intensity.

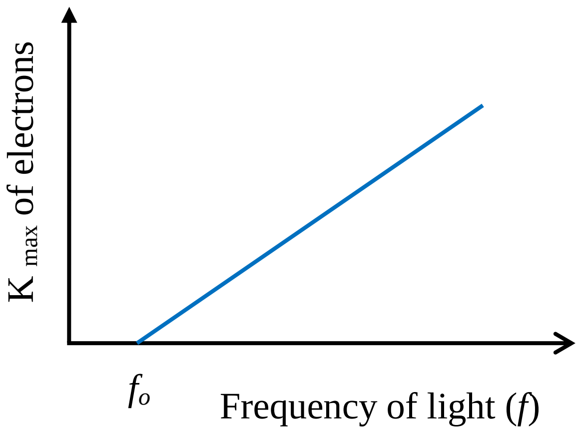


Figure 8.32

2 If the frequency of the light is increased, the maximum kinetic energy of the electrons increases linearly, according to Eq. $K_{max}=hf-W_o$. This relationship is plotted in fig. 8.32.

3 If the frequency f is less than the «cutoff» frequency f_o, where $hf_o = W_0$, no electrons will be ejected, no matter how great the intensity of the light.

These predictions of the photon theory are clearly very different from the predictions of the wave theory. In 1913-1914, careful experiments were carried out photon theory.

One other aspect of the photoelectric effect also confirmed the photon theory. If extremely low light intensity is used, the wave theory predicts a time delay before electron emission so that an electron can absorb enough energy to exceed the work function. The photon theory predicts no such delay - it only takes one photon (if its frequency is high enough) to eject an electron and experiments showed no delay. This too confirmed Einstein's photon theory.

8.4 Compton effect

The particle nature or corpuscular nature of light was more firmly established by the discovery of the Compton effect. In 1923, **A. H. Compton** (USA, 1892 - 1962) discovered that the scattering of *X*- rays by a crystal *P*, fig. 8.33, can be explained well on the basis of the particle nature of light. Of course, the phenomenon that *X*-rays are scattered by crystals *P* had been well-known before. Compton found that, if we consider that *X*-rays collide with the electrons in a crystal.

To formulate this process, we have to define the ***momentum of a light quantum***. It has been discussed that a light quantum is a «particle» with energy $h\nu$. This «particle» is considered to carry a ***momentum*** at the same time. We know that light gives a pressure on the surrounding wall. How large is the amount of the momentum? Let us study this below. Consider a container filled with light of frequency ν. Let the pressure given on the wall of the container by the light be *P* and the energy of the light per unit volume be *U*.

We have a relation $P=U/3$ which is proved by experiment. (This relation can also be derived from the classical theory.) From this relation, we see that the momentum *p* of a light quantum is given as $p=\nu h/c=h/\lambda$. Namely, we can say that ***the momentum of a light quantum is given by dividing the energy by the light speed***. This result can be obtained by a method similar to that through which we derived the relation between the molecular motion in a gas and its pressure.

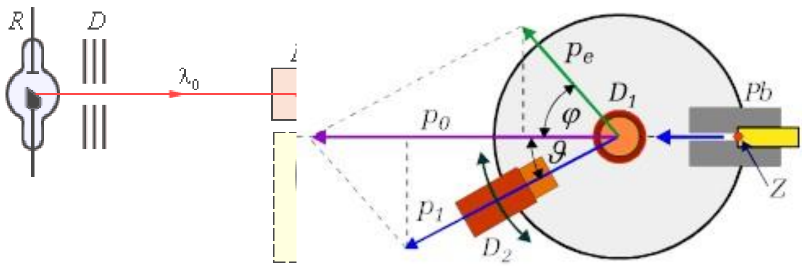


Figure 8.33

Compton found that, when the monochromatic *X*-rays are illuminated on on a graphite (a kind of carbon crystal), the wavelength of the scattered *X*-rays would be longer as the scattering angle becomes larger. рисунокThis cannot be explained with the classical theory.

Compton analyzed Compton scattering as follows. He thought that the incident *X*-rays collide against the electron in the graphite as a «particle» with the energy $h\nu$ and the momentum $h\nu/c$. Suppose that the energy and the momentum of the *X*-rays scattered in the scattering angle θ are $h\nu'$ and $h\nu'/c$, respectively.

The electron the mass *m* recoils with a momentum *mv*. The energies and momenta in Compton scattering are shown in the following fig. 8.34.

The momentum conservation relation is written $m^2v^2=h^2(\nu^2+\nu'^2-2\nu\nu'\cos\theta)$. Since $\nu\approx\nu'$, we have $0=(\nu-\nu')^2=\nu^2+\nu'^2-2\nu\nu'$.

Inserting this into the above momentum conservation relation, we get $m\upsilon^2=2h^2\nu\nu'(1-\cos\theta)/mc^2$.

On the other hand, the energy conservation is written $m\upsilon^2=2h(\nu-\nu')$.

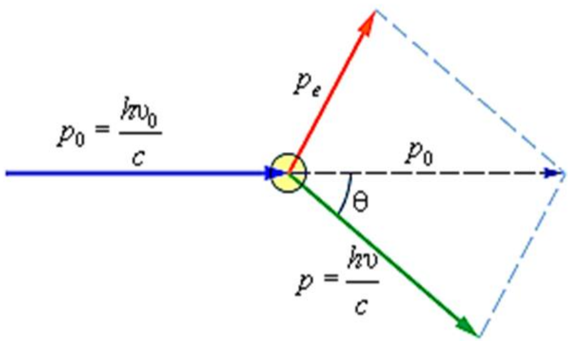


Figure 8.34

Therefore, the difference between the wavelength of the incident and scattered *X*-rays becomes $\Delta\lambda=\lambda'-\lambda=c/\nu'-c/\nu=c(\nu-\nu')/\nu\nu'=h(1-\cos\theta)/mc$.

Accordingly, the wavelength of the scattered *X*-rays becomes longer as the scattering angle θ increases.

Compton's results at the scattering angles, 0º, 45º, 90º and 135º, are shown in the following fig.8.35. Each graph represents the intensity of *X*-rays (ordinate) as a function of wavelength (abscissa).

As the scattering angle increases in the above fig. 8.35, the intensity of *X*-rays separates into two peaks; the right one of the longer wavelength λ' shifts to longer region. This wavelength λ' is well fit to the formula presented above.

The wavelength of another peak is just the same as that of the incident *X*-ray beam. This is that scattered by the whole atom whose mass is quite large, so that the wavelength seems not to be varied. Thus the particle nature of *X*-rays was completely confirmed.

After Einstein proposed the ***hypothesis of light quanta*** in 1905, people have been doubtful of the idea of the particle nature of light for about 20 years.

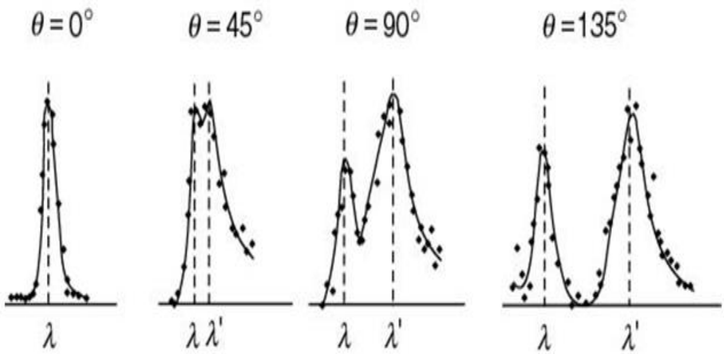


Figure 8.35

However, once they look at the experimental results of the Compton effect, they cannot help convincing themselves about the theory of light quanta. Then, the particle of light (light quantum) has been called ***photon***, which has been admitted into the brotherhood of «particles» like electrons or protons.

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