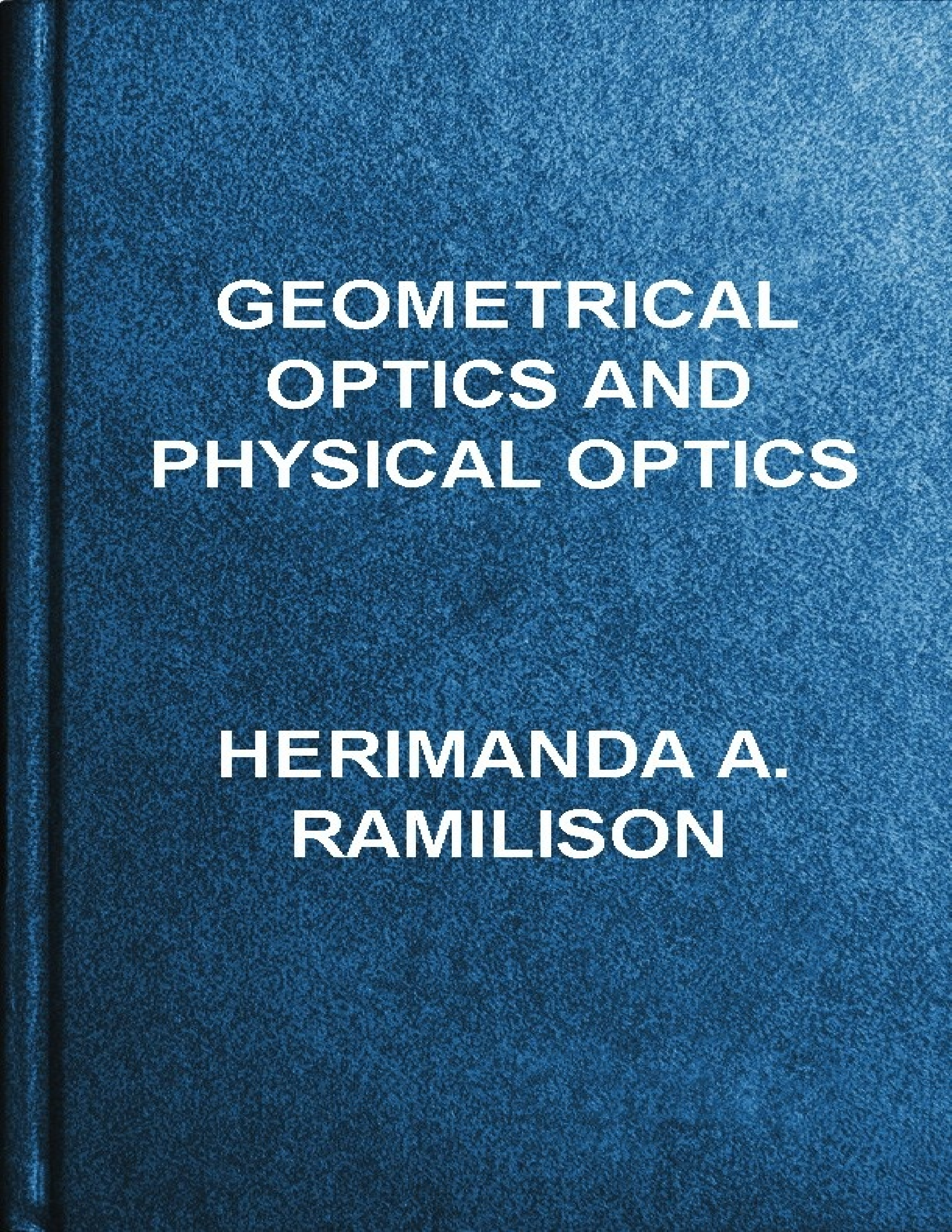
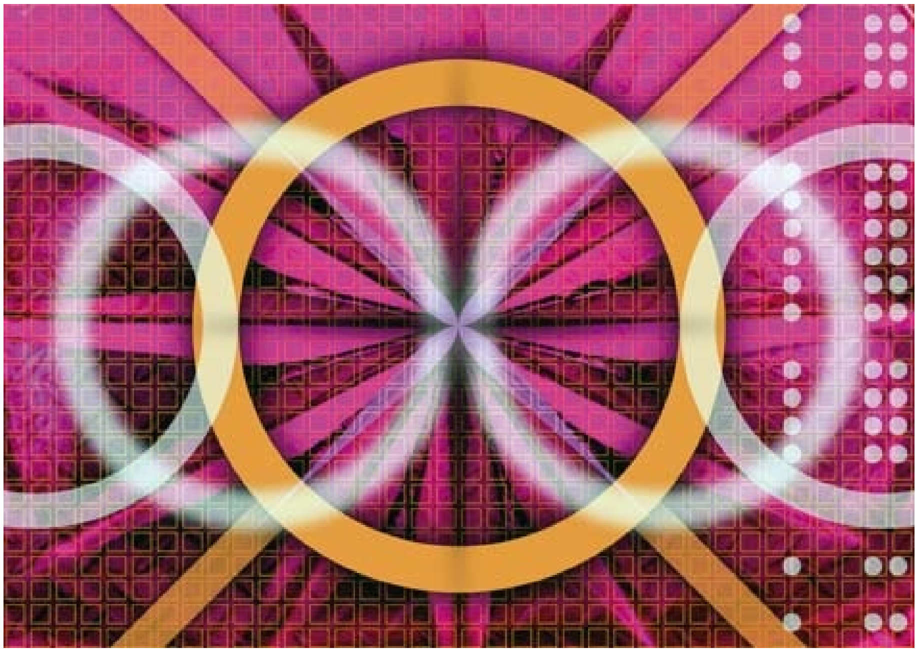


GEOMETRICAL OPTICS AND PHYSICAL OPTICS

HERIMANDA A. RAMILISON



Geometrical
Optics and
Physical
Optics

By Herimanda A. **Ramilison**

African Virtual university

Université Virtuelle Africaine

Universidade Virtual Africana

African Virtual University

African Virtual University

Table of ConTenTs

African Virtual University

I. Geometrical optics and Physical optics

Herimanda A. Ramilison (This section is unnecessary and should be deleted)

II. Introductory Course or basic notions

Required

To follow this module, the learner must master the following concepts:

Trigonometric equations, solution of first order equations with a single unknown variable, the concept of mirror images;

The fundamental principles of dynamics (vectorial representation of a force, graphical representation using a coordinates system);

General theorems of kinetic energy, angular momentum;

The following energy-related definitions: kinetic and potential energy stored in a capacitor, in a coil, mechanical or electrical (system?); (The highlighted in yellow is vague)

Ohm’s Law (study of electronic oscillators);

The mesh or loop rule applied to an electrical circuit;

The potential difference at the terminals of a coil, a resistor and a capacitor;

Solution of the following differential equations: second order, linear, with constant coefficients, with or without a second variable;

Sinusoidal movements;

Complex representation of a sinusoidal magnitude with respect to time;

Fresnel vectors;

Partial derivative (differential?) equations.;

III. Timetable Distribution

Unit 1 Geometrical Optics : 50 hours

Unit 2 Oscillations : 15 hours

Unit 3 Waves: 15 hours

Unit 4 Sound waves : 10 hours

Unit 5 Interference of Light: 30 hours

IV. Teaching Material

Computer with CD-ROM, video projector, television, Internet access, word processor, Excel, PowerPoint…

V. Module Justification/Importance

The current module is part of a teacher training program.

It will enable the learners to understand what they see (rainbows, mirages…), comprehend how to improve vision (eyeglasses, a magnifying glass, a microscope, a telescope…).

To possess knowledge about vibratory or oscillatory movement relative to a common notion: waves. This module explains the fact that it is impossible to obtain a very narrow ray of light simply by decreasing the diameter of the exit point.

VI. Contents

6.1

Overview

In this module, the concept of light’s behavior when reflected from the same medium or at the interface between two different media will be treated.

The construction of images obtained through optical systems and different types of lenses will be discussed. Certain optical systems will be presented in this module: the eye, a magnifying glass, a microscope, a telescope, a camera, along with the way they work by calculating focal lengths, magnification and vergency (optical power). The module explains the comprehension and correction of vision problems: farsightedness, nearsightedness.

The next step will be to explain essential wave-related concepts, along with the way they interact. The observation that the pitch of sound from a siren changes when the source or receiver or both moves will be elucidated. The concept of phase will allow the understanding of phenomena such as interference or diffraction when two apparently identical phenomena are superimposed.

African Virtual University

The current module deals with:

- Reflection, refraction,
- Polarization, Brewster’s Law,
- Plane mirrors, curved mirrors,
- Curved refractive surfaces,
- Thin lenses,
- Optical instruments,
- Harmonic oscillators,
-

Standing waves and resonance,

-

The Doppler Effect,

-

Beats,

-

The Superposition Principle,

-

Light wave interference and diffraction.

6.2 Schematic Representation

Geometrical

Optics

Fermat’s Principle

Reflection

Plane surface,

Astigmatism

Refraction

lenses

Snell-Descartes Laws

Paraxial (or Gauss)

Approximation

Optical

Aberration

Systems

Oscillation

Diffraction

Oscillator movement

Light interference

Mechanical Waves

Sound waves

Traveling waves and

Transverse waves and

stationary waves

longitudinal waves

African Virtual University

VII. General objectives

The learner must be able to :

Knowledge Goals

-

Recall Descartes’ Laws,

-

Recall Brewster’s Law,

Method Goals

Theoretical Abilities:

- Understand polarisation,
- Understand the functioning of optical systems,
- Understand oscillatory movement;
- Understand characteristic wave elements ;
- Understand wave superposition ;
- Understand the elaboration of a simple question ;

(how will understanding be measured?)

Practical or Experimental Abilities

- In a team, demonstrate an experiment about reflection using a mirror, paper and needles ;
- Find the image of a real object using a converging lens ;
- Converse with colleagues by chatting online.(A social chat? Be specific)

VIII. specific learning objectives (learning Goals)

Unit 1 Geometrical Optics

Specific Knowledge Goals:

Recall Descartes’ Laws;

Describe a thin lens using its definition;

Describe the optical components of a microscope;

Specific Theoretical Ability Goals:

Apply Descartes’ Laws;

Apply the Paraxial Approximation;

Determine the focal length for a curved mirror,

Determine the focal length for a thin lens;

Determine vergency; (optical power)

Determine magnification;

Determine lens characteristics required to correct myopia;

Specific Practical Ability Goals

In a team, carry out the reflection experiment using a mirror, paper and needles;

Experimentally determine an object’s image through a thin lens;

Build an object’s image using a combination of several thin lenses

Build an image for a farsighted person;

Unit 2 Oscillations

Specific Knowledge Goals:

Recall the definitions for oscillatory movement characteristics;

Specific Theoretical Ability Goals :

Determine the characteristic elements of oscillatory movement;

Use the equations related to oscillations;

Unit 3 Waves and Sound Waves

Specific Knowledge Goals:

Recall the definitions for wave characteristics;

Recall sound wave equations

Specific Theoretical Ability Goals:

Identify the different wave types;

Explain energy transfer;

Apply the wave equation to sound;

Explain the nature of the decibel scale;

Describe sound waves emitted from a point source;

Explain the effects of relative movement between sources of sound

Unit 4 Light Interference

Specific Knowledge Goals:

Recall the conditions needed to produce interferences;

Specific Theoretical Ability Goals:

Identify interferences by wave front division;

Identify interferences by amplitude division;

Explain the effects of superposition;

Explain diffraction.

Optional Educational Objective:

Create a short question

TIC integration (Specify what TIC means)

Communicate via the Web (What is the specific reason for this?)

IX.

Teaching and learning activities

9.1

Preliminary / Initial Evaluation

Preliminary Evaluation Title

Geometrical Optics and Physical Optics

Justification

This consists of finding out what the learner already knows about optics and waves.

QUESTIONS

1. The mirror image of a point A is point A’, which can be observed by any observer O if all the beams reflected by the mirror M from A seem to come from point A’.

a. True

b. False

2. A lens is a centered system made up of a ………….. homogenous and ………… medium and restricted by two …………. surfaces with radii R 1 and R , respectively.

2

Fill in the blanks with one word each.

3. Match up the following columns by associating the right letter and number together: (each formula describes one of the concepts)

a. Vergency (optical power)

1.

AʹB

A ʹ *B*

� (� A

(ʹB

A ʹ *B*

� =

� longueur

= *image* × · de·l

length ')

)

image

AB

A

B

(AB

A

B = longueur

object × · de·l

length ')

)

objet

α ʹ �

((

� *image*

diamètre· *apparent*

×

· *diameter*

×

)

image

)

b. Magnification

2.

α �

((*object*

diamètre· *apparent*

×

· *diameter*

×

)

objet

)

1

c. Enlargement

3. *f*

African Virtual University

4. A magnifying glass is used to:

a. decrease the apparent diameter of an object’s image compared to the object

as seen by the naked eye.

b. enlarge the apparent diameter of an object’s image compared to the object

as seen by the naked eye.

c. shift the apparent diameter of an object’s image compared to the object as seen by the naked eye.

Check off the right answer(s).

5. Observing a solar eclipse with a magnifying glass:

a. can cause blindness

b. can cause short-sightedness

c. can cause far-sightedness

d. is not harmful

Check off the right answer(s).

6. A plane mirror has a surface that is

a. flat,

b. curved,

c. transparent,

d. polished,

e. reflective.

Check off the right answer(s).

7. In a plane mirror, the image of an object is:

a. reversed

b. upside-down

c. superimposable onto the object

Check off the right answer(s).

8. With a converging lens, the image of an object is:

a. real

b. virtual

Check off the right answer.

9. If the height of the waves in relation to sea level is 2 meters, their amplitude

is:

a. 1 meter

b. 2 meter

c. 4 meter

Check off the right answer.

10. If the matter is moving in a direction that is parallel to the wave's direction of propagation, the wave is said to be:

a. traveling

b. stationary

c. longitudinal

d. transverse

Check off the right answer(s).

11. If the matter is moving in a direction that is perpendicular to the wave's direction of propagation, the wave is said to be:

a. traveling

b. stationary

c. longitudinal

d. transverse

Check off the right answer(s).

12. Two waves with the same frequency are superimposed; constructive interference is obtained when the phase difference is:

π

a. 0

b. 2

c.π

Check off the right answer(s).

13. Two waves with the same frequency are superimposed; destructive interference is obtained when the phase difference is :

π

a. 0

b. 2

c.π

Check off the right answer(s).

14. The sound of an ambulance’s siren as it approaches:

a. does not change

b. becomes more high-pitched

c. becomes more low-pitched

Check off the right answer.

African Virtual University

Preliminary Evaluation Title

Geometrical Optics and Physical Optics

Answer key

1.

a. Good answer. You certainly know how to construct the image of an object through a mirror.

b. Be careful, take your time to answer.

2. A lens is a centered system made up of a **transparent**, homogenous and **isotropic** medium restricted by two **curved** surfaces with radii R and R ,

1

2

respectively.

Very good. You understand the definition of a lens.

If the student switches certain words by writing isotropic instead of transparent, for example, give the following feedback: You’ve confused isotropic and transparent, please try again.

If the student writes transparent instead of curved, give the following feedback: You have confused transparent and curved, please try again.

3.

a3. Good combination. The expression truly is the vergency (optical power) formula.

b1. Good job. The formula really is the one that describes magnification.

c2. Good answer. This equation is used to determine enlargement.

4.

a. Try again. You most likely have never used a magnifying glass.

b. Good job, you know what a magnifying glass does.

c. Careful, a magnifying glass doesn’t have that role.

5.

a. Congratulations. You have understood that you must never look at a solar eclipse with a magnifying glass.

b. It’s stronger than myopia.

c. It’s more acute than far-sightedness.

d. Watch out, a magnifying glass does indeed damage the eye.

6.

a. Good job. A plane mirror’s surface is indeed flat, just like its name suggests.

b. Careful. Why curved?

c. Do you know what transparent means?

d. Good answer. A plane mirror’s surface must be polished.

e. Very good. In fact, a plane mirror’s surface must be reflective or we would not be able to see our reflection.

7.

a. Good answer. You noticed that right and left are switched around.

b. Certainly not ; the head is not on the bottom with the feet on top is it ?

8.

a. Very good. The image truly is real.

b. Why virtual? It is not a diverging lens.

9

a. Sea-level must not be below the height of the waves.

b. Good answer; average sea-level is the same as the height of the waves.

c. Sea-level cannot be twice the height of the waves.

10.

a. Try again.

b. Careful, most definitely not stationary.

c. Congratulations. The wave that is moving in a direction that is parallel to the direction of propagation is indeed called longitudinal.

d. Take your time, a transverse wave travels perpendicularly to the direction of propagation.

11.

a. Try again after rereading the question

b. Careful, most definitely not stationary.

c. A longitudinal wave travels parallel to the direction of propagation. Try again.

d. Good job. If the wave is moving perpendicularly to the direction of propagation, it is called transverse.

12.

a. Good answer. The interference will be constructive.

b. Give it some thought before answering.

c. Read the question again. The two waves are not opposed to one another.

13. Two waves with the same frequency that have a phase difference of � will produce a destructive interference.

a. Careful, the two waves are out of phase.

π

b. Careful, what does a phase difference of 2 remind you of?

c. Good answer. In this case, the interference is destructive since π represents opposing phases.

14. The sound of an ambulance’s siren is more high-pitched as it approaches.

a. Careful, the sound cannot keep the same pitch as the ambulance is moving.

b. Good job. The siren’s sound does indeed become more high-pitched as the ambulance gets closer.

c. Most certainly not, try again.

Preliminary Evaluation Title

Geometrical Optics and Physical Optics

Educational comments for the learner

If you have obtained over 75 %, your interest in optics is obvious. I encourage you to continue on with this work since I am convinced that we will be able to work very well together. You will see that studying optics is a very fascinating field.

You have between 50 % and 75 %, you result is very promising, optics are not unknown to you. We will have lots of work to do throughout this course. I can assure you that you have chosen a very fascinating subject. Good luck.

You have between 35 % and 50 %, which of course is not perfect. Yet I feel that you are truly willing to succeed in this field, and we are going to need that will power. To be honest with you, the field you have chosen is very fascinating, but it takes a lot of work. To begin with, there will be a certain amount of catching up for you to do. That will be the condition for us to achieve success.

You have obtained less than 35 %. You have lots of work ahead of you, since in addition to the current module you will have to review your previous optics courses.

X.

Key Concepts (Glossary)

1. **Amplitude**: The scalar measurement (a coordinate) of a positive number that describes the magnitude of a wave’s oscillation compared to its average value.
2. **Diffraction**: A wave’s behavior when it comes across an obstacle that isn’t perfectly transparent to it. (This definition can be made more precise)
3. **Boundary**: The surface between two transparent media. The rays remain rectilinear through a homogenous and isotropic medium; they are deviated when they cross a boundary or when they meet a reflective surface.
4. **Interference**: A phenomenon caused when waves meet.
5. **Wavelength**: The distance between two successive peaks or troughs on a periodic wave. (You may generalize this by noting that iy is the repeat distance of a point on a wave)
6. **Wave**: The propagation of a perturbation that creates reversible local physical property variations as it passes by. Since the perturbation’s intensity can be simulated using energy, a wave can be described as the transportation

of energy without the transportation of matter. A wave is described by a

r

r

function A(x ,t), x being its position in space (vector) and t being time.

(tidy up the highlighted so that they are properly aligned)

7. **Polarization**: A property of vectorial waves, like light. The fact that these waves are described by vectors helps to differentiate them from other types of waves, like sound waves, and implies the presence of the polarization phenomenon. (This definition could be made more precise by using standard textbooks or physics dictionary)

8. **Reflection**: A wave's sudden change of direction at the interface between two environments. After being reflected, the wave remains in its initial propagation environment. (This definition does not distinguish reflection from refraction which also involves change in direction. Combine the two sentences)

9. **Refraction**: The deviation of a wave as it crosses from one medium to another. Generally speaking, refraction is the result of a medium's change in impedance (acoustic impedance?), where a wave's speed will change between two media.

10. **Astigmatism**: A system is said to be *rigorously stigmatic* when all of the rays coming from a single point (an isogenous source) and going through the system all have converging supports (Vague translation. Use of Physics dictionary would help in the definition) .

XI.

Mandatory Reading

Reading #1

Complete Reference : **RAMILISON, H. A**. (2006). Fondements de l’optique géométrique Madagascar. Antanarivo University. Unpublished course. (A reference that is not widely available except at the author’s institution cannot be a mandatory reading)

Abstract: The course is an introduction to geometrical optics. It includes a brief history of optics and emphasizes the eye’s sensitivity limitations which are limited to visible wavelengths. In spite of ALHAZEN (965-1039), an Arabian physicist who was the first to understand that the eye does not emit rays that examine objects, but that objects themselves, when illuminated by a source, are at the origin of rectilinear rays, popular belief, that a hypnotist is able to submit people to his will simply with the ‘power’ of his gaze, still persists. This course will show us that geometrical optics is nothing but an approximation of wave theory. A better understanding of the concept of a beam or ray of light will be obtained with this theory and will help us to comprehend the different principles and limits related to geometrical optics. The laws of optics that will be introduced here might be ancient, but they have the merit of being based on simple observations. This course will familiarize us with the nature of objects and images.

Justification: This reading will help readers comprehend the justifications and limitations so that they may:

- understand the necessary conditions that result in near sighted astigmatism;
- familiarize themselves with the nature of objects and images.
- know the definitions of concepts such as: ray of light, incidence point, reflection, refraction, etc.

Reading #2

Complete Reference : **RAMILISON, H. A.** (2006). Dioptre et miroir plans Madagascar Antanarivo University. Unpublished course.

Abstract : The course is an application of the Snell-Descartes Laws. It will accentuate/bring out the existence of a critical refraction angle at the interface of two media in relation to their refractive indexes. Above that angle light is completely reflected back. Those properties will be applied in the study of mirrors and plane boundaries. The fact that the nature of an object or an image is always the opposite of itself, when applied to mirrors and plane boundaries, will be emphasized. The conditions for astigmatism will be addressed and the established conjugate relations.

Justification: This reading will help readers comprehend the justifications and limitations so that they may:

- understand the existence of the critical refraction angle;
- understand the necessary conditions that result in nearsighted astigmatism;
- familiarize themselves with the nature of objects and images;
- be able to graphically interpret Snell-Descartes' Laws;
- be able to draw an angle of incidence, emergence, reflection, refraction, etc.

Reading #3

Complete Reference : **RAMILISON, H.A.** (2006). Dioptre et miroir sphérique. Madagascar. Antanarivo University. Unpublished course.

Abstract: This course is an introduction to the study of lenses, essentials elements in any optical system. It will describe the characteristics of a curved boundary. A brief study of rigorous astigmatism will allow us to define the necessary conditions for near sighted astigmatism also know as the Gauss or paraxial conditions. With those conditions, we will be able to define the key points that describe a curved boundary. We will then establish the different conjugate relations depending on the origin's position: at the vertex (Descartes), at the focal point (Newton), or at the center. Under the Gauss conditions (paraxial conditions) we will then be able to define the characteristic planes such as principal planes or focal planes, which will facilitate the drawing of light paths and therefore the possibility of solving graphs. It will also be easier to transition from curved boundaries to curved mirrors since the only requirement will be to realize that there is total internal reflection in a mirror. All of the previous results will therefore be used and we will also obtain the conjugate equations. We will be able to follow a Power Point presentation about drawing beam paths and graphically determining the images in a curved mirror under the Gauss conditions.

Justification: This reading will help readers comprehend the justifications and limitations so that they may:

- understand the necessary conditions that result in nearsighted astigmatism;
- familiarize themselves with the nature of objects and images;
- familiarize themselves with the concept of vergency (opticalpower).
- learn the definitions for concepts such as : magnification, focal planes and principal planes.

Reading #4

Référence Complète : **RAMILISON, H. A.** (2006)**.** Les lentilles. Madagascar. Antanarivo University. Unpublished course:

Abstract : The different optical systems that we will be using daily employ thin lenses. In this course, we will see how and under which conditions thin lens simplification is possible, to optimize its usage.

Justification: This course will get us ready to study the different optical systems (magnifying glass, microscope, telescope…). To do so we will need to study thick lenses (calculate the characteristics). It will then be possible to define the conditions for drawing a representation scaled down to a portion of straight line perpendicular to the main axis. We will call it a thin lens. Those same elements will facilitate the determination (graphical or analytical) of thin lens characteristics.

Reading # 5

DIOUF, S. (2004). L'Evaluation des apprentissages (Learning Evaluation). Sénégal. Université Cheikh Anta DIOP de Dakar. FASTEF (ex ENS)

Abstract : *It is highly recommended to read this text to be able to answer the optional formative educational evaluation. This text is composed of different sections including:*

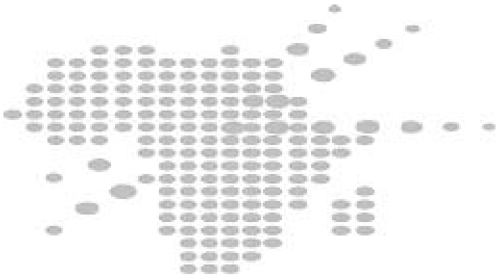
Issues relative to the evaluation, which address different evaluation-related questions

The different types of evaluations, where the evaluations' roles and times are also discussed.

Information gathering strategies. In this section you will find the objective correction questions and the subjective correction questions.

You will also find the steps to creating exam topics and evaluation characteristics.

Justification : Reading this text will allow the learners to correctly answer the optional formative education evaluation questions. All of the necessary elements to do so are present in this text.



XII. Mandatory Resources

Resource #1

Complete Reference:

Tipler, P. A. (1991). *Physics for Scientists and Engineers*, Third Edition. New York: Worth Publishers

Abstract: This reading teaches the learners about physical and geometrical optics.

Justification: The information in this book will help the learners to complete certain evaluations from this module. This reading could be useful to the students.

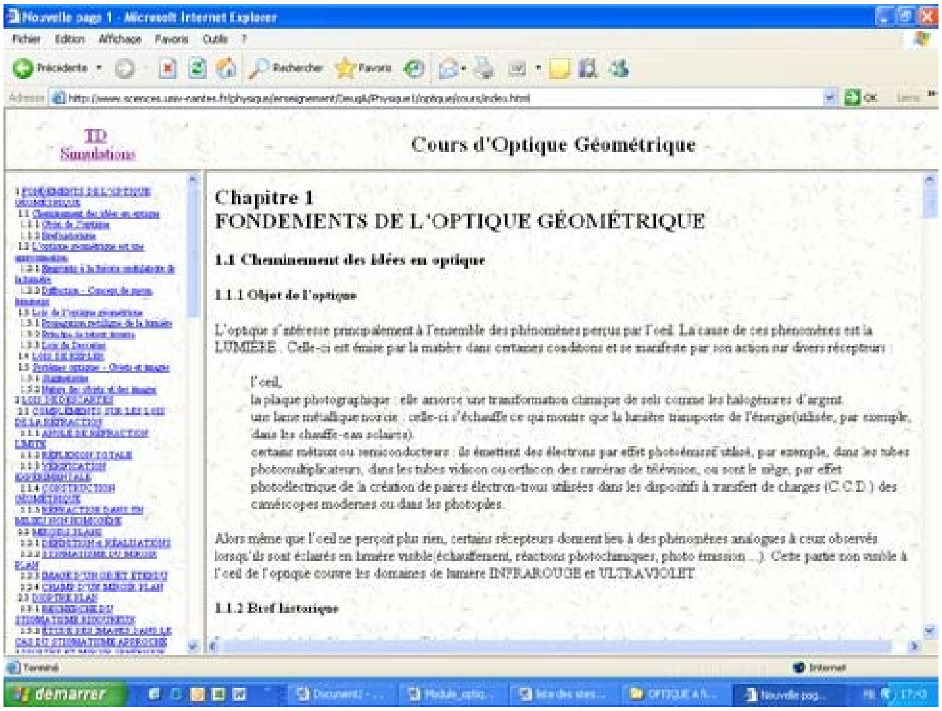
Resource #2

Complete Reference:

CRAWFORD, F. S. Jr. (1968). *Cours de physique, volume 3* : *Ondes*, Paris : Librairie Armand Colin (1972). *Berkeley:* (Is'nt there a more recent edition?)

Abstract: This reading gives information about wave theory.

Justification: Reading this book helps the learners prepare themselves to adequately complete the educational activities included in the module. It is complementary to the optics courses that are presented in this module.



http://www.sciences.univ-nantes.fr/physique/enseignement/DeugA/Physique1/optique/cours/index.html

Cours d'Optique Géométrique

Chapitre 1
FONDEMENTS DE L'OPTIQUE GÉOMÉTRIQUE

1.1 Cheminement des idées en optique

1.1.1 Objet de l'optique

L'optique s'intéresse principalement à l'ensemble des phénomènes perçus par l'oeil. La cause de ces phénomènes est la LUMIÈRE. Celle-ci est émise par la matière dans certaines conditions et se manifeste par son action sur divers récepteurs :

l'oeil,
la plaque photographique : elle amorce une transformation chimique de sels comme les halogénures d'argent.
une lame métallique noircie : celle-ci s'échauffe ce qui montre que la lumière transporte de l'énergie(utilisée, par exemple, dans les chauffe-eau solaires).
certains métaux ou semiconducteurs : ils émettent des électrons par effet photoémissif utilisé, par exemple, dans les tubes photomultiplicateurs, dans les tubes vidicon ou orthicon des caméras de télévision, ou sont le siège, par effet photoélectrique de la création de paires électron-trous utilisées dans les dispositifs à transfert de charges (C.C.D.) des caméscopes modernes ou dans les photopiles.

Alors même que l'oeil ne perçoit plus rien, certains récepteurs donnent lieu à des phénomènes analogues à ceux observés lorsqu'ils sont éclairés en lumière visible(échauffement, réactions photochimiques, photo émission ...). Cette partie non visible à l'oeil de l'optique couvre les domaines de lumière INFRAROUGE et ULTRAVIOLET

1.1.2 Bref historique

African Virtual University

XIII. Useful links

Useful Link #1

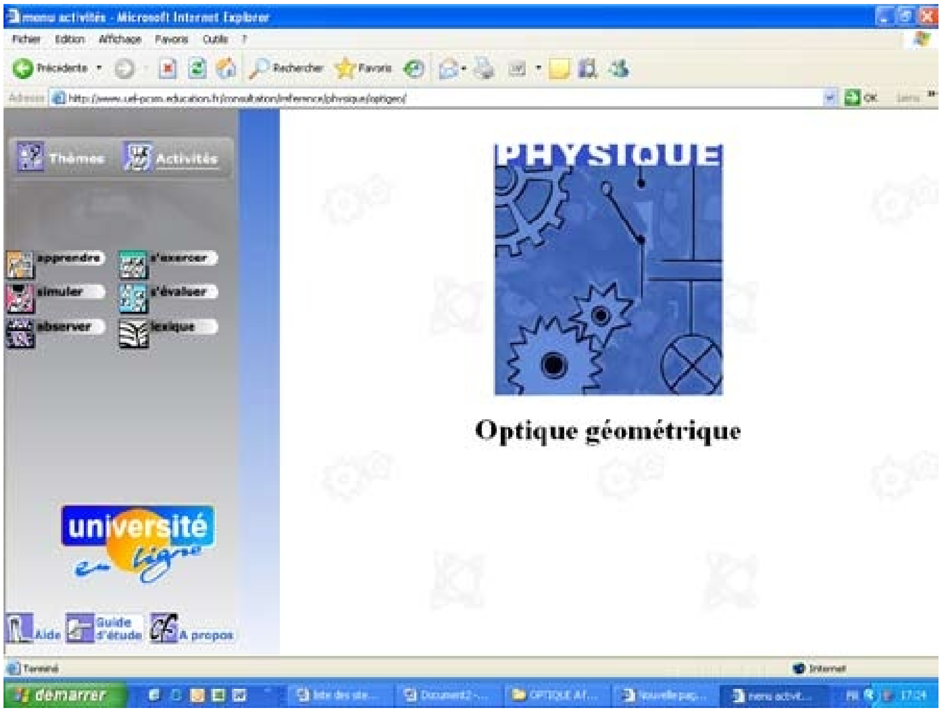
Title : Cours d’optique géométrique (Geometrical Optics Course)

URL: http://www.sciences.univ-nantes.fr/physique/enseignement/DeugA/Physique1/optique/cours/index.html

Screenshot :

Description: This is a complete geometrical optics course, with simulations and animations that illustrate the demonstrations, laws or formulas obtained.

Justification: The content, the animations and demonstrations allowing for a better understanding of the different elements in our course were inspired by this course.



Useful Link #2

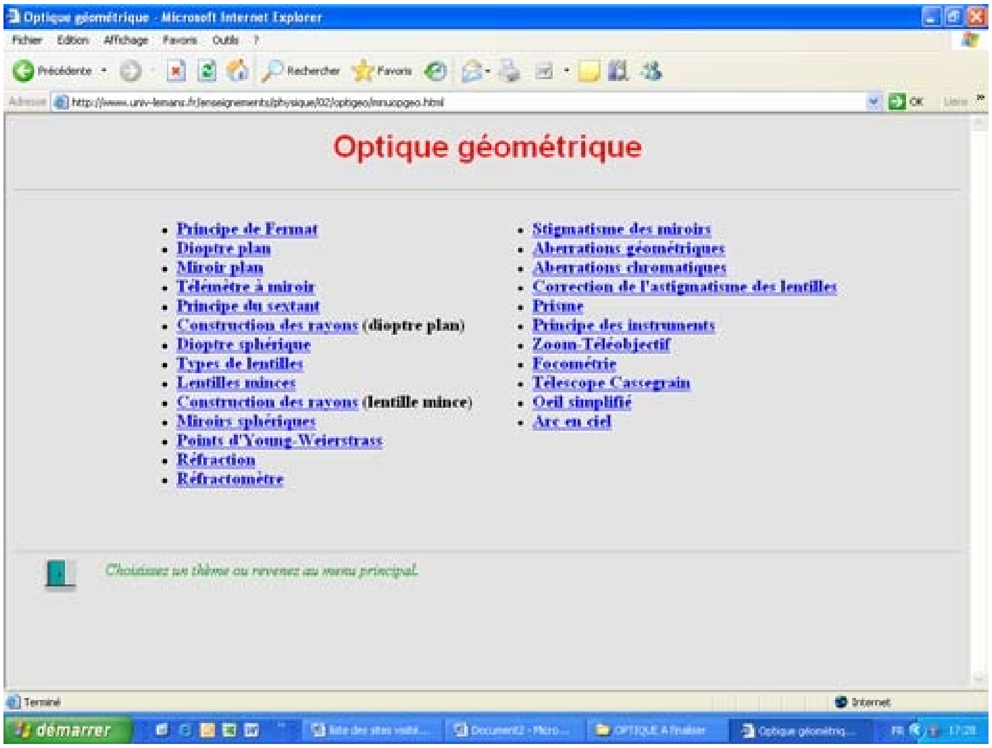
Title : Optique géométrique (Geometrical Optics)

URL: http://www.uel-pcsm.education.fr/consultation/reference/physique/optigeo/

Screenshot :

Description: This is a very complete site for learning Geometrical Optics. On it you can find many headings: ‘apprendre (learning)’ course framework, ‘simuler (simulate)’ access to QuickTime animations and Flash or Java simulations, ‘observer (observe)’ access to experiment movies, ‘s’exercer (practice)’ gives exercises for each chapter, ‘s’évaluer (evaluate)’ presents self-evaluations.

Justification: This very comprehensive site allows you to acquire the necessary knowledge to master geometrical optics. The notation varies but that can be part of the exercises, to help you adapt to the different sites you might encounter.



Optique géométrique

- Principe de Fermat
- Dioptre plan
- Miroir plan
- Télémètre à miroir
- Principe du sextant
- Construction des rayons (dioptre plan)
- Dioptre sphérique
- Types de lentilles
- Lentilles minces
- Construction des rayons (lentille mince)
- Miroirs sphériques
- Points d'Young-Weierstrass
- Réfraction
- Réfractomètre
- Stigmatisme des miroirs
- Aberrations géométriques
- Aberrations chromatiques
- Correction de l'astigmatisme des lentilles
- Prisme
- Principe des instruments
- Zoom-Téléobjectif
- Focométrie
- Télescope Cassegrain
- Oeil simplifié
- Arc en ciel

Choisissez un thème ou revenez au menu principal.

Useful Link #3

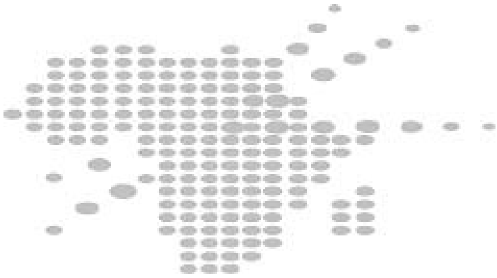
Title : Optique géométrique (Geometrical Optics)

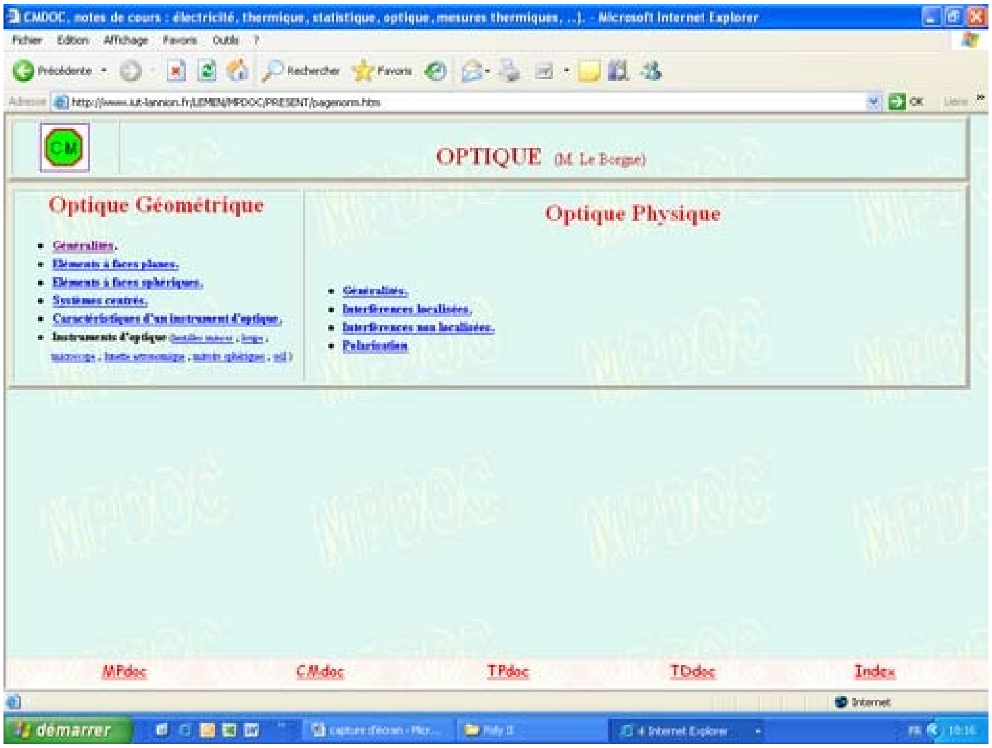
URL : http://www.univ-lemans.fr/enseignements/physique/02/optigeo/mnuopgeo.html

Screenshot :

Description: This site discusses the different topics related to geometrical optics. Each topic is developed through reminders of essential course elements or definitions as well as results. An interactive simulation allows you to see and also solve different problems by manipulating the mouse.

Justification: This site will allow you to imagine different possible situations for a specific topic. Modifying a situation is done using a simple click or with the keyboard. The fact that it is interactive makes this site a very good tool.





OPTIQUE (M. Le Borgne)

Optique Géométrique

- Généralités.
- Eléments à faces planes.
- Eléments à faces sphériques.
- Systèmes centrés.
- Caractéristiques d'un instrument d'optique.
- Instruments d'optique (lentilles minces, loupe, microscope, lunette astronomique, miroirs sphériques, œil)

Optique Physique

- Généralités.
- Interférences localisées.
- Interférences non localisées.
- Polarisation

African Virtual University

Useful Link #4

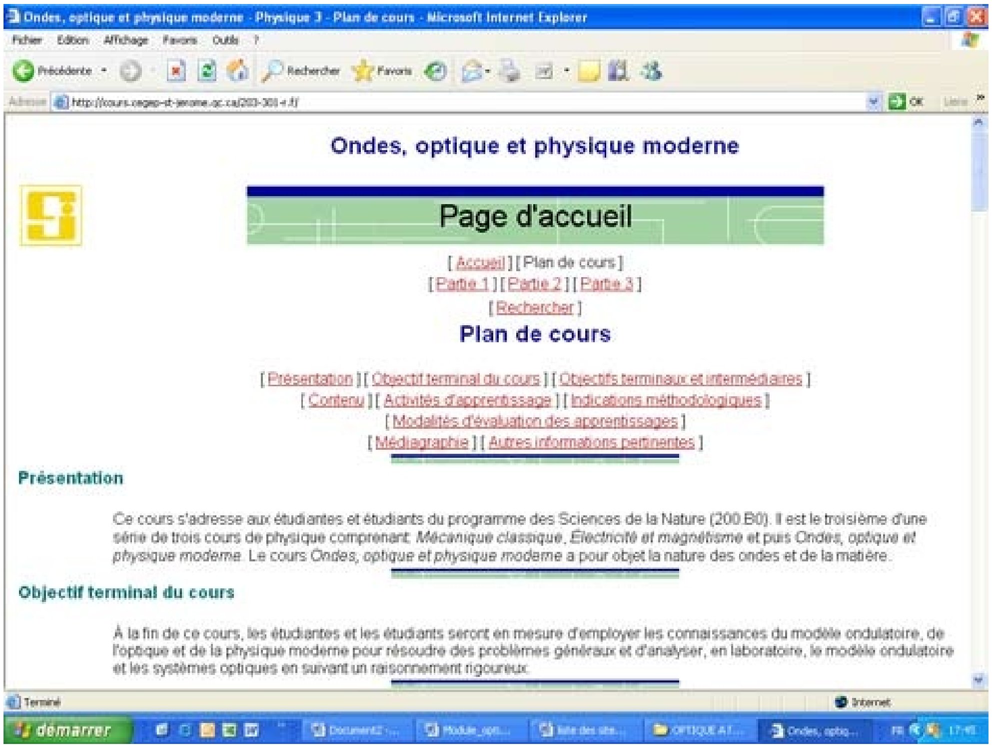
Title : Optique *(M. Le Borgne)* **(Optics)**

URL : http://www.iut-lannion.fr/LEMEN/MPDOC/PRESENT/pagenorm.htm

Screenshot :

Description: This site gives a very detailed summary of geometrical and physical optics courses. The key points and results that need to be known are presented.

Justification: The demonstrations are a little brief but its main quality is the simple way the results and hypotheses are presented. This site is recommended to those who would like to get a feel for geometrical and physical optics ; more detailed demonstrations and results can be found on other sites.



Ondes, optique et physique moderne

Page d'accueil

[Accueil] [Plan de cours]
[Partie 1] [Partie 2] [Partie 3]
[Rechercher]

Plan de cours

[Présentation] [Objectif terminal du cours] [Objectifs terminaux et intermédiaires]
[Contenu] [Activités d'apprentissage] [Indications méthodologiques]
[Modalités d'évaluation des apprentissages]
[Médiagraphie] [Autres informations pertinentes]

Présentation

Ce cours s'adresse aux étudiantes et étudiants du programme des Sciences de la Nature (200.B0). Il est le troisième d'une série de trois cours de physique comprenant: *Mécanique classique*, *Électricité et magnétisme* et puis *Ondes, optique et physique moderne*. Le cours *Ondes, optique et physique moderne* a pour objet la nature des ondes et de la matière.

Objectif terminal du cours

À la fin de ce cours, les étudiantes et les étudiants seront en mesure d'employer les connaissances du modèle ondulatoire, de l'optique et de la physique moderne pour résoudre des problèmes généraux et d'analyser, en laboratoire, le modèle ondulatoire et les systèmes optiques en suivant un raisonnement rigoureux.

Useful Link #5

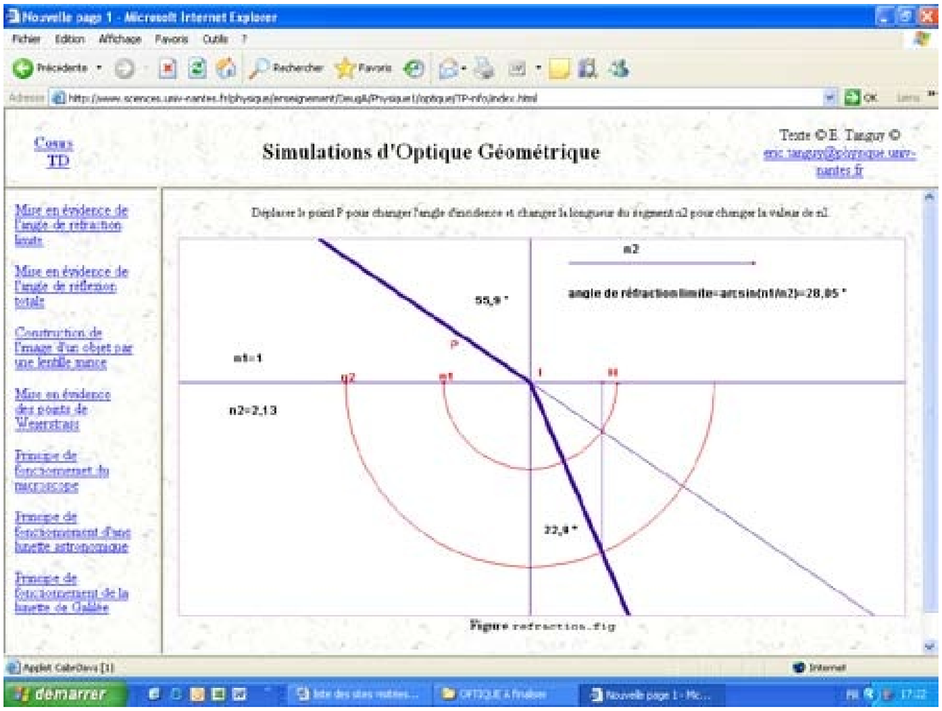
Title : Ondes, optique et physique moderne (Waves, Optics and Modern Physics)

URL : http://cours.cegep-st-jerome.qc.ca/203-301-r.f/

Screenshot :

Description: This site gives information about oscillations, waves, geometrical optics and physical optics. Corrected exercises related to each chapter are also presented.

Justification: This site allows someone to get an idea about the different topics. Its interest resides in the lists of key points and the immediate application of those points in concrete examples.



Déplacer le point P pour changer l'angle d'incidence et changer la longueur du segment n2 pour changer la valeur de n1.

Useful Link #6

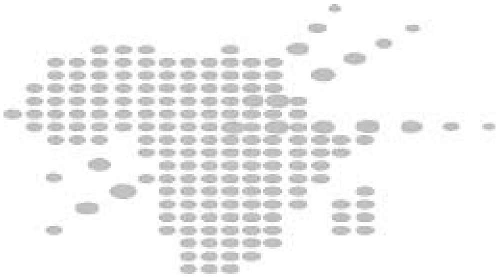
Title : Simulations d'Optique Géométrique (Geometrical Optics Simulations)

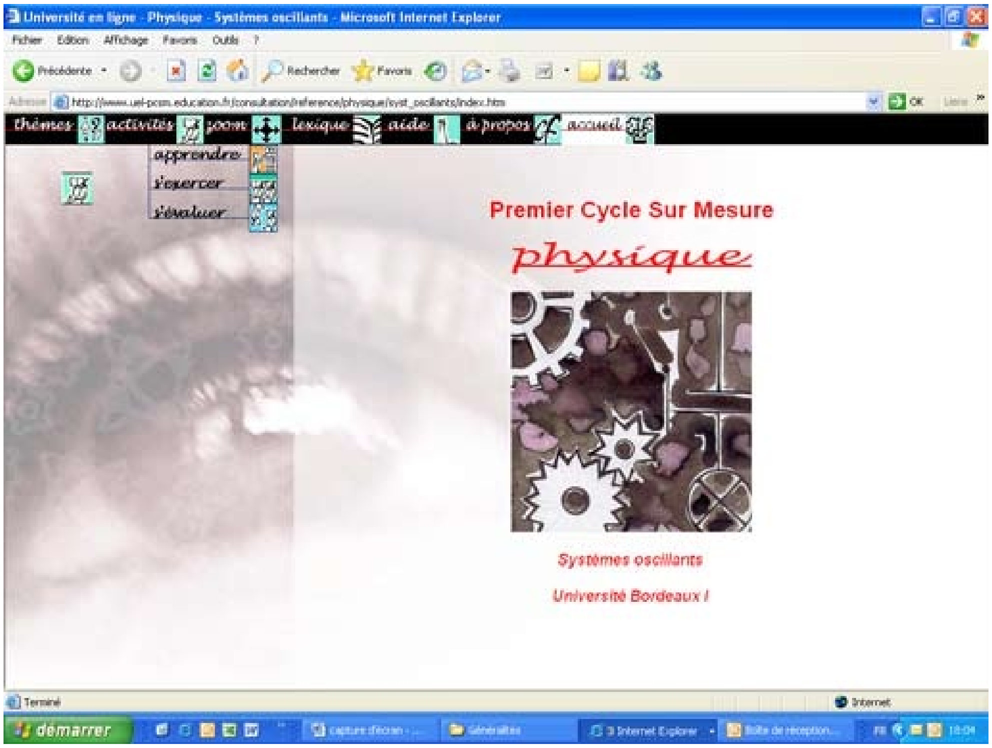
URL : http://www.sciences.univ-nantes.fr/physique/enseignement/DeugA/Physique1/optique/TP-info/inde.html

Screenshot :

Description: This interactive site highlights the properties of light and optical systems. The simulations that are presented allow you to consider all of the possible combinations simply by changing the variables and by moving the cursors or the mouse.

Justification: The interactive and educational approach allows for a better understanding of geometrical optics results. The possibilities are limited only by the learner's own imagination.





Université en ligne - Physique - Systèmes oscillants - Microsoft Internet Explorer

http://www.uel-pcsm.education.fr/consultation/reference/physique/syst_oscillants/index.htm

Premier Cycle Sur Mesure

physique

Systèmes oscillants

Université Bordeaux I

Useful Link #7

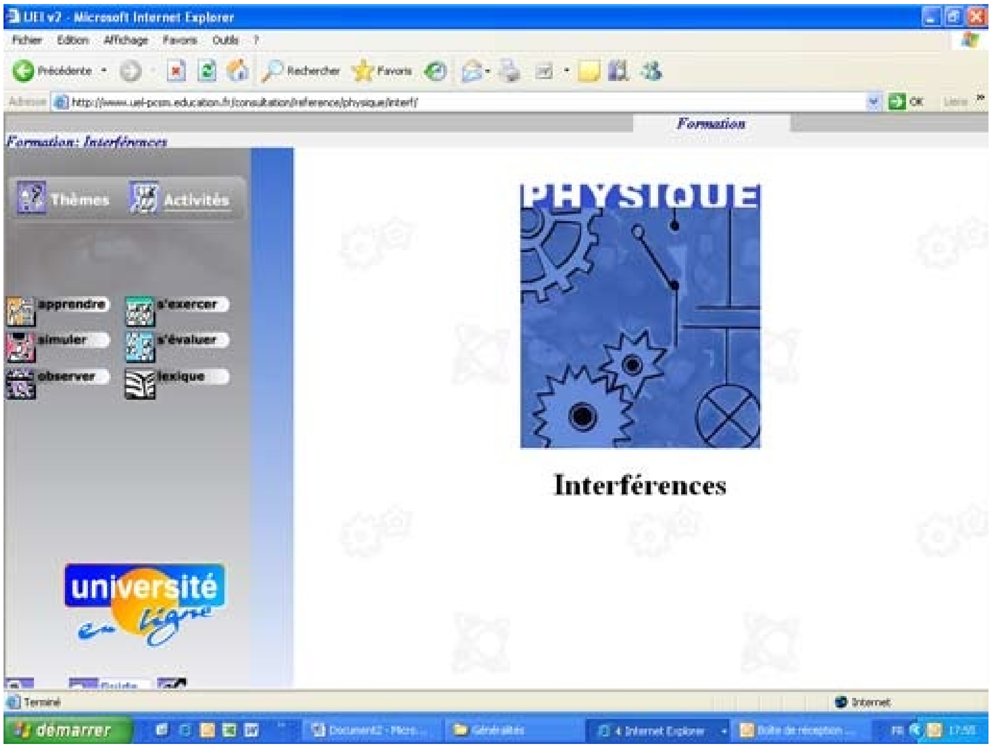
Title : Systèmes oscillants (Oscillatory Systems)

URL : http://www.uel-pcsm.education.fr/consultation/reference/physique/syst_oscillants/index.htm

Screenshot :

Description: This is a very complete site for understanding the behavior of oscillatory systems. On it you can find many headings : 'apprendre (learning)' course framework, 's'exercer (practice)' gives exercises for each chapter, 's'évaluer (evaluate)' presents self-evaluations.

Justification: This very comprehensive site allows you to acquire the necessary knowledge to master an oscillator's different characteristics. Solving general oscillating system equations allow the comprehension of the analogy between oscillators independently from the nature of the pulse.



African Virtual University

Useful Link #8

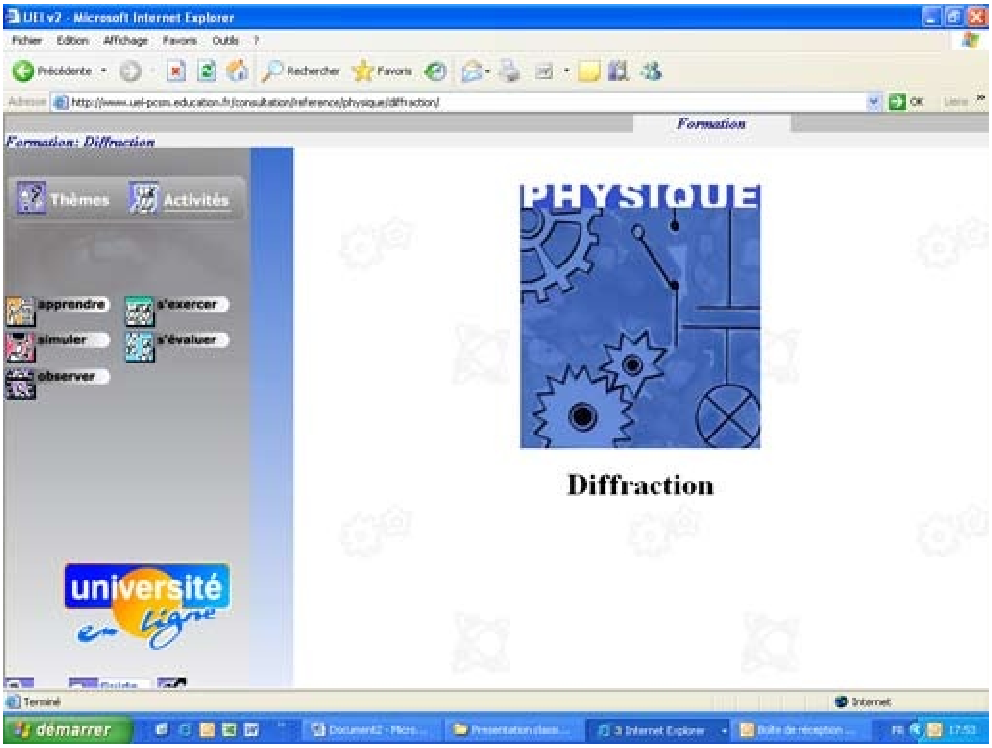
Title : Interférences (Interference)

URL : http://www.uel-pcsm.education.fr/consultation/reference/physique/interf/

Screenshot :

Description: This is a very complete site for understanding and interpreting the conditions that are essential to producing an interference, along with its characteristics. On it you can find many headings : ‘apprendre (learning)’ course framework, ‘simuler (simulate)’ access to QuickTime animations and Flash or Java simulations, ‘observer (observe)’ access to experiment movies, ‘s’exercer (practice)’ gives exercises for each chapter, ‘s’évaluer (evaluate)’ presents self-evaluations.

Justification: This very comprehensive site allows you to acquire the necessary knowledge to master the different characteristics related to interferences. A highlight of this website is the use of Fresnel representations (or phasers according to certain authors) as well as analytical calculations.



Useful Link #9

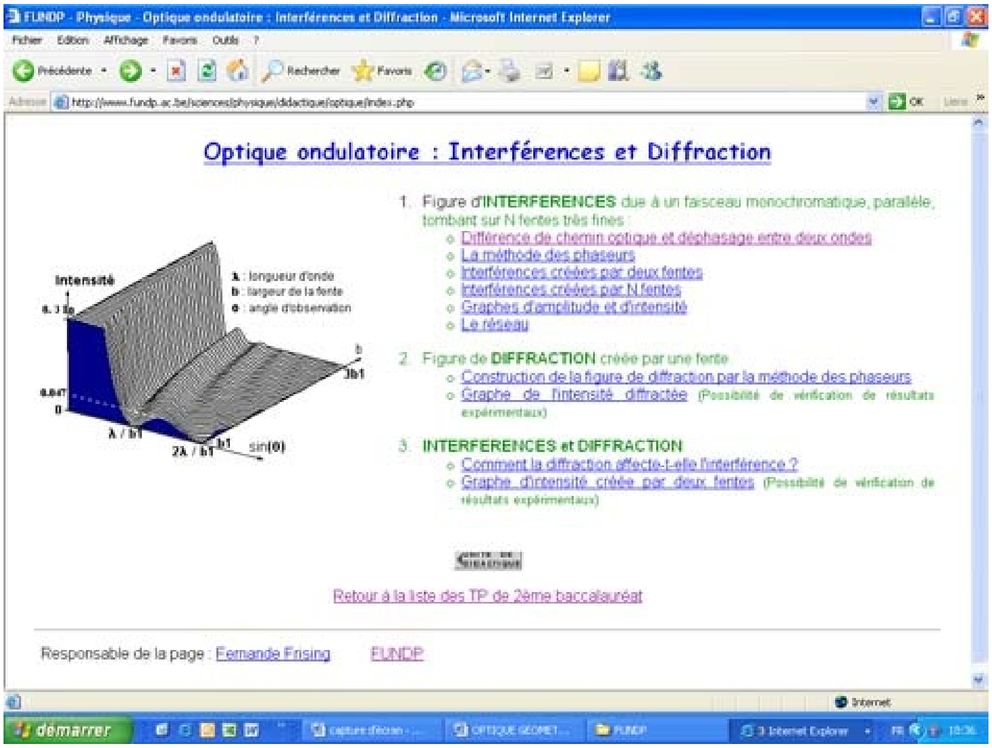
Title :Diffraction (Diffraction)

URL : http://www.uel-pcsm.education.fr/consultation/reference/physique/diffraction/

Screenshot :

Description: This is a very complete site for understanding diffraction characteristics. On it you can find many headings : ‘apprendre (learning)’ course framework, ‘simuler (simulate)’ access to QuickTime animations and Flash or Java simulations, ‘observer (observe)’ access to experiment movies, ‘s’exercer (practice)’ gives exercises for each chapter, ‘s’évaluer (evaluate)’ presents self-evaluations.

Justification: This very comprehensive site allows you to acquire the necessary knowledge to master diffraction characteristics. The highlight of this site is the graphical representation of each phenomenon using the results that were obtained.



Optique ondulatoire : Interférences et Diffraction

1. Figure d'**INTERFERENCES** due à un faisceau monochromatique, parallèle, tombant sur N fentes très fines :
    - Différence de chemin optique et déphasage entre deux ondes
    - La méthode des phaseurs
    - Interférences créées par deux fentes
    - Interférences créées par N fentes
    - Graphes d'amplitude et d'intensité
    - Le réseau
2. Figure de **DIFFRACTION** créée par une fente
    - Construction de la figure de diffraction par la méthode des phaseurs
    - Graphe de l'intensité diffractée (Possibilité de vérification de résultats expérimentaux)
3. **INTERFERENCES et DIFFRACTION**
    - Comment la diffraction affecte-t-elle l'interférence ?
    - Graphe d'intensité créée par deux fentes (Possibilité de vérification de résultats expérimentaux)

Retour à la liste des TP de 2ème baccalauréat

Responsable de la page : Fernande Frising   FUNDP

Useful Link #10

Title : Optique ondulatoire : Interférences et Diffraction (Wave Optics : Interference and Diffraction)

URL : http://www.fundp.ac.be/sciences/physique/didactique/optique/index.php

Screenshot :

Description: Following a short review, this site defines the necessary conditions for producing interferences and diffraction. A simulation allows you to highlight the evolution of an interference or diffraction pattern. The variables can be modified, thus allowing you to observe the way an interference evolves.

Justification: The different simulations provide a better understanding of how to construct interference or diffraction figures. It is possible to observe all of a slit's diffraction characteristics since you are able to change the slit's width, the focal length and the wavelength.

XIV. learning activities

Learning Activity 1

Activity Title

Geometrical Optics Basic

Required Time

4 hours

Specific Objectives

- Recognize the characteristic magnitudes of a light wave
- Recite Descartes' Laws
- Describe the concept of a ray of light
- Describe the characteristics for an image created by an optical system

Activity Summary

Through this activity, you will learn how the concept of optics and, later on, of light and similar phenomena has changed, even when the phenomena cannot be directly detected by human beings. The history about the way optics laws were developed will help you understand the different steps required to establish current knowledge and applications. This has helped information technology progress rapidly: lasers, fiber optics... Those elements will allow us to define conditions and limitations for geometrical optics related laws and principles. You will then have to identify and categorize the different natures of optical system objects and images.

Key Concepts

Optics: For close to two thousand years, the study of optics is considered to be a field that specializes in the phenomena that are seen by the eye. Its main goal is to research vision mechanisms, but starting in the XVIIth century, it begins to include all that concerns light and similar phenomena, even when the phenomena cannot be directly detected by human beings.

Light Waves can be considered as the stacking of monochromatic (of a single colour) sinusoidal waves.

A medium's refractive index (n) is the relation between the speed of light (c) in a vacuum and the speed of light (v) in the medium.

Diffraction is the way a wave behaves when confronted with an obstacle that is not completely transparent to it. (vague diffraction and may be misleading.)

The incidence point I is the spot where a ray of light meets the boundary between two media.

Activity Description

This educational activity consists of understanding the evolution of the way light and similar phenomena have been understood. To do so, knowledge of a brief history of the development of optics laws will allow an understanding of the necessity to define the limitations and conditions for establishing geometrical optics laws and principles. To gain a better understanding of the problem you will need to learn characteristic light wave magnitudes, understand the reason certain bodies are white, colored or black depending on the nature of the environment. The comprehension of the concept of a light wave is essential since it will allow us to characterize the limitations of geometrical optics. The more elaborate principles and laws will be addressed in physical optics to show that geometrical optics is an approximation of a more extensive concept. Since the laws and rules of optics will mostly be applied to optical instruments, from a lighthouse mirror to a microscope, we will need to familiarize ourselves with the nature of optical system objects and images (real or virtual).

Relevant Reading

HERIMANDA A. RAMILISON (2006) : Fondements de l’optique géométrique. Madagascar. Antanarivo University. Unpublished course. (Give more accessible relevant reading)

Reading Summary

It includes a brief history of optics and emphasizes the eye’s sensitivity limitations which are limited to visible wavelengths. In spite of ALHAZEN (965-1039), an Arabian physicist who was the first to understand that the eye does not emit rays that examine objects, but that objects themselves, when illuminated by a source, are at the origin of rectilinear rays, popular belief, that a hypnotist is able to submit people to his will simply with the ‘power’ of his gaze, still persists. This course will show us that geometrical optics is nothing but an approximation of wave theory. A better understanding of the concept of a beam or ray of light will be obtained with this theory and it will help us to comprehend the different principles and limits related to geometrical optics. The laws of optics that will be introduced here might be ancient, but they have the merit of being based on simple observations. This course will familiarize us with the nature of objects and images.

Reading Justification

This reading will help readers comprehend the justifications and limitations so that they may:

- understand the necessary conditions that result in nearsighted astigmatism;
- familiarize themselves with the nature of objects and images.
- know the definitions of concepts such as: ray of light, incidence point,

reflection, refraction, etc.

Useful Links (Give relevant links in English also)

http://www.sciences.univ-nantes.fr/physique/enseignement/DeugA/Physique1/

optique/cours/chap1.html#x1-92005

http://www.uel-pcsm.education.fr/consultation/reference/physique/optigeo/

menumodule/menuthemes/menu_reduit.html

http://www.univ-Lemans.fr/enseignements/physique/02/optigeo/

http://fr.wikipedia.org/wiki/Optique

http://cours.cegep-st-jerome.qc.ca/203-301-r.f/prtie2/chap6/default.htm

African Virtual University

Activity Introduction

You are in the dark, you cannot see at all. To be able to see you need to light a candle, for example. To do so you strike a match, then you burn the candle’s wick with the match’s flame. You then notice that the candle’s light projects your shadow onto the wall. These elements emphasize the point that the Arabian physicist ALHAZEN (965-1039) was trying to get across; that the eye does not emit rays that examine objects, but that objects themselves, when illuminated by a source, are at the origin of rectilinear rays. The demonstration we just did seems quite elementary but it is not, since it has taken a long time to end up with the knowledge we have now.

Formative Evaluation

1) Draw a sketch, with commentary, that emphasizes the fact that the shadow of

an opaque disc projected onto a screen is homothetic (not clear in English) to the object no matter what the distance between the disc and the screen is.

2) Complete the following sentence: A beam of light is composed of rectilinear ………………

3) Is it possible to separate a ray of light from a beam of light?

4) How many geometrical optics laws exist? Detail these laws using a diagram.

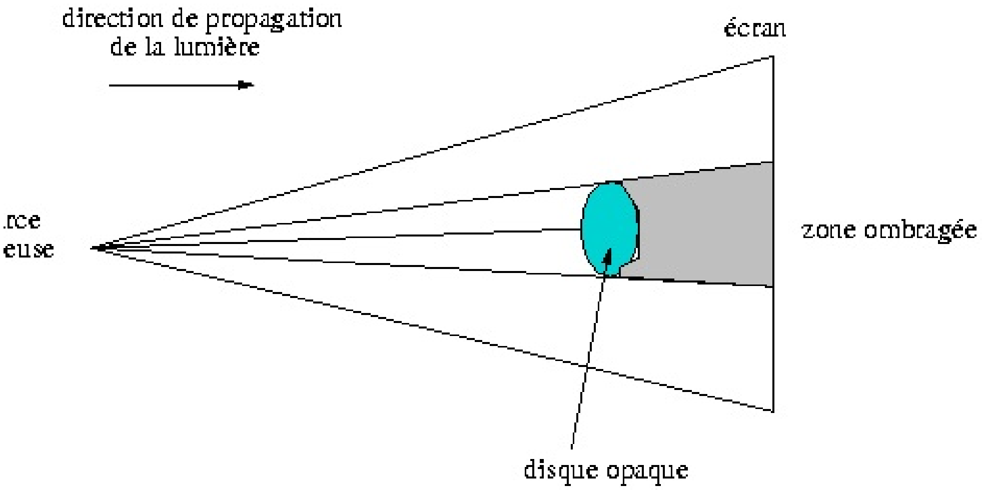
Learning Activities

To answer the following questions the learners must:

- Read all the recommended readings
- Complete all of the exercises with clear and precise diagrams
- Organize themselves into a **collaborative work** group

The group members will work together to solve each exercise. Each group will designate a spokesperson; the spokespersons from every group will then share the answers to each exercise through chatting, under the guidance of a tutor. The tutor will be able to let them know when the correct answer for a question has been found and will suggest that they continue on to the next exercise.

When all of the problems are solved, the chat window is closed. Since the discussions are recorded, the tutor will be able to review the chat session at any time and tell which group suggested the best solutions through each spokesperson.


direction de propagation
de la lumière
écran
rce
euse
zone ombragée
disque opaque

African Virtual University

Answer Key

1)Illustration

(The annotations in the figure must also be translated into English)

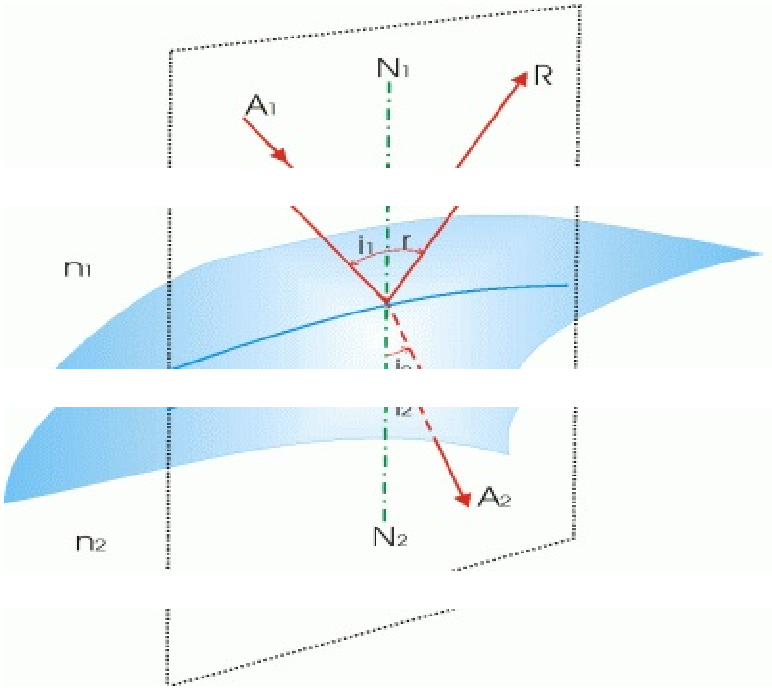
The shadow of an opaque disc projected onto a screen is homothetic to the object

no matter what the distance between the disc and the screen is.

2) A beam of light is composed of rectilinear rays of light.

3) Let us complete the following diagram:

We are looking to isolate a ray of light by making a cylindrical beam of light pass through several successive screens.



Diffraction occurs when the hole is too small.

The spot gets larger as the diaphragm’s aperture gets smaller: this phenomenon is called diffraction.

It is therefore impossible to separate a ray of light from a beam.

It is still possible to consider that a beam of light is made up of many rays: the study of the propagation of these rays is the main topic in geometrical optics.

A single ray of light is the ideal situation, it is physically impossible to obtain but it is used as a model.

4) There are three geometrical optics laws.

Established by SNELL in England in 1621 and independently discovered by DESCARTES in France in 1637 experimentally, we now know that the laws of geometrical optics are the result of the wavelike nature of light.

1st Law: The reflected ray and the refracted ray are both in the same plane as the plane of incidence.

2nd Law: The angle of incidence and reflection are equal and in opposite directions: $r = -i1$

3rd Law: For all monochromatic light, the sine of the incident angle and of the refraction angle are related by the equation: 1

$n \sin 1i = n2 \sin i2$.

African Virtual University

Experiments

1- Demonstration: Take a burning candle and place it near a light-coloured wall that will act as a projection screen. Place an opaque object between the candle and the screen. The opaque object stops its shadow from being projected onto the wall.

a. True

b. False

Check off the right answer.

2- Without moving the object, bring the candle further away from the wall; how does the size of the object's shadow change? The shadow's size:

a. gets bigger

b. gets smaller

c. does not change

Check off the right answer(s).

3- Now, without moving the candle, bring the object closer to the wall; how does the size of the object's shadow change? The shadow's size:

a. gets bigger

b. gets smaller

c. does not change

Check off the right answer(s).

4- What happens to the sharpness of the shadow projected onto the wall? The shadow is:

a. blurrier

b. clearer

c. the same

Check off the right answer(s).

5- Prepare 5 sheets of opaque cardboard. In the middle of the first sheet, cut out a circular hole with a 2 cm radius. In the middle of the second sheet, cut out a circular hole with a 1 cm radius. In the middle of the third sheet, cut out a circular hole with a 0.5 cm radius. In the middle of the fourth sheet, cut out a circular hole with a 0.25 cm radius. In the middle of the fifth sheet, cut out a circular hole with a 1 mm radius. Place the first sheet between the sun and a wall that will work as a projection screen. How is the ray of sunlight projected onto the wall? The ray of sunlight is:

a. bigger than the circular hole

b. smaller than the circular hole

c. the same size as the circular hole.

Check off the right answer(s).

6- Place the second sheet between the first sheet and the wall, taking care to line the hole up with the ray of sunlight coming out of the first sheet. How is the ray of sunlight projected onto the wall? The ray of sunlight is:

a. bigger than the circular hole

b. smaller than the circular hole

c. the same size as the circular hole.

Check off the right answer(s).

7- Place the third sheet between the second sheet and the wall, taking care to line the hole up with the ray of sunlight coming out of the second sheet. How is the ray of sunlight projected onto the wall? The ray of sunlight is:

a. bigger than the circular hole

b. smaller than the circular hole

c. the same size as the circular hole.

Check off the right answer(s).

8- Place the fourth sheet between the third sheet and the wall, taking care to line the hole up with the ray of sunlight coming out of the third sheet. How is the ray of sunlight projected onto the wall? The ray of sunlight is:

a. bigger than the circular hole

b. smaller than the circular hole

c. the same size as the circular hole.

Check off the right answer(s).

9- Place the fifth sheet between the fourth sheet and the wall, taking care to line the hole up with the ray of sunlight coming out of the fourth sheet. How is the ray of sunlight projected onto the wall? The ray of sunlight is:

a. bigger than the circular hole

b. smaller than the circular hole

c. the same size as the circular hole.

Check off the right answer(s).

10- A virtual image can be seen on a screen.

a. True

b. False

11- A real image can be seen on a screen.

a. True

b. False

12- Match up the following columns by associating the right letter and number together:

a) a real object in an optical system

1) is found behind the exit point

b) a virtual object in an optical system 2) is found in front of the entry point

c) a real image in an optical system

3) is found in front of the exit

point

d) a virtual image in an optical system 4) is found behind the entry point

13- A virtual object in an optical system always produces a virtual image.

a. True

b. False

14- A real image can play the role of a virtual object in an optical system.

a. True

b. False

Answer Key

1.

a. Careful, try the experiment and you will see that the shadow is projected

onto the wall

b. Good answer, the opaque object does not stop its shadow from being

projected onto the wall

2.

a. Good answer

b. Think it through before answering

c. Take your time to answer

3.

a. Take your time to answer

b. Very good

c. Think it through before answering

4.

a. You have not made the right choice

b. Good answer

c. Wrong answer

5.

a. Wrong answer

b. Take your time and try again

c. Good answer

6.

a. Wrong answer

b. Take your time and try again

c. Good answer

7.

a. Try again

b. This is definitely not the right answer

c. Excellent, you have the perfect answer

8.

a. Careful, take your time to answer

b. Try again

c. Very good

9.

a. Good job.

b.

c.

10.

a. You definitely answered too fast

b. Very good answer

11.

a. Very good, it is in fact possible

b. Be careful about your choice, you have not thought it through enough

12.

a2; b4; c1; d3. Good job, you have made the right combinations.

13. – False

a. Be careful, you’ve misread the question

b. Good answer. You’re right, it isn’t always possible

14.

a. Good answer

b. Review your course

Self-evaluation

The learners write down the difficulties they encountered while solving the problems. Following those difficulties, each group will be oriented towards one of the subsequent experiments and will then brief the tutor about their results in an attachment sent by e-mail.

Teacher Guidelines

The tutor will open the chat window, correct all of each group's answers and briefings sent in an attachment by e-mail. The appropriate feedback will be sent back to each group by e-mail and the activity's general solution will be posted on the 'Student' workspace. The grade received from this activity accounts for 20% of the module evaluation.

African Virtual University

Learning Activity 2

Activity Title

Applications of Snell-Descartes' Laws

Required Time

8 hours

Specific Objectives

Describe how light is refracted according to the refractivity of the media through which it travels

- Describe the fundamental properties of a plane mirror

- Describe the formation of an image in a plane mirror

- Describe the formation of an image through a plane boundary

Activity Summary

With this activity you will apply the Snell-Descartes' Laws. You will establish light's behavior at the surface of a boundary between two media with different refractivity. You will discover the existence of the critical angle of refraction according to a medium's refractivity. Solving methods, using graphs, will be presented.

You will learn how a plane mirror or boundary produces a virtual image when a real object is placed before it, and also how to use reflection rules to draw the reflected ray or beam that corresponds to the incident ray or beam on a plane mirror or boundary.

Key Concepts

Reflection: A wave's sudden change of direction at the interface between two environments. After being reflected, the wave remains in its initial propagation environment.

Refraction: The deviation of a wave as it crosses from one medium to another. Generally speaking, refraction is the result of a medium's change in impedance (specify type of impedance), where a wave's speed will change between two media.

Boundary: The surface between two transparent media. The rays remain rectilinear through a homogenous and isotropic medium; they are deviated when they cross a boundary or when they meet a reflective surface.

Plane mirror: A flat, polished and reflective surface.

Field of view: The portion of space that can be seen in the mirror

Activity Description

This activity consists of gaining a better understanding of the applications of the Snell-Descartes Laws. Knowing the relative indices of two media can allow us to predict a ray of light's path at the boundary between the two media: reflection and/or refraction. You will notice that there is always a reflected ray, no matter what the incident angle on the boundary between two media with different indexes is. You will identify the critical angle of refraction between two media: above this angle there will be total internal reflection. We will be able to bring out a ray's behavior through graphical representation of the related rules, with a method that uses refractive indices. Specifically, a graphical representation of the reflected and refracted rays, knowing the two environments' refractive indices.

The plane mirror being an example of a system that completely reflects light, you will learn that it is rigorously stigmatic for all points. You will learn to graphically define an incident beam's corresponding reflected beam on a plane mirror.

The plane boundary is often encountered in day to day life. You will learn the necessary conditions for rigorous stigmatism to exist. You will also study images under nearsighted stigmatism. You will then have to establish conjugate relations.

This learning activity is made up of problems related to plane mirror and boundary characteristics. They are multiple choice questions and the learner will have to check off the answers that he or she believes to be the right ones. All of the problems must be completed.

Relevant Reading

RAMILISON, H. A. (2006). Dioptre et miroir plans Madagascar Antanarivo University. Unpublished course. (Give more easily accessible relevant readings)

Reading Summary

The course is an application of the Snell-Descartes Laws. It will accentuate the existence of a critical refraction angle at the interface of two media in relation to their refractive indexes. Above that angle light is completely reflected back. Those properties will be applied in the study of mirrors and plane boundaries. The fact that the nature of an object or an image is always the opposite of itself, when applied to mirrors and plane boundaries, will be emphasized. The conditions for astigmatism will be addressed and the established conjugate equations.

African Virtual University

Justification

This reading will help readers comprehend the justifications and limitations so that they may:

- understand the existence of the critical refraction angle;
- understand the necessary conditions that result in near sighted astigmatism;
- familiarize themselves with the nature of objects and images;
- be able to graphically interpret Snell-Descartes' Laws;
- be able to draw an angle of incidence, emergence, reflection, refraction, etc.

Useful Links (Give relevant links in English also)

optique/cours/chap2.html#x1-92005

http://www.uel-pcsm.education.fr/consultation/reference/physique/optigeo/menumodule/menuthemes/menu_reduit.html

http://www.univ-Lemans.fr/enseignements/physique/02/optigeo/

http://fr.wikipedia.org/wiki/Optique

http://cours.cegep-st-jerome.qc.ca/203-301-r.f/prtie2/chap6/default.htm

Activity Introduction

Let us take a glass of water and dip a spoon into it. What seems to happen? The spoon looks like it’s bending where it meets the water. The submerged part of the spoon makes the glass look shallower than it is, and we can see the reflection of the part of the spoon that is above water. All of these elements demonstrate the way the light’s behavior changes as it goes through the water’s surface, i.e., the reflection on the surface can only be the image of the part of the spoon that is emerging from the water’s surface that is acting as a reflective material. We will be explaining all of these observations in this chapter.

Formative Evaluation

1- Draw a commented (annotated?) sketch that highlights the Snell-Descartes Laws; (but this sketch has already been given in the text earlier)

2- Recall the physical meaning of each element of the Snell-Descartes Laws;

3- If light passes from one medium (1) to another medium (2) with n < n , which

2

inequality describes the relation between angles i and i ?

1

2

a) i < i

1

2

b) i > i

1

2

c) i = i

1

2

Check off the right answer(s).

4- In that case, how is the ray refracted with respect to the normal? The refracted

ray:

a) moves closer to the normal

b) moves away from the normal

c) stays in the same line as the incident ray

Check off the right answer(s).

5- Therefore, when the angle of incidence increases, the angle of the refracted

ray will reach a maximum value.

a. True

b. False

6- If light passes from one medium (1) to another medium (2) with n > n , which

1

2

inequality describes the relation between angles i and i ? You may use the

1

2

answer to question 3 by applying the opposite light rule.

a) i < i

1

2

b) i > i

1

2

c) i = i

1

2

Check off the right answer(s).

7- In that case, how is the ray refracted with respect to the normal? The refracted

ray:

a) moves closer to the normal

b) moves away from the normal

c) stays in the same line as the incident ray

Check off the right answer(s).

8- Therefore, when the angle of incidence increases, the angle of the refracted ray will reach a maximum value. You may use the answer to question 5 by applying the opposite light rule.

a. True

b. False

9- **Geometrical construction:** Recall the definition for the plane of incidence.

10- Recall the definition of the point of incidence I;

11- Take the plane of incidence for a figure plane and draw an incident ray A I,

1

where I is the point of incidence. Draw a circle with center I and radius in proportion to n . Extending the incident ray will intersect the circle at point A.

1

Take TT', the line representing the plane tangent by I to the surface boundary between the two media with indices n and n , with AH being the normal at

1

2

TT' and passing through A. Draw a circle with center I and radius in proportion to n . Extending AH will intersect the circle proportional to n at point

2

2

A . The refracted ray is IA . Please note that for n > n , the circle with radius

2

2

2

1

n is inside the circle with radius n and the construction is still possible. On

1

2

the contrary, if n < n the uttermost ray that can penetrate into medium with

2

1

index n intersects the circle with radius n at a point B such as the normal

2

1

BH is tangent to the circle of radius n . We have now graphically construed

2

the critical angle l ′ = l . Using this method, double-check the answers you

have chosen for questions 3 to 8.

12- Problem 1: A beam of light passes from the air to a liquid; it is deviated by

19º and the angle of incidence is 52º. Select the liquid’s refractive index from

the following values:

a) 0.83

b) 1.45

c) 2.42

d) 1.20

Check off the right answer(s).

13- Problem 2: With respect to the horizontal, in which direction does a diver

at the bottom of the ocean see a sunset? The water’s refractive index is n =

2

1.333 and the air’s is n =1.

1

a) 0°

b) 41.4°

c) 48.6°

d) 90°

Check off the right answer(s).

African Virtual University

14- Problem 3: When a diver at the bottom of a lake looks up to a perfectly calm surface, it looks dark to her, except in a circular area that is exactly above her. Determine the angle implied by this illuminated area. The water’s refractive index is n = 1.333 and the air’s refractive index is n =1.

2

1

a) 41.4°

b) 48.6°

c) 82.8°

d) 97.2°

Check off the right answer(s).

15- Define a plane mirror.

16- The mirror-image A’ of a point A is symmetrical to A in relation to the mirror’s plane.

a. True

b. False

17- A written text, reflected by a mirror is reversed.

a. True

b. False

18- We place two mirrors face to face, each one with a length of 1.5 m. The distance between them is 15 cm. A ray of light falls onto the edge of one of the mirrors, with an angle of incidence of 15º. How many times will the ray be reflected before it makes it to the other edge?

To solve this problem, draw a sketch that represents the reflection angles and then determine the horizontal distance that the ray travels between two reflections. There will be:

a) 15 reflections

b) 30 reflections

c) 37 reflections

d) 74 reflections

Check off the right answer(s).

African Virtual University

19- Problem 5: Two plane mirrors are parallel to and 20 cm away from each other. A glowing spot is placed between them, 5 cm away from the first mirror. Determine the distances of the three nearest images that appear in each mirror in relation to the other. For the first mirror, the images are at:

For the first mirror

For the second mirror

a-) 5 cm

a-) 5 cm

b-) 10 cm

b-) 10 cm

c-) 15 cm

c-) 15 cm

d-) 20 cm

d-) 20 cm

e-) 25 cm

e-) 25 cm

f-) 35 cm

f-) 35 cm

g-) 40 cm.

g-) 40 cm

20- Teamwork:

Required material: Mirror, large sheet of paper, needles.

Procedure: Place the large sheet of paper on a table and place the mirror on top, taking care to secure the mirror orthogonally to the table. Trace along the bottom of the mirror. One group will plant some needles vertically onto the sheet of paper, taking care to line them up at equal distances and push them in at the same height. A second group will plant some needles vertically onto the sheet of paper, in the same way as the first group and taking care to line them up with the images of the needles planted by the first group.

Double-check that the needles planted by the second group are perfectly lined up

with the needles planted by the first group.

Take down the assembly and keep track of the holes from the needles that were

planted. Draw a line (D) through the positions of the needles planted by the first

1

group, and do the same with a line (D) for the second group. Make sure the two

2

lines intersect at a point I that is on the line that was traced along the bottom

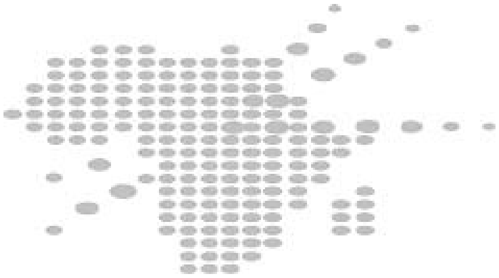
of the mirror. Draw a line (D) perpendicular to the mirror starting from point I.

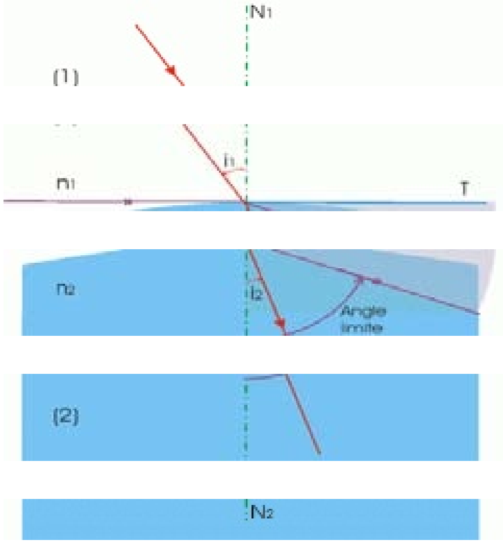
Make sure that the lines D and D are symmetrical to D. This demonstrates the

1

2

law of reflection.





African Virtual University

Answer Key

1-) and

2-) Critical Refractive Angle

If light travels from a less refractive medium (1) to a more refractive medium (2),

as in if n < n , according to DESCARTES’ 3rd law we will have:

1

2

n sin i

sin i

2

2 = n1

1

or,

$n1 < n2 \Rightarrow \sin i2 < \sin i1$

therefore, $i2 < i1$

Since both angles are acute and have the same sign, any incident ray A I will

1

correspond to a refracted ray IA which gets closer to the normal as it enters

2

the more refractive medium. **(**The annotations, where applicable must also be

translated into English**)**

Feedback: Excellent diagram and commentary.

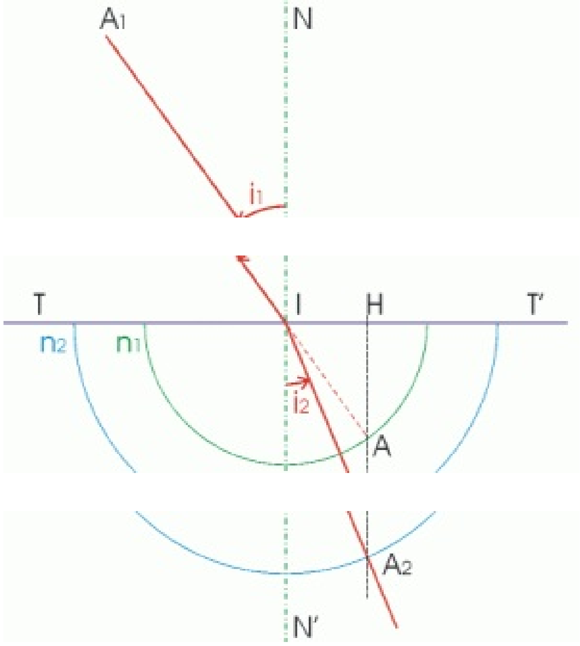
3.

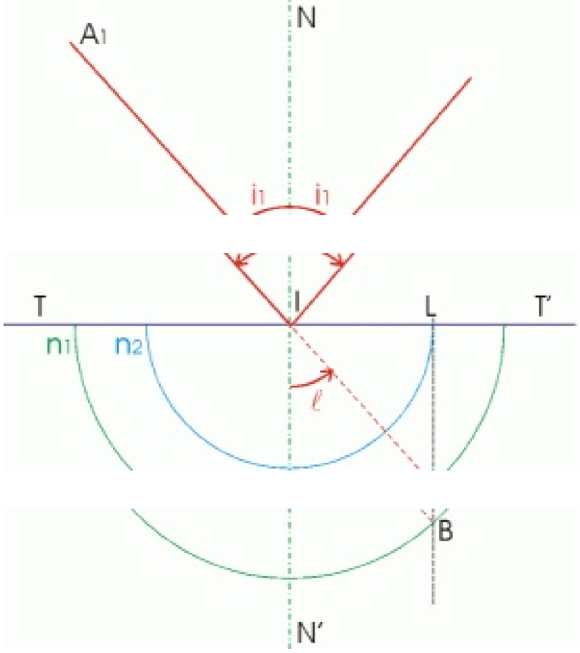
a. Read the question again.

b. Very good answer. The refractive indexes are indeed inversely proportional

to the angle of incidence.

c. Think about the relation between the angle of refraction and the angle of incidence.





African Virtual University 0

4.

a. Excellent, your answer is correct.

b. Review the lesson on refraction.

c. Carefully read the question again.

5.

a. Good job, a does indeed end up with the maximum incidence skimming

1

value of 90°. The value of a is limited and smaller than 90°.

2

b. Read the question again to understand it better.

6.

a. Good answer, since medium 1 is more refractive than medium 2, we do

indeed obtain i <i

1

2

b. Please try again.

c. You have misread the question

7.

a. Try again

b. Great answer.

c. Review the lesson.

8.

a. This is the wrong choice.

b. Very good answer. When the incident ray’s angle increases, there is indeed

no more refracted ray. There is total internal reflection.

9-10- 11. Geometrical construction

Feedback : Good diagrams and commentary.

Surface Index Method.

The plane of incidence is used as the figure plane.

Using the point of incidence I as the center, we draw two circles with radii proportional to n and n . Extending the incident ray A1I intersects the circle with

1

2

radius n1 at point A. If TT' represents the plane that is tangent by I to the surface separating the two media with indexes n and n , the normal AH it intersects the

1

2

half-circle with radius n at point A2. The refracted ray is IA2.

2

When n > n , the circle with radius n is inside the circle with radius n and the

2

1

1

2

construction is still possible. On the contrary, if n < n the uttermost ray that

2

1

can penetrate into medium with index n intersects the circle with radius n at a

2

1

point B such as the normal BH is tangent to the circle of radius n . We have now

2

graphically construed the critical angle l ′ = l .

12.

a. This is the wrong answer.

sin 52°

b. Good answer, as a matter of fact n =

sin (52° −19°)

c. Think about the relation between the refractive index and the angle of incidence.

d. Read the question once more and then try again.

13.

a. Careful, Try again.

b. The critical angle for refraction is 48.6°. In relation to the horizontal, we have 90°- 41.4°.

c. Try again

d. Read the question once more and then try again.

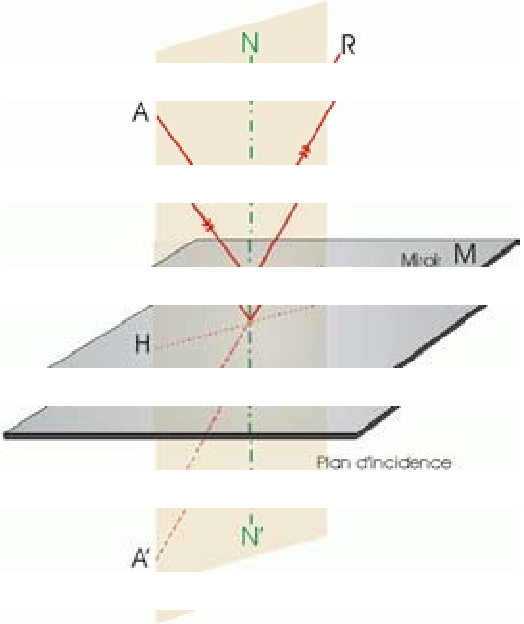
14.

a. Take your time to read the question before answering.

b. Try again

c. Try one more time

d. Good answer, the implied angle is indeed equal to double the critical angle of refraction.



15. Mirror-image

The ray AH, normal to the mirror, doubles back on itself: the image of A, if it exists, is therefore on the normal.

The reflected ray IR of some incident ray AI is in the plane of incidence AIN which also includes AH (since AH and IN are parallel, like lines that are perpendicular to the same plane, and that by definition, A is part of the plane of incidence.

IR's support meets AH at a point A'. **(**The annotations, where applicable must also be translated into English**)**

(It is important to number the figures are appropriately refer to them in the text)

In the triangle AIA', the height IH is also the bisector. The triangle is therefore an isosceles triangle. Thus, IH is also the median and we get AH = HA'.

This shows that A' is symmetrical to A with respect to the mirror's plane, no matter which incident ray is considered. A’ is the image of A.

16.

a. Good answer.

b. You have misread the question.

17.

a. Good answer

b. You have not thought it through before answering.

18.

a. Try again

b. Careful, you answered too fast. Try again

c. Very good.

d. Please try again, you have misunderstood the question.

19) For the first mirror : a-e-f. Very good.

For the second mirror: b-d-g. Very good.

Give the following feedback for all other answers : review a mirror’s characteristics.

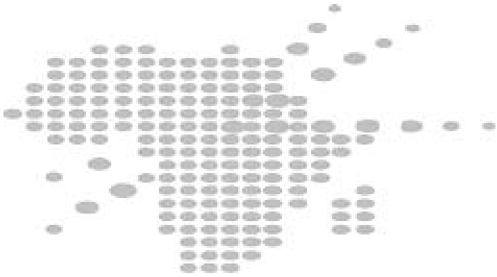
Self Evaluation

The learners write down the difficulties they encountered while solving the problems. Following those difficulties, each group will be oriented towards the Power Point presentations or the interactive animated website at the following address: http://www.sciences.univ-nantes.fr/physique/enseignement/DeugA/

Physique1/optique/TP-info/index.html. (any equivalent site in English?) Each group will then debrief the tenured teacher or tutor about their results in an attachment sent by e-mail.

Teacher Guidelines

The tutor will open the chat window, correct all of each group's answers and briefings sent in an attachment by e-mail. The appropriate feedback will be sent back to each group by e-mail and the activity's general solution will be posted on the 'Student' workspace. The grade received from this activity accounts for 20% of the module evaluation.



African Virtual University

Learning Activity 3

Activity Title

Boundaries and Curved Mirrors

Required Time

8 hours

Specific Objectives

The learner should be able to:

Describe a curved boundary;

•

Describe a curved mirror;

-

Construct the image of a real object placed before a curved boundary

-

Construct the emerging ray that corresponds to an incident ray

Determine a curved boundary’s characteristics using the conjugate equations

Describe the characteristics of an image produced by a curved boundary.

Activity Summary

Through this activity you will learn how to describe a curved boundary and a curved mirror and also be able to determine their characteristics. With these elements the conditions for astigmatism, or at least near-sighted astigmatism, will be defined and the conjugate relations will be established.

You will then have to define the characteristics of a curved boundary followed by those of a curved mirror. This way you will be able to draw the path of a ray of light and predict experimental results using the characteristics of a curved boundary.

Key Concepts

Main Boundary Axis: The diameter of the sphere that is perpendicular to the dome’s useful surface, also known as the optical axis.

Object Focal Point: The point where the rays coming from the object meet the optical axis and come out parallel to it.

Image Focal Point: The object rays that are parallel to the optical axis exit the curved boundary and meet the optical axis at the image focal point. **Image Focal**

Plane: Home to the image's 'secondary focal points' like Φ where the cylindri-

2

cal beams parallel toC Φ converge. This plane passes through the image focal

2

point and is orthogonal to the main axis. (These symbols have not been defined. Which figure is being referred to?)

Magnification: The relation between the dimensions of an image in the frontal plane in A and the corresponding dimensions of the object in A . (These symbols

2

1

have not been defined. Which figure is being referred to?)

Activity Description

This educational activity consists of gaining a better understanding of the definitions and reasoning behind the different demonstrations used to establish the rules and characteristics relative to a curved boundary. You will have to know how to calculate the curved boundary's different characteristics using the conjugate relations. You will also be expected to know how to graphically solve curved boundary problems.

This learning activity is made up of problems related to curved mirror and boundary characteristics. They are multiple choice questions and the learner will have to check off the answers that he or she believes to be the right ones. All of the problems must be completed.

Relevant Reading

RAMILISON, H.A. (2006). Dioptre et miroir sphérique. Madagascar. Antanarivo University. Unpublished course. (Give also more accessible reading lists)

Reading Summary

This course is an introduction to the study of lenses, essentials elements in any optical system. It will describe the characteristics of a curved boundary, a brief study of rigorous astigmatism will allow us to define the necessary conditions for near sighted astigmatism also know as the Gauss conditions. With these conditions, we will be able to define the key points that describe a curved boundary. We will then establish the different conjugate relations depending on the origin's position: at the vertex (Descartes), at the focal point (Newton), or in the center. Under the Gauss conditions we will then be able to define the characteristic planes like principal planes, focal planes, which will facilitate the drawing of light rays and therefore the possibility of solving graphs. It will also be easier to transition from curved boundaries to curved mirrors since the only requirement will be to realize that there is total internal reflection in a mirror. All of the previous results will therefore be used and we will also obtain the conjugate formulas. We will be able to follow a Power Point presentation about drawing beam paths and graphically determining the images in a curved mirror under the paraxial conditions.

Reading Justification

This reading will help readers comprehend the justifications and limitations so that they may:

- understand the necessary conditions that result in near sighted astigmatism;
- familiarize themselves with the nature of objects and images;
- familiarize themselves with the concept of vergency (optical power).
- learn the definitions for concepts such as: magnification, focal planes and principal planes.

Useful Links

http://www.sciences.univ-nantes.fr/physique/enseignement/DeugA/Physique1/optique/cours/chap3.html#x1-92005

http://www.uel-pcsm.education.fr/consultation/reference/physique/optigeo/menumodule/menuthemes/menu_reduit.html

http://www.univ-Lemans.fr/enseignements/physique/02/optigeo/

http://fr.wikipedia.org/wiki/Optique

http://cours.cegep-st-jerome.qc.ca/203-301-r.f/prtie2/chap6/default.htm

Activity Introduction

There are many spherical aquariums. When we look at fish as they swim around inside of one, we notice that the fish’s shape and size change depending on his position. In the same way, it is possible to find mirrors that magnify. When we look more closely we can notice lots of imperfections in the image but it still has the added bonus of covering a larger visible area in the curved mirror compared to the plane mirror.

Formative evaluation

1. Draw a diagram, with commentary, that allows you to define a curved boundary's characteristic elements, as well as the orientation conventions.

2. Complete the following sentences:

The conditions for nearsighted astigmatism are related in the following two hypotheses:

a) the plane that is perpendicular to the axis in I can be confused with ……

b) for the axis' neighboring rays, the angles i and i are ……….

1

2

3. Match up the following columns by associating the right letter and number together:

1- An incident ray that is parallelto the

a. is not deviated as it crosses the

boundary's optical axis

boundary.

2- An incident ray traveling through

b. is refracted as it crosses the

the boundary's object focal point

boundary's image focal point.

3- An incident ray traveling through

c. is refracted parallel to the

the middle of the boundary

boundary’s optical axis.

4. Consider a sphere with center O, radius R = 3 cm and refractive index n= 4/3, surrounded by air. Using the curved boundary conjugate relation with a central origin (under the Gauss conditions), choose the value that describes the position OA’ of image A through the sphere if OA = 6 cm.

a) 9 cm;

b) –1.5 cm;

c) +9 cm;

d) +1.5 cm;

e) ∞

Check off the right answer(s).

5. Consider a curved boundary (D) with vertex S, center C, radius R=SC and image focal point F’, that separates the air of refractive index n = 1 and a

1

medium with refractive index n . Stigmatism is assumed to be achieved. Us-

2

ing the conjugate relation for a vertex origin, express the position SF’ of the image focal point in terms of R, n and n Choose the answer that describes

1

2.

n if SF’= 2R.

2

a) 1.25;

b) 1.33;

c) 2;

d) 2.14.

Check off the right answer(s).

6. Using the conjugated equations for a central origin, determine the position of the image produced by the real object AB relative to the center of the mirror and the magnification G for a concave mirror with radius R.=.4.m. The object AB is sitting 2 m away from the center of the mirror, and the Gauss conditions are verified. The value of CA’ and of G is:

a) CA’= - 1 m

1-) G= -0.5

b) CA’= 1 m

2-) G= +0.5

c) CA’= 2 m

3-) G= 1

Check off the right answer(s).

7. Using the conjugate equations for a vertex origin, determine the position of the image produced by the real object AB relative to the center of the mirror and the magnification G for a concave mirror with radius R.=.4.m. The object AB is sitting 2m away from the mirror’s vertex, and the Gauss conditions are verified. The value of CA’ and of G is:

a) CA’= - 1 m

1-) G= -0.5

b) CA’= 1 m

2-) G= +0.5

c) CA’= 2 m

3-) G= 1

Check off the right answer(s).

Learning Activities

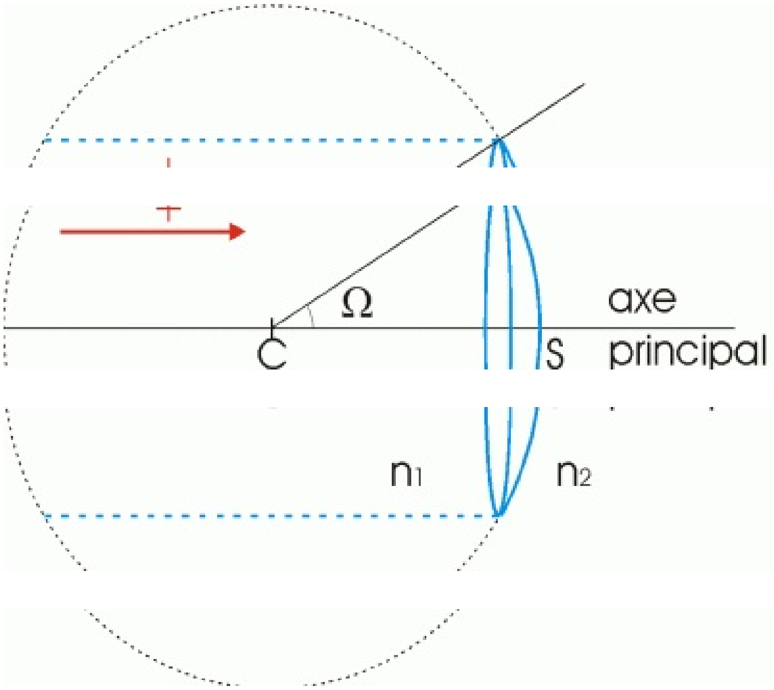
To be able to answer the questions the learners must:

- read all of the recommended readings;
- draw diagrams describing all of the different origins for the conjugate formulas;
- pay very close attention to the Power Point presentation about drawing light paths for a curved mirror;
- complete all of the problems and exercises with clear and precise diagrams
-

organize themselves into a work group

The group members will work together to solve each exercise. Each group will designate a spokesperson; the spokespersons from every group will then share the answers to each exercise through chatting, under the guidance of a tutor. The tutor will be able to let them know when the correct answer for a question has been found and will suggest that they continue on to the next exercise.

When all of the problems are solved, the chat window is closed. Since the discussions are recorded, the tutor will be able to review the chat session at any time and tell which group suggested the best solutions through each spokesperson.



Answer Key

1. A curved boundary is made up of two transparent, homogenous and isotropic media that have different refractive indices and are separated by a curved surface. **(**The annotations, where applicable must also be translated into English**)**

The middle of the boundary and its radius are the sphere’s own center algebraic radius R = SC. We have chosen the positive direction as the one following the light’s direction of propagation and the angles are trigonometrically oriented in a positive direction as well. The medium with refractive index n is identi-

1

fied as the object medium and the one with refractive index n is identified as

2

the image medium.

The main boundary axis is the diameter of the sphere that is perpendicular to the dome’s useful surface, also known as the optical axis. The main axis intersects the boundary at its vertex S. **Ù** is equal to half of the boundary’s angular aperture.

Perfect diagram and commentary.

2. The conditions for nearsighted astigmatism are related in the following two hypotheses:

a) the plane that is perpendicular to the axis in I can be confused with **the plane tangent with S.** Very good

b) for the axis’ neighboring rays, the angles i and i are **always small.** Very

1

2

good.

3.

1-b. Very good

2-c. Very good

3-a. Very good

For all other combinations like: 1a, 1c, 2b, 2a, 3b, 3c = Read the question again before trying a second time..

4

a. Take your time to reread the question.

b. Be careful, you need to use the conjugate equation for a curved boundary with a central origin.

c. Think about it, we said with the origin in the center.

d. Start over, you must have misunderstood.

f. Take your time.

e. Good answer, point A does coincide with the object focal point. We can use the course's relation 3.11.

5.

a. Take your time to answer.

b. Read the question over again.

c. Very good. We can use relation 3.2 from the course to determine the focal length.

d. Watch out for the refractive index equations.

6.

b-1. Very good answer. We can use relations 3.18 from the course.

Give the following feedback for answers (a1, a2, a3, b2, b3, c1, c2, c3) :

Reread the question to understand it better. The origin is in the center.

7.

b-2. Very good answer. We can use relations (3.15) from the course.

Give the following feedback for answers (a1, a2, a3, b1, b3, c1, c2, c3):

Reread the question to understand it better. The origin is at the vertex.

African Virtual University

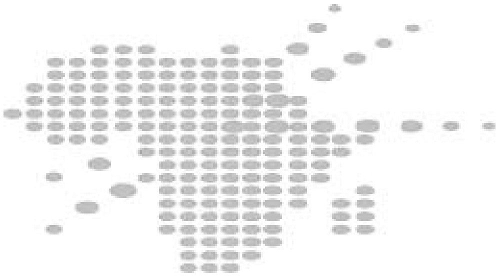
Self Evaluation

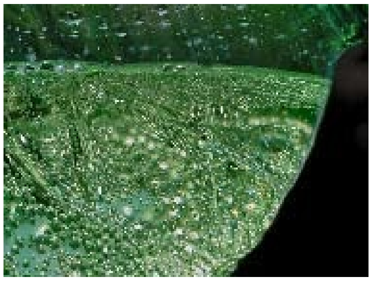
The learners write down the difficulties they encountered while solving the problems. Following those difficulties, each group will be oriented towards the Power Point presentations or the interactive animated website at the following address: http://www.sciences.univ-nantes.fr/physique/enseignement/DeugA/ Physique1/optique/TP-info/index.html. (Give also equivalent site written in English) Each group will then debrief the tenured teacher or tutor about their results in an attachment sent by e-mail.

Teacher Guidelines

The tutor will open the chat window, correct all of each group’s answers and debriefings sent in an attachment by e-mail. The appropriate feedback will be sent back to each group by e-mail and the activity’s general solution will be posted on the ‘Student’ workspace. The grade received from this activity accounts for

20% of the module evaluation.





Learning Activity 4

Activity Title

Study of Lenses

Required Time

8 hours

Specific Objectives

The learners should be able to:

- Describe a thick lens
- Describe a thin lens
- Differentiate and characterize the various types of thin lenses
- Build the image of a real object perpendicular to the axis
-

Build the emerging ray that corresponds to an incident ray

- Determine a lens' characteristics using the conjugate relations
- Describe an optical system's image characteristics

Activity Summary

Through this activity you will learn how to describe a thick lens and to determine its characteristics. Using those elements, we will establish the necessary conditions for drawing a representation scaled down to a portion of straight line that is perpendicular to the lens' principal axis. This representation will define a thin lens.

You will then use the thin lens' characteristics to identify and categorize the different types of thin lenses. This way you will be able to draw the path of a ray of light and predict experimental results. You will need to establish the conjugate relations that will be used to build optical systems later on.

Key Concepts

Thin Lens: A lens is considered to be thin when its thickness is negligible in relation to the radii of curvature for each face.

Object Focal Length: The distance between the optical center and the object focal point.

Object Focal Point: The point where the rays coming from the object meet up with the optical axis and exit the lens parallel to it.

Image Focal Point: The rays coming from the object traveling parallel to the optical axis exit the lens and meet the axis at the image focal point.

Optical Center: It is the point on the axis that for every ray that propagates through the lens and crossing that point there is a parallel emerging ray and an incident ray.

Activity Description

This learning activity is made up of problems related to lens characteristics. They are multiple choice questions and the learner will have to check off the answers that he or she believes to be the right ones. All of the problems must be completed.

Relevant Reading

RAMILISON, H. A. (2006)**.** Madagascar. Antanarivo University. Unpublished course: Chapter 5 Lenses. (see earlier comments)

Reading Summary

This course will use the relations and equations established for curved boundaries to define the characteristics for a thick lens. From these elements we will be able to define the conditions for using the thin lens representation, and those conditions will amount to all of the characteristics for a thin lens. Geometrical interpretations have allowed us to draw the path of a ray of light and predict experimental results related to thin lens problems.

Justification

This reading will help the readers follow the justifications and demonstrations so that they may

- understand the necessary conditions for obtaining thin lenses;

- familiarize themselves with the symbolism, nature and shape of lenses;
- learn the different concepts such as: object point, image point, optical center, focal points…
- understand the different methods that are used to graphically determine the elements of a thin lens.

Useful Links

http://www.sciences.univ-nantes.fr/physique/enseignement/DeugA/Physique1/optique/cours/chap5.html#x1-92005

http://www.uel-pcsm.education.fr/consultation/reference/physique/optigeo/menumodule/menuthemes/menu_reduit.html

http://www.univ-Lemans.fr/enseignements/physique/02/optigeo/

http://fr.wikipedia.org/wiki/Optique

http://cours.cegep-st-jerome.qc.ca/203-301-r.f/prtie2/chap6/default.htm

Activity Introduction

The study of boundaries, particularly curved ones, have allowed us to establish light’s propagation characteristics when it travels through two media with different refractive indices. The results for curved boundaries are quite relevant for the study of lenses since the faces are restricted by curved boundaries. We will therefore need to describe thin lenses’ fundamental properties by sorting them and learning to draw light’s path through them, along with determining the conjugate relations used to characterize the resulting images.

Formative Evaluation

Part One

5

Consider a glass biconcave lens with refractive index n = . Each face has a

3

radius of curvature equal to 12 cm and their vertices are 1.2 cm apart, following

a sketch drawn using an appropriate scale going from left to right.

1-1 Give the correct algebraic values for the variables used in the equations.

a.) S C = R = +12 cm

1

1

1

b.) S C = R = +12 cm;

2

2

2

c.) e = S S = +12 mm;

1 2

d.) S C = R = -12 cm;

1

1

1

e.) S C = R = -12cm;

2

2

2

f.) e = S S = -12 mm.

1 2

Check off the right answer(s).

1-2 Calculate the lens’ image focal length.

The image focal length Φ is:

a.) 90 mm;

b.) 88.235 mm

c.) -90 mm ;

d.) -88.235 mm

Check off the right answer(s).

1-3 If we consider that the distance between the vertices is negligible for the radii

of curvature, which answer describes the correct focal length value?

a.) 90 mm ;

b.) 88.235 mm

c.) -90 mm ;

d.) -88.235 mm

Check off the right answer(s).

1-4 What is the approximation error?

The approximation error is :

a.) 20%

b.) 5%

c.) 2%

d.) 0.5%

Check off the right answer(s).

2- Recall the expression for the optical center.

3- Calculate the position of a lens' optical center.

4- Geometrically interpret the optical center's position for different types of lenses.

5- Part Two

5-1 Once again using the biconcave lens, calculate the position of the lens' optical center.

The position of the lens' optical center OS is:

2

a.) 0

b.) + 2mm

c.) + 6mm

d.) - 2mm

e.) - 6 mm

Check off the right answer(s).

5-2 Geometrically interpret the value of the position of the optical center.

The optical center is:

a.) merged into the lens' left vertex;

b.) between the middle of the lens and its left vertex;

c.) in the middle of the lens;

d.) between the middle of the lens and its right vertex;

e.) merged into the lens’ right vertex;

Check off the right answer(s)

6- Under which conditions can a lens’ thickness be considered negligible with the optical center merged into the middle of the lens?

7- Define a thin lens.

8- A biconvex lens approximated to a thin lens is:

a.) convergent;

b.) divergent;

c.) of focal length 90 mm;

e.) of focal length 88.235 mm

f.) of focal length -90 mm;

g.) of focal length -88.235 mm

Check off the right answer(s)

9- Determine the focal lengths for a thin lens.

10- Give a geometrical interpretation of the characteristics for a thin lens.

11- Graphically determine the image of an object.

12- Graphically determine the emerging ray for an incident ray.

13 : Calculate the image and object focal lengths for a biconvex thin lens.

13-1 : The image focal length is :

a. +180 mm

b. +300 mm

c. + 88.235 mm

d. -180 mm

e. -300 mm

f. - 88.235 mm

Check off the right answer(s).

13-2 : The object focal length is:

a. +180 mm

b. +300 mm

c. + 88.235 mm

d. -180 mm

e. -300 mm

f. - 88.235 mm

Check off the right answer(s).

14- Using the conjugate formulas for centered systems, write the conjugate equations for thin lenses.

15- Part Three:

Determine the position of the thin lens’ principal planes.

15-1. The position of the image’s principal plane defined as S is equal to:

2H ʹ

a.) +3.53 mm

b.) +3.235 mm

c.) -3.53 mm

d.) -3.235 mm

Check off the right answer(s)

15-2 The position of the object’s principal plane defined as S H is equal to:

1

a.) +3.53 mm

b.) +3.235 mm

c.) -3.53 mm

d.) -3.235 mm

Check off the right answer(s)

Learning Activity

The learners must complete all of the recommended reading before answering the questions. They must complete all of the exercises. They will be divided into work groups. Each group must solve the problems and will designate a spokesperson. After a certain amount of time (4 hours) decided by the tutor, each spokesperson will write up a report, making sure that the first and last name of each group member is included, and will then send their report by e-mail to the tenured teacher for the course.

Answer Key

Question 1-1 : b. ; c. ; d. ; Comments: The distances are algebraic values and are defined from left to right.

Give the correct algebraic values for the variables used in the equations

a. You have mixed up the variables.

b. Great answer, the distances are indeed algebraic values defined from left to right.

c. Great answer, the distances are indeed algebraic values defined from left to right..

d. Great answer, the distances are indeed algebraic values defined from left to right.

e. Careful, you have not correctly identified the variables.

f. Try again.

Question 1-2 :

a. Careful, this is a diverging lens.

b. You are confused between a diverging and a converging lens.

c. Think it through before answering.

d. Good answer, the lens is divergent and we did not use the thin lens approximation.

Question 1-3

a. Reread the question before answering.

b. Think it through some more.

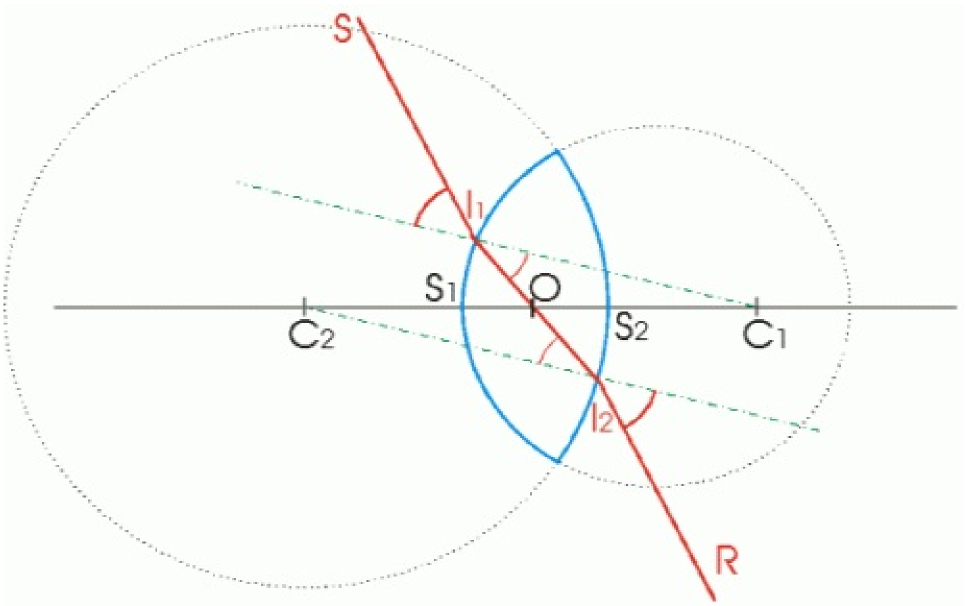
c. Great answer, the lens is indeed divergent and we consider its thickness to be negligible.

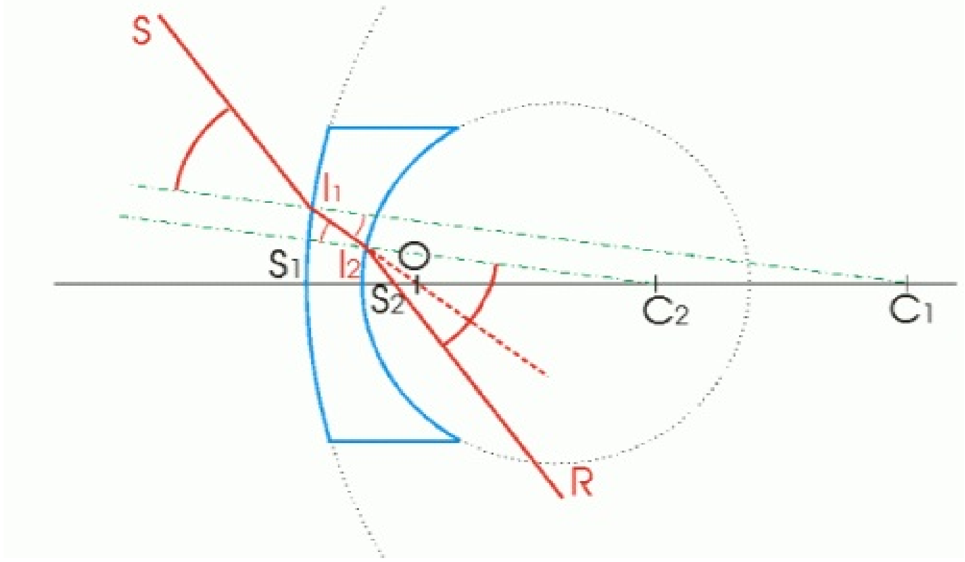
Question 1-4

a. Try again.

b. Reread the question before trying again.

c. Very good.





Question 2.

A lens’ optical center O is a point on the axis belonging to the refractive medium

n, that can be inside or outside the segment S S , in a way that every ray that

1 2

travels through the lens and intersecting that point has a parallel emerging ray and incident ray.

Good answer, You have understood the question.

Question 3: Point O divides the segment S S in the relation between the radii of

1 2

curvature’s algebraic values and is therefore unique. O does not depend on the

refractive index for the glass that the thick lens is made of. O is positioned between

S and S if R and R are of opposite signs. O is outside of S S if R and R are

1

2

1

2

1 2

1

2

of the same sign. O is always closest to the face with the most curvature.

OS

R

R

Therefore:

1

1

1

=

⇒ OS = e

1

OS −OS

R − R

R − R

2

1

2

1

2

1

OS −OS

R − R

R

In the same way:

2

1

2

1

2

=

⇒ OS = e

2

OS

R

R − R

2

2

2

1

Perfect answer.

Question 4: The optical center O is the image of the lens' object nodal point N

through the entrance boundary, where the image of the optical center O through

the exit boundary is the image nodal point N'.

We can therefore consider that O and S (as well as O and S) merge if the thic-

2

1

kness S S is small compared to the absolute value of the difference between

1 2

the radii of curvature's algebraic R - R . The optical center O could then merge

2

1

with the vertices S and S ; the nodal points and principal points will also merge

1

2

with O. Good answer

Question 5-1

a. Try again.

b. You are mistaken, Try again.

c. Good answer, relation 5-6 from the course gives the same result.

d. Review your course.

e. You are confused.

Question 5-2.

a. Take your time.

b. Try again.

c. Good answer

d. Review your course.

e. You are confused.

Question 6 A lens is considered to be thin when its thickness is negligible in relation to its face’s radii of curvature. The vertices can then merge into one point S, and we can consider that O and S (as well as O and S) merge if

2

1

the thickness S S is small compared to the absolute value of the difference

1 2

between the radii of curvature’s algebraic R - R . When those two conditions

2

1

are satisfied, the optical center O can merge with the vertices S and S ; the

1

2

nodal points and principal points will also merge with O. Very good, is can see that you understand.

Question 7: A thin lens is a centered system whose principal planes merge with the optical center. This allows us to draw a scaled down representation of a portion of straight line that is perpendicular to the lens’ principal axis. Very good.

Question 8

a. Careful, it isn’t a converging lens.

b. Very good, such a lens is a diverging lens.

c. Think about it some more.

d. Carefully reread the question.

e. Take your time.

f. Very good, the vergency is negative since the lens is divergent.

g. Please try again.

Question 9: As is the case for all centered systems, a thin lens has an object focal length f and an image focal length f’. Since it is a centered system with identical terminal media with indexes equal n , ‘THE’ focal length for the

0

lens is its image focal length that we will call . This focal length is related to the through the equation:

1

⎛ 1

1 ⎞

⎛ 1

1 ⎞

V =

= (n − n)

(n n)

0

−

=

−

⎜

0

−

⎟

⎜⎟

⎟⎟

⎜

⎟

Φ

⎝ R

R

1

2 ⎠

⎝ S C

S C

1 1

2

2)

for a thin lens, which means that S and S merge with the optical center O.

1

2

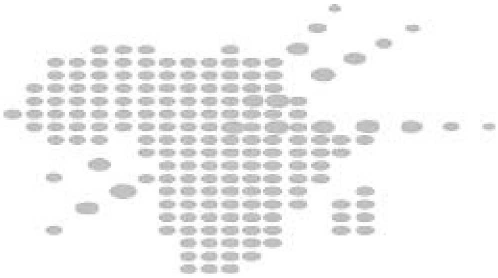
Question 10: The expression that relates the vergency (optical power) V of a thin lens allow us to see that two types of thin lenses can exist:

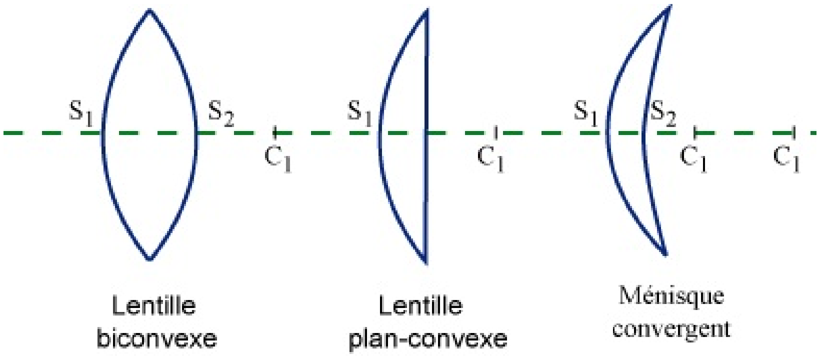
-

Converging thin lenses for which f’ is positive. The object focal point F is in the object space and the image focal point F’ lies in the image space. The two focal points are real. Excellent.

-

Diverging thin lenses for which f’ is negative and the focal points are virtual. SC will be considered positive if the face is convex and negative if the face si concave.

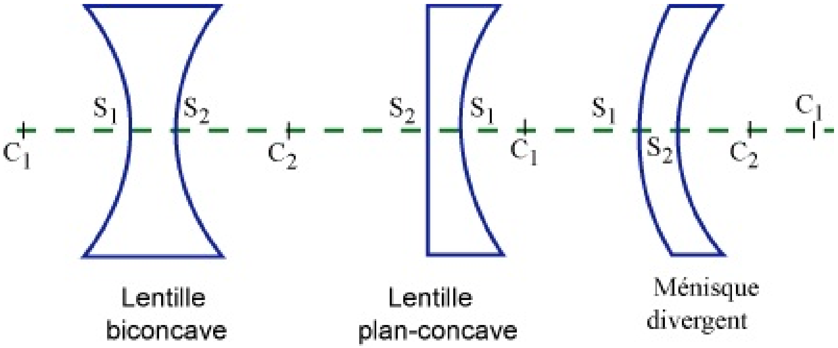




Lentille biconvexe

Lentille plan-convexe

Ménisque convergent



African Virtual University

(The annotations, where applicable must also be translated into English**)**

Therefore, the biconvex lens, convexe plane or meniscus that converge with

S C S

C are **converging** lenses**. Very good.**

1 1

2

2

(The annotations, where applicable must also be translated into English**)**

On the other hand, the biconcave lens S C 0 , concave plane S C 0   or the

1

1

1

1

diverging meniscus S C S

C are **diverging** lenses. **Very good.**

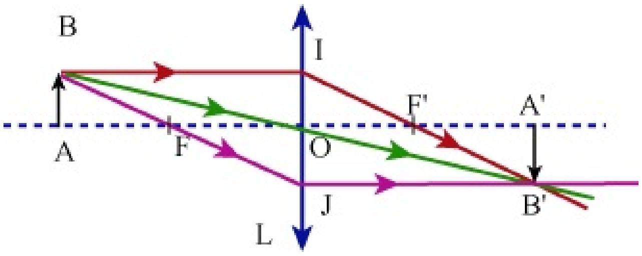
2

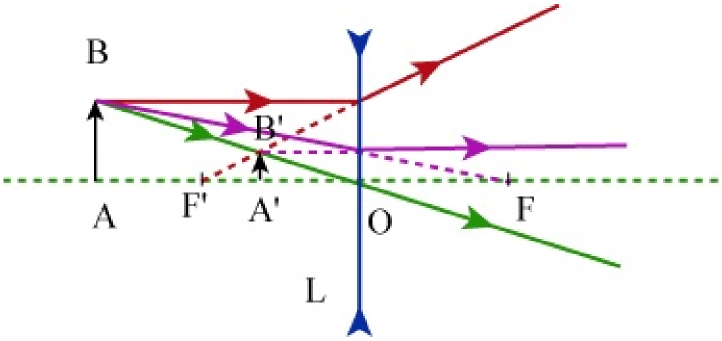
2

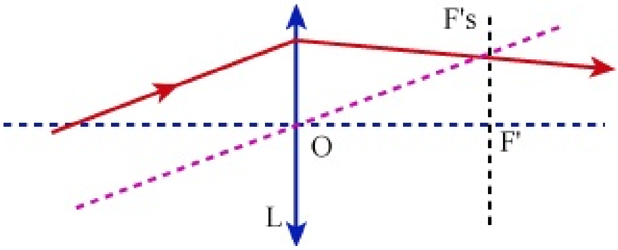
1 1

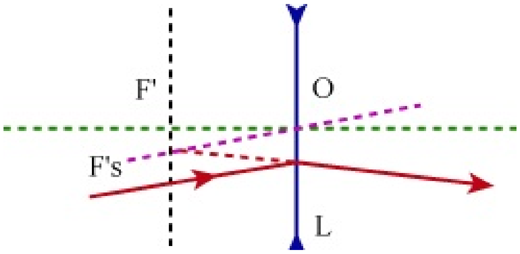
Question 11: Using the paraxial approximation (or Gauss approximation), the

image A'B' of an object AB perpendicular to the axis is also perpendicular to the axis. To find the image A’B’ of AB all we need to do is determine the image B’ of B and then lower a perpendicular line to the axis the height of B’ to find A’.









To accomplish this we can use two of the rays that come from B:

-

the ray that intersects the optical center O and is not deviated.

-

the ray that intersects the lens’ object focal point F and emerges parallel to the principal axis.

-

the ray that starts off parallel to the principal axis and intersects the image focal point F’ as it emerges.

Question 12: We are looking for the point when the incident ray intersects the object focal point F ; the emerging ray will run parallel to F O.

s

s

We draw a line parallel to the incident ray that intersects the optical center O and intersects the image focal plane at F’ ; the ray exits the lens by intersecting the

s

secondary focal point F’ .

s

Feedback : Excellent commentary ; nice precise and clear sketches.

Question 13-1.

a. Careful, the subject is a biconvex lens

b. Careful, we are talking about the image focal length.

c. Carefully reread the question.

d. Very good, the lens is biconvex and thus the image focal length is negative.

Question 13-2

a. Carefully reread the question.

b. Very good, the lens is biconvex and thus the image focal length is positive.

c. Careful, the subject is a biconvex lens

d. Careful, we are talking about the image focal length.

Question 14:

Conjugate relations for a central origin:

1

1

1

Using: p = OA

and

′

p = OA′ we get − + =

p p′ f ′

A B

′ ′

OA′

p′

Magnification is described by: Γ =

=

=

AB

OA

p

Conjugate relations for a focal point origin:

Using: $FA = x$ and $F'A' = x'$ $x.x' = -f'^2$

f'

x'

magnification is described by : $\Gamma =$

$= -$

x

f'

(Which figure(s) are being referred to in this question?)

Feedback: Very good, the equations are correct.

Question 15-1

a. Think it through before answering.

b. Careful, the subject is the image plane not the object plane.

c. Good answer, the image plane’s position is indeed negative.

d. This is not the right answer. Try again.

Question 15-2

The object principal plane’s position is described by SH and is equal to:

1

a. Great answer, you understand.

b. This is not quite the right value.

c.. Be careful, the distance is not negative.

d. Double-check your formula, this is not the right answer.

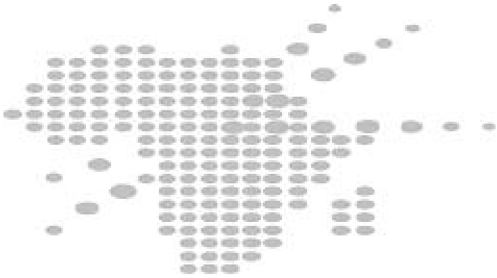
(Which figure(s) are being referred to in this question?)

Self Evaluation

The learners write down the difficulties they encountered while solving the problems. This will allow them to review the course sections they did not understand as well and to prepare them for the summary evaluation.

Teacher Guidelines

The tutor will correct each group’s report and send out the appropriate feedback. The answers will be posted on the ‘Student’ workspace. The grade received from this activity is the same for each group member and accounts for 20% of the module evaluation.



African Virtual University

Optional Educational Formative Evaluation

Activity Title

Rules for creating a short question.

Required Time

4 hours

Specific Objectives

To be able to:

- Recall the three rules for creating a simple question;
- Create a simple question using the three rules.

Applicable Reading

DIOUF, S. (2004). L’évaluation des apprentissages. UCAD of Dakar. FASTEF(ex ENS). Unpublished course. (a more easily accessible reading list is required)

Applicable Reading Justification

The text about evaluating what has been learned gives the reader information on the questions relative to, the types and the functions of the evaluations, along with the objectively corrected problems including short questions, the different types of feedback, etc.

Activity Summary

For this activity, it is not necessary to complete the sentences. The goal is for you to read the recommended text so that you may identify the rules for creating certain questions like short (simple) questions.

Formative Evaluation

1. Recall the rules for creating a simple question.

2. Which of the subsequent sentences follow those rules:

a. Some incident rays meet a boundary with an angle of incidence that is larger than the critical angle and are therefore subject to …………………….

b. Some ………………… meet a boundary with an angle of incidence that is larger than the critical angle and are therefore subject to total internal reflection.

c. Some incident rays meet a boundary with an angle of incidence that is ………………………………….. and are therefore subject to total internal reflection.

Learning Activities

The learners read the recommended text while focusing on the part that is related to the exercise. After three hours of reading, they answer the two questions. They then write up an individual report and send it as an attachment in an e-mail to the tutor for the course.

Answer Key

1. There are three rules for creating a short question.

The space to fill must not be at the beginning of a sentence.

The length of the space must not act as a hint to the answer.

The space to fill must always be at the end of a sentence.

2. Only sentence a obeys the rules.

Self Evaluation

This evaluation allows the learners to realize the difficulty in creating an evaluation and to be aware of the way they should choose evaluation tools later on.

Teacher Guidelines

This evaluation is optional and is therefore not mandatory. Only those who wish will complete it. The tutor will correct their work and can ask them to make up some simple questions. The grade for this activity will not be considered in the final evaluation.

XV.

Module synthesis

This training module is made up of a prerequisite exam and four Leaning Units, among other things. The prerequisite test is mandatory for all of the learners; the terms of success are included. Each Learning Unit includes specific objectives and a learning activity.

In each learning activity there is recommended reading, useful links, resources and corrected problems. Each exercise assesses the specific learning objectives for one of the units. All of the steps that the students must take to solve the problems are included. The useful links presented in the module as well as in the learning activities are websites that are related to the content that the students must master.

It is strongly recommended that the students consult them. Just like the readings and resources, they are helpful with the learning process.

In the module you will also find an optional educational formative evaluation. Just like its name indicates, it is not mandatory but is nonetheless necessary for future teachers. A summary evaluation will close the different evaluations in this module.

XVI. summary evaluation

1. Complete the following sentences:

a. A medium that has the same properties in every point is said to be …………….

b. A medium whose properties observed at a certain point do not depend on the direction of observation is said to be ……………

c. In a homogenous and isotropic medium, light propagates ……………….

2. By definition: a medium's refractive index is equal to:

a. the product of the speed c of light in a vacuum with the speed v of light in the medium.

b. the ratio between the speed c of light in a vacuum and the speed v of light in the medium.

c. the ratio between the speed v of light in the medium and the speed c of light in a vacuum.

d. the product of the speed v of light the medium with the speed c of

light in a vacuum.

3. Choose the right answer among the following equations:

(T is the period, λ is the wavelength, ν is the frequency, ω is the pulse**)**

1

a. $T =$

λ

b. $T = \lambda\nu$

1

c. $T = \nu$

1

d. $T =$

ω

African Virtual University

4. Complete the following sentence:

The surface of two homogenous isotropic media constitutes …………………

5. A teacher presents the following rules to his students as the Snell-Descartes Laws. Which of the following propositions is correct?

a. 1st Law: The angles of incidence and of reflection are equal and in opposite

directions to one another.

b. 2nd Law: For every monochromatic light, the sines of the angle of incidence

and of refraction are joined by the relation: $n \sin i = n \sin i$

1

1

2

2

c. 3rd Law: The reflected ray and the refracted ray are on the plane of incidence.

6. Choose laws' proper order among the following options:

abc

acb.

cba

cab

bac

bca

7. A medium (1) with refractive index n is less refractive than a medium

1

(2) with refractive index n means that :

2

a. n < n

1

2

b. n = n

1

2

c. n > n

1

2

d. n = 2n

1

2

n 2

e. n =

1

2

8. A plane boundary is only rigorously stigmatic in two situations:

8.1. When the point source is on the boundary’s surface; the image point therefore merges with the object point.

(what is required of the learner here?)

8.2. When the point source is at infinity; its pinpoint image is itself at infinity.

a. True

b. False

Circle the right answer.

9. A system is stigmatic if for a certain object point there is a unique image point.

a. True

b. False

10. A plane mirror is a flat surface capable of:

a. reflecting light.

b. refracting light.

c. diffracting light.

d. absorbing light.

Choose the right answer.

11. The ratio between the focal lengths for a curved boundary is equal to :

a. the ratio between the refractive indices.

b. the ratio between the refractive indices with the signs changed.

c. the product of the refractive indices.

d. the sum of the refractive indices.

12. If a boundary's image focal point F is real and all of the incident paraxial

2

rays that run parallel to the axis converge at F , **the boundary is :**

2

a. divergent

b. nondescript

c. convergent

13. **The center of a converging boundary is always found:**

a. in the most refractive medium ;

b. in the least refractive medium.

14. The center of a diverging boundary is always found:

a. in the most refractive medium;

b. in the least refractive medium.

15. Vergency (optical power) is expressed:

a. in diopters

b. in meters power -1 : m-1

c. without any units

(This question has been asked before at the beginning of the module albeit in a different form)

16. Lenses that are thin at the periphery are:

a. diverging

b. converging

17. Lenses that are thick at the periphery are:

a. diverging

b. converging

18. For a converging lens:

a. the ray coming from the object and intersecting the optical center O is never refracted.

b. the ray coming from the object and intersecting the lens' object focal point F is always reflected.

c. the ray coming from the object, parallel to the principal axis, emerges through the image focal point F'.

Which of these assertions are false?

19. An oscillator is a system whose state is described by a variable x. x varies periodically on either side of a value, X , and between two extreme values,

0

X and X , such that X <X <X .

max

min

min

0

max

a.. True

b. False.

20. Complete the following sentences:

An oscillator’s oscillations are often related to a system’s state of ……… ……

A harmonic oscillator is a system whose time describing variable is a …… …..

of time.

21. The harmonic oscillator’s total energy is constant over time.

a. True

b. False.

22. The pseudo-period describes the period of an anharmonic oscillator.

a. . True

b. False.

23. An oscillator’s period depends on:

a.) the amplitude A

b.) the wavelength λ

c.) the natural frequency ω_0

d.) the phase ϕ

Check off the right answer(s).

24. The initial conditions are optional when studying an oscillator.

a. True

b. False.

25. The oscillations are said to be damped when the external force applied to the system to set it in motion is very brief, and disappears as soon as the system starts to oscillate.

a. True

b. False.

26. Free oscillation is characterized by:

a.) an amplitude A

b.) a wavelength λ

c.) a pseudo-period T_1

d.) a natural frequency ω_0

e.) a phase ϕ

Check off the right answer(s).

27. For a damped harmonic oscillator, it is possible for there to be no more oscillation.

a True

b. False.

28. A damped harmonic oscillator is characterized by:

a.) the viscous damping coefficient λ

b.) the period T0

c.) the natural frequency ω0

d.) the phase ϕ

Check off the right answer(s).

29. Match up the following two columns by associating each number with the

right letter.

A damped harmonic oscillator's speed evolves:

1-) aperiodically when

a-) λ < ω0

2-) pseudo-periodically when b-) λ = ω0

3-) critically when

c-) λ > ω0

30. The logarithmic decrement measures the decrease in:

a.) the pseudo-period T1

b.) the amplitudes

c.) the viscous damping coefficient λ

d.) the natural frequency ω0

e.) the phase ϕ

Check off the right answer(s).

31. The quality factor Q and the viscous damping coefficient l are:

a.) proportional

b.) inversely proportional

c.) independent

Check off the right answer(s).

32. The quality factor Q and the natural frequency w_0 characterize the damped harmonic oscillator.

a. True

b. False.

Answer Key

1a. homogenous. Good answer,

1b. isotropic. Good job.

1c. in a straight line. Very good

2.

a. Try again, n is definitely not the product of two speeds.

b. Very good, n is indeed the ratio c/v.

c. n is a ratio, but not in that order.

d. Think about it before answering.

3.

a. The period is not the reciprocal of the wavelength.

b. The period is not equal to the product of the wavelength and the frequency.

c. Good answer, the period is indeed the reciprocal of the frequency.

d. The period is not equal to the reciprocal of the pulse.

4. a boundary. Very good, you understand well the definition of a boundary.

5. A teacher presents the following rules to his students as the Snell-Descartes Laws. Which of the following propositions is correct?

a. This is not the first law.

b. This is not the second law.

c. This is not the third law.

6.

abc . Too bad, this is not the right order.

acb. This is not the right order.

cba. This is not the right order, give it some thought.

cab. Very good, this is indeed the right order, you know Newton's laws very well. bac. This is not the right order, try again.

bca. This is not the right order, try again.

7.

a. Good answer, less refractive is represented by the 'smaller than' sign.

b Less refractive does not mean equal.

c. Give it some thought, less refractive does not mean 'greater than'.

d. There is no reason for one of the indexes to be double the other.

e. This is not the right answer. Why half?

8.

a. Good job, these assertions are correct.

b. Carefully reread the two situations to identify the right one.

9.

a. Good answer, this is the definition of astigmatism.

b. You do not seem to know the definition of astigmatism.

10.

a. Good job, mirrors do indeed reflect light.

b. A plane mirror never refracts light.

c. A plane mirror never diffracts light.

d. A plane mirror never absorbs light.

11.

a. The focal lengths are not proportional to the refractive indexes.

b. The ratio between a boundary’s focal lengths is positive.

c. Good answer, the ratio between the focal lengths is indeed equal to the product of the refractive indexes.

d. Reread the question.

12.

a. Good job. As a matter of fact, if it were otherwise, the rays could not converge.

b. Try again.

c. If the rays converge, the boundary cannot be convergent.

13.

a. Good answer, for a converging boundary, the center must be in the most refractive medium.

b. Careful, the boundary is converging not diverging.

14.

a. Reread the question.

b. Excellent answer, it must always be in a less refractive medium.

15. Vergency (optical power) is expressed:

a. Very good, the diopter is indeed the unit used for vergency (optical power).

b. m-1 is the reciprocal of a unit describing length.

c. Vergency (optical power) is not an abstract number.

16.

a. Diverging is indeed the expression associated with diverging lenses.

b. Very good, a thin periphery is used in converging lenses.

17.

a. Good answer, thick periphery goes with diverging.

b. Converging is used for thin lenses.

18.

a. Careful, this assertion is actually correct, it is not at all false.

b. Good answer, this ray is indeed neither deviated or reflected.

c. Careful, this assertion is not false, it is true.

19.

a. Good answer, the oscillator does indeed oscillate for a certain value.

b. Careful, reread the question.

20. An oscillator's oscillations are often related to a system's state of *stable equilibrium*. Good answer, you have understood the concept.

A harmonic oscillator is a system whose time describing variable is a *sinusoidal function* of time. Good answer, you have good knowledge of oscillators.

21

a. Very good, the harmonic oscillator's total energy is indeed constant over time.

b. You have not made the right choice.

22.

a. You were definitely in a rush to answer.

b. Good answer, the pseudo-period is not used for an anharmonic oscillator.

23.

a. An oscillator's period is not related to its amplitude.

b. An oscillator's period is not related to its wavelength.

c. Good answer, an oscillator's period is inversely proportional to its pulse.

d. Review the equation for the period : it is not related to the phase j.

24.

a. Give it some thought before answering.

b. Good answer, on the contrary!

25.

a. You have definitely misunderstood the question.

b. Good job, it is rather valid for free oscillations.

26.

a. Good answer, all oscillations have amplitude.

b. Careful, an oscillation is not characterized by a wavelength.

c. Take your time, oscillation doesn’t go with pseudo-period.

d. Very good, every oscillation has its own natural frequency.

e. Good job, every oscillation has phase j .

27.

a. Good answer, this is the case for strong damping.

b. This is not the right answer.

28.

a. Good answer, the viscous damping coefficient l does characterize the harmonic oscillator.

b. Careful, the period T does not characterize the harmonic oscillator.

0

c. Good job, the natural frequency w does characterize the harmonic os-

0

cillator.

d. Phase j does not characterize the harmonic oscillator. Try again.

29.

1-c. Good answer, you understand the meaning of aperiodical.

2-a Very good, you understand the meaning of pseudo-periodical.

3-b. Good job, you understand the meaning of critical speed.

1a, 1b, 2b, 2c, 3a, 3c. For each of these answers : Review your course, you have misunderstood the terms.

30.

a. Careful, the logarithmic decrement does not measure the pseudo-period’s reduction.

b. Good answer, the logarithmic decrement does indeed measure the decrease in amplitude.

c. Try again, the viscous damping coefficient l is not related to the logarithmic decrement.

d. Think it over, the logarithmic decrement is not related to the natural frequency ω .

0

31.

a. Careful, try to remember the quality factor formula.

b. Very good, the quality factor is indeed inversely proportional to the viscous damping coefficient.

c. Careful, they cannot be independent from one another, they are linked.

32.

a. Good answer, the quality factor does indeed depend on these two factors.

b **.** Take your time answering.

XVII. References

MAGER, R-F. (1975). Comment définir les objectifs pédagogiques. Bordas. Paris

RAMILSON, H.A. (2006). Cours d’optique physique et géométrique. Madagascar. Ecole Normale Supérieure d’Antanarivo. Unpublished course.

Tipler, P. A. (1991). *Physics for Scientists and Engineers,* Third Edition. New York: Worth Publishers

CRAWFORD, F. S..Jr. (1968). *Cours de physique, volume 3 :Ondes,* Paris : Librairie Armand Colin (1972). *Berkeley:*

DIOUF, S. (2004). L’évaluation des apprentissages. UCAD de Dakar. FASTEF(ex ENS). Unpublished course.

DE KETELE, J.M. (1986). L’évaluation : approche descriptive ou prescriptive ? De Boeck Université

DE LANDSHEERE , G (1984). Evaluation continue et examens. Précis de docimologie. Editions Labor. Education 2000.

DAWOUD. M. (1995). Elaboration d’un examen de rendement scolaire. Techniques et procédures. Editions Nouvelles.

ODILE, et VESLIN, J. (1992). Corriger des copies. Evaluer pour former.

DEPOVER , C et al .(1994) La conception des logiciels éducatifs (titre provisoire). Inédit

Websites

http://www.sciences.univ-nantes.fr/physique/enseignement/DeugA/Physique1/optique/cours/index.html

http://www.uel-pcsm.education.fr/consultation/reference/physique/optigeo/menumodule/menuthemes/menu_reduit.html

http://fr.wikipedia.org/wiki/Optique

http://cours.cegep-st-jerome.qc.ca/203-301-r.f/partie2/chap5/default.htm

http://www.univ-Lemans.fr/enseignements/physique/02/optigeo/

http://www.fundp.ac.be/sciences/physique/didactique/optique/intro.html

XVIII. about the author

HERIMANDA A. RAMILISON

Former student at the ‘Ecole Normale Supérieure Cachan’, France.

Agrégé in Mechanics

Researching eacher, Associate Professor at the ‘Ecole Normale Supérieure d’Antananarivo’, Madagascar

Mechanics teacher to future Physics and Chemistry teachers at the ‘Lycées de Madagascar’.

Member of the ‘Cellule d’évaluation et de coordination des projets’ for the ‘Ecole Normale Supérieure’.

Researcher in information and communiations applied to education in the Department of Continuing Studies at the ‘Ecole Normale Supérieure’.

e-mail : herimand@yahoo.fr

herimanda@hotmail.com

XIX. file and Document structure

Name of the module (WORD) file :

- Geometrical Optics Basics
- The Snell-Descartes Laws
- Plane Mirrors and Boundaries
- Lenses

Name of all other files (WORD, PDF, PPT, etc.) for the module

- Plane Boundary Image.ppt
- Curved Mirror Path.ppt
- Learning Evaluation (word)

GEOMETRICAL OPTICS AND PHYSICAL OPTICS

Required Readings

Source: Wikipedia.org

1

Table of Contents

Reflection (physics)

The reflection of Mount Hood in Trillium Lake.

Reflection is the change in direction of a wavefront at an interface between two different media

so that the wavefront returns into the medium from which it originated. Common examples

include the reflection of light, sound and water waves. The *law of reflection* says that for

specular reflection the angle at which the wave is incident on the surface equals the angle at which it is reflected. Mirrors exhibit specular reflection.

In acoustics, reflection causes echoes and is used in sonar. In geology, it is important in the study of seismic waves. Reflection is observed with surface waves in bodies of water. Reflection is observed with many types of electromagnetic wave, besides visible light. Reflection of VHF and higher frequencies is important for radio transmission and for radar. Even hard X-rays and

gamma rays can be reflected at shallow angles with special "grazing" mirrors.

] Reflection of light

Double reflection: The sun is reflected in the water, which is reflected in the paddle.

4

Reflection of light is either *specular* (mirror-like) or *diffuse* (retaining the energy, but losing the image) depending on the nature of the interface. Furthermore, if the interface is between a dielectric and a conductor, the phase of the reflected wave is retained, otherwise if the interface is between two dielectrics, the phase may be retained or inverted, depending on the indices of refraction. [*citation needed*]

A mirror provides the most common model for specular light reflection, and typically consists of a glass sheet with a metallic coating where the reflection actually occurs. Reflection is enhanced in metals by suppression of wave propagation beyond their skin depths. Reflection also occurs at the surface of transparent media, such as water or glass.

Diagram of specular reflection

In the diagram at left, a light ray **PO** strikes a vertical mirror at point **O**, and the reflected ray is **OQ**. By projecting an imaginary line through point **O** perpendicular to the mirror, known as the *normal*, we can measure the *angle of incidence*, θ i and the *angle of reflection*, θ r. The *law of reflection* states that θ i = θ *r, or in other words, the angle of incidence equals the angle of reflection.*

An Indian triggerfish reflecting in the water surface through total internal reflection.

In fact, reflection of light may occur whenever light travels from a medium of a given refractive index into a medium with a different refractive index. In the most general case, a certain fraction of the light is reflected from the interface, and the remainder is refracted. Solving Maxwell's equations for a light ray striking a boundary allows the derivation of the Fresnel equations, which 5

can be used to predict how much of the light reflected, and how much is refracted in a given situation. Total internal reflection of light from a denser medium occurs if the angle of incidence is above the critical angle.

Total internal reflection is used as a means of focussing waves that cannot effectively be reflected by common means. X-ray telescopes are constructed by creating a converging "tunnel" for the waves. As the waves interact at low angle with the surface of this tunnel they are reflected toward the focus point (or toward another interaction with the tunnel surface, eventually being directed to the detector at the focus). A conventional reflector would be useless as the X-rays would simply pass through the intended reflector.

When light reflects off a material denser (with higher refractive index) than the external medium, it undergoes a polarity inversion. In contrast, a less dense, lower refractive index material will reflect light in phase. This is an important principle in the field of thin-film optics.

Specular reflection forms images. Reflection from a flat surface forms a mirror image, which appears to be reversed from left to right because we compare the image we see to what we would see if we were rotated into the position of the image. Specular reflection at a curved surface forms an image which may be magnified or demagnified; curved mirrors have optical power. Such mirrors may have surfaces that are spherical or parabolic.

[] Laws of regular reflection

Specular reflection at a curved surface of sea foam, which is made out of plankton

Main article: Specular reflection

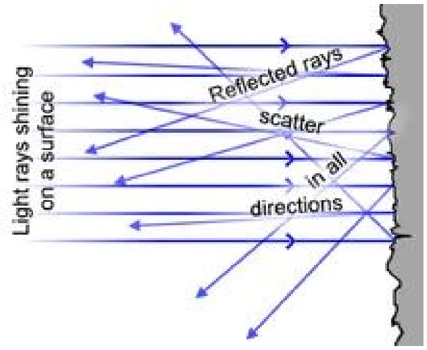
If the reflecting surface is very smooth, the reflection of light that occurs is called specular or regular reflection. The laws of reflection are as follows:

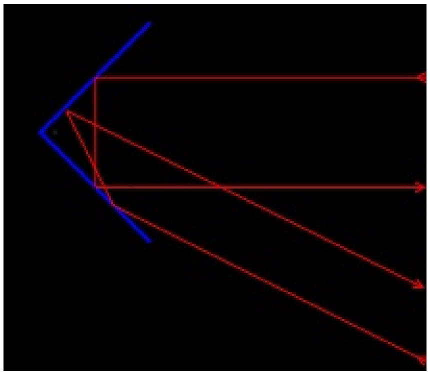
1. The incident ray, the reflected ray and the normal to the reflection surface at the point of the incidence lie in the same plane.

2. The angle which the incident ray makes with the normal is equal to the angle which the reflected ray makes to the same normal.

3. Light paths are reversible.

6





[] Other types of reflection

[] Diffuse reflection

Diffuse reflection

Main article: Diffuse reflection

When light strikes a rough or granular surface, it bounces off in all directions due to the microscopic irregularities of the interface. Thus, an 'image' is not formed. This is called *diffuse reflection*. The exact form of the reflection depends on the structure of the surface. One common model for diffuse reflection is Lambertian reflectance, in which the light is reflected with equal luminance (in photometry) or radiance (in radiometry) in all directions, as defined by Lambert's cosine law.

[] Retroreflection

Working principle of a corner reflector

Main article: Retroreflector

Some surfaces exhibit *retroreflection*. The structure of these surfaces is such that light is returned in the direction from which it came.

When flying over clouds illuminated by sunlight the region seen around the aircraft's shadow will appear brighter, and a similar effect may be seen from dew on grass. This partial retroreflection is created by the refractive properties of the curved droplet's surface and reflective properties at the backside of the droplet.

Some animal' s retinas act as retroreflectors, as this effectively improves the animal's night vision. Since the lenses of their eyes modify reciprocally the paths of the incoming and outgoing light the effect is that the eyes act as a strong retroreflector, sometimes seen at night when walking in wildlands with a flashlight.

A simple retroreflector can be made by placing three ordinary mirrors mutually perpendicular to one another (a corner reflector). The image produced is the inverse of one produced by a single mirror.

A surface can be made partially retroreflective by depositing a layer of tiny refractive spheres on it or by creating small pyramid like structures. In both cases internal reflection causes the light to be reflected back to where it originated. This is used to make traffic signs and automobile license plates reflect light mostly back in the direction from which it came. In this application perfect retroreflection is not desired, since the light would then be directed back into the headlights of an oncoming car rather than to the driver's eyes.

[] Complex conjugate reflection

Light bounces exactly back in the direction from which it came due to a nonlinear optical process. In this type of reflection, not only the direction of the light is reversed, but the actual wavefronts are reversed as well. A conjugate reflector can be used to remove aberrations from a beam by reflecting it and then passing the reflection through the aberrating optics a second time.

[] Neutron reflection

Materials that reflect neutrons, for example beryllium, are used in nuclear reactors and nuclear weapons. In the physical and biological sciences, the reflection of neutrons off atoms within a material is commonly used to determine its internal structures. [1]

[] Sound reflection

Sound deflection panel for midrange frequencies

When a longitudinal sound wave strikes a flat surface, sound is reflected in a coherent manner provided that the dimension of the reflective surface is large compared to the wavelength of the sound. Note that audible sound has a very wide frequency range (from 20 to about 17000 Hz),

8

and thus a very wide range of wavelengths (from about 20 mm to 17 m). As a result, the overall nature of the reflection varies according to the texture and structure of the surface. For example, porous materials will absorb some energy, and rough materials (where rough is relative to the wavelength) tend to reflect in many directions—to scatter the energy, rather than to reflect it coherently. This leads into the field of architectural acoustics, because the nature of these reflections is critical to the auditory feel of a space. In the theory of exterior noise mitigation, reflective surface size mildly detracts from the concept of a noise barrier by reflecting some of the sound into the opposite direction.

[] Seismic reflection

Seismic waves produced by earthquakes or other sources (such as explosions) may be reflected by layers within the Earth. Study of the deep reflections of waves generated by earthquakes has allowed seismologists to determine the layered structure of the Earth. Shallower reflections are used in reflection seismology to study the Earth' s crust generally, and in particular to prospect for petroleum and natural gas deposits.

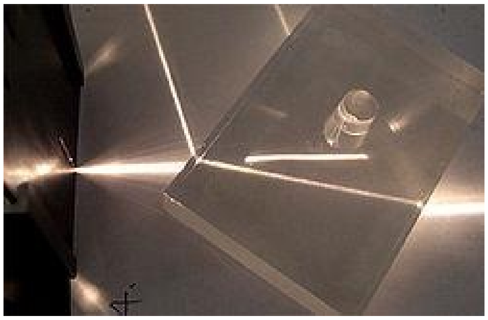
[] Quantum interpretation

Light waves incident on a material induce small oscillations of polarisation in the individual atoms, causing each atom to radiate a weak secondary wave (in all directions like a dipole antenna). All of these waves add up to specular reflection (following Hero's equi-angular reflection law) and refraction. Light–matter interaction in terms of photons is a topic of quantum electrodynamics, and is described in detail by Richard Feynman in his popular book *QED: The Strange Theory of Light and Matter*.

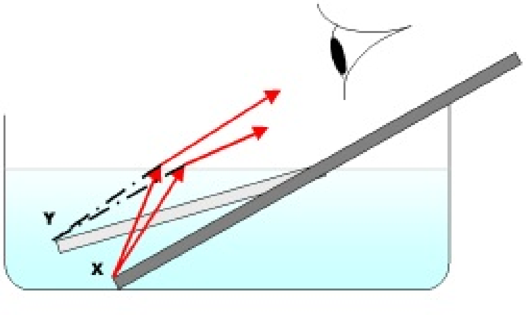
Refraction

An image of the Golden Gate Bridge is refracted and bent by many differing three dimensional pools of water

9



$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$



Refraction in a Perspex (acrylic) block.

Refraction is the change in direction of a wave due to a change in its speed. This is most commonly observed when a wave passes from one medium to another at an angle. Refraction of

light is the most commonly observed phenomenon, but any type of wave can refract when it interacts with a medium, for example when sound waves pass from one medium into another or when water waves move into water of a different depth. Refraction is described by Snell's law,

which states that the angle of incidence θ_1 is related to the angle of refraction θ_2 by where v_1 and v_2 are the wave velocities in the respective media, and n_1 and n_2 the refractive

indices. In general, the incident wave is partially refracted and partially reflected; the details of this behavior are described by the Fresnel equations.

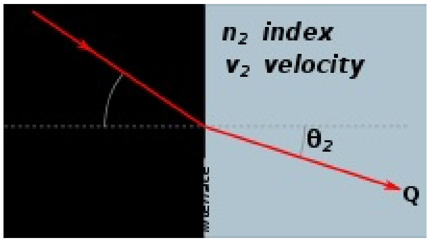
] Explanation

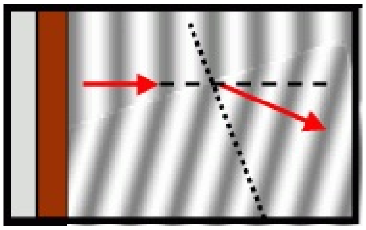
Refraction of light waves in water. The dark rectangle represents the actual position of a pencil

sitting in a bowl of water. The light rectangle represents the apparent position of the pencil.

Notice that the end (X) looks like it is at (Y), a position that is considerably shallower than (X).

10





The straw appears to be broken, due to refraction of light as it emerges into the air.

Refraction of light at the interface between two media of different refractive indices, with n2 > n

), the angle of refraction θ

1. Since the phase velocity is lower in the second medium (v2 < v1

2 is

less than the angle of incidence θ1; that is, the ray in the higher-index medium is closer to the

normal.

Photograph of refraction of waves in a ripple tank

Diagram of refraction of water waves

11

In optics, refraction occurs when light waves travel from a medium with a given refractive index

to a medium with another at an angle. At the boundary between the media, the wave' s phase velocity is altered, usually causing a change in direction. Its wavelength increases or decreases but its frequency remains constant. For example, a light ray will refract as it enters and leaves glass, assuming there is a change in refractive index. A ray traveling along the normal (perpendicular to the boundary) will change speed, but not direction. Refraction still occurs in this case. Understanding of this concept led to the invention of lenses and the refracting telescope. Refraction can be seen when looking into a bowl of water. Air has a refractive index of about 1.0003, and water has a refractive index of about 1.33. If a person looks at a straight object, such as a pencil or straw, which is placed at a slant, partially in the water, the object appears to bend at the water's surface. This is due to the bending of light rays as they move from the water to the air. Once the rays reach the eye, the eye traces them back as straight lines (lines of sight). The lines of sight (shown as dashed lines) intersect at a higher position than where the actual rays originated. This causes the pencil to appear higher and the water to appear shallower than it really is. The depth that the water appears to be when viewed from above is known as the *apparent depth*. This is an important consideration for spearfishing from the surface because it will make the target fish appear to be in a different place, and the fisher must aim lower to catch the fish.

The diagram on the right shows an example of refraction in water waves. Ripples travel from the left and pass over a shallower region inclined at an angle to the wavefront. The waves travel more slowly in the shallower water, so the wavelength decreases and the wave bends at the boundary. The dotted line represents the normal to the boundary. The dashed line represents the original direction of the waves. This phenomenon explains why waves on a shoreline tend to strike the shore close to a perpendicular angle. As the waves travel from deep water into shallower water near the shore, they are refracted from their original direction of travel to an angle more normal to the shoreline.[1] Refraction is also responsible for rainbows and for the splitting of white light into a rainbow-spectrum as it passes through a glass prism. Glass has a higher refractive index than air. When a beam of white light passes from air into a material having an index of refraction that varies with frequency, a phenomenon known as dispersion occurs, in which different coloured components of the white light are refracted at different angles, i.e., they bend by different amounts at the interface, so that they become separated. The different colors correspond to different frequencies.

While refraction allows for beautiful phenomena such as rainbows, it may also produce peculiar

optical phenomena, such as mirages and Fata Morgana. These are caused by the change of the refractive index of air with temperature.

Recently some metamaterials have been created which have a negative refractive index. With metamaterials, we can also obtain total refraction phenomena when the wave impedances of the two media are matched. There is then no reflected wave.[2]

Also, since refraction can make objects appear closer than they are, it is responsible for allowing

water to magnify objects. First, as light is entering a drop of water, it slows down. If the water's

surface is not flat, then the light will be bent into a new path. This round shape will bend the light

outwards and as it spreads out, the image you see gets larger.

A useful analogy in explaining the refraction of light would be to imagine a marching band as

they march at an oblique angle from pavement (a fast medium) into mud (a slower medium). The

marchers on the side that runs into the mud first will slow down first. This causes the whole band

to pivot slightly toward the normal (make a smaller angle from the normal).

[] Clinical significance

In medicine, particularly optometry, ophthalmology and orthoptics, *refraction* (also known as *refractometry*) is a clinical test in which a phoropter may used by the appropriate eye care

professional to determine the eye' s refractive error and the best corrective lenses to be prescribed.

A series of test lenses in graded optical powers or focal lengths are presented to determine which provide the sharpest, clearest vision.[3]

[] Acoustics

In underwater acoustics, refraction is the bending or curving of a sound ray that results when the ray passes through a sound speed gradient from a region of one sound speed to a region of a different speed. The amount of ray bending is dependent upon the amount of difference between

sound speeds, that is, the variation in temperature, salinity, and pressure of the water.[4] Similar

acoustics effects are also found in the Earth's atmosphere. The phenomenon of refraction of sound in the atmosphere has been known for centuries;[5] however, beginning in the early 1970s, widespread analysis of this effect came into vogue through the designing of urban highways and

noise barriers to address the meteorological effects of bending of sound rays in the lower atmosphere.[6]

Snell's law

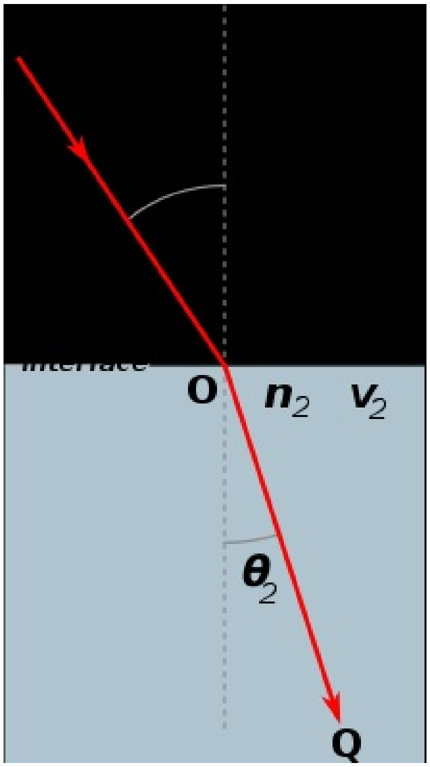
In optics and physics, **Snell's law** (also known as **Descartes' law**, the **Snell–Descartes law**, and the **law of refraction**), is a formula used to describe the relationship between the angles of

incidence and refraction, when referring to light or other waves passing through a boundary between two different isotropic media, such as water and glass. The law says that the ratio of the

sines of the angles of incidence and of refraction is a constant that depends on the media.

In optics, the law is used in ray tracing to compute the angles of incidence or refraction, and in experimental optics and gemology to find the refractive index of a material.

13



$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \ .$$

Refraction of light at the interface between two media of different refractive indices, with n2 > n

), the angle of refraction θ

1. Since the velocity is lower in the second medium (v2 < v1

2 is less

than the angle of incidence θ1; that is, the ray in the higher-index medium is closer to the normal.

Snell's law is also satisfied in the metamaterials which allow light to be bent "backward" at a

negative index, with a negative angle of refraction.

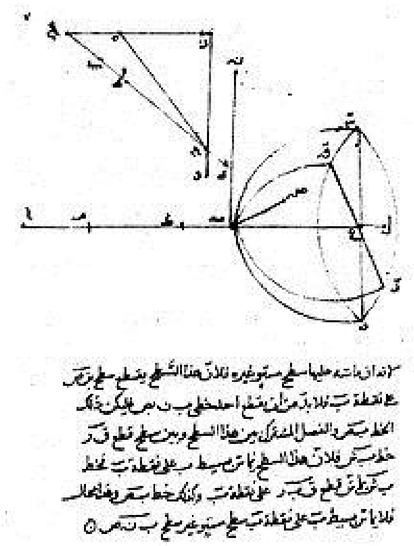
Named after Dutch mathematician Willebrord Snellius, one of its discoverers, Snell's law states that the ratio of the sines of the angles of incidence and refraction is equivalent to the ratio of

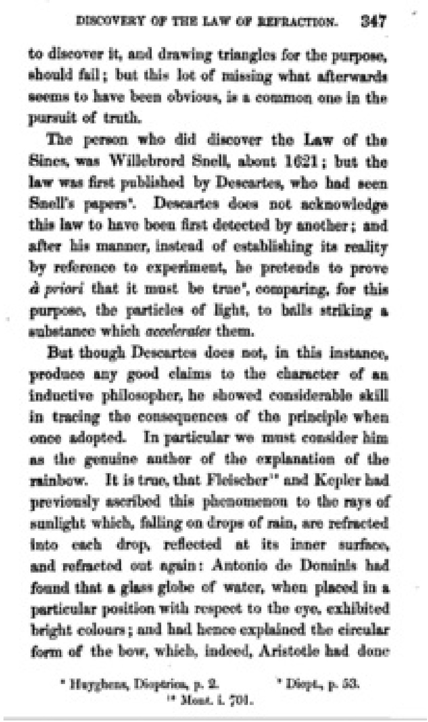
velocities in the two media, or equivalent to the opposite ratio of the indices of refraction: or

Snell's law follows from Fermat's principle of least time, which in turn follows from the propagation of light as waves.

] History

14





DISCOVERY OF THE LAW OF REFRACTION. 347

to discover it, and drawing triangles for the purpose, should fail; but this lot of missing what afterwards seems to have been obvious, is a common one in the pursuit of truth.

The person who did discover the Law of the Sines, was Willebrord Snell, about 1621; but the law was first published by Descartes, who had seen Snell's papers[8]. Descartes does not acknowledge this law to have been first detected by another; and after his manner, instead of establishing its reality by reference to experiment, he pretends to prove *à priori* that it must be true[9], comparing, for this purpose, the particles of light, to balls striking a substance which *accelerates* them.

But though Descartes does not, in this instance, produce any good claims to the character of an inductive philosopher, he showed considerable skill in tracing the consequences of the principle when once adopted. In particular we must consider him as the genuine author of the explanation of the rainbow. It is true, that Fleischer[10] and Kepler had previously ascribed this phenomenon to the rays of sunlight which, falling on drops of rain, are refracted into each drop, reflected at its inner surface, and refracted out again: Antonio de Dominis had found that a glass globe of water, when placed in a particular position with respect to the eye, exhibited bright colours; and had hence explained the circular form of the bow, which, indeed, Aristotle had done

[8] Huyghens, Dioptrica, p. 2.

[9] Diopt., p. 53.

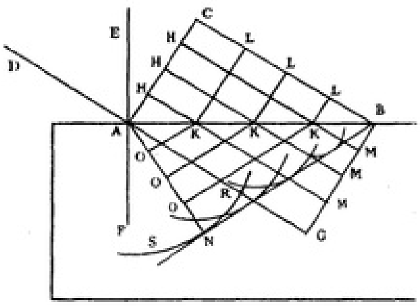
[10] Mont. i. 701.

Reproduction of a page of Ibn Sahl' s manuscript showing his discovery of the law of refraction.

Ptolemy, of the Thebaid, had found a relationship regarding refraction angles, but which was inaccurate for angles that were not small. Ptolemy was confident he had found an accurate

empirical law, partially as a result of fudging his data to fit theory (see: confirmation bias). [1]

An 1837 view of the history of "the Law of the Sines"[2]



Snell's law was first accurately described in a mathematical form by Ibn Sahl, of Baghdad, in the manuscript *On Burning Mirrors and Lenses* (984).[3][4] He made use of it to work out the shapes of lenses that focus light with no geometric aberrations, known as anaclastic lenses.

It was rediscovered by Thomas Harriot in 1602,[5] who however did not publish his results although he had corresponded with Kepler on this very subject.

In 1621, Willebrord Snellius (Snel) derived a mathematically equivalent form, that remained unpublished during his lifetime. René Descartes independently derived the law using heuristic momentum conservation arguments in terms of sines in his 1637 treatise *Discourse on Method,* and used it to solve a range of optical problems. Rejecting Descartes' solution, Pierre de Fermat arrived at the same solution based solely on his principle of least time.

According to Dijksterhuis[6], "In *De natura lucis et proprietate* (1662) Isaac Vossius said that Descartes had seen Snell's paper and concocted his own proof. We now know this charge to be undeserved but it has been adopted many times since." Both Fermat and Huygens repeated this accusation that Descartes had copied Snell.

In French, Snell's Law is called "la loi de Descartes" or "loi de Snell-Descartes."

Christiaan Huygens' construction

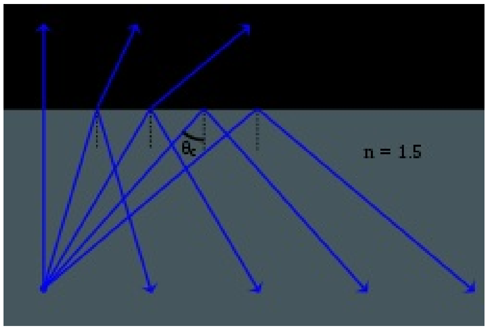
In his 1678 *Traité de la Lumiere*, Christiaan Huygens showed how Snell's law of sines could be explained by, or derived from, the wave nature of light, using what we have come to call the Huygens–Fresnel principle.

Although he spelled his name "Snel", as noted above, it has conventionally been spelled "Snell" in English, apparently by misinterpreting the Latin form of his name, "Snellius" .[7]

[] Explanation

Snell's law is used to determine the direction of light rays through refractive media with varying indices of refraction. The indices of refraction of the media, labeled *n* 1, *n* 2 and so on, are used to represent the factor by which a light ray's speed decreases when traveling through a refractive medium, such as glass or water, as opposed [8] to its velocity in a vacuum.

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$



As light passes the border between media, depending upon the relative refractive indices of the two media, the light will either be refracted to a lesser angle, or a greater one. These angles are measured with respect to the *normal line*, represented perpendicular to the boundary. In the case of light traveling from air into water, light would be refracted towards the normal line, because the light is slowed down in water; light traveling from water to air would refract away from the normal line.

Refraction between two surfaces is also referred to as *reversible* because if all conditions were identical, the angles would be the same for light propagating in the opposite direction.

Snell's law is generally true only for isotropic or specular media (such as glass). In anisotropic media such as some crystals, birefringence may split the refracted ray into two rays, the *ordinary* or *o*-ray which follows Snell's law, and the other *extraordinary* or *e*-ray which may not be co-planar with the incident ray.

When the light or other wave involved is monochromatic, that is, of a single frequency, Snell's law can also be expressed in terms of a ratio of wavelengths in the two media, λ1 and λ2:

[] Total internal reflection and critical angle

Demonstration of no refraction at angles greater than the critical angle.

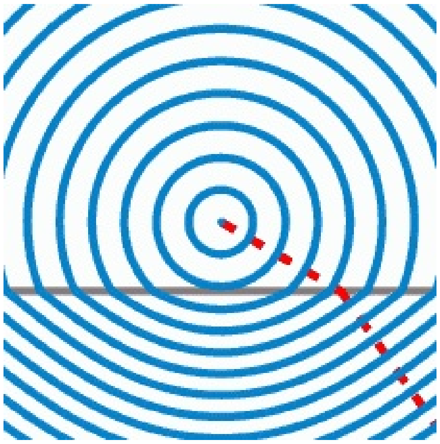
Main article: Total internal reflection

When light travels from a medium with a higher refractive index to one with a lower refractive index, Snell's law seems to require in some cases (whenever the angle of incidence is large enough) that the sine of the angle of refraction be greater than one. This of course is impossible, and the light in such cases is completely reflected by the boundary, a phenomenon known as total internal reflection. The largest possible angle of incidence which still results in a refracted ray is called the **critical angle**; in this case the refracted ray travels along the boundary between the two media.

17

$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1 = 1.333 \cdot 0.766 = 1.021,$$

$$\theta_{\text{crit}} = \arcsin\left(\frac{n_2}{n_1}\sin\theta_2\right) = \arcsin\frac{n_2}{n_1} = 48.6^\circ.$$



For example, consider a ray of light moving from water to air with an angle of incidence of 50°.

The refractive indices of water and air are approximately 1.333 and 1, respectively, so Snell's law

gives us the relation

which is impossible to satisfy. The critical angle θcrit is the value of θ1 for which θ2 equals 90°:

[] Derivations

Wavefronts from a point source in the context of Snell's law. The region below the grey line has a higher index of refraction, and proportionally lower speed of light, than the region above it.

Snell's law may be derived from Fermat's principle, which states that the light travels the path which takes the least time. By taking the derivative of the optical path length, the stationary point

is found giving the path taken by the light (though it should be noted that the result does not

show light taking the least time path, but rather one that is stationary with respect to small

variations as there are cases where light actually takes the greatest time path, as in a spherical

mirror). In a classic analogy, the area of lower refractive index is replaced by a beach, the area of

higher refractive index by the sea, and the fastest way for a rescuer on the beach to get to a

drowning person in the sea is to run along a path that follows Snell's law.

Alternatively, Snell's law can be derived using interference of all possible paths of light wave

from source to observer—it results in destructive interference everywhere except extrema of

phase (where interference is constructive)—which become actual paths.

Another way to derive Snell’s Law involves an application of the general boundary conditions of

Maxwell equations for electromagnetic radiation.

18

$\vec{k}$

$$k_0 = \frac{2\pi}{\lambda_0} = \frac{\omega}{c}$$

$$\cos\theta_1 = \mathbf{n} \cdot (-\mathbf{l})$$

$$\cos\theta_2 = \sqrt{1 - \left(\frac{n_1}{n_2}\right)^2 \left(1 - (\cos\theta_1)^2\right)}$$

$$\mathbf{v}_{\mathrm{reflect}} = \mathbf{l} + (2\cos\theta_1)\,\mathbf{n}$$

$$\mathbf{v}_{\mathrm{refract}} = \left(\frac{n_1}{n_2}\right)\mathbf{l} + \left(\frac{n_1}{n_2}\cos\theta_1 - \cos\theta_2\right)\mathbf{n}$$

$\mathbf{n} \cdot (-\mathbf{l})$

$$\mathbf{v}_{\mathrm{refract}} = \left(\frac{n_1}{n_2}\right)\mathbf{l} + \left(\frac{n_1}{n_2}\cos\theta_1 + \cos\theta_2\right)\mathbf{n}.$$

$$\mathbf{l} = \{0.707107, -0.707107\},\ \ \mathbf{n} = \{0, 1\},\ \ \frac{n_1}{n_2} = 0.9$$

$$\cos\theta_1 = 0.707107,\ \ \cos\theta_2 = 0.771362$$

$$\mathbf{v}_{\mathrm{reflect}} = \{0.707107, 0.707107\},\ \ \mathbf{v}_{\mathrm{refract}} = \{0.636396, -0.771362\}$$

Yet another way to derive Snell's law is based on translation symmetry considerations [9]. A

homogeneous surface perpendicular to say the z direction can not change the transverse

momentum. Since the propagation vector is proportional to the photon's momentum, the

transverse propagation direction (*kx*, *ky*,0) must remain the same in both regions. Assuming

without loss of generality a plane of incidence in the *z, x* plane *kxRegion* 1 = *kxRregion* 2. Using the well known dependence of the wave number on the refractive index of the medium, we derive Snell's

law immediately.

kxRegion 1 = *kxRregion* 2

n

sinθ

sinθ

1 *k* 0

1 = *n* 2 *k* 0

2

n sinθ

sinθ

1

1 = *n* 2

2

where

is the wavenumber in vacuum. Note that no surface is truly

homogeneous, in the least at the atomic scale. Yet full translational symmetry is an excellent

approximation whenever the region is homogeneous on the scale of the light wavelength.

[] Vector form

Given a normalized light vector **l** (pointing from the light source toward the surface) and a

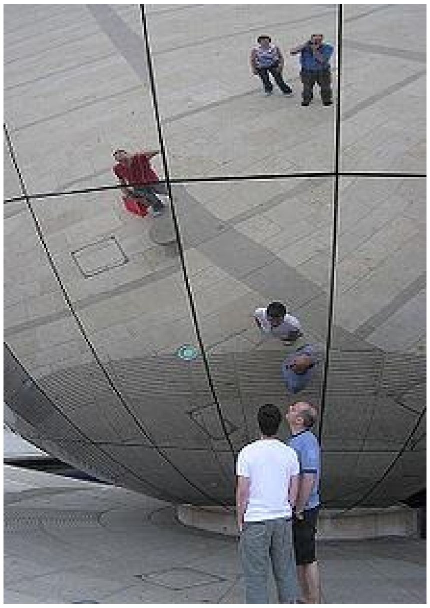
normalized plane normal vector **n**, one can work out the normalized reflected and refracted

rays[10].:

Note:

must be positive. Otherwise, use

Example:



The cosines may be recycled and used in the Fresnel equations for working out the intensity of the resulting rays.

Total internal reflection is indicated by a negative radicand in the equation for cosθ2. In this case, an evanescent wave is produced, which rapidly decays from the surface into the second medium.

Conservation of energy is maintained by the circulation of energy across the boundary, averaging

to zero net energy transmission.

[] Dispersion

Main article: Dispersion (optics)

In many wave-propagation media, wave velocity changes with frequency or wavelength of the

waves; this is true of light propagation in most transparent substances other than a vacuum.

These media are called dispersive. The result is that the angles determined by Snell's law also

depend on frequency or wavelength, so that a ray of mixed wavelengths, such as white light, will

spread or disperse. Such dispersion of light in glass or water underlies the origin of rainbows, in

which different wavelengths appear as different colors.

In optical instruments, dispersion leads to chromatic aberration; a color-dependent blurring that sometimes is the resolution-limiting effect. This was especially true in refracting telescopes,

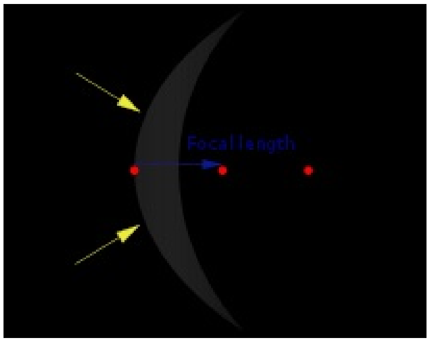
before the invention of achromatic objective lenses.

Curved mirror

From Wikipedia, the free encyclopedia

Jump to: navigation, search

20



Reflections in a spherical convex mirror. The photographer is seen reflected at top right

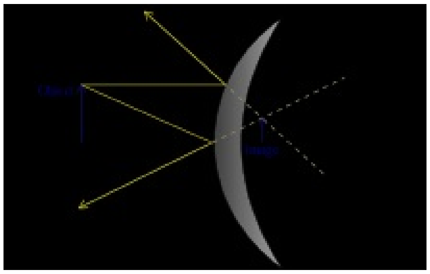
A **curved mirror** is a mirror with a curved reflective surface, which may be either *convex* (bulging outward) or *concave* (bulging inward). Most curved mirrors have surfaces that are shaped like part of a sphere, [*citation needed*] but other shapes are sometimes used in optical devices. The most common non-spherical type are parabolic reflectors, found in optical devices such as reflecting telescopes that need to image distant objects, since spherical mirror systems suffer from spherical aberration.

Contents

[hide]

[] Convex mirror

A convex mirror diagram showing the focus, focal Length, centre of curvature, principal axis, etc A **convex mirror**, **fish eye mirror** or **diverging mirror**, is a curved mirror in which the reflective surface bulges toward the light source. Convex mirrors reflect light outwards, therefore they are not used to focus light. Such mirrors always form a virtual image, since the focus *F* and 21



the centre of curvature *2F* are both imaginary points "inside" the mirror, which cannot be reached. Therefore images formed by these mirrors cannot be taken on screen. (As they are inside the mirror)

A collimated (parallel) beam of light diverges (spreads out) after reflection from a convex mirror, since the normal to the surface differs with each spot on the mirror.

[] Image

Convex mirror image formation

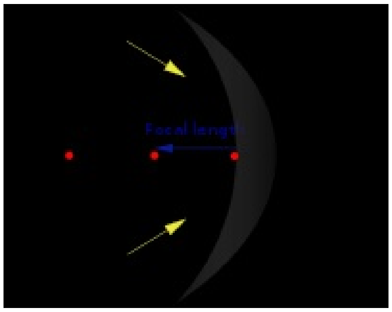
The image is always *virtual* (rays haven't actually passed though the image), *diminished* (smaller), and *upright* . These features make convex mirrors very useful: everything appears smaller in the mirror, so they cover a wider field of view than a normal plane mirror does as the image is "compressed".

[] Uses

Convex mirror lets motorists see around a corner.

The passenger-side mirror on a car is typically a convex mirror. In some countries, these are labelled with the safety warning "Objects in mirror are closer than they appear", to warn the driver of the convex mirror's distorting effects on distance perception.

Convex mirrors are used in some automated teller machines as a simple and handy security feature, allowing the users to see what is happening behind them. Similar devices are sold to be attached to ordinary computer monitors.



Some camera phones use convex mirrors to allow the user correctly aim the camera while taking a self-portrait.

[] Concave mirrors

A concave mirror diagram showing the focus, focal Length, centre of curvature, principal axis, etc.

A **concave mirror**, or **converging mirror**, has a reflecting surface that bulges inward (away from the incident light). Concave mirrors reflect light inward to one focal point, therefore they are used to focus light. Unlike convex mirrors, concave mirrors show different image types depending on the distance between the object and the mirror.

These mirrors are called "converging" because they tend to collect light that falls on them, refocusing parallel incoming rays toward a focus. This is because the light is reflected at different angles, since the normal to the surface differs with each spot on the mirror.

[] Image

Effect on image of object's position relative to mirror focal point

Object's

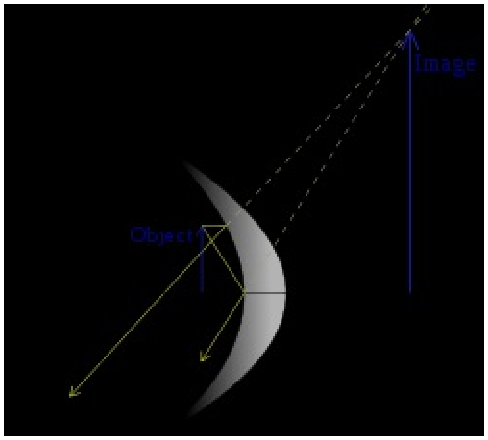
position (*S*),

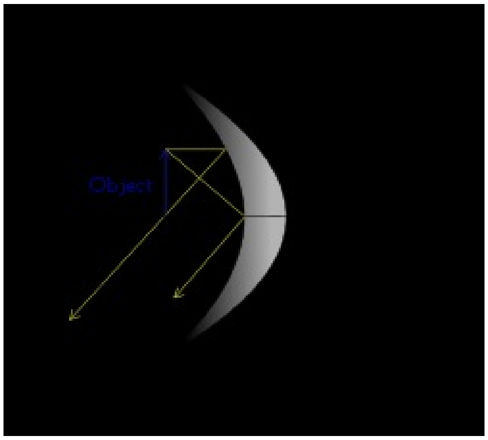
Image

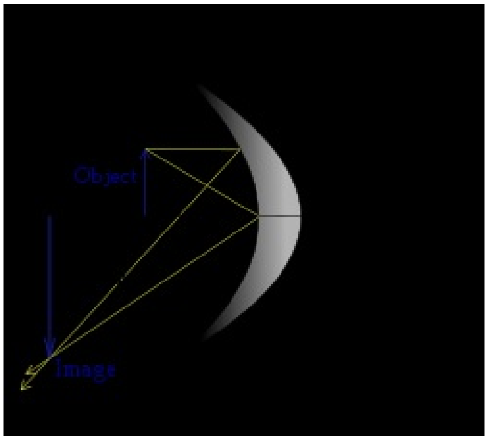
Diagram

focal point (*F*)

23







S* < *F

Virtual

(Object

Upright

between focal

Magnified (larger)

point and

mirror)

the image is formed at infinity.

$S = F$

(Object at

(Note that the reflected light rays are

focal point) parallel and do not meet the others. In

this way, no image is formed or more

properly the image is formed at infinity.)

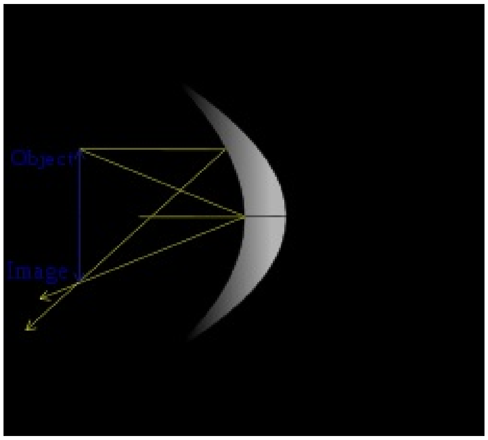
Real

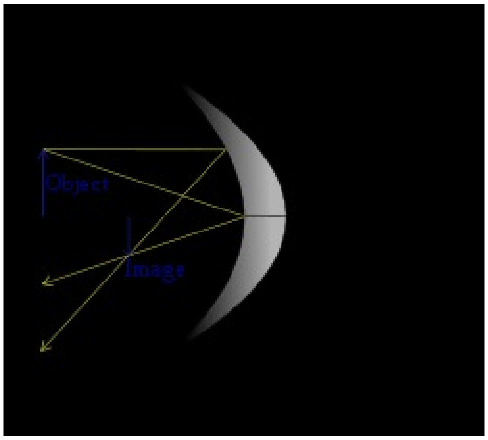
Inverted (vertically)

$F < S < 2F$

Magnified (larger)

24





$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

S* = 2 *F

Real

(Object at

Inverted (vertically)

centre of

Same size

curvature)

Real

Inverted (vertically)

S* > 2 *F

Diminished (smaller)

[] Mirror shape

Most curved mirrors have a spherical profile. These are the simplest to make, and it is the best shape for general-purpose use. Spherical mirrors, however, suffer from spherical aberration. Parallel rays reflected from such mirrors do not focus to a single point. For parallel rays, such as those coming from a very distant object, a parabolic reflector can do a better job. Such a mirror can focus incoming parallel rays to a much smaller spot than a spherical mirror can.

See also: Toroidal reflector

[] Analysis

[] Mirror equation and magnification

The Gaussian mirror equation relates the object distance (*d* o) and image distances (*d* i) to the focal length (*f*):

.

25

$$m \equiv \frac{h_\mathrm{i}}{h_\mathrm{o}} = -\frac{d_\mathrm{i}}{d_\mathrm{o}}$$

$$-\frac{1}{f}$$

The magnification of a mirror is defined as the height of the image divided by the height of the object:

.

The negative sign in this equation is used as a convention. By convention, if the magnification is positive, the image is upright. If the magnification is negative, the image is inverted (upside down).

[] Ray tracing

Main article: Ray tracing (physics)

The image location and size can also be found by graphical ray tracing, as illustrated in the figures above. A ray drawn from the top of the object to the surface vertex (where the optical axis meets the mirror) will form an angle with that axis. The reflected ray has the same angle to the axis, but is below it (See Specular reflection).

A second ray can be drawn from the top of the object passing through the focal point and reflecting off the mirror at a point somewhere below the optical axis. Such a ray will be reflected from the mirror as a ray parallel to the optical axis. The point at which the two rays described above meet is the image point corresponding to the top of the object. Its distance from the axis defines the height of the image, and its location along the axis is the image location. The mirror equation and magnification equation can be derived geometrically by considering these two rays.

[] Ray transfer matrix of spherical mirrors

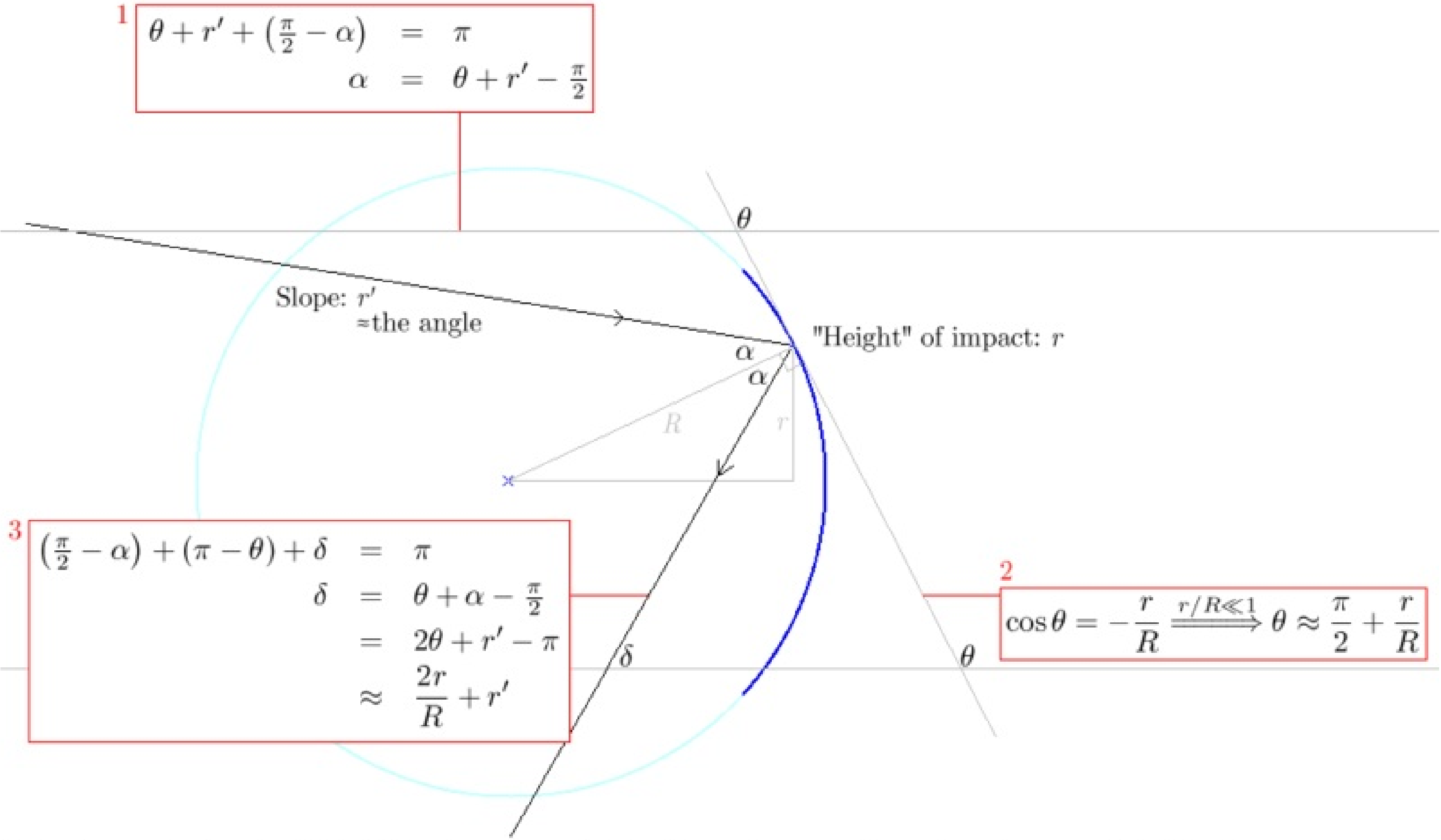
Further information: Ray transfer matrix analysis

The mathematical treatment is done under the paraxial approximation, meaning that under the first approximation a spherical mirror is a parabolic reflector. The ray matrix of a spherical mirror is shown here for the concave reflecting surface of a spherical mirror. The *C* element of

the matrix is

, where *f* is the focal point of the optical device.

26



No change in the height of the beam, and the slope changes linearly: $r'_{\text{out}} = r'_{\text{in}} + 2r/R$.

$$\begin{pmatrix} r_{\text{out}} \\ r'_{\text{out}} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ \frac{2}{R} & 1 \end{pmatrix} \begin{pmatrix} r_{\text{in}} \\ r'_{\text{in}} \end{pmatrix}$$

$$\arccos\left(-\frac{r}{R}\right)$$

Boxes **1** and **3** feature summing the angles of a triangle and comparing to π radians (or 180°).

Box **2** shows the Maclaurin series of

up to order 1. The derivations of the ray

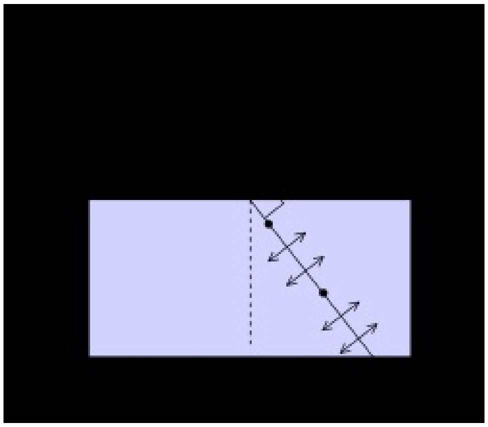
matrices of a convex spherical mirror and a thin lens are very similar.

Brewster's angle

From Wikipedia, the free encyclopedia

Jump to: navigation, search

27



An illustration of the polarization of light which is incident on an interface at Brewster's angle.

Brewster's angle (also known as the **polarization angle**) is an angle of incidence at which light with a particular polarization is perfectly transmitted through a surface, with no reflection. The angle at which this occurs is named after the Scottish physicist, Sir David Brewster (1781–1868).

[] Explanation

When light moves between two media of differing refractive index, generally some of it is reflected at the boundary. At one particular angle of incidence, however, light with one particular polarization cannot be reflected. This angle of incidence is Brewster's angle, θB. The polarization that cannot be reflected at this angle is the polarization for which the electric field of the light waves lies in the same plane as the incident ray and the surface normal (i.e. the plane of incidence). Light with this polarization is said to be *p-polarized*, because it is parallel to the plane. Light with the perpendicular polarization is said to be *s-polarized*, from the German *senkrecht*—perpendicular. When unpolarized light strikes a surface at Brewster's angle, the reflected light is always *s*-polarized. Although 's' and 'p' polarization states were not named for this convention, it may be convenient to remember that 's' polarized light will "skip" off a Brewster boundary and 'p' polarized light will "plunge" through.

The physical mechanism for this can be qualitatively understood from the manner in which electric dipoles in the media respond to *p*-polarized light. One can imagine that light incident on the surface is absorbed, and then reradiated by oscillating electric dipoles at the interface between the two media. The polarization of freely propagating light is always perpendicular to

the direction in which the light is travelling. The dipoles that produce the transmitted (refracted)

light oscillate in the polarization direction of that light. These same oscillating dipoles also

generate the reflected light. However, dipoles do not radiate any energy in the direction along

which they oscillate. Consequently, if the direction of the refracted light is perpendicular to the

direction in which the light is predicted to be specularly reflected, the dipoles will not create any reflected light. Since, by definition, the *s*-polarization is parallel to the interface, the

corresponding oscillating dipoles will always be able to radiate in the specular-reflection

direction. This is why there is no Brewster's angle for *s*-polarized light.

28

$$\theta_1 + \theta_2 = 90^\circ,$$

$$n_1 \sin\left(\theta_1\right) = n_2 \sin\left(\theta_2\right),$$

$$n_1 \sin\left(\theta_B\right) = n_2 \sin\left(90 - \theta_B\right) = n_2 \cos\left(\theta_B\right).$$

$$\theta_B = \arctan\left(\frac{n_2}{n_1}\right),$$

With simple trigonometry this condition can be expressed as:

where θ1 is the angle of incidence and θ2 is the angle of refraction.

Using Snell's law,

we can calculate the incident angle θ =θ

1

B at which no light is reflected:

Rearranging, we get:

where *n* 1 and *n* 2 are the refractive indices of the two media. This equation is known as **Brewster's law**.

Note that, since all *p*-polarized light is refracted (i.e. transmitted), any light reflected from the

interface at this angle must be *s*-polarized. A glass plate or a stack of plates placed at Brewster's

angle in a light beam can thus be used as a polarizer.

For a glass medium (*n* ≈1.5) in air (≈1), Brewster's angle for visible light is approximately 56°

2

n 1

to the normal while for an air-water interface (*n* ≈1.33), it's approximately 53°. Since the

2

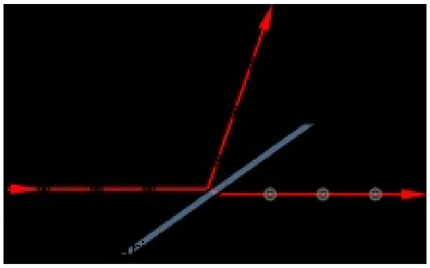
refractive index for a given medium changes depending on the wavelength of light, Brewster's angle will also vary with wavelength.

The phenomenon of light being polarized by reflection from a surface at a particular angle was first observed by Etienne-Louis Malus in 1808. He attempted to relate the polarizing angle to the refractive index of the material, but was frustrated by the inconsistent quality of glasses available at that time. In 1815, Brewster experimented with higher-quality materials and showed that this angle was a function of the refractive index, defining Brewster's law.

Although Brewster's angle is generally presented as a zero-reflection angle in textbooks from the late 1950s onwards, it truly is a polarizing angle. The concept of a polarizing angle can be extended to the concept of a Brewster wavenumber to cover planar interfaces between two linear bianisotropic materials.

[] Applications

29



Polarized sunglasses use the principle of Brewster's angle to reduce glare from the sun reflecting off horizontal surfaces such as water or road. In a large range of angles around Brewster's angle

the reflection of *p*-polarized light is lower than *s*-polarized light. Thus, if the sun is low in the sky reflected light is mostly *s*-polarized. Polarizing sunglasses use a polarizing material such as

polaroid film to block horizontally-polarized light, preferentially blocking reflections from horizontal surfaces. The effect is strongest with smooth surfaces such as water, but reflections

from road and the ground are also reduced.

Photographers use the same principle to remove reflections from water so that they can

photograph objects beneath the surface. In this case, the polarizing filter camera attachment can be rotated to be at the correct angle (see figure).

Photographs taken of mudflats with a camera polarizer filter rotated to two different angles. In

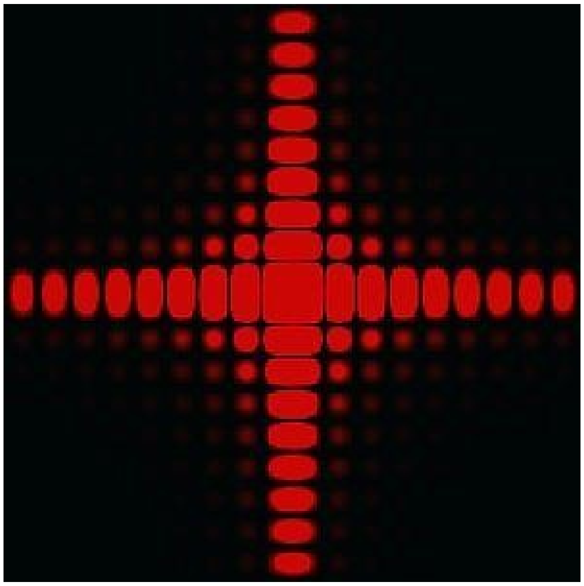
the first picture, the polarizer is rotated to maximize reflections, and in the second, it is rotated

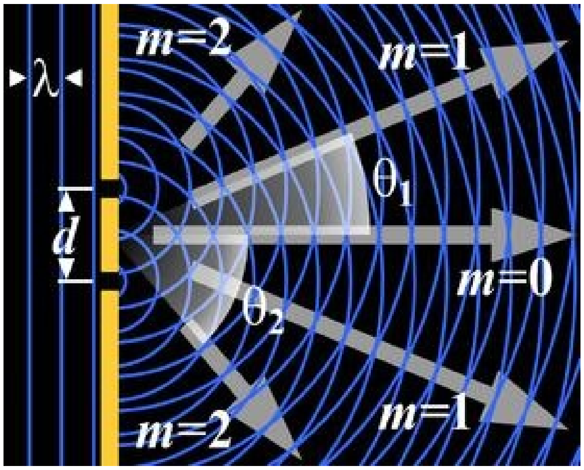
90° to minimize reflections - almost all reflected sunlight is eliminated.

[] Brewster windows

A Brewster window

Gas lasers typically use a window tilted at Brewster's angle to allow the beam to leave the laser tube. Since the window reflects some *s*-polarized light but no *p*-polarized light, the gain for the *s*





polarization is reduced but that for the *p* polarization is not affected. This causes the laser's output to be *p* polarized, and allows lasing with no loss due to the window.[1]

Diffraction

From Wikipedia, the free encyclopedia

Jump to: navigation, search

The intensity pattern formed on a screen by diffraction from a square aperture

Diffraction

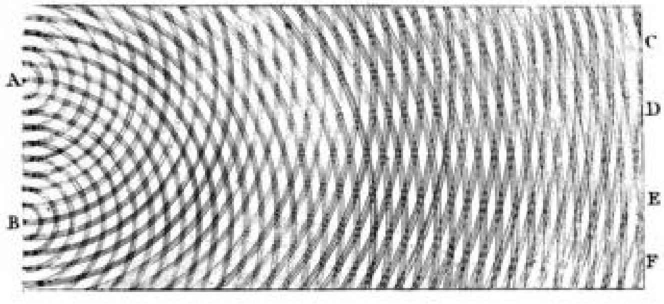
Colors seen in a spider web are partially due to diffraction, according to some analyses.[1]

Diffraction refers to various phenomena which occur when a wave encounters an obstacle. It is described as the apparent bending of waves around small obstacles and the spreading out of waves past small openings. Similar effects are observed when light waves travel through a medium with a varying refractive index or a sound wave through one with varying acoustic impedance. Diffraction occurs with all waves, including sound waves, water waves, and electromagnetic waves such as visible light, x-rays and radio waves. As physical objects have wave-like properties (at the atomic level), diffraction also occurs with matter and can be studied according to the principles of quantum mechanics.

While diffraction occurs whenever propagating waves encounter such changes, its effects are generally most pronounced for waves where the wavelength is on the order of the size of the diffracting objects. If the obstructing object provides multiple, closely-spaced openings, a complex pattern of varying intensity can result. This is due to the superposition, or interference, of different parts of a wave that traveled to the observer by different paths (see diffraction grating).

The formalism of diffraction can also describe the way in which waves of finite extent propagate in free space. For example, the expanding profile of a laser beam, the beam shape of a radar antenna and the field of view of an ultrasonic transducer are all explained by diffraction theory.

[] Examples



Solar glory at the steam from hot springs. A **glory** is an optical phenomenon produced by light backscattered (a combination of diffraction, reflection and refraction) towards its source by a cloud of uniformly-sized water droplets.

The effects of diffraction can be regularly seen in everyday life. The most colorful examples of diffraction are those involving light; for example, the closely spaced tracks on a CD or DVD act as a diffraction grating to form the familiar rainbow pattern we see when looking at a disk. This principle can be extended to engineer a grating with a structure such that it will produce any diffraction pattern desired; the hologram on a cr card is an example. Diffraction in the atmosphere by small particles can cause a bright ring to be visible around a bright light source like the sun or the moon. A shadow of a solid object, using light from a compact source, shows small fringes near its edges. The speckle pattern which is observed when laser light falls on an optically rough surface is also a diffraction phenomenon. All these effects are a consequence of the fact that light propagates as a wave.

Diffraction can occur with any kind of wave. Ocean waves diffract around jetties and other obstacles. Sound waves can diffract around objects, which is why one can still hear someone calling even when hiding behind a tree.[2] Diffraction can also be a concern in some technical applications; it sets a fundamental limit to the resolution of a camera, telescope, or microscope.

[] History

Thomas Young's sketch of two-slit diffraction, which he presented to the Royal Society in 1803

33

The effects of diffraction of light were first carefully observed and characterized by Francesco

Maria Grimaldi, who also coined the term *diffraction*, from the Latin *diffringere*, 'to break into pieces', referring to light breaking up into different directions. The results of Grimaldi's

observations were published posthumously in 1665.[3][4][5] Isaac Newton studied these effects and attributed them to *inflexion* of light rays. James Gregory (1638–1675) observed the diffraction patterns caused by a bird feather, which was effectively the first diffraction grating to be discovered.[6] Thomas Young performed a celebrated experiment in 1803 demonstrating interference from two closely spaced slits.[7] Explaining his results by interference of the waves emanating from the two different slits, he deduced that light must propagate as waves. Augustin-

Jean Fresnel did more definitive studies and calculations of diffraction, made public in 1815[8]

and 1818,[9] and thereby gave great support to the wave theory of light that had been advanced by

Christiaan Huygens[10] and reinvigorated by Young, against Newton's particle theory.

[] The mechanism of diffraction

Photograph of single-slit diffraction in a circular ripple tank

Diffraction arises because of the way in which waves propagate; this is described by the

Huygens–Fresnel principle. The propagation of a wave can be visualized by considering every point on a wavefront as a point source for a secondary radial wave. The subsequent propagation

and addition of all these radial waves form the new wavefront. When waves are added together,

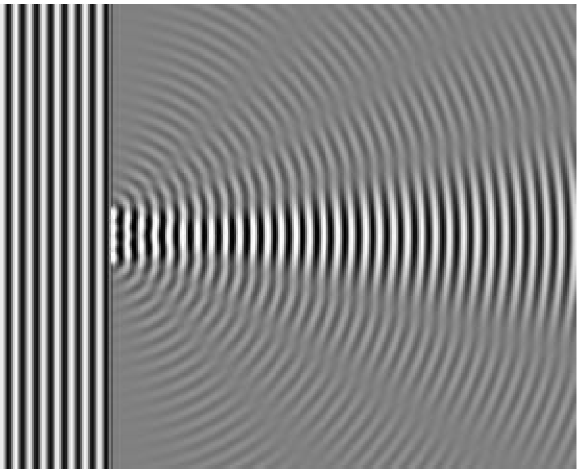
their sum is determined by the relative phases as well as the amplitudes of the individual waves,

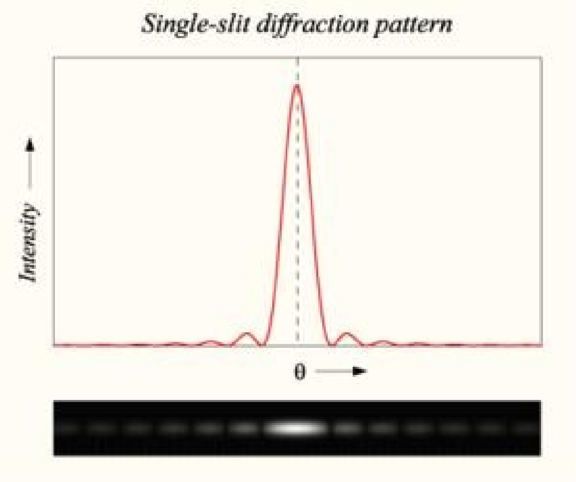
an effect which is often known as wave interference. The summed amplitude of the waves can have any value between zero and the sum of the individual amplitudes. Hence, diffraction patterns usually have a series of maxima and minima.

The form of a diffraction pattern can be determined from the sum of the phases and amplitudes of the Huygens wavelets at each point in space. There are various analytical models which can be used to do this including the Fraunhofer diffraction equation for the far field and the Fresnel Diffraction equation for the near field. Most configurations cannot be solved analytically, but can yield numerical solutions through finite element and boundary element methods.

[] Diffraction systems

It is possible to obtain a qualitative understanding of many diffraction phenomena by considering how the relative phases of the individual secondary wave sources vary, and in particular, the conditions in which the phase difference equals half a cycle in which case waves will cancel one another out.





The simplest descriptions of diffraction are those in which the situation can be reduced to a two-dimensional problem. For water waves, this is already the case, water waves propagate only on the surface of the water. For light, we can often neglect one direction if the diffracting object extends in that direction over a distance far greater than the wavelength. In the case of light shining through small circular holes we will have to take into account the full three dimensional nature of the problem.

Some of the simpler cases of diffraction are considered below.

[] Single-slit diffraction

Main article: Diffraction formalism

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.

$$\frac{d\sin(\theta)}{2}$$

$$d\ \sin\theta_{\text{min}} = \lambda$$

$$d\ \sin\theta_n = n\lambda$$

$$I(\theta) = I_0 \operatorname{sinc}^2(d\sin\theta/\lambda)$$

Graph and image of single-slit diffraction

A long slit of infinitesimal width which is illuminated by light diffracts the light into a series of circular waves and the wavefront which emerges from the slit is a cylindrical wave of uniform intensity.

A slit which is wider than a wavelength has a large number of point sources spaced evenly across the width of the slit. The light at a given angle is made up of contributions from each of these point sources and if the relative phases of these contributions vary by 2π or more, we expect to find minima and maxima in the diffracted light.

We can find the angle at which a first minimum is obtained in the diffracted light by the following reasoning. The light from a source located at the top edge of the slit interferes destructively with a source located at the middle of the slit, when the path difference between them is equal to $\lambda/2$. Similarly, the source just below the top of the slit will interfere destructively with the source located just below the middle of the slit at the same angle. We can continue this reasoning along the entire height of the slit to conclude that the condition for destructive interference for the entire slit is the same as the condition for destructive interference between two narrow slits a distance apart that is half the width of the slit. The path difference is given by so that the minimum intensity occurs at an angle θ min given by

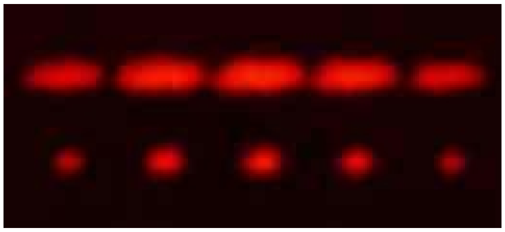
where d is the width of the slit.

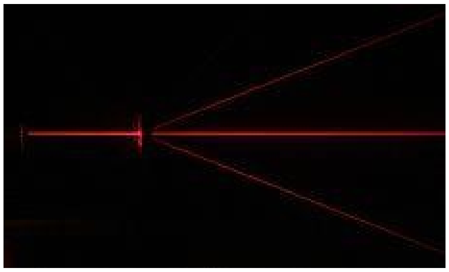
A similar argument can be used to show that if we imagine the slit to be divided into four, six, eight parts, etc, minima are obtained at angles θn given by

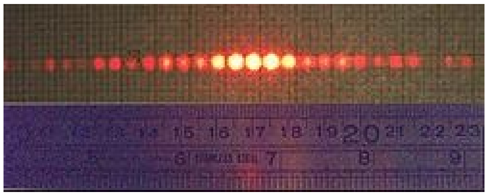
where n is an integer other than zero.

There is no such simple argument to enable us to find the maxima of the diffraction pattern. The intensity profile can be calculated using the Fraunhofer diffraction integral as where the sinc function is given by $\mathrm{sinc}(x) = \sin(\pi x)/(\pi x)$ if $x \neq 0$, and $\mathrm{sinc}(0) = 1$.

It should be noted that this analysis applies only to the far field, that is, at a distance much larger than the width of the slit.







$$d\left(\sin\theta_m + \sin\theta_i\right) = m\lambda.$$

2-slit (top) and 5-slit diffraction of red laser light

Diffraction of a red laser using a diffraction grating

A diffraction pattern of a 633 nm laser through a grid of 150 slits

[] Diffraction grating

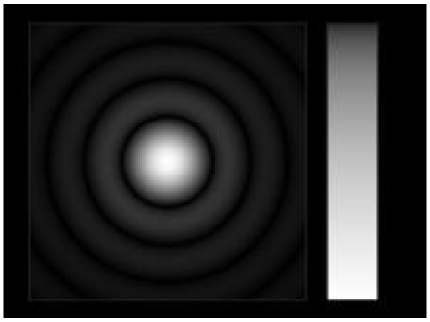
Main article: Diffraction grating

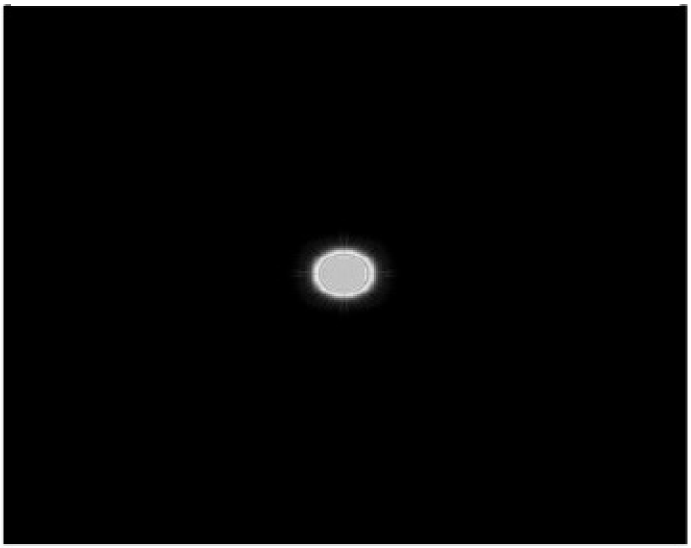
A diffraction grating is an optical component with a regular pattern. The form of the light diffracted by a grating depends on the structure of the elements and the number of elements present, but all gratings have intensity maxima at angles θm which are given by the grating equation

where θi is the angle at which the light is incident, *d* is the separation of grating elements and *m* is an integer which can be positive or negative.

The light diffracted by a grating is found by summing the light diffracted from each of the elements, and is essentially a convolution of diffraction and interference patterns.

The figure shows the light diffracted by 2-element and 5-element gratings where the grating spacings are the same; it can be seen that the maxima are in the same position, but the detailed structures of the intensities are different.





$$I(\theta) = I_0 \left(\frac{2 J_1(ka \sin\theta)}{ka \sin\theta} \right)^2$$

A computer-generated image of an **Airy disk**

Computer generated light diffraction pattern from a circular aperture of diameter 0.5micron at a wavelength of 0.6micron (red-light) at distances of 0.1cm – 1cm in steps of 0.1cm. One can see the image moving from the Fresnel region into the Fraunhofer region where the Airy pattern is seen.

[] Diffraction by a circular aperture

Main article: Airy disk

The far-field diffraction of a plane wave incident on a circular aperture is often referred to as the Airy Disk. The variation in intensity with angle is given by where *a* is the radius of the circular aperture, *k* is equal to 2π/λ and J1 is a Bessel function. The smaller the aperture, the larger the spot size at a given distance, and the greater the divergence of the diffracted beams.

[] Propagation of a laser beam

The way in which the profile of a laser beam changes as it propagates is determined by diffraction. The output mirror of the laser is an aperture, and the subsequent beam shape is

$$d = 1.22\lambda N,$$

$$\sin\theta = 1.22\frac{\lambda}{D},$$

determined by that aperture. Hence, the smaller the output beam, the quicker it diverges. Diode lasers have much greater divergence than He–Ne lasers for this reason.

Paradoxically, it is possible to reduce the divergence of a laser beam by first expanding it with one convex lens, and then collimating it with a second convex lens whose focal point is coincident with that of the first lens. The resulting beam has a larger aperture, and hence a lower divergence.

[] Diffraction-limited imaging

Main article: Diffraction-limited system

The Airy disk around each of the stars from the 2.56m telescope aperture can be seen in this *lucky image* of the binary star zeta Boötis.

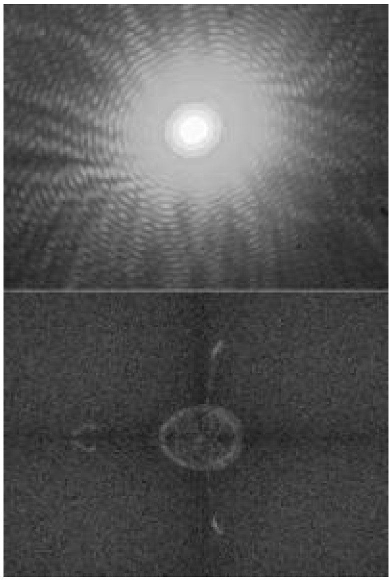
The ability of an imaging system to resolve detail is ultimately limited by diffraction. This is because a plane wave incident on a circular lens or mirror is diffracted as described above. The light is not focused to a point but forms an Airy disk having a central spot in the focal plane with radius to first null of

where λ is the wavelength of the light and *N* is the f-number (focal length divided by diameter) of the imaging optics. In object space, the corresponding angular resolution is where *D* is the diameter of the entrance pupil of the imaging lens (e.g., of a telescope's main mirror).

Two point sources will each produce an Airy pattern – see the photo of a binary star. As the point sources move closer together, the patterns will start to overlap, and ultimately they will merge to form a single pattern, in which case the two point sources cannot be resolved in the image. The

Rayleigh criterion specifies that two point sources can be considered to be resolvable if the separation of the two images is at least the radius of the Airy disk, i.e. if the first minimum of

one coincides with the maximum of the other.



Thus, the larger the aperture of the lens, and the smaller the wavelength, the finer the resolution

of an imaging system. This is why telescopes have very large lenses or mirrors, and why optical

microscopes are limited in the detail which they can see.

[] Speckle patterns

Main article: speckle pattern

The speckle pattern which is seen when using a laser pointer is another diffraction phenomenon.

It is a result of the superpostion of many waves with different phases, which are produced when

a laser beam illuminates a rough surface. They add together to give a resultant wave whose

amplitude, and therefore intensity varies randomly.

[] Common features of diffraction patterns

The upper half of this image shows a diffraction pattern of He-Ne laser beam on an elliptic

aperture. The lower half is its 2D Fourier transform approximately reconstructing the shape of

the aperture.

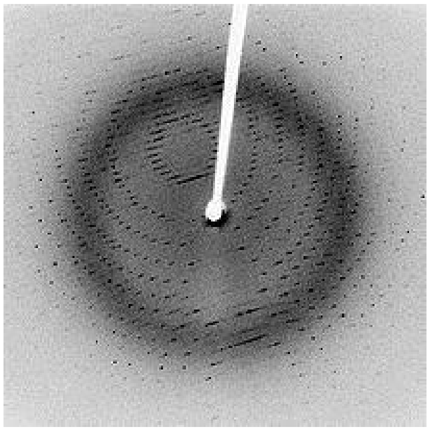
Several qualitative observations can be made of diffraction in general:

The angular spacing of the features in the diffraction pattern is inversely proportional to the dimensions of the object causing the diffraction. In other words: The smaller the diffracting object, the 'wider' the resulting diffraction pattern, and vice versa. (More precisely, this is true of the sines of the angles.)

The diffraction angles are invariant under scaling; that is, they depend only on the ratio of the wavelength to the size of the diffracting object.

When the diffracting object has a periodic structure, for example in a diffraction grating, the features generally become sharper. The third figure, for example, shows a comparison of a double-slit pattern with a pattern formed by five slits, both sets of slits having the same spacing, between the center of one slit and the next.

$$\lambda = \frac{h}{p}$$



[] Particle diffraction

See also: neutron diffraction and electron diffraction

Quantum theory tells us that every particle exhibits wave properties. In particular, massive particles can interfere and therefore diffract. Diffraction of electrons and neutrons stood as one of the powerful arguments in favor of quantum mechanics. The wavelength associated with a particle is the de Broglie wavelength

where h is Planck's constant and p is the momentum of the particle (mass × velocity for slow-moving particles) . For most macroscopic objects, this wavelength is so short that it is not meaningful to assign a wavelength to them. A sodium atom traveling at about 30,000 m/s would have a De Broglie wavelength of about 50 pico meters.

Because the wavelength for even the smallest of macroscopic objects is extremely small, diffraction of matter waves is only visible for small particles, like electrons, neutrons, atoms and small molecules. The short wavelength of these matter waves makes them ideally suited to study the atomic crystal structure of solids and large molecules like proteins.

Relatively larger molecules like buckyballs were also shown to diffract.[11]

[] Bragg diffraction

Following Bragg's law, each dot (or *reflection*), in this diffraction pattern forms from the constructive interference of X-rays passing through a crystal. The data can be used to determine

the crystal's atomic structure.

$$m\lambda = 2d\sin\theta$$

For more details on this topic, see Bragg diffraction.

Diffraction from a three dimensional periodic structure such as atoms in a crystal is called Bragg diffraction. It is similar to what occurs when waves are scattered from a diffraction grating.

Bragg diffraction is a consequence of interference between waves reflecting from different crystal planes. The condition of constructive interference is given by *Bragg's law*:

where

λ is the wavelength,

d is the distance between crystal planes,

θ is the angle of the diffracted wave.

and *m* is an integer known as the *order* of the diffracted beam.

Bragg diffraction may be carried out using either light of very short wavelength like x-rays or matter waves like neutrons (and electrons) whose wavelength is on the order of (or much smaller than) the atomic spacing[12]. The pattern produced gives information of the separations of crystallographic planes *d*, allowing one to deduce the crystal structure. Diffraction contrast, in electron microscopes and x-topography devices in particular, is also a powerful tool for examining individual defects and local strain fields in crystals.

[] Coherence

Main article: Coherence (physics)

The description of diffraction relies on the interference of waves emanating from the same source taking different paths to the same point on a screen. In this description, the difference in phase between waves that took different paths is only dependent on the effective path length. This does not take into account the fact that waves that arrive at the screen at the same time were emitted by the source at different times. The initial phase with which the source emits waves can change over time in an unpredictable way. This means that waves emitted by the source at times that are too far apart can no longer form a constant interference pattern since the relation between their phases is no longer time independent.

The length over which the phase in a beam of light is correlated, is called the coherence length. In order for interference to occur, the path length difference must be smaller than the coherence length. This is sometimes referred to as spectral coherence, as it is related to the presence of different frequency components in the wave. In the case of light emitted by an atomic transition, the coherence length is related to the lifetime of the excited state from which the atom made its transition.

If waves are emitted from an extended source, this can lead to incoherence in the transversal direction. When looking at a cross section of a beam of light, the length over which the phase is correlated is called the transverse coherence length. In the case of Young's double slit

experiment, this would mean that if the transverse coherence length is smaller than the spacing between the two slits, the resulting pattern on a screen would look like two single slit diffraction patterns.

In the case of particles like electrons, neutrons and atoms, the coherence length is related to the spatial extent of the wave function that describes the particle.