UNIVERSITÉ CATHOLIQUE DE LILLE 1875

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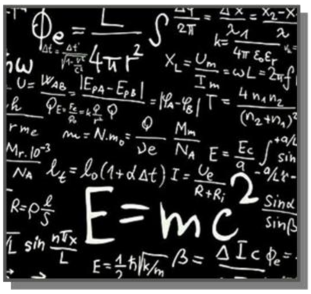
Physics II part 2 booklet



This document has been designed to help you transition into a new learning environment and approach the fundamental concepts covered in chapters 31 to 36 of your textbook with greater ease. The goal of this booklet is not to replace the course but to provide you with resources and activities ahead of each chapter, allowing you to familiarize yourself with key concepts before or during studying them in detail. You will find:

- **Online videos to** serve as a reminder of previous course material and concepts, but they also introduce and explain the current chapter from different perspectives.
- **Activities** using simulation tools to experiment and develop your physical intuition before tackling the mathematical formalism.
- **Numerical application exercises and MCQ** to practice essential calculations and reinforce your understanding of the concepts covered in class. Some exercises may require you to have read or have access to the course material.

This booklet is not mandatory, but it is designed to help you make a smoother transition into your studies and feel more confident when approaching new topics. It is a tool to support your learning and give you a head start.

Happy studying, and welcome to France!

Useful constants:

$\varepsilon_0 = 8.85 \times 10^{-12}\, F/m$ $\mu_0 = 4\pi \times 10^{-7}\, H/m$

$c = 3.00 \times 10^{8}\, m/s$ $e = 1.6 \times 10^{-19} C$

Chapter 31 :
Electromagnetic Oscillations in RLC Circuits

Videos links

AC Circuits: Crash Course Physics #36
https://youtu.be/Jveer7vhjGo?si=vbzaRMFo6tySQFFZ

What is LC Oscillation Circuit
https://youtube.com/shorts/S4kw3_4tWpw?si=gF2ugElkgf-9rANL

The beauty of LC Oscillations!
https://youtu.be/2_y_3_3V-so?si=USMKK2xHCGhAaaA3

What the HECK is a Phasor? Alternating Current Explained.
https://www.youtube.com/watch?v=7weMCsff0xw

How Power Gets to Your Home: Crash Course Physics #35
https://youtu.be/9kgzA0Vd8S8?si=JDfeirNRcVwHwUsm

How does a Transformer work ?
https://youtu.be/vh_aCAHThTQ?si=H7Nz2Uth1RJZARN8

The scariest thing you learn in Electrical Engineering | The Smith Chart
https://youtu.be/pXWbdxOAuDs?si=uiJAKFWIVDR7SX9c

Prelude to Alternating-Current Circuits

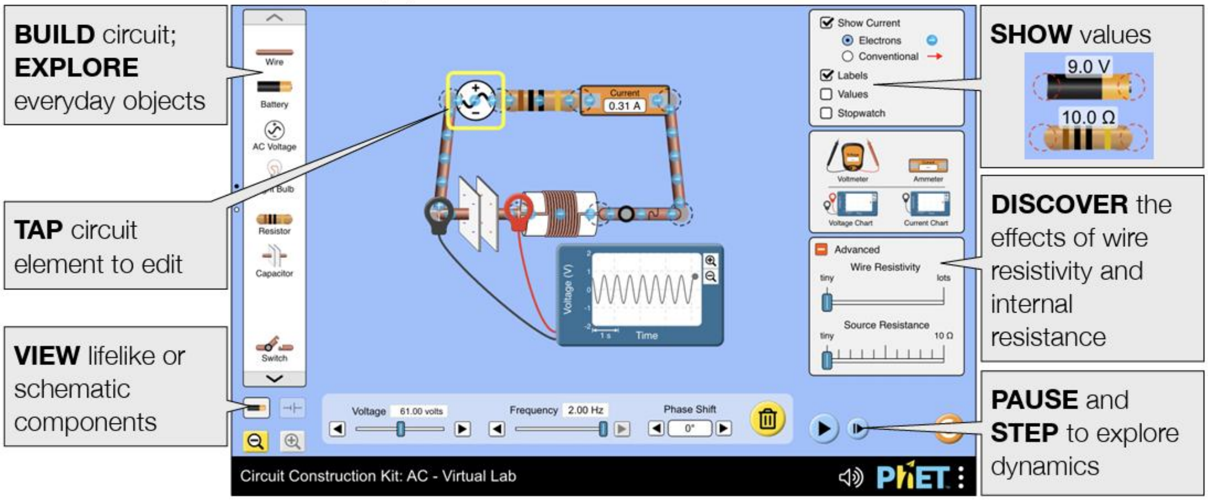
Electric power reaches our homes as alternating current (AC) through high-voltage transmission lines. Transformers adjust the voltage, allowing efficient long-distance transmission with minimal resistive losses and safe delivery at lower voltages. This process is more challenging with direct current (DC) since constant potential differences are unaffected by transformers.

The current supplied to our homes is alternating current (AC), transmitted through power lines and distributed by local power stations and transformers. This chapter explains how transformers work, enabling power to be transmitted at high voltages with minimal heating losses.

Previously, we examined resistors, capacitors, and inductors in DC circuits with batteries. These components also play key roles in AC circuits, but instead of a constant emf from a battery, AC circuits use a voltage source that produces an oscillating emf.

CHAPTER 31: Fundamental online activities:

Go to the RLC simulation tool on https://phet.colorado.edu/sims/html/circuit-construction-kit-ac/latest/circuit-construction-kit-ac_all.html



Activity 1: Exploring LC Circuit

1) Insert a capacitor, left click and set the capacitance to $0.15F$.
2) Create a circuit with a battery to charge the capacitor. When is fully charged, the capacitor possesses an energy $U_E = \frac{1}{2}CV^2$ due to the electric field between two plates
3) Press pause at the bottom of the screen and disconnect the battery and remove it from the simulation.
4) Connect an inductor in series with the capacitor. Change Inductance to $3.0\ H$. Press play arrow. Note any observations you see. What happens to the charges in the wire and in the metallic plates of the capacitor?
5) Insert a Current Chart and place the detector on a wire in the circuit between the capacitor and inductor. Adjust the y-axis using the +/- arrows so that you can see the full sinusoidal curve and maximum current. Note the maximum/minimum current.
6) To your best ability write down the period between maximum peaks. Convert the period you measured into an angular frequency $\omega = 2\pi/Period$.
7) How do ω you previously measured relate to natural angular frequency $\omega_0 = \frac{1}{\sqrt{LC}}$
8) Insert Voltage Chart and place the detectors on either side of the capacitor. Add a second chart on both sides of the inductor. Make sure the polarity of the detectors is consistent. Adjust the y-axis using the +/- arrows so that you can see the full sinusoidal curve and maximum voltage on each graph. Qualitatively note the similarities and differences between the curves.
9) Are they peaking at the same time? To your best ability write down the period between maximum peaks of the voltages across C and L, are they the same? Compare the period with the one measured in 6.

Activity 2: Exploring Resonance in an RLC Circuit

1) Create a circuit with an AC voltage source in series with a resistor, inductor, and capacitor. Change the capacitance to $0.10\ F$, the inductance to $2.0\ H$, and the resistance to $10\ \Omega$, as was done in Activity 1.
2) Left-click the AC voltage source and set the voltage V_{max} to 20 V. Set the frequency to $1\ Hz$.
3) Place a Voltage Chart around each element in the circuit, including the AC voltage source. Make sure the polarity is consistent.
4) Mark the maximum and minimum voltages on each graph. Qualitatively note the similarities and differences between the graphs. Which graphs are in phase with one another? Which graphs are not? What about the sign of the amplitude?
5) Using the RMS voltages ($V_{RMS} = V_{max}/\sqrt{2}$), show that the RMS voltage of the AC source is consistent with the sum of the RMS voltages across each element:
$$V_{RMS,AC} = \sqrt{\left(V_{RMS,R}\right)^2 + \left(V_{RMS,L} - V_{RMS,C}\right)^2}.$$
6) Place a Current Chart after the battery in the circuit. Note the maximum current value and measure the ratio V_{max}/I. Since this is an AC system and not DC, this ratio between voltage and current is not the resistance but is called the impedance Z.
7) Change the frequency of the AC voltage source. What happens to the impedance $Z = V_{max}/I$?
8) Compare the value of Z calculated from the previous question to the theoretical value given by: $z = \sqrt{R^2 + \left(2\pi f\, L - \frac{1}{2\pi f\, C}\right)^2}$
9) Set the frequency to obtain the highest current amplitude in the circuit. Does this frequency correspond to the natural frequency of the LC circuit, given by: $f_0 = \frac{1}{2\pi\sqrt{LC}}$
10) Conclude: What does it mean for an RLC circuit, or any physical system, to be at resonance?
11) We can repeat this experiment by changing the values of L and C and see if these relationships remain consistent.

📐 Activity 3: Average Power

1) Create an RLC circuit with resonant frequency of your own choosing. Initially set the resistance to 10 Ω. For at least 7 values of frequency fill out the table below. Make sure you have at least three points above, below, and including the resonant frequency. Note I_{RMS} and V_{RMS} are the values leaving the AC Voltage. Refer to your lecture notes on how to calculate Z and average power.

$\boldsymbol{R = 10\ \Omega}$					
$f\ (Hz)$	$\omega\ (rad/s)$	$Z\ (\Omega)$	$I_{rms}(A)$	V_{rms}	$P_{avg}(W)$

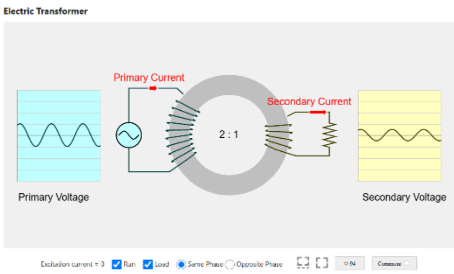
2) Using Microsoft Excel or Google Sheets make a graph of the average power (y-axis) versus ω (x-axis). Make sure the graph has axes labeled with units included.

3) Repeat with now R=100 Ω and the circuit otherwise unchanged.

$\boldsymbol{R = 100\ \Omega}$					
$f\ (Hz)$	$\omega\ (rad/s)$	$Z\ (\Omega)$	$I_{rms}(A)$	V_{rms}	$P_{avg}(W)$

4) Compare the two graphs qualitatively. What role does the resistance play in an RLC circuit?

📐 Activity 4: Transformer



Got to :

https://javalab.org/en/electric_transformer_en/

or to

https://demonstrations.wolfram.com/ACTransformers/ and play with the number of turns, what observation can you make between the primary and the secondary voltage?

CHAPTER 31: Numerical application exercises

Exercise 31.1: Total energy and maximum current in a series circuit

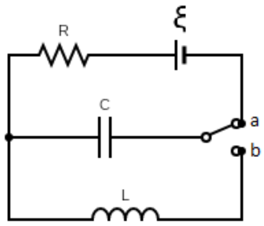
An oscillating LC circuit consists of a $75.0\ mH$ inductor and a $3.60\ \mu F$ capacitor. If the maximum charge on the capacitor is $2.90\ \mu C$, what are (a) the total energy in the circuit and (b) the maximum current?

Exercise 31.2: Basic Resonant Frequency Calculation

Calculate the resonant frequency of an RLC circuit with L=10 mH and C=250 nF.

Exercise 31.3: LC oscillations

In the following figure, $R = 14.0\ \Omega$, $C = 6.20\ \mu F$, $L = 54.0\ mH$, and the ideal battery has emf $\xi = 34.0\ V$. The switch is kept at a for a long time and then thrown to position b. What are the (a) frequency and (b) current amplitude of the resulting oscillations?



Exercise 31.4: Frequency Response Analysis

For a series RLC circuit ($R = 20\ \Omega$, $L = 100\ mH$, $C = 500\ nF$), calculate the inductive and capacitive reactance and then the total impedance at $f = 1\ kH$ and $f = 5\ kHz$. Compare the results.

Exercise 31.5: Phase Angle Calculation

Determine the phase angle between the voltage and current in an RLC circuit at $f = 8\ kHz$ if $R = 10\ \Omega$, $L = 50\ mH$, and $C = 100\ nF$.

Exercise 31.6: Phase Angle Calculation by voltage

In a series RLC circuit, the voltage across the resistor is $V_R = 10\ V$, the voltage across the inductor is $V_L = 15\ V$, and the voltage across the capacitor is $V_C = 5\ V$. Calculate the phase angle ϕ between the total voltage and the current.

Exercise 31.7: Analysis of an Oscillating LC Circuit

In an oscillating LC circuit with $C = 64.0\ \mu F$, the current is given by:

$$i(t) = (1.60)\ sin(2500t + 0.680)\ ,$$

where t is in seconds, i in amperes, and the phase constant in radians. (a) How soon after $t = 0$ will the current reach its maximum value? What are (b) the inductance L and (c) the total energy?

Chapter 32 :

Maxwell's Equations & Magnetism of Matter

Videos links:

Magnetism: Crash Course Physics #32
https://youtu.be/s94suB5uLWw?si=Kl11BMLRD8Rhbq3r

Ampère's Law: Crash Course Physics #33
https://youtu.be/5fqwJyt4Lus?si=94EAqm0czgg_zx8S

Maxwell's Equations: Crash Course Physics #37
https://youtu.be/K40lNL3KsJ4?si=kBEhPFS3AYaPWvzp

Here's What Maxwell's Equations ACTUALLY Mean.
https://www.youtube.com/watch?v=XAKAlNH9dDw

The 4 Maxwell Equations. Get the Deepest Intuition! (more mathematical point of view)
https://youtu.be/hJD8ywGrXks?si=63lxwKTJgfCxi3C8

MAGNETS: How Do They Work?
https://www.youtube.com/watch?v=hFAOXdXZ5TM

How do magnets work?
https://www.youtube.com/watch?v=hFAOXdXZ5TM

Paramagnetism and ferromagnetism in solids
https://www.youtube.com/watch?v=4KKwn363LRc

What the HECK are Magnets? (Electrodynamics)
https://www.youtube.com/watch?v=XczMRsiq9mk

Prelude to Magnetism of Matter

In preceding chapters, we saw that a moving charged particle produces a magnetic field. This connection between electricity and magnetism is exploited in electromagnetic devices, such as a computer hard drive. In fact, it is the underlying principle behind most of the technology in modern society, including telephones, television, computers, and the internet.

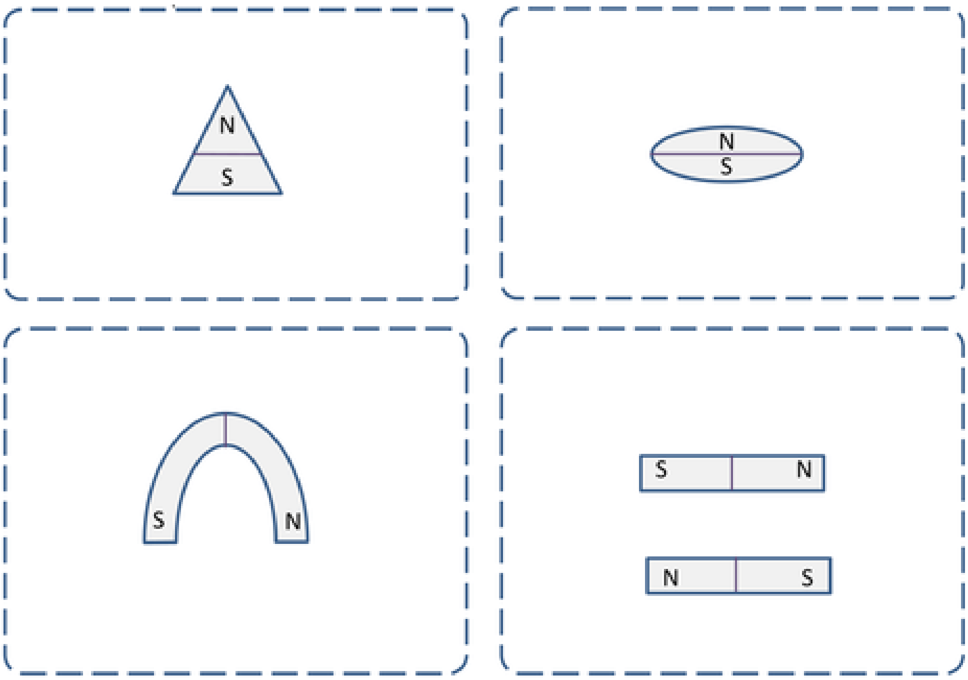
An external hard drive attached to a computer works by magnetically encoding information that can be stored or retrieved quickly. A key idea in the development of digital devices is the ability to produce and use magnetic fields in this way. (credit: modification of work by "Miss Karen"/Flickr)

We explored how electric currents generate magnetic fields using the Biot-Savart law and examined the forces between current-carrying wires. Now, we shift to atomic-scale systems, analyzing magnetic fields from current loops and how different materials respond to magnetic fields.

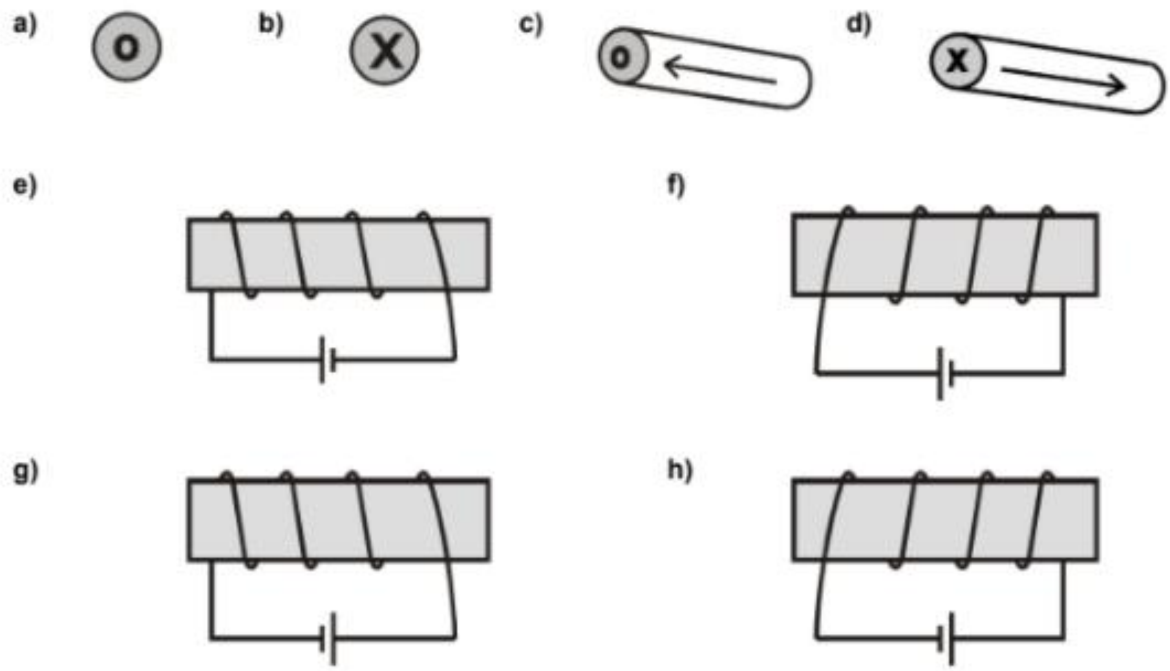
CHAPTER 32 : Fundamental online activities:

Activity 1: Magnetic field lines

Draw the magnetic field lines around these groups of one or two magnets. (the field lines start at right angle to the surface of the magnet)



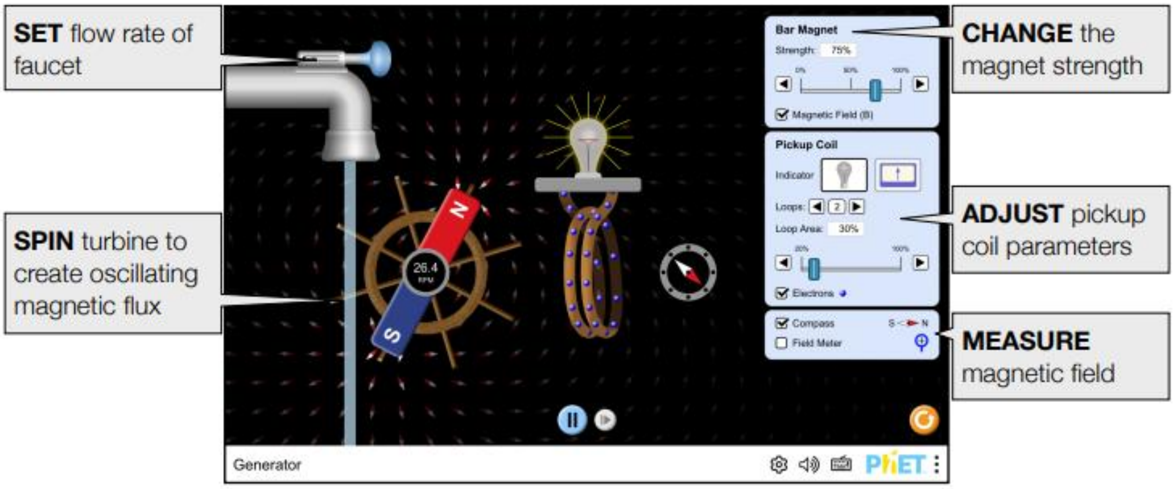
Draw the magnetic field lines around each of the following conductors (the direction of the current is represented by the arrow or by the polarization of the generator).



Activity 2: reminder of induction

Go to https://phet.colorado.edu/sims/html/generator/latest/generator_all.html

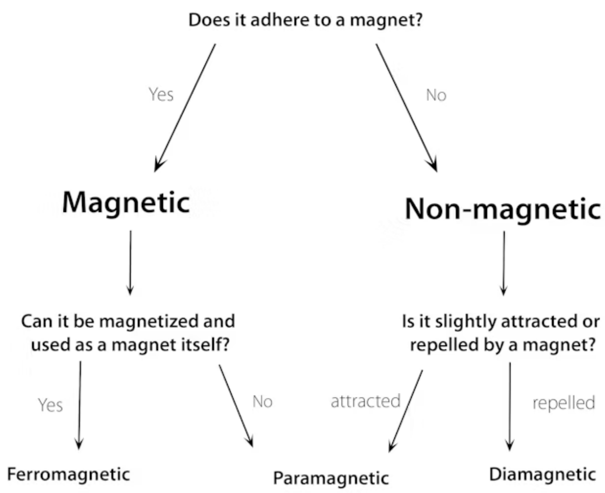
The Generator simulation allows you to generate electricity with a bar magnet and discover the principles of an electric generator hidden in the Maxwell equations.



1) Find all of the ways to make the light bulb brighter.
2) Predict what happens to the brightness of the bulb when the number of turns in the pickup coil is reduced by half, but the speed of the magnet remains the same.
3) Compare and contrast how both a light bulb and voltmeter can be used to show characteristics of the induced current.
4) Explain what causes induction.
5) Describe how a generator produces electricity.

Activity 2: magnetic and non-magnetic materials

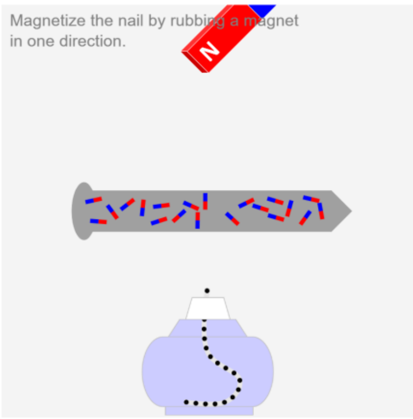
Materials can be divided into three types: ferromagnetic, paramagnetic, and diamagnetic, depending on how they react to an external magnetic field.
Using a strong magnet, find at home which materials correspond to the definition of a paramagnetic, diamagnetic, or ferromagnetic material (the repelling can be hard to see, even with a really strong magnet)



📐 Activity 3: Magnetization of Paramagnetic substance

Go to https://javalab.org/en/magnetization_en/

Magnetization of Paramagnetic substance



1) Find a way to align all the "magnets" in the same direction.
2) What do you think these "unitary magnets" represent?
3) What happens if you ignite a fire below the magnetized bar?

CHAPTER 32 : MCQ

32.1. Where can we find magnetism in nature?
A) By the presence of iron in materials
B) By the motion of electric charges (electric current)
C) Some materials exhibit some magnetic properties somehow
D) In the interaction between neutrons and protons

32.2. What happens when an electric charge moves?
A) It creates a gravitational field
B) It generates a magnetic field
C) It emits light
D) It loses energy

32.3. What happens if we keep cutting a magnet into smaller pieces, down to the size of a single atom?
A) The magnetic properties disappear
B) We create a single north or south pole
C) Each piece becomes a smaller magnet with both a north and south pole
D) The pieces become neutral and lose all magnetism

32.4. What is the source of magnetism in individual atoms?
A) The charge of the protons in the nucleus
B) The orbital motion of electrons around the nucleus
C) The temperature of the material
D) The gravitational force acting on the atom

32.5. What do we call the contribution to the magnetic moment arising from the motion of an electron around the nucleus in an atom?

A) Spin magnetic dipole moment
B) Orbital magnetic dipole moment
C) Total magnetic moment
D) Electric dipole moment

32.6. How can we represent or visualize a magnetic dipole moment?

A) As an infinitesimally small bar magnet with a north and south pole
B) As a vector pointing from the south pole to the north pole
C) As a spinning electric dipole
D) As a current loop creating a magnetic field

32.7. Actually, according to quantum mechanics, electrons do not really orbit or move around the atom in the classical sense. Instead, they exist in regions called orbitals, and also carry an intrinsic magnetic property called:

A) Charge
B) Polarization
C) Spin
D) Flux

32.8. What is the difference between the orbital magnetic moment and spin magnetic moment of an atom?

A) Spin is the actual physical rotation of the electron, while magnetic moment is an external magnetic field.
B) Magnetic moment is related to the orbital motion of electrons and spin, whereas spin magnetic moment is related to an intrinsic property of the electron.
C) Magnetic moment only occurs in charged particles, whereas spin is a property of neutral particles.
D) There is no difference; magnetic moment and spin are the same thing.

32.9. What is spin in the context of magnetism?

A) The actual rotation of electrons around their own axis
B) A quantum property of electrons that gives rise to a magnetic moment
C) The motion of electrons in a circular orbit around the nucleus
D) The oscillation of the electron's charge

32.10. How is the magnetic moment of an atom related to the spins of its electrons?

A) The magnetic moment is only related to the orbital motion of electrons, not their spin.
B) The magnetic moment is determined by the combined contribution of both the electron spins and the orbital motion.
C) The magnetic moment is determined only by the spins of unpaired electrons in the atom.
D) The magnetic moment is determined only by the orbital motion of the electrons in the atom.

32.11. What do we call a material in which magnetic moment are in the same direction, creating a net magnetic moment?

A) Atomic magnet
B) Magnetic material
C) Ferromagnetic material
D) Diamagnetic material

Chapter 33 :

Electromagnetic waves

Videos links:

How Did We Figure Out What Light Is? (history of light)
https://www.youtube.com/watch?v=ak7GB74Qlug

Light Is Waves: Crash Course Physics #39
https://www.youtube.com/watch?v=IRBfpBPELmE

Spectra Interference: Crash Course Physics #40
https://www.youtube.com/watch?v=-ob7foUzXaY

The origin of Electromagnetic waves, and why they behave as they do
https://www.youtube.com/watch?v=V_jYXQFjCmA&t=613s

Understanding Electromagnetic Radiation!
https://www.youtube.com/watch?v=FWCN_ul5ygY
https://youtu.be/KTzGBJPuJwM?si=-NElVZ86qBrVvZX4

Prelude to Electromagnetic waves

Our view of objects in the night sky, the warmth of the sun, sunburns, cell phone conversations, and X-rays revealing broken bones are all thanks to electromagnetic waves. These waves play an essential role in vision, technological applications, and transporting solar energy across space to sustain life on Earth.

The general phenomenon of electromagnetic waves was predicted before light was recognized as one. In the mid-19th century, James Clerk Maxwell developed a unified theory of electricity and magnetism, which he summarized in Maxwell's equations. These equations predicted electromagnetic waves traveling at the speed of light and described how they carry both energy and momentum. A striking example is the tail of comets, such as Comet McNaught, where solar light heats the comet, releasing dust and gas, while the momentum of the light shapes the tail. The solar wind produces a second tail, as explained in this chapter.

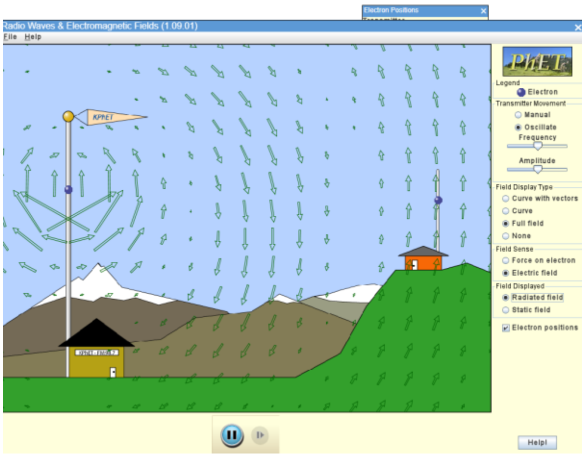
The pressure from sunlight predicted by Maxwell's equations helped produce the tail of Comet McNaught.
(credit: modification of work by Sebastian Deiries—ESO)

In this chapter, we explore Maxwell's theory, how it predicts electromagnetic waves, and how these waves are produced. We also examine how they carry energy and momentum and conclude with their various practical applications.

CHAPTER 33: Fundamental online activities:

📐 Activity 1: Radio Waves

Use the simulation on https://phet.colorado.edu/sims/cheerpj/radio-waves/latest/radio-waves.html?simulation=radio-waves to broadcast radio waves. Wiggle the transmitter electron manually or have it oscillate automatically. Display the field as a curve or vectors. The strip chart shows the electron positions at the transmitter and at the receiver.



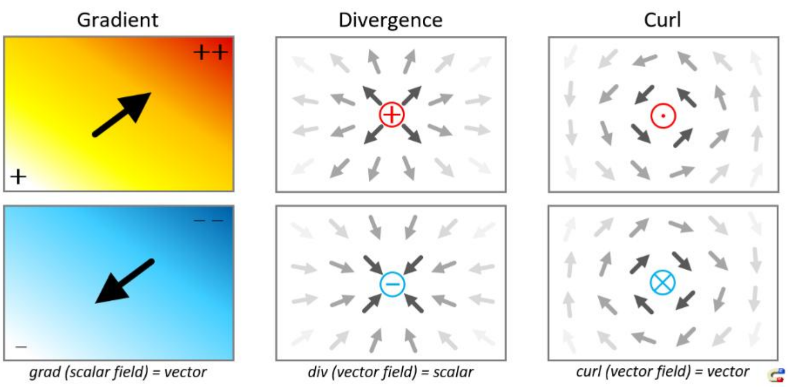
CHAPTER 33: Exercices

33.1. Gradient, divergence and curl

The **gradient** (grad or ∇)) is a mathematical tool that transforms a scalar field into a vector field. It points in the direction of the greatest increase of the scalar field and indicates how fast the change happens, like how a hill's steepness tells you which way and how quickly you'd go downhill.

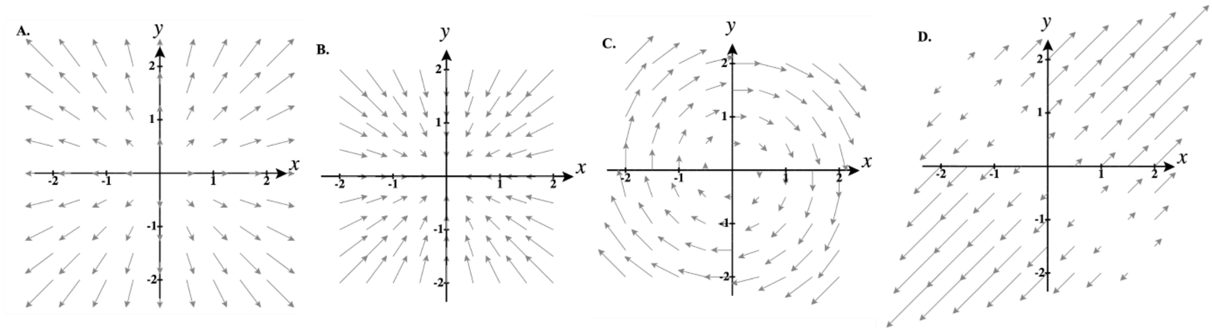
The **divergence** (div or $\nabla .$) is a mathematical tool that transforms a vector field into a scalar field. It measures how much a field spreads out from a point. It tells you how much vector flow is entering or exiting a region.

The **curl** (or $\nabla \times$) is a mathematical tool that transforms a vector field into another vector field. It measures how much a field swirls around a point, like how water spins when you stir it with a spoon.



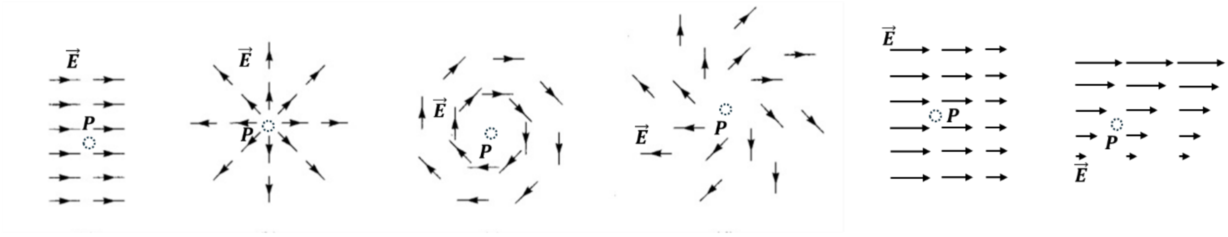
1) Which of the vector fields above have positive divergence at all points?

A. B. C. D.



2) Determine the sign (>0, >0 or =0) of the divergence and the out of plane curl at point P

A. B. C. D. E. F.



A.	B.	C.	D.	E.	F.
$\nabla.\vec{E}$	$\nabla.\vec{E}$	$\nabla.\vec{E}$	$\nabla.\vec{E}$	$\nabla.\vec{E}$	$\nabla.\vec{E}$
$\nabla\times\vec{E}$	$\nabla\times\vec{E}$	$\nabla\times\vec{E}$	$\nabla\times\vec{E}$	$\nabla\times\vec{E}$	$\nabla\times\vec{E}$

indicate >0, >0 or =0

33.2. Maxwell's equations

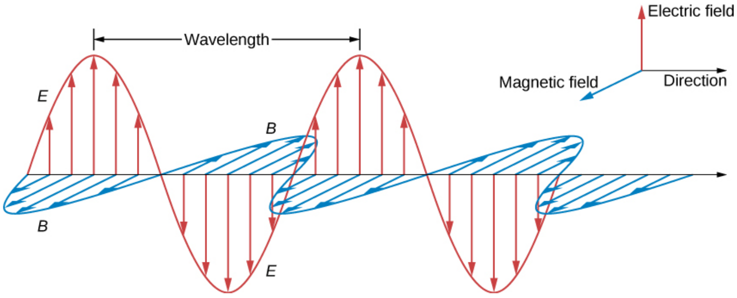
Maxwell's equations are a set of four equations that form the theoretical basis for describing classical electromagnetism. James Clerk Maxwell was a Scottish scientist who was the first to calculate that the speed of propagation of electromagnetic waves is the same as the speed of light, *c*. He introduced, in integral form, how electric charges and electric currents produce magnetic and electric fields, and vice versa. These equations are essentially a combination of the four fundamental laws of electromagnetism.

Link the physical meaning of each Maxwell equation to its correct differential and integral form.

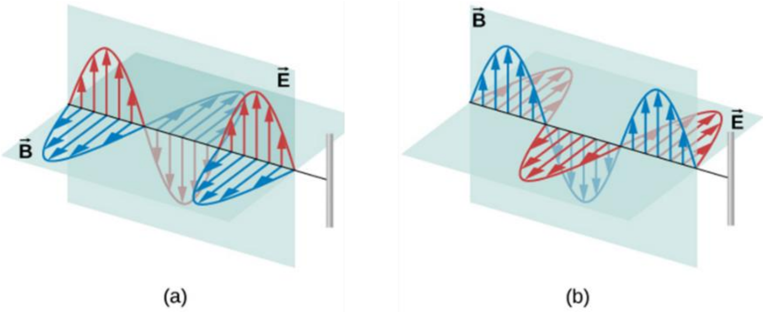
	Integral form	Differential form
Maxwell - Gauss for electrostatics Relates the electric flux to the enclosed electric charge •	• $\oiint \vec{B}\,.\,d\vec{A} = 0$ •	• $\nabla.\vec{E} = \frac{\rho}{\epsilon_0}$
Maxwell - Gauss for magnetostatics There is no magnetic monopole •	• $\oint \vec{B}\,.\,d\vec{S} = \mu_0\epsilon_0 \frac{d\phi_E}{dt} + \mu_0 i_{enc}$ •	• $\nabla\times\vec{B} = \mu_0\epsilon_0 \frac{\partial\vec{E}}{\partial t} + \mu_0 j_{enc}$
Maxwell-Faraday Relates the induced electric field to the varying magnetic field •	• $\oiint \vec{E}\,.\,d\vec{A} = \frac{q_{enc}}{\epsilon_0}$ •	• $\nabla.\vec{B} = 0$
Maxwell-Ampere Relates the induced magnetic field to the current and the varying electric field •	• $\oint \vec{E}\,.\,d\vec{S} = -\frac{d\phi_B}{dt}$ •	• $\nabla\times\vec{E} = -\frac{\partial\vec{B}}{\partial t}$

33.3. Plane Electromagnetic Waves and Wave equation

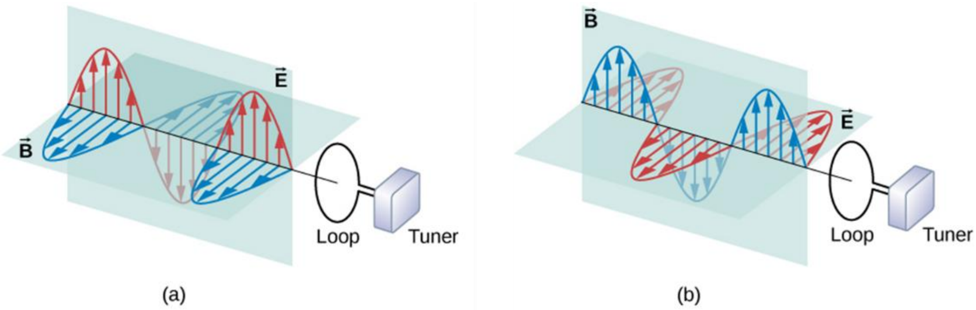
An electromagnetic wave consists of an electric field, defined as usual in terms of the force per charge on a stationary charge, and a magnetic field, defined in terms of the force per charge on a moving charge. The EM field is assumed to be a function of only 1D dimension of space and time.



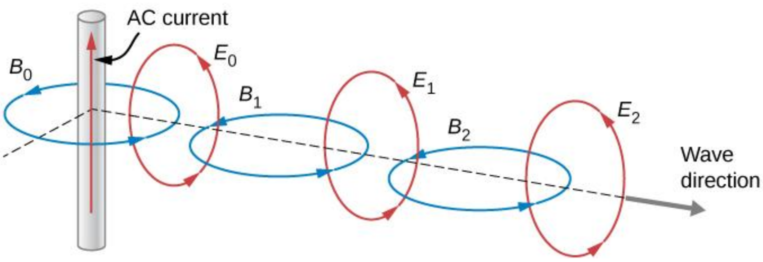
1) If the electric field of an electromagnetic wave is oscillating along the y-axis and the magnetic field is oscillating along the z-axis, in what possible direction is the wave traveling?
2) In which situation shown below will the electromagnetic wave be more successful in inducing a current in the wire? Explain.



3) In which situation shown below will the electromagnetic wave be more successful in inducing a current in the loop? Explain.



4) The wave equation was obtained by (1) finding the $\vec{E}$ field produced by the changing $\vec{B}$ field, (2) finding the $\vec{B}$ field produced by the changing $\vec{E}$ field, and combining the two results. Which of Maxwell's equations was the basis of step (1) and which of step (2)?



Because we are assuming free space, there are no free charges or currents, so we can set $\rho = 0$ and $j = 0$ in Maxwell's equations.

The electric field is then written as $\vec{E} = \begin{pmatrix} 0 \\ E_0 \sin(kx - \omega t) \\ 0 \end{pmatrix}$

and the magnetic field as $\vec{B} = \begin{pmatrix} 0 \\ 0 \\ B_0 \sin(kx - \omega t) \end{pmatrix}$.

5) Rewrite the differential **Maxwell - Faraday's law** in 1D (x direction) in free space to find a relation between E_0, B_0 anc c

We give $\nabla . \vec{E} = \begin{pmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \\ \frac{\partial}{\partial z} \end{pmatrix} \cdot \begin{pmatrix} E_x \\ E_y \\ E_z \end{pmatrix} = \begin{pmatrix} \frac{\partial E_x}{\partial x} \\ \frac{\partial E_y}{\partial y} \\ \frac{\partial E_z}{\partial z} \end{pmatrix}$ and $\nabla \times \vec{E} = \begin{pmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \\ \frac{\partial}{\partial z} \end{pmatrix} \times \begin{pmatrix} E_x \\ E_y \\ E_z \end{pmatrix} = \begin{pmatrix} \frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} \\ \frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} \\ \frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} \end{pmatrix}$

6) Do the same, use, the differential **Maxwell - Ampère's law** to find the relationship between the speed of light c, μ_0 and ϵ_0

7) What conclusions did our analysis of Maxwell's equations lead to about these properties of a plane electromagnetic wave:
   - the relative directions of wave propagation, of the E field, and of B field,
   - the speed of travel of the wave and how the speed depends on frequency, and
   - the relative magnitudes of the E and B fields.

33.4. How the E and B Fields Are Related

What is the maximum strength of the B field in an electromagnetic wave that has a maximum E-field strength of 1000 V/m?

Strategy :*To find the B-field strength, we rearrange the equation obtain from previous question to solve for B, yielding* $B = \frac{E}{c}$

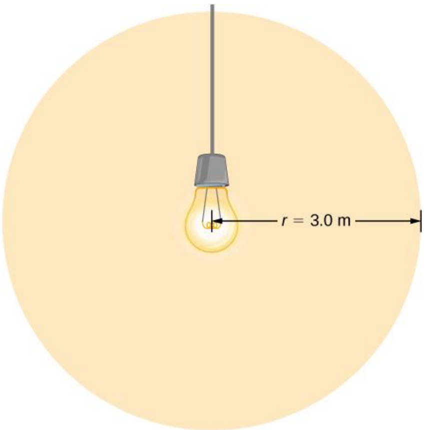
33.5. A laser beam

The beam from a small laboratory laser typically has an intensity of about $1.0 \times 10^{-3}\ W/m^2$. Assuming that the beam is composed of plane waves, calculate the amplitudes of the electric and magnetic fields in the beam.

Strategy : *Use the equation expressing intensity in terms of electric field* $I = S_{avg} = \frac{1}{2} c \varepsilon_0 E_0^2$ *to calculate the electric field from the intensity.*

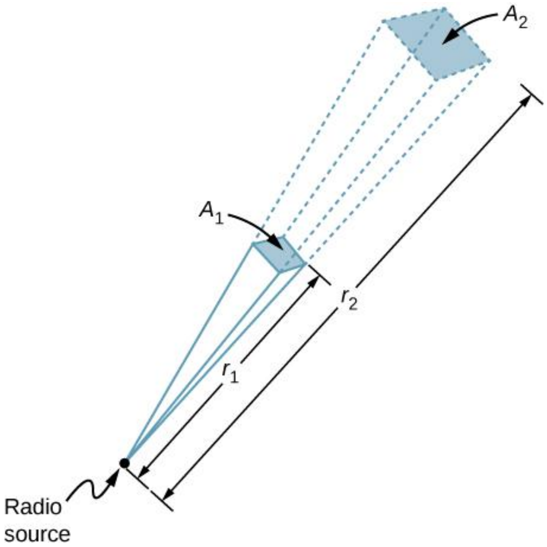
33.6. A light bulb

A light bulb emits 5.00 W of power as visible light. What are the average electric and magnetic fields from the light at a distance of 3.0 m?



33.7. A radio range

A 60-kW radio transmitter on Earth sends its signal to a satellite 100 km away. At what distance in the same direction would the signal have the same maximum field strength if the transmitter's output power were increased to 90 kW?

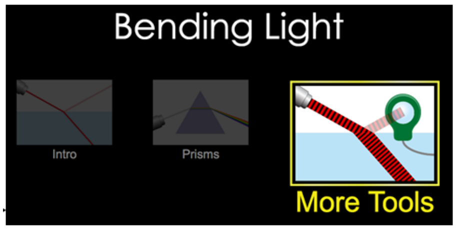


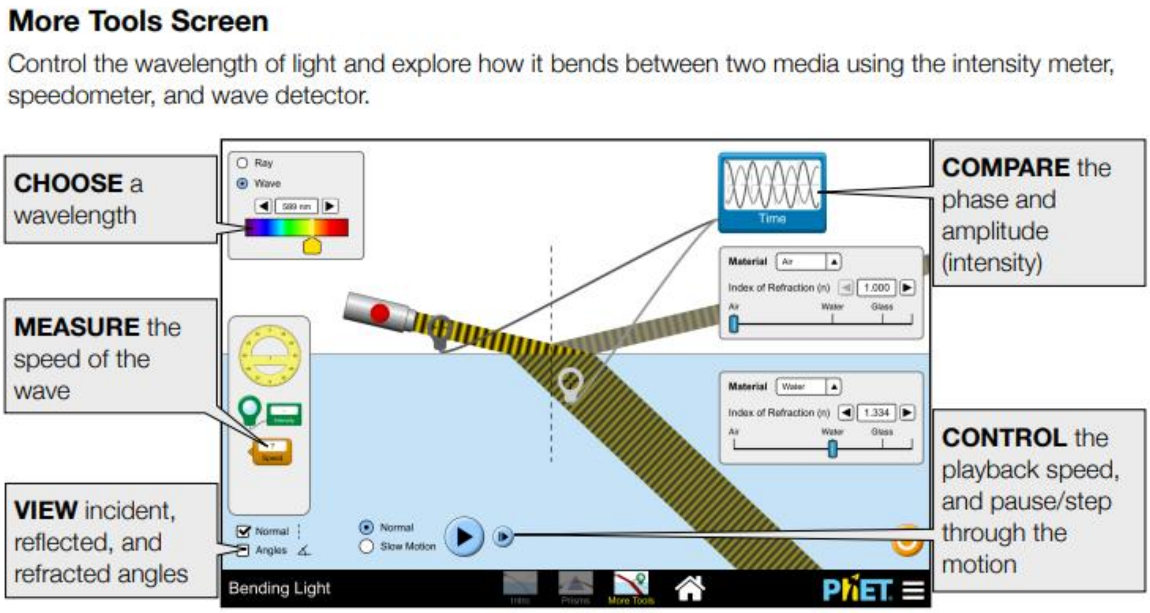
Strategy : *The area over which the power in a particular direction is dispersed increases as distance squared. Change the power output P by a factor of (90 kW/60 kW) and change the area by the same factor to keep* $I = \frac{P}{A} = \frac{c\varepsilon_0 E_0^2}{2}$ *the same. Then use the proportion of area* ***A*** *in the diagram to distance squared to find the distance that produces the calculated change in area.*

CHAPTER 32 : Fundamental online activities:

Activity 2: Bending of light

Play with the simulation tool on https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_all.html?locale=en in the **More tools** screen option to visualize the impact of medium on the propagation of an EM wave.





Choose **wave mode** in the top left corner and start with **zero angle** (normal incident light) at the interface of the two medium.

1) **Changing the Wavelength**
   - Change the wavelength of incident light using the slider.
   - What happens to the wavelength in the second medium? Does it change the color of the light?
   - Using the time tool on the left side, compare the frequency in air and in the medium. Are they the same?
   - How does a change in the wavelength not affect the color of the light?
   - Measure the speed of light (using the tool on the left side) in the air and in the medium and calculate the ratio of these speeds (air/medium). Does the result correspond with the ratio (medium/air) of what we called the index n of refraction?
   - Find a relation between c_{air}, c_{medium}, n_{air} and n_{medium}.
   - Knowing the frequency f are the same in both medium and the relation you found before, find the formula to calculate the new wavelength in the medium.

2) Changing the incident angle

- Turn on the laser and drag the circular protractor such that the protractor is centered along the normal line and the boundary between the two mediums. Also, drag the speed indicator tool out from the tools located at the lower left of the simulation. The laser can be dragged to change the incident angle (You can use the ray trace to spot the center of the propagation wave)
- Does a change in the incident angle modify the wavelengths? The speeds in each medium? The frequencies?
- Set the following initial data parameters and complete the table below. Write all velocities in terms of the speed of light c. Record your values for $\sin\theta_1$ and $\sin\theta_2$ and calculate λ_2 in nanometers (using the formula from the previous question).

Data Set 1	Data Set 2	Data Set 3
$\lambda_1 = 650nm$	$\lambda_1 = 460nm$	$\lambda_1 = 542nm$
$n_1 = 1.250$	$n_1 = 1.000$	$n_1 = 1.500$
$n_2 = 1.548$	$n_2 = 1.333$	$n_2 = 1.224$
$\theta_1 = 55.0°$	$\theta_1 = 35.0°$	$\theta_1 = 40.0°$

	θ_2	c_1	c_2	$\sin\theta_1$	$\sin\theta_2$	λ_2
Data Set 1						
Data Set 2						
Data Set 3						

- Use the above data and complete the table below for the ratio's given.

	$\frac{\sin\theta_1}{\sin\theta_2}$	$\frac{n_2}{n_1}$	$\frac{c_1}{c_2}$	$\frac{\lambda_1}{\lambda_2}$
Data Set 1				
Data Set 2				
Data Set 3				

- Based upon the pattern you see above for the ratios across different data sets, write a complete mathematical expression for Snell's Law. Verify your expression by looking up Snell's Law in your textbook, the internet.

3) Total internal reflection or TIR

As you may have seen in your observations (such as in Data Set 3), when light travels **from a more dense medium**, such as water ($n = 1.33$) **to a less dense medium**, such as air ($n = 1.00$), the light ray bends away from the normal (the dashed line). At a specific angle, called the critical angle, the light ray will bend 90° from the normal.

- Set the following initial data parameters and complete the table below.

Data Set1

$\lambda_1 = 650nm$
$n_1 = 1.250$
$n_2 = 1.548$
$\theta_1 = 55.0°$

incident angle θ_1 *(degrees)*	*refracted angle* θ_2 *(degrees)*	***reflected*** *angle (degrees)*
20		
40		
60		
80		

- What happens when the refracted angle approaches 90 degrees?
- Based upon what happens, estimate the critical angle θ_c , for the water-air interface.
- Use Snell's Law to derive a formula for the critical angle in terms of n_1, n_2 and $\sin\theta_c$ where $\sin\theta_2 = \sin 90°$ and $\sin\theta_1 = \sin\theta_c$. Verify your formula using your textbook, the internet.

- Calculate the critical angle for a "Mystery A" – air boundary.
- Using the internet, determine what "Mystery A" might be.

CHAPTERS 34:

GEOMETRICAL OPTICS

Videos links

Geometric Optics: Crash Course Physics #38
https://www.youtube.com/watch?v=Oh4m8Ees-3Q

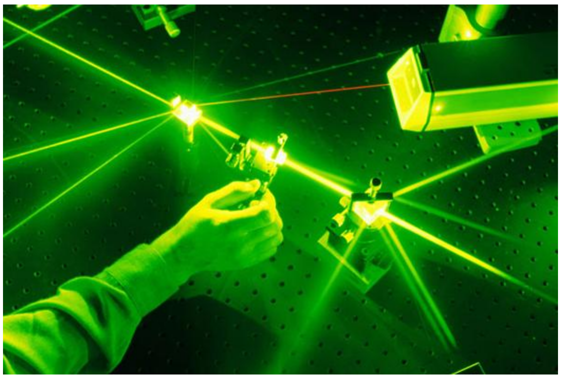
Focusing Light with Different Lenses #shorts
https://www.youtube.com/shorts/OUNP6gekWSQ

Complete lesson

Class 1 - Postulates and Rules in Ray Optics https://youtu.be/tfwDtM38wcs
Class 2 – Mirrors https://youtu.be/FZGNJsWOXFg
Class 3 - Planar Boundaries, Refraction, Reflection https://youtu.be/6tLYm8VreYI
Class 4 - Spherical Boundaries and Lenses https://youtu.be/wL3786py_Nw

PRELUDE TO GEOMETRICAL OPTICS

Our ability to see the world around us, from the shape of distant mountains to the clarity of a printed page, is thanks to the principles of geometrical optics. We have seen that visible light is an electromagnetic wave; however, its wave nature becomes evident only when light interacts with objects with dimensions comparable to the wavelength (about 500 nm for visible light). Therefore, the laws of geometric optics only apply to light interacting with objects much larger than the wavelength of the light. This branch of optics explains how light interacts with various surfaces and how we perceive images formed by mirrors, lenses, and other optical elements. From the lenses in our glasses to the cameras in our phones, the applications of geometrical optics are vast and critical to modern technology



In this lesson, we will explore the fundamental concepts of geometrical optics, including the behavior of light rays, reflection, refraction, and how these principles are used to form images. We'll also look at how mirrors and lenses are designed and applied in optical instruments, from simple magnifying glasses to complex telescopes. Understanding geometrical optics not only deepens our knowledge of vision and light but also opens the door to many technological innovations.

CHAPTER 34 : Fundamental online activities:

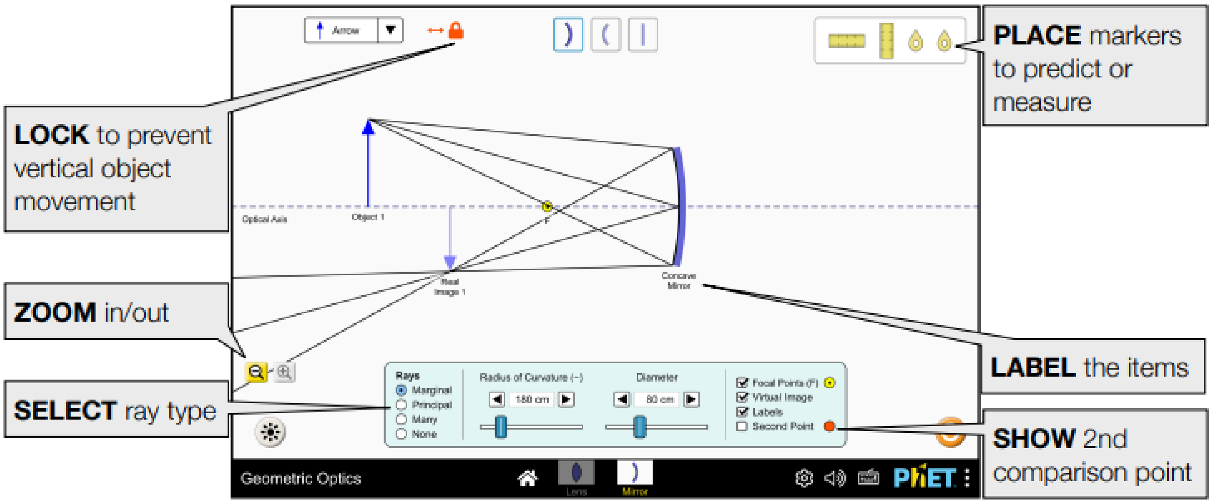
📐 Activity 1: Curved Mirror Simulation

Goal: Understand the nature of images formed by curved mirrors and the ray diagrams that be used to locate images.

- Open the simulation by clicking on the link: https://phet.colorado.edu/sims/html/geometric-optics/latest/geometric-optics_all.html and select : **Mirror**

Mirror Screen

Explore spherical and flat mirrors. Adjust the radius of curvature and diameter of the mirror and observe the effects on the image position, magnification, and brightness.



Sign convention

We use a sign convention to measure distance and height:

In optics, we determine the sign of distances using **a sign convention**. Here's how it works:

1. **Choose a Reference Point**: Typically, the optical center of the lens or of the mirror is chosen as the origin (c) of the optical axis.
2. **Direction of Light**: Light is assumed to travel from left to right.
3. **Distances** are typically measured **from the object or image to the center of the mirror or lens**
4. **Sign Convention for object (p) or image (i)**:
    1. Distances are **positive** if measured in the **same direction** as light travel.
    2. Distances are **negative** if measured in the **opposite direction** as light travel.
5. At contrary **Focal Length (*f*)** is measured from the optical center of the lens or the pole of the mirror to the focal point. The sign of ***f*** **depends on the type of lens or mirror**: **Positive** ***f*** indicates a **converging lens or concave mirror,** and **negative** ***f*** indicates a **diverging lens or convex mirror**.

6. Height can be positive or negative according to the central axis.

1) Focal point

- Make sure the boxes for 'Focal Points', 'Virtual Image', and 'Labels' toward the bottom right are all checked.
- Choose either 'Concave' or 'Convex' depending on the chart.
- The distance from the focal point ('F') to the front of the mirror is called the '**Focal Length**'. Don't worry about the location of the object for this part.
- What happens to the distance of the focal length from the mirror as we increase the diameter (size) of the **concave or convexe** mirror?
- Now set the diameter to **90 cm**. Choose either 'Concave' or 'Convex' depending on the chart. Change the radius of curvature to the given values on the table. Using the horizontal ruler from the top right of the page, measure the Focal Length. Again, don't worry about the location of the object for this part.

Type of Mirror	**Radius of Curvature (cm)**	**Focal Length (cm)**		**Type of Mirror**	**Radius of Curvature (cm)**	**Focal Length (cm)**
Concave	150			Convexe	150	
Concave	175			Convexe	175	
Concave	200			Convexe	200	
Concave	225			Convexe	225	
Concave	250			Convexe	250	
Concave	275			Convexe	275	
Concave	300			Convexe	300	

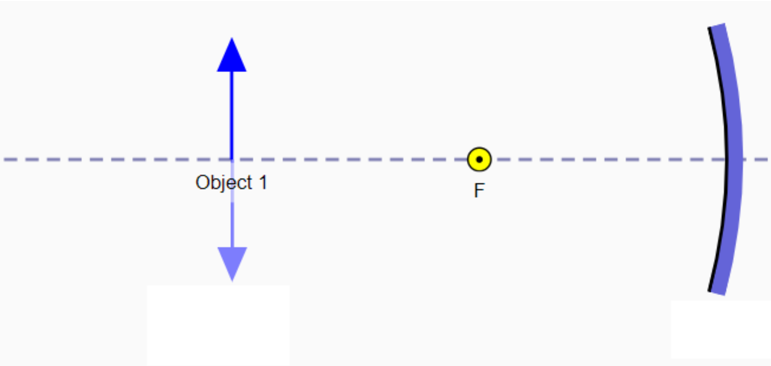
- What appears to be the relationship between the focal length and radius of curvature?
- Does it depend on whether the lens is concave or convex?

1) Describing Images

- Set up the simulation:
  Choose the ARROW
  Turn on PRINCIPAL Rays
  Set the Radius of Curvature to 150 cm
  Pull out the rulers
  Turn on Focus Points, Virtual Image
- What type of mirror (planar, concave, convexe) is shown in the simulation to start? How do you know?
- Move the object closer to the focal point but don't go past it. Observe the general image characteristics and how they change as you move the object closer.
- Move the object past the focus and closer to the mirror. Observe the general image characteristics and how they change as you move the object closer

2) Drawing and Measuring:

- Move the object back until you see the image directly below the object. Draw TWO rays (with a ruler) that help you locate the image. Measure and complete the chart:



Object-Mirror distance: p=________

Focus-Mirror distance: f=_________

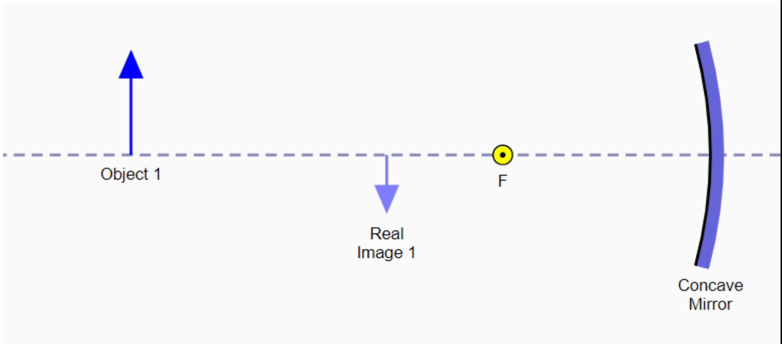
Image-Mirror distance: i=_________

Object Height: ___________________

Image Height:____________________

Does the image of object 1 appear **IN FRONT OF** or **BEHIND** the mirror? Is the image **REAL** or **VIRTUAL**? Is it **UPRIGHT** or **UPSIDE DOWN**?

- Move the object to the approximate locations as shown. Draw TWO rays (with a ruler) that help you locate the image. Measure and complete the chart:



Object-Mirror distance: p=________

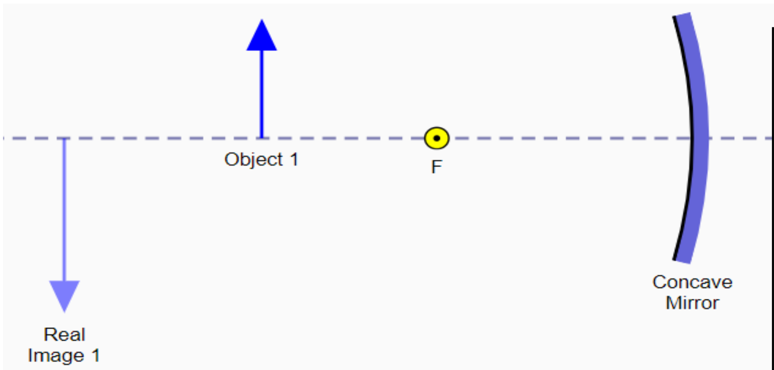
Focus-Mirror distance: f=_________

Image-Mirror distance: i=_________

Object Height: ___________________

Image Height:____________________

Does the image of object 1 appear **IN FRONT OF** or **BEHIND** the mirror? Is the image **REAL** or **VIRTUAL**? Is it **UPRIGHT** or **UPSIDE DOWN**?



Object-Mirror distance: p=________

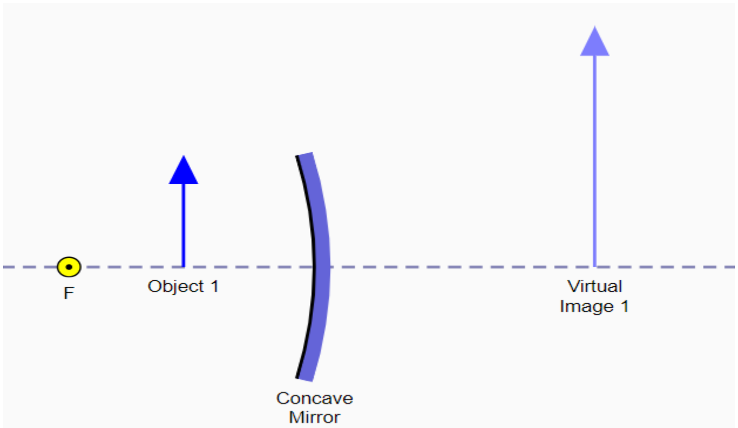
Focus-Mirror distance: f=_________

Image-Mirror distance: i=_________

Object Height: ___________________

Image Height:____________________

Does the image of object 1 appear **IN FRONT OF** or **BEHIND** the mirror? Is the image **REAL** or **VIRTUAL**? Is it **UPRIGHT** or **UPSIDE DOWN**?



Object-Mirror distance: p=________

Focus-Mirror distance: f=_________

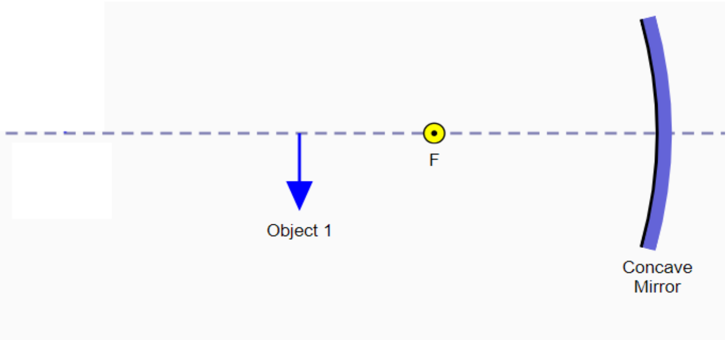
Image-Mirror distance: i=_________

Object Height: ___________________

Image Height:____________________

Does the image of object 1 appear **IN FRONT OF** or **BEHIND** the mirror? Is the image **REAL** or

- Drag the arrow until it appears as shown and is located 120 cm from the mirror (use the ruler to measure!). Locate the image using 2 rays and confirm your diagram with the simulation



What type of image is this? (real or virtual). How do you know?

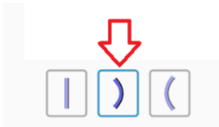
Is this image UPRIGHT or INVERTED? How do you know?

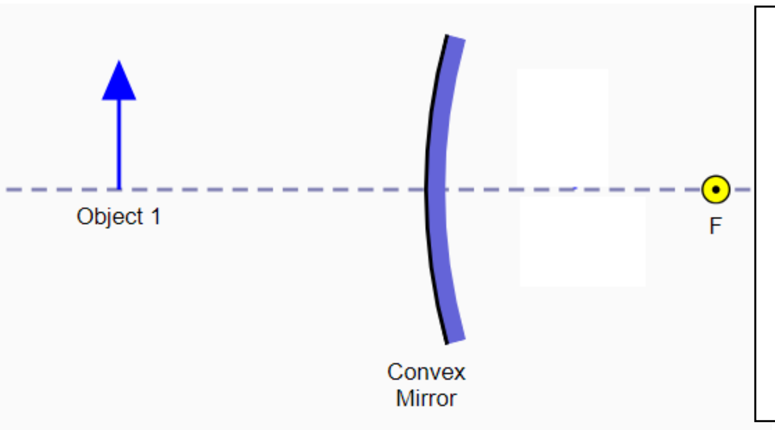
- In all cases, through which point do rays parallel to the central axis always pass?

- Can you identify other specific rays that consistently follow the same behavior??

3) Convex Mirror Exploration

- Switch to the Convex Mirror as shown. Place the object 80.0 cm from the mirror. Draw TWO rays to locate the image and complete the chart.





Object-Mirror distance: p=_________

Focus-Mirror distance: f=__________

Image-Mirror distance: i=__________

Object Height: ____________________

Image Height:_____________________

Does the image of object 1 appear **IN FRONT OF** or **BEHIND** the mirror? Is the image **REAL** or **VIRTUAL**? Is it **UPRIGHT** or **UPSIDE DOWN**?

4) Generalization for spherical mirrors

Record all your measurements in the chart below. Do they adhere to the generalized mirror formula: $\frac{1}{f} = \frac{1}{p} + \frac{1}{i}$ and magnification formula $m = \frac{Image\ height}{Object\ height} = -\frac{i}{p}$?

	$\frac{Image\ height}{Object\ height}$	$-\frac{i}{p}$	$\frac{1}{f}$	$\frac{1}{p} + \frac{1}{i}$
Convex case 1				
Convex case 2				
Convex case 3				
Convex case 4				
Convex case 5				
Concave case 5				

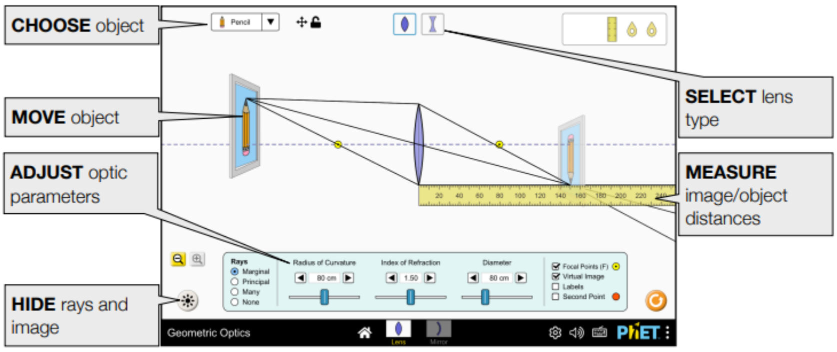
Activity 2: Thin lenses

Goal: Understand and observe how changing the lens (radius, index and diameter) effects where the image appears and how it looks (magnification, brightness and inversion)

- Go to the [Geometric Optics] simulation page from PhET Interactive Simulations

Lens Screen

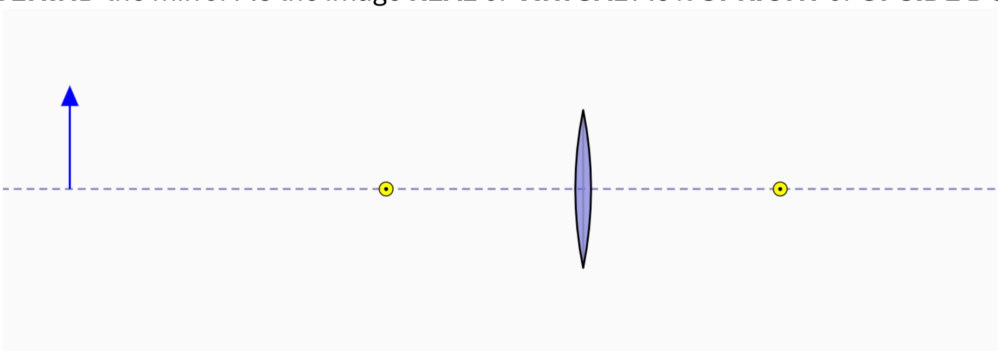
Determine how radius of curvature and index of refraction affect the focal length of a lens. Create real and virtual images and experiment with a spotlight.



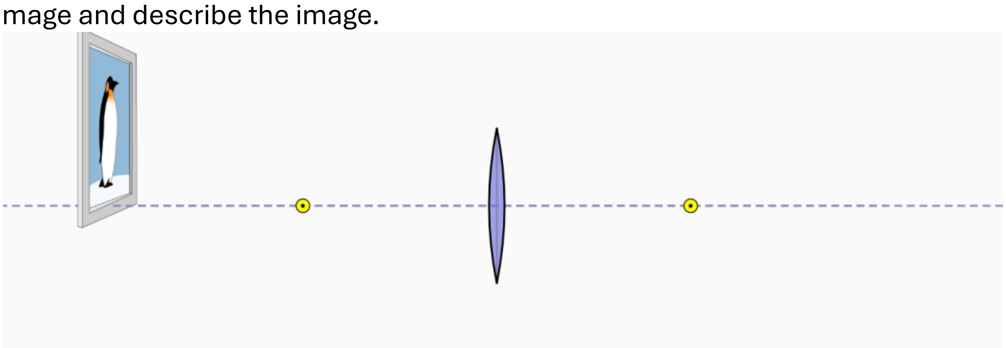
1) Converging lenses

- Choose **principal rays**
- Change the **radius of curvature** to 100 cm and keep **index of refraction** equal to 1.50 and **diameter** with 80 cm
- Choose **Ruler** to measure the distances. You may change the shape of the object you see in the simulation by available options on the left top corner of the page.

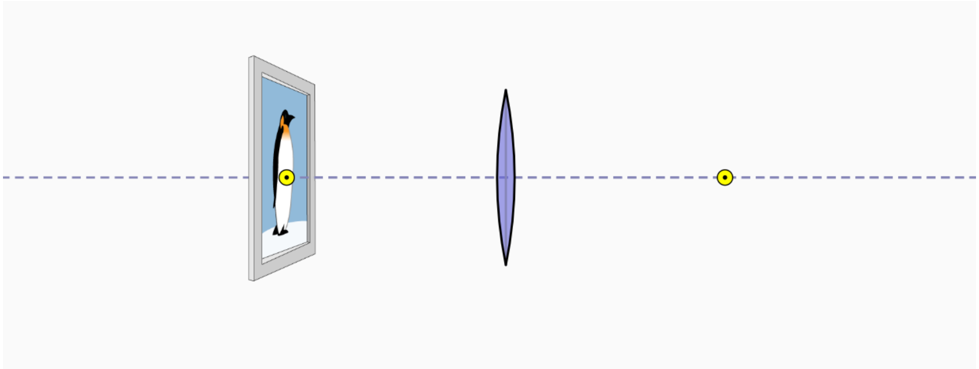
- Place the object **beyond 2F** and find the location of the image. Draw TWO rays to locate the image and describe the image. Does the image of the object appear **IN FRONT OF** or **BEHIND** the mirror? Is the image **REAL** or **VIRTUAL**? Is it **UPRIGHT** or **UPSIDE DOWN**



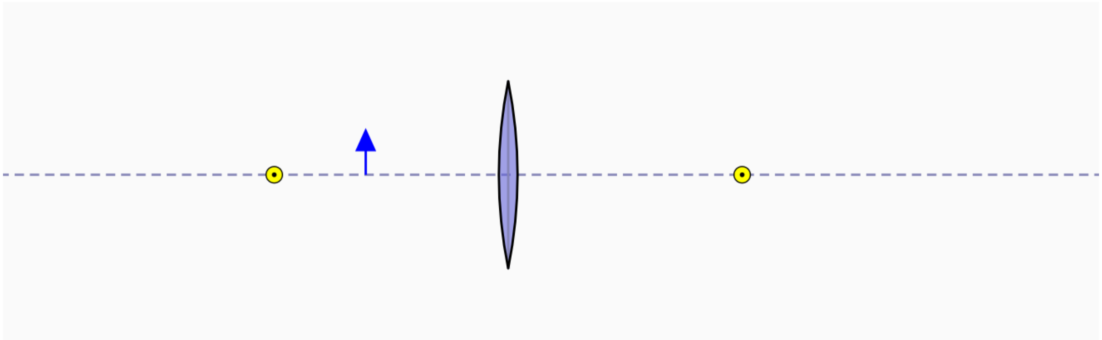
- Place the object **at 2F** and find the location of the image. Draw TWO rays to locate the image and describe the image.



- Place the object **at F**. Is it possible to locate the image?



Place the object **between F and the lens** (in focal length). Choose the **Virtual Image** in the simulation screen and Observe. Draw TWO rays to locate the image and describe the image.



- How can you change the focal length of the lens? In other words, what happens if you change the **refractive index/index of refraction** of the lens.

- What happens to the image when you change the **refractive index** of the lens?

- What happens to the image when you change the curvature radius of the lens?

- What happens if you change the **diameter** of the lens? In other words, how the image is impacted by changing the **diameter** of the lens?

2) Diverging lenses

- Do the same thing as before with a diverging lens

3) Focus point

- Choose **marginal rays** in the simulation screen, change the **curvature radius** to 50 cm and keep **refractive index** equal to 1.50 and **diameter** with 100 cm, like what you see in the figure below. Choose **Ruler** to measure the distances. You can have a **screen** by selecting light as an object in the simulation and you can drag it to different locations.

- The focal length is 50 cm, and the source of light is 120 cm away from the center of the lens. Where is the screen located to have a clear image of that?

CHAPTER 34: MCQ and exercices

34.1. Complete the sentences using your knowledge from the previous chapter.

The bending of light as it passes at an angle from one medium into another of different optical density is called _____________.

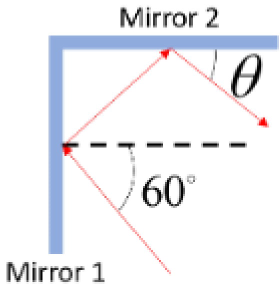
The ratio of the speed of light in a vacuum to its speed in a given substance is called __________.

When a ray of light passes at an angle from a medium of lesser to one of greater optical density, it bends ____________ from the normal.

The limiting angle of incidence in the denser medium resulting in angle of refraction of 90° is known as _____________.

34.2. Perpendicular mirrors.

Between the two mirrors, there is an angle of 90°, as the figure shows. Consider that on the Mirror 1 impinges a beam with an angle of 60° respect to the normal. What is the angle θ in which the beam reflected on the Mirror 2?



A) 15°
B) 30°
C) 45°
D) 60°

34.3. Image formed by plane Mirror is aways

A) Real and inverted
B) Virtual and erect
C) Real and erect
D) virtual and inverted

34.4. Virtual Images are

A) Always erect
B) magnified or diminished
C) can be obtained on screen
D) Can be seen by looking through the optical device
E) all the above
F) Non of above

34.5. Using convex mirror in the simulation tool, the focal length f is related to the radius of curvature r of the spherical convex mirror by

A) $f = +\frac{r}{2}$
B) $f = -r$
C) $= -\frac{r}{2}$
D) $= +r$

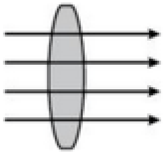
34.6. What is the nature of the image formed due to the concave mirror when an object is placed beyond center of curvature?

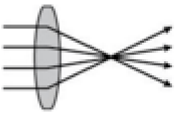
A) Real and inverted
B) Virtual and erect
C) Real and erect
D) None of above

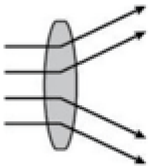
34.7. What happens if any light ray passes through the central axis of a lens?

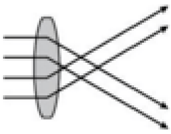
A) It changes direction
B) It is transmitted without any changing direction
C) It is completely reflected
D) t is refracted parallel to the central axis

34.8. Which figure represents the path light takes through a converging lens?

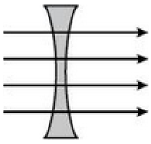

A)

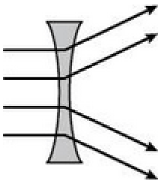

B)

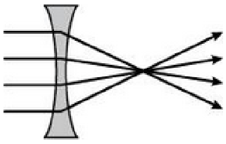

C)

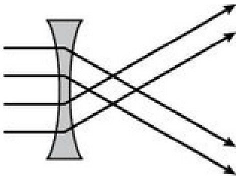

D)

34.9. Which lens represents the path light takes through a diverging lens?


A)


B)


C)

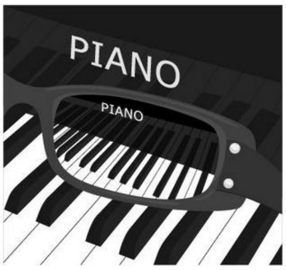

D)

34.10. A magnifying glass is a

A) Convex mirror
B) Concave lens
C) Convex lens
D) More than one of above

34.11. What type of lens creates the image seen in the eyeglasses?

A) Convex
B) Concave
C) Plane
D) None of above



34.12. Classify the image produced by the projector lens.

A) Real
B) Virtual
C) larger than original
D) smaller than original

34.13. An object is placed 20 cm from a convex lens of focal length 15 cm. What is the image distance and the nature of the image?

A) Image not formed
B) 30 cm, real image
C) 15 cm, virtual image
D) 60 cm, real image

34.14. What is meant by negative magnification ? What is meant by a magnification that is less than 1 in magnitude?

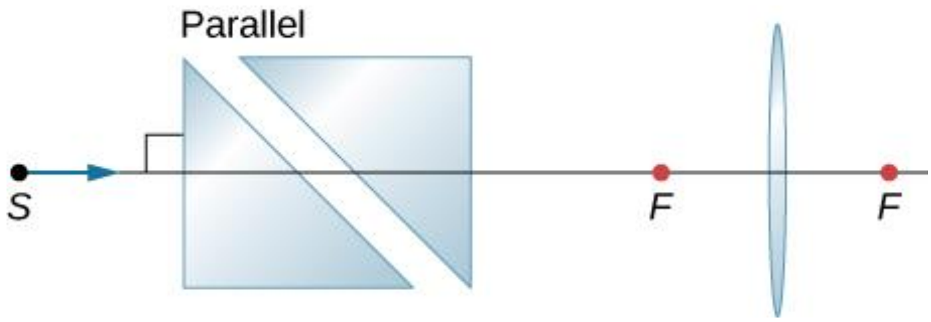
34.15. Keratometer

A keratometer is a device used to measure the curvature of the cornea of the eye, particularly for fitting contact lenses. Light is reflected from the cornea, which acts like a convex mirror, and the keratometer measures the magnification of the image. The smaller the magnification, the smaller the radius of curvature of the cornea. If the light source is $12\,cm$ from the cornea and the image magnification is 0.032, what is the radius of curvature of the cornea?

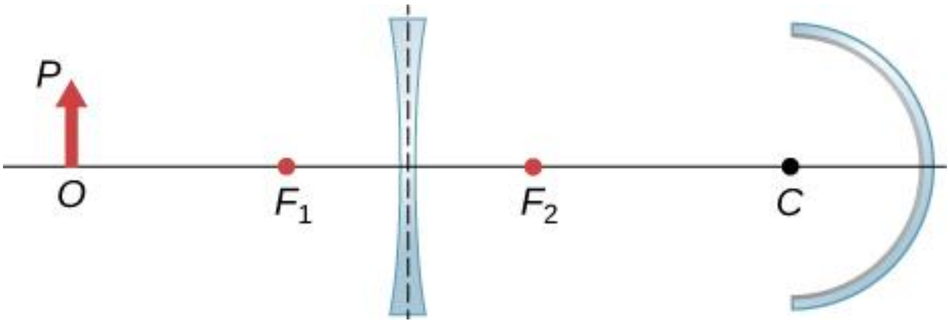
> ***Strategy :*** *If you find the focal length of the convex mirror formed by the cornea, then you know its radius of curvature (it's twice the focal length). The object distance is* $p = 12cm$ *and the magnification is* $m = 0.032$*. First find the image distance* i *and then solve for the focal length* f *from the formula given in activity 1.4*

34.16. Ray tracing (challenging exercise 💪)

1) Trace to find how a horizontal ray from S comes out. Use $n_{prism} = 1.33$ for the prism material. The two prisms have their bases parallel to each other at an angle of 45 degrees to the horizontal. To the right of this is a bi-convex lens.



2) Draw rays to figure out the intermediate (after the lens) and the final image (after the spherical mirror) of the arrow OP



CHAPTERS 35:

INTERFERENCES

Videos links:

Interference, Reflection, and Diffraction
https://www.youtube.com/watch?v=eW5VGGJuWtQ

What Color Is A Mirror?
https://youtu.be/-yrZpTHBEss?si=RdckA0HUsYCVYMf9

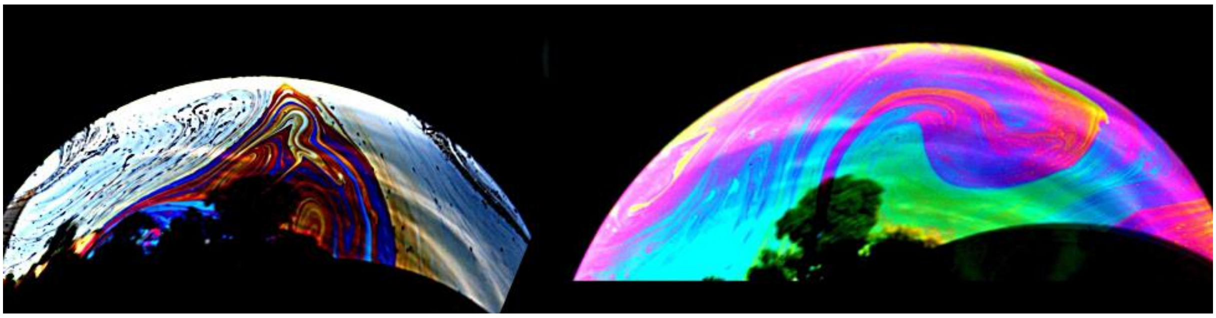
All Optics is Scattering
https://www.youtube.com/watch?v=mv_90PC5XKw

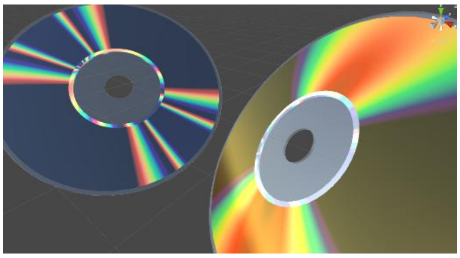
How do we KNOW light is a wave?
https://www.youtube.com/watch?v=aQ4KzsoCfYg

Diffraction interference patterns with phasor diagrams
https://www.youtube.com/watch?v=NazBRcMDOOo

PRELUDE TO INTERFERENCES

The colorful patterns we see in soap bubbles, the iridescence of a peacock's feathers, and the vivid colors in a CD or DVD are all examples of the fascinating phenomena of diffraction and interference. These effects occur when light waves interact with obstacles or openings and demonstrate the wave nature of light and cannot be fully explained by geometric optics alone. Diffraction and interference are not just beautiful demonstrations of physics, but also crucial in technologies like holography, optical microscopes, and lasers.





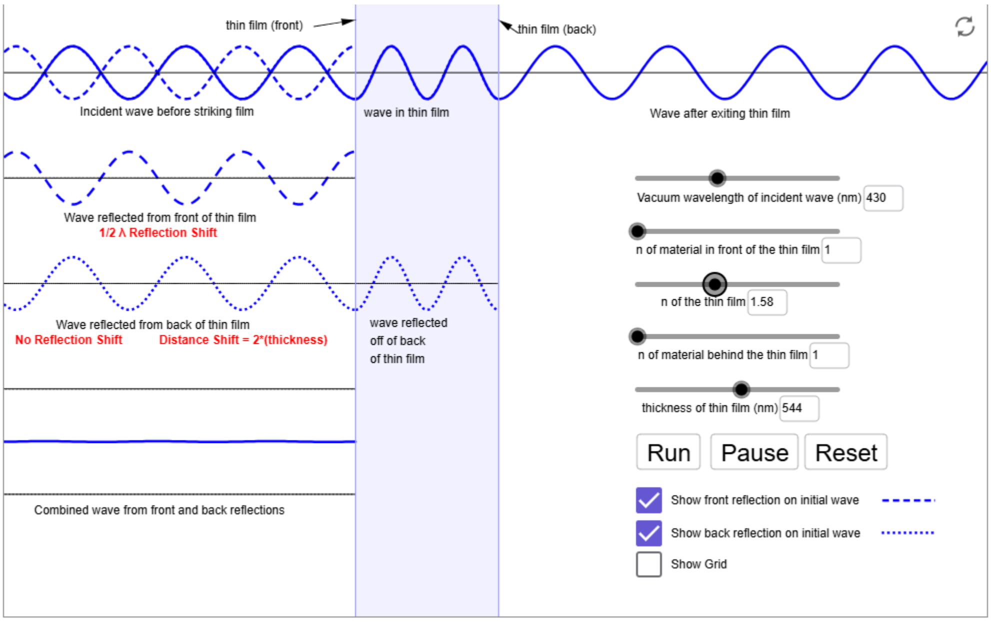
In this lesson, we will explore the principles of diffraction and interference, focusing on how light behaves when it encounters slits, edges, or other barriers. We'll examine the conditions under which these effects occur, and how they give rise to patterns of constructive and destructive interference. Additionally, we'll look at how diffraction and interference are applied in practical devices and experiments, and how these phenomena deepen our understanding of the wave-like behavior of light.

CHAPTER 35: Fundamental online activities

📐 Activity 1: Thin Film interference

Goal: Understand how light interacts with thin films and how interference patterns arise depending on film thickness and wavelength.

Go to: https://ophysics.com/l6.html



1) **Observe the Initial Setup**
    - Open the simulation: oPhysics Thin Film Interference.
    - Identify the incident light, the film, the reflected rays and the combined wave from front and back reflections of the thin film (interference pattern).

2) **Varying Film Thickness**
    - Adjust the film thickness (t) slider.
    - Observe how the combined wave from front and back reflections changes (we will call it the interference.
    - At what thickness do you observe constructive and destructive interference for a given wavelength?

3) **Changing the Wavelength**
    - Change the wavelength of incident light using the slider.
    - Observe the effect on the interference pattern.
    - How does the color of reflected light change as you increase/decrease the wavelength?

4) **Effect of Refractive Index**
    - Modify the refractive index of the film (n_2).
    - Observe how this changes the interference.
    - What happens when n_2 is greater than n_1? What about when it is smaller?

5) **Problem Statement:**

A thin film of **soap ($n_2 = 1.33$)** is floating in the air ($n_{air} = 1.00$). A light source emits **green light** with a wavelength of **550 nm in air**.

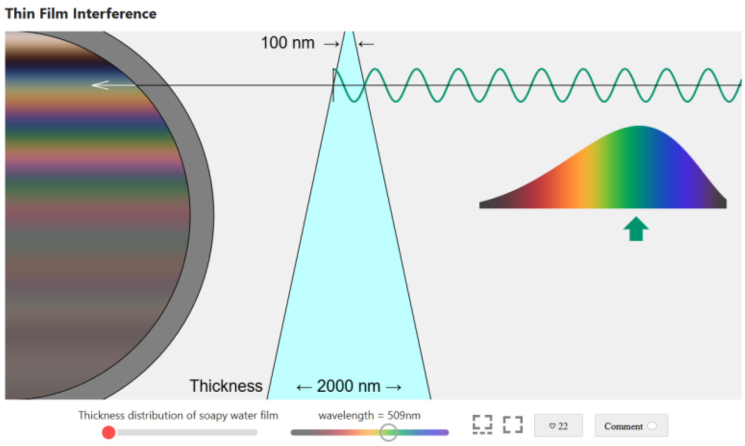
- Find the minimum thickness of the soap film that will create destructive interference in reflected light.
- Find the next possible thickness that also leads to destructive interference.
- Does your calculation matches with the theoretical value of the light intensity of the interference pattern *given by :*

$$\text{Bright condition } 2nt = (m + 12)\lambda$$
$$\text{Dark conditions } 2nt = m\lambda$$

where n: Refractive index of soap t: film thickness (nm) λ: Wavelength of light (nm)
and m = 0, 1, 2... (for two consecutive bright or dark condition: m=1)

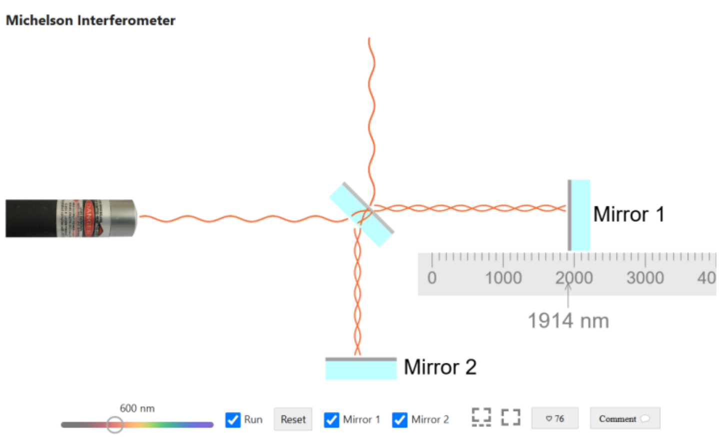
📐 Activity 2: Thin Film interference

Using the simulation tool at https://javalab.org/en/thin_film_interference_en/, how can you interpret the color patterns that appear on a thin oil film floating on water ?



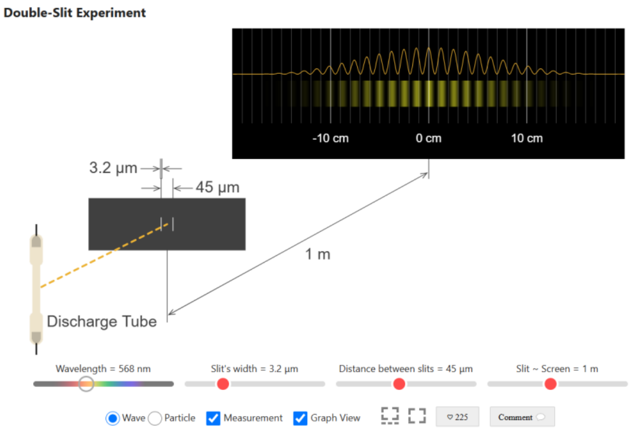
📐 Activity 3: Interferometer

Play with the simulation tool https://javalab.org/en/michelson_interferometer_en/
to figure out how an interferometer works to measure small distance variation.



📐 Activity 4: Double slit experiment

Play with https://javalab.org/en/double_slit_en/, select graph view to independently explore and understand the phenomena of interference and diffraction using a double-slit experiment simulation.



For a given wavelength and distance to the screen.

1) Exploring Interference:

- Observe how the bright and dark fringes change as you adjust the slit separation.
- Complete the chart using the symbols ↗ (for increase), ↘ (for decrease), or = (for staying the same):

	Distance between bright fringes
If λ ↗	
If distance d between slits ↗	
If slit's width a ↗	
If distance D to the screen ↗	

- Adjust your setup $(\lambda, a, d \; or \; D)$ in order to achieve approximately 2.5 cm between two consecutive bright fringes. This distance, called L, is the same as the distance from the central axis to the first bright fringe.
- The path of the two waves from the slit to the screen is given by arctan $\left(\frac{L}{D}\right)$. This path creates a small angle θθ from the central axis, which can be approximated as $\theta \approx \frac{L}{D}$ for small angles.
- Using your values of $\lambda, d \; and \; D$ for $L = 2.5cm$, compute the following chart:

L/D	$\sin\theta$	$d \sin\theta$ (m)	λ (m)	Are the last two columns equal?
				Yes / No

- You can also explore a 3D version of the double-slit experiment to understand how interference arises from phase differences caused by the varying paths of the two rays: https://www.geogebra.org/m/FDcPqfBQ

2) Exploring Diffraction:

- Adjust the slit width (width of each individual slit) while keeping the slit separation constant.
- Observe how the spread of the pattern changes as you adjust the slit width. This phenomena will be discussed in the next chapter.

CHAPTER 35 : MCQ and exercices

35.1. Diffraction and Interference of light are evidence that ___

A) the speed of light is very large

B) light is a transverse wave

C) light is electromagnetic in character

D) light is a wave phenomenon

35.2. What is a general definition of wave interference?

A) When a wave bounces off an object

B) When more than one wave meet and interact in the same medium

C) When a wave bends around a corner

D) When a wave creates static

35.3. If two light waves travel through different media with different refractive indices, what will happen to their interference pattern?

A) It will remain unchanged

B) It will become brighter

C) It will shift due to phase differences

D) It will disappear completely

35.4. What is a phase difference?

A) The difference in the speed of two waves

B) The difference in the wavelengths of two waves

C) The difference in the positions of two waves in their cycle

D) The difference in the amplitudes of two waves

35.5. Which of the following is NOT a factor that can cause a phase difference between two waves?

A) Different path lengths

B) Different speeds in various media

C) Different frequencies

D) Different amplitudes

35.6. When two light waves interfere destructively, their phase difference is:

A) 0 degrees

B) 90 degrees

C) 180 degrees

D) 270 degrees

35.7. In thin-film interference, what causes the colorful patterns observed?

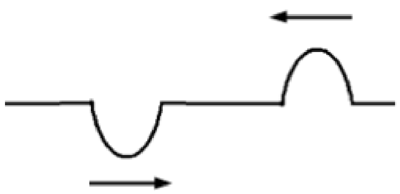
A) Reflection of light from the surface

B) Phase differences due to path length differences in the film

C) Absorption of light by the film

D) Scattering of light by the film

35.7. What will be the result after these two waves overlap?



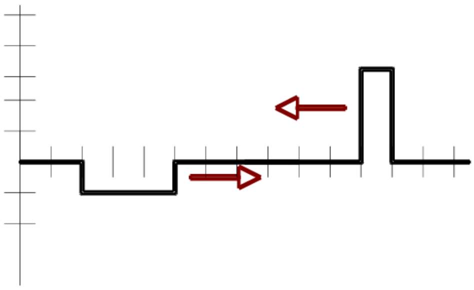
A) A taller wave

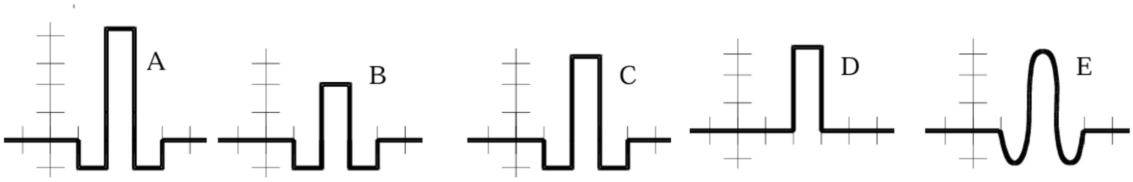
B) A shorter wave

C) A wave with no amplitude

D) 3 waves

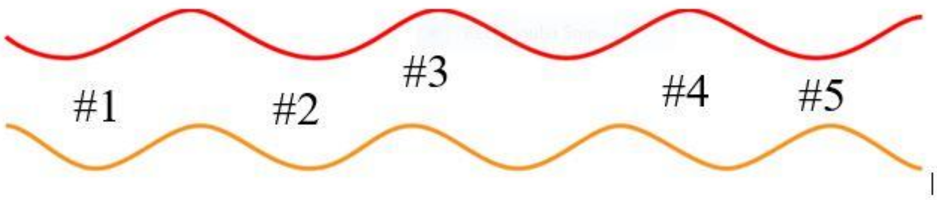
35.8. The pulse on the left is moving right, the pulse on the right is moving left. What do you see when the pulses overlap?





35.9. Look at the diagram.

1) At which positions will the overlapping waves have the most constructive interference?



A) Positions #1 & #5
B) Positions #2 & #3
C) Positions #3 & #4
D) Positions #4 & #5

2) At which positions will the overlapping waves have the most destructive interference?

A) Positions #1 & #5
B) Positions #2 & #3
C) Positions #3 & #4
D) Positions #4 & #5

35.10. Why is monochromatic light used in the double slit experiment?

35.11. Young's double-slit experiment breaks a single light beam into two sources. Would the same pattern be obtained for two independent sources of light, such as the headlights of a distant car? Explain.

35.12. Finding a Wavelength from an Interference Pattern

Suppose you pass light from a He-Ne laser through two slits separated by 0.0100 mm and find that the third bright line on a screen is formed at an angle of 10.95° relative to the incident beam. What is the wavelength of the light?

> ***Strategy*** *: The third bright line is due to third-order constructive interference, which means that m=3. We are given d=0.0100mm and θ=10.95°. The wavelength can thus be found using* $m\lambda = d \sin\theta$ *for constructive interference.*

35.13. Calculating the Highest Order Possible

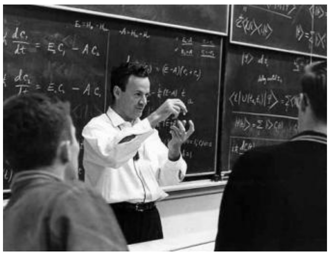
Interference patterns do not have an infinite number of lines, since there is a limit to how big m can be. What is the highest-order constructive interference possible with the system described in the preceding example?

> ***Strategy*** *: Equation* $m\lambda = d\ sin\ \theta$ *describes constructive interference from two slits. For fixed values of* d *and* λ*, the larger* m *is, the larger* $sin\theta$ *is. However, the maximum value that* $sin\theta$ *can have is 1, for an angle of 90°. (Larger angles imply that light goes backward and does not reach the screen at all.) Let us find what value of* m *corresponds to this maximum Diffraction angle.*

35.14. First and second order

In the system used in the preceding examples, at what angles are the first and the second bright Fringes formed?

"No one has ever been able to define the difference between interference and diffraction in a really satisfactory way. It is just a question of usage, and there is no specific, physically important difference between them. The best we can do, roughly speaking, is to say that when there are only a few sources, say ***two sources, interfering, then the result is usually called interference****, but if there is a very* ***large number of sources, the word diffraction is more often used****."*



Richard Feynman, The Feynman Lectures on Physics

Chapters 36:

Diffraction

Videos links:

Light Is Waves: Crash Course Physics #39
https://www.youtube.com/watch?v=IRBfpBPELmE

Spectra Interference: Crash Course Physics #40
https://www.youtube.com/watch?v=-ob7foUzXaY

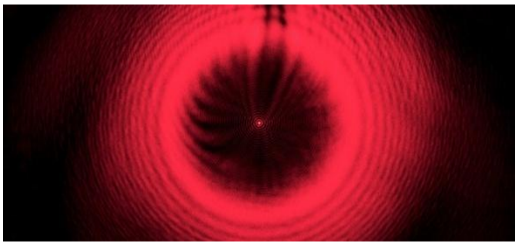
Diffraction and interference of light
https://www.youtube.com/watch?v=VmN3i4HW5l0

Prelude to Diffraction

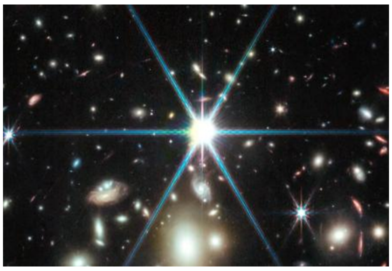
Imagine directing a monochromatic light beam through a narrow slit, slightly wider than the light's wavelength. Instead of casting a simple shadow of the slit on a screen, you will observe an interference pattern, even with just one slit.

In the chapter on interference, we learned that interference typically requires two wave sources. So, how can an interference pattern emerge with only one slit? In "The Nature of Light," we discovered that, according to Huygens's principle, a wavefront can be thought of as an infinite number of point sources. Thus, light passing through a slit behaves not as a single wave but as countless point sources, which can interfere with each other, creating an interference pattern without needing a second slit. This phenomenon is known as diffraction.

Another perspective is to recognize that a slit has a small but finite width. Previously, we treated slits as having positions but no size. However, when slits have a finite width, each point along the opening acts as a point source of light, aligning with Huygens's principle. Since real-world optical instruments must have finite apertures to allow light in, diffraction significantly influences how we interpret their output. For instance, diffraction limits our ability to resolve images or objects, a topic we will explore further in this chapter.



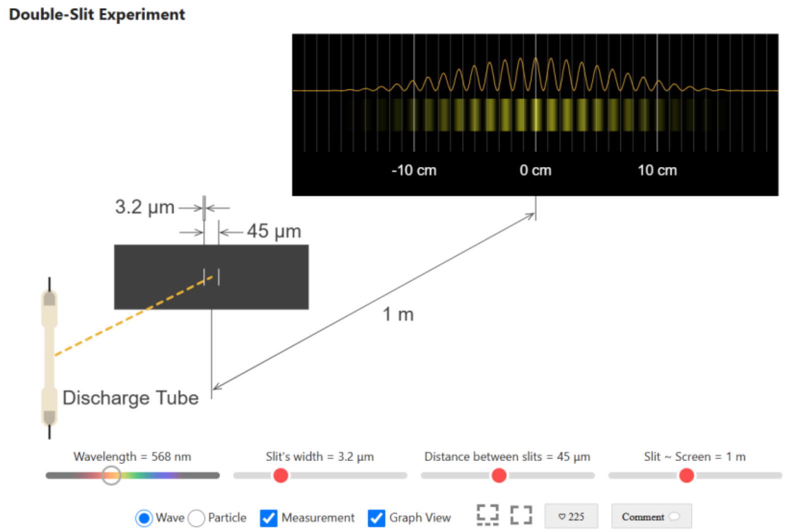
A laser-illuminated steel ball bearing doesn't cast a sharp shadow but instead displays diffraction fringes and a central bright spot, known as Poisson's spot. Augustin-Jean Fresnel first predicted this effect due to light wave diffraction, while Siméon-Denis Poisson initially disputed it based on ray optics. (Image credit: Harvard Natural Science Lecture Demonstrations)



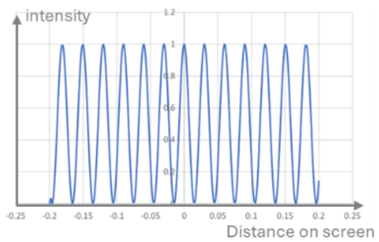
The James Webb Space Telescope's images of stars show a central bright spot with six diffraction spikes, forming a cross. This pattern is caused by the telescope's hexagonal mirror segments and the three support struts for the secondary mirror, which diffract the starlight.

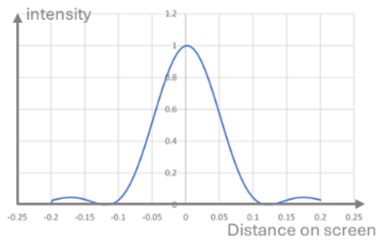
📐 Activity 1: Diffraction and interference

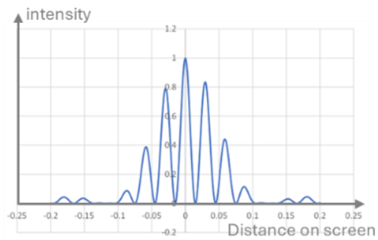
Play with https://javalab.org/en/double_slit_en/ to figure out the link between the aperture of the slits and diffraction.



Link each graph to the correct wave phenomenon:







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•   •   •

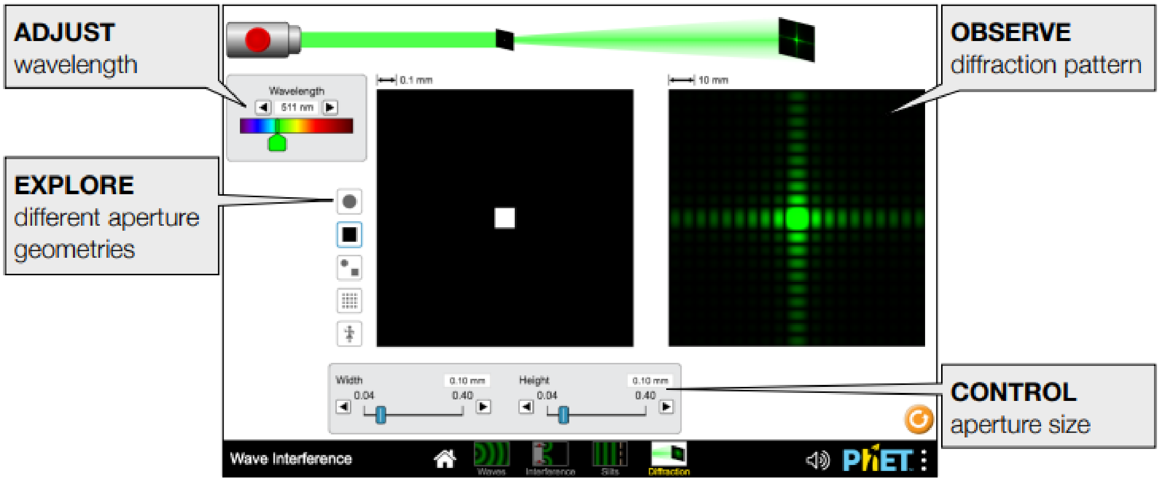
Diffraction + interference pattern   ***Interference pattern***   ***Diffraction pattern***

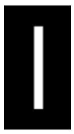
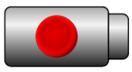
📐 Activity 2: Diffraction

Go to: https://phet.colorado.edu/sims/html/wave-interference/latest/wave-interference_all.html, choose **Diffraction** and et familiar with all the controls, make changes, interact with the simulation

Diffraction Screen

Experiment with diffraction through elliptical, rectangular, or irregular apertures. Adjust the aperture dimensions and/or wavelength to discover the effect on the diffraction pattern.



1) Now that you are familiar with the simulation, select the box  ; adjust the width and height so you get a tall, narrow opening 
2) Select a wavelength near one end of the color spectrum – you choose and then turn on the light  and observe the diffraction pattern that appears.
3) How is the diffraction pattern oriented, relative to the opening?
4) Now make the opening short and wide and observe the diffraction pattern that appears.
5) Max out the width and height of the opening, then Minimize the width and height of the opening and comment on the difference of the diffraction pattern that appears.
6) Now, change the wavelength from the two sides of the spectrum. What observations can you make about the diffraction pattern that appears.
7) Switch to a circular aperture and compare the pattern with that of the square aperture.
8) Identify the central maximum and secondary maxima for each aperture shape.
9) Use a periodic arrangement of circular apertures and observe the diffraction pattern produced by the periodic structure.
10) What features of the diffraction pattern are affected by the size of the individual apertures?
11) How does the lattice spacing of the periodic arrangement affect the diffraction pattern, and in what ways?

📐 **Activity 2: Measuring the Size of a Hair Using Laser Diffraction**

Goal: Measure the diameter of a human hair using the diffraction pattern created by a laser pointer.

Materials Needed:

- A laser pointer (ensure it is a low-power, safe-to-use laser)
- A single strand of hair
- A ruler or measuring tape
- A dark room or a box to create a dark environment and a white screen or sheet of paper to project the diffraction pattern

Safety Precautions:

- Never look directly into the laser beam.
- Use a low-power laser pointer (less than 1 mW) to avoid eye injury.
- Handle the laser pointer responsibly and keep it out of reach of young children.

Procedure:

1) **Prepare the Hair:**

   - Secure a single strand of hair vertically using tape or a clamp, ensuring it is taut and straight.
   - Position the hair in the path of the laser beam, approximately halfway between the laser pointer and the screen.

2) **Observe the Diffraction Pattern:**

   - Observe the diffraction pattern that appears on the screen. You should see a central bright spot with alternating bright and dark fringes on either side.

3) **Measure the Diffraction Pattern:**

   - Measure the distance from the central bright spot to the first dark fringe on either side. This distance is the fringe spacing (L).
   - Measure the distance from the hair to the screen (D).

4) **Calculate the Hair Diameter:**

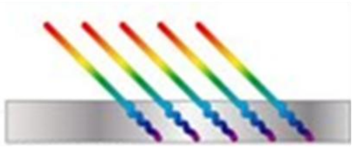
   - Use the formula for single-slit diffraction: $a\,sin(\theta) = m\lambda,$ where a is the hair diameter, θ is the angle of diffraction. The order of the fringe, m, indicates the number of wavelengths in the path difference, with $m = 1$ for the first dark fringe, $m = 2$ for two consecutive bright fringes, and so on. and λ is the wavelength of the laser light (typically around 650 nm for a red laser).
   - Approximate θ using $\theta \approx L/D$ for small angles.
   - Rearrange the formula to solve for the hair diameter a and compare your result to average a value found on Internet.

CHAPTER 36 : MCQ and exercices

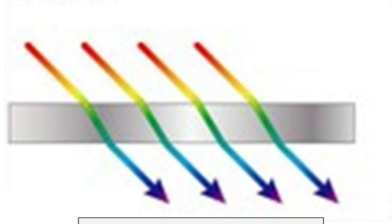
36.1. Use the following terms to describe the different phenomena:

Reflection - Refraction - Scattering - Diffraction - Absorption - Dispersion

A.

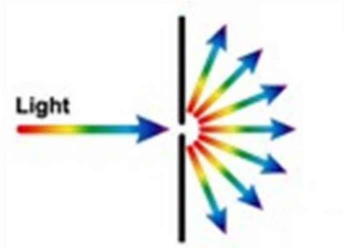


B.

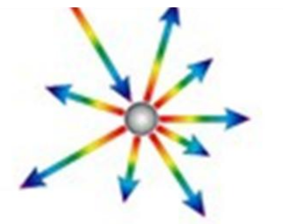


C.

D.



E.



F.

35.2. How does diffraction work ?

A) Is a beam of light stopping at a wall

B) It bounces off of light

C) it goes through water and air

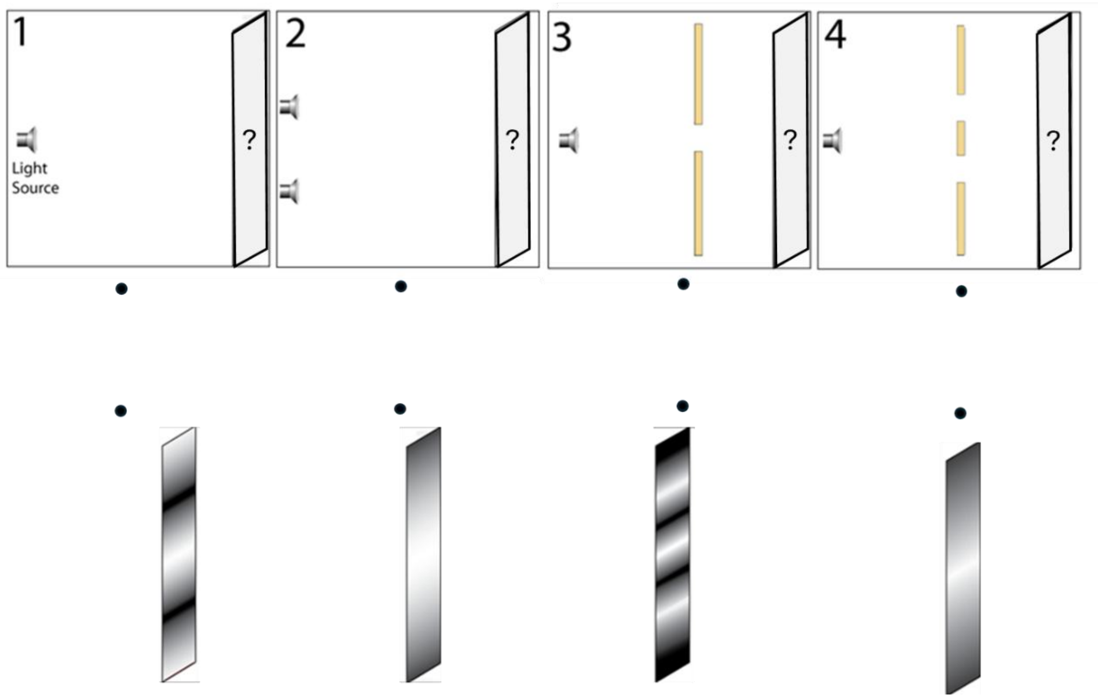
D) is the bending of light as it passes around the edge of an object

35.3. Sound waves cannot be diffracted.

A) True B) False

35.4. Wave interference

Consider the four pictures shown below, showing pure yellow light shining toward a screen. In 3 and 4, there is a solid wall between the light and screen, with one or two slits cut in it to let the light through. Link experiment with what you will observe as intensity on a screen.



35.5. Calculating Single-Slit Diffraction

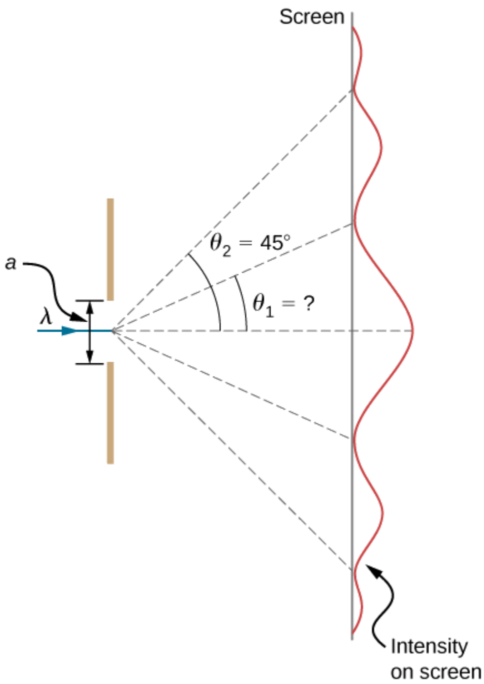
Visible light of wavelength 550 nm falls on a single slit and produces it second diffraction minimum at an angle of 45.0° relative to the incident direction of the light, as in the figure:

1) What is the width of the slit?

2) At what angle is the first minimum produced?

Strategy : *From the given information, and assuming the screen is far away from the slit, we can use the equation* $a\ sin\theta = m\lambda$ *first to find a, and again to find the angle for the first minimum* θ_1.

3) Suppose the slit width in is increased to $1.8 \times 10^{-6}m$. What are the new angular positions for the first, second, and third minima? Would a fourth minimum exist?



35.6. What changes are observed in a diffraction pattern if the whole apparatus is immersed in water?

A) The Wavelength of light increases

B) Width of central maximum increases

C) Width of central maximum decreases

D) Frequency of light decreases

35.7. How shall a diffraction pattern change when white light is used instead of a monochromatic light?

A) The pattern will no longer be visible

B) The shape of the pattern will change from hyperbolic to circular

C) The colored pattern will be observed with a white bright fringe at the center

D) The bright and dark fringes will change position

35.8. What is resolution in optics?

A) A firm decision to do or not to do something.

B) The ability to see properly

C) Producing two separate distinguishabe images from two separate objects

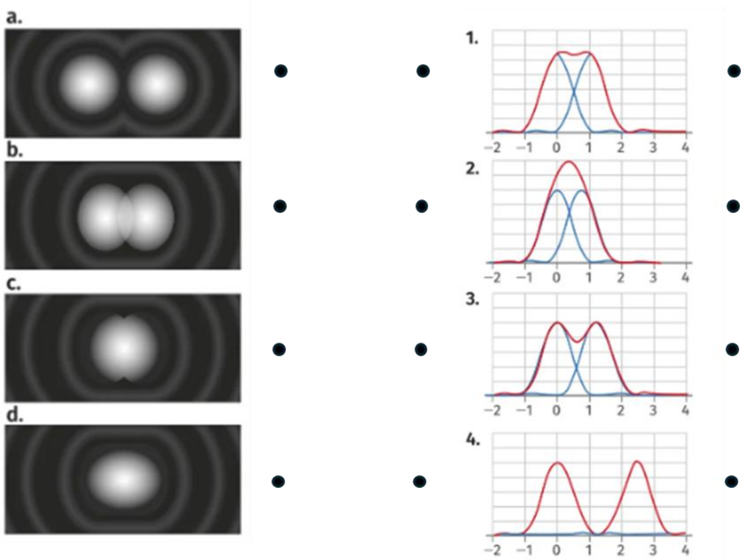
D) the quality of being determined or resolute

35.9. Diffraction and Resolution Criteria

Diffraction limits the resolving power of optical instruments such as telescopes. The image of a point is not a point but a diffraction pattern called an Airy disk. Different criteria exist to determine whether two points are resolved by an optical instrument:

- According to the **Schuster criterion**, two points are separable if the central lobes (peaks) of their diffraction patterns' intensity profiles do not overlap.
- According to the **Rayleigh criterion**, two points are separable if the first intensity minimum of one point's profile corresponds to the maximum intensity of the other.
- According to the **Sparrow criterion**, two points are separable if the central lobes of the intensity profiles overlap in such a way as to form a saddle point for the maximum intensity values
- Two points are **not resolved** when the diffraction patterns overlap almost entirely**.**

Match each criterion to the corresponding diffraction pattern and intensity profile



• **Not resolved**

• **Sparrow criterion**

• **Rayleigh criterion**

• **Schuster criterion**

35.10. The diameter of a satellite also

A) Behaves as an aperture

B) Produces it's own light

C) Quite annoys many people

D) Affects the diffraction of light through it

Solution of exercises:

31 Alternating current

31.1

(a) The total energy E_{tot} in an LC circuit is constant and equals the energy stored in the capacitor and in the inductor. Since the capacitor is fully charged, there is no current flowing through the inductor, and hence, no energy is stored in the inductor, so:

$$E_{tot} = U_C = \frac{Q^2}{2C} = \frac{(2.90 \times 10^{-6})^2}{2 \times 3.6 \times 10^{-6}} = 1.17\mu J$$

(b) The maximum current I_{max} occurs when all the energy is transferred in the inductor:

$E_{tot} = U_L = \frac{LI_{max}^2}{2}$ so $I_{max} = \sqrt{\frac{2E_{tot}}{L}} = \sqrt{\frac{2\times1.17\times10^{-6}}{75\times10^{-3}}} = 5.58\ mA$

31.2

$f_0 = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{10\times10^{-3}\times250\times10^{-9}}} \approx 10.1\ kHz$

31.3

(a) To solve this problem, we need to analyze the behavior of the LC circuit when the switch is moved to position *b*. Initially, the switch is at position *a* for a long time, allowing the capacitor to charge fully to the voltage of the battery. When the switch is moved to position *b*, the circuit begins to oscillate at a natural frequency given by:

$f = \frac{\omega}{2\pi} = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{54.0\times10^{-3}\times6.20\times10^{-6}}} \approx 275\ Hz$

(b) When the switch is thrown, the initial energy is stored in the capacitor to $V = 34V$ and the current throw the circuit is zero.

$E_{tot} = U_C = \frac{Q^2}{2C}$ with $Q = CV$ so : $E_{tot} = \frac{CV^2}{2} = \frac{6.20\times10^{-6}\times 34^2}{2} = 3.58 \times 10^{-3}J$

The maximum energy in the circuit during oscillation is also given by the energy stored in the inductor when the amplitude of current is at its maximum:

$E_{tot} = U_L = \frac{LI_{max}^2}{2}$ so $I_{max} = \sqrt{\frac{2E_{tot}}{L}} = \sqrt{\frac{2\times3.58\times10^{-3}}{54\times10^{-3}}} = 0.365\ mA$

31.4

At $f = 1\ kHz$:

$X_L = \omega L = 2\pi f L = 628.3\ \Omega$, $X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C} = 318.31\Omega$, $Z = \sqrt{(R^2 + (X_L - X_C)^2} = 310.6\ \Omega$

At $f = 5\ kHz$:

$X_L = 2\pi f L = 3141.6\ \Omega$, $X_C = 63.66\ \Omega$, $Z = 3078\ \Omega$

31.5

$X_L = 2513\,\Omega$, $X_C = 198.9\,\Omega$, $Z = 2314\,\Omega$

$\phi = tan^{-1}\left(\frac{X_L - X_C}{R}\right) = 89.75\text{ deg} = 1.566\,rad$

31.6

The total voltage V is the phasor sum of the voltages across the components:

$$V = \sqrt{({V_R}^2 + (V_L - V_C)}^2 = \sqrt{(10^2 + (15-5)^2} = 14.14\,V$$

The phase angle ϕ is given by:

$\phi = tan^{-1}\left(\frac{X_L - X_C}{R}\right) = tan^{-1}\left(\frac{(V_L - V_C)/I}{V_R/_I}\right) = tan^{-1}\left(\frac{V_L - V_C}{V_R}\right)$

$\phi = tan^{-1}\left(\frac{15-5}{10}\right) = tan^{-1}(-1) = +0.785 rad = 45\,deg$

The phase angle is 0.785 rad or 45o. If the current lags the voltage, the angle would be positive. If the current leads the voltage, the angle would be negative. In a typical RLC circuit, the sign depends on whether the circuit is predominantly inductive or capacitive.

If the circuit is predominantly inductive (as implied by $V_L > V_C$), the phase angle is positive. If it were predominantly capacitive, the phase angle would be negative.

31.7

(a) The current i(t) reaches its maximum value when the sine function equals 1.
This occurs when: $2500t + 0.680 = \frac{\pi}{2} + 2k\pi$
and the first maximum occurs for $k = 0$ so for $2500t + 0.680 = \frac{\pi}{2}$.
Solving for t we got: $t = \frac{\frac{\pi}{2} - 0.680}{2500} = 0.356\,ms$

(b) The angular frequency ω of the oscillating LC circuit is given by the coefficient of t in the sine function ($i(t) = I_{max} sin(\omega t + \phi)$) so $\omega = 2500 rad/s$

The inductance L can be calculated using the formula for the angular frequency in an LC circuit:
$\omega = \frac{1}{\sqrt{LC}}$ so $L = \frac{1}{\omega^2 C} = \frac{1}{2500^2 \times 64 \times 10^{-6}} = 2.5 mH$

(c) The total energy E in the LC circuit is constant and equals the maximum energy stored in either the capacitor or the inductor.
The maximum current $I_{max} = 1.60\,A$. The energy stored in the inductor when the current is at its maximum is: $E = \frac{LI_{max}^2}{2} = \frac{2.5 \times 10^{-3} \times 1.60^2}{2} = 3.20\,mJ$

32 Magnetism of matter

32.1

Answer: **B and C**)

(Explanation: Magnetism originates from moving electric charges. But in some materials, like iron, the atomic structure itself gives rise to intrinsic magnetism.)

32.2

Answer: **B**)

(Explanation: A moving charge, such as an electron, generates a magnetic field around it. This is a fundamental principle of electromagnetism.)

32.3

Answer: **C**)

(Explanation: At the atomic scale, even when a magnet is divided into tiny pieces, each piece behaves like a tiny magnet with its own north and south poles due to the alignment of atomic magnetic moments.)

32.4

Answer: **B**)

(Explanation: The magnetic moment of an atom is primarily due to the motion of electrons in orbit around the nucleus, which creates a tiny magnetic dipole.)

32.5

Answer: **B**)

(Explanation: The orbital magnetic dipole moment arises from the motion of electrons in their orbitals around the nucleus. This motion generates a magnetic field similar to a current loop and contributes to the total magnetic moment of the atom. The spin magnetic moment comes from the intrinsic spin of the electrons, and both effects combine to give the atom its overall magnetic properties.)

32.6

Answer: **D**)

(Explanation: The magnetic dipole moment can be visualized as an infinitesimally small bar magnet, but it is also a vector quantity that points from the south pole to the north pole. This vector representation is essential in physics, as it helps describe how a dipole interacts with external magnetic fields.)

32.7

Answer: **C**)

(Explanation: In quantum mechanics, electrons are described by wavefunctions, and their motion is better understood as a probability distribution. However, electrons also have an intrinsic angular momentum called spin, which contributes to the atom's magnetic moment.)

32.8

Answer: **B**)

Magnetic moment is related to the orbital motion of electrons and spin, whereas spin magnetic moment is related to an intrinsic property of the electron.

(Explanation: The magnetic moment of an atom arises from both the orbital motion of its electrons and their intrinsic spin. Spin is a quantum property that gives rise to a magnetic moment, but the two are not the same. The magnetic moment is the observable effect of the electron's movement and spin.)

32.9

Answer: **B**)

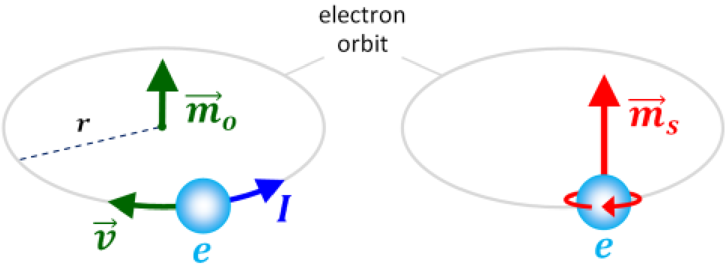
A quantum property of electrons that gives rise to a magnetic moment

(Explanation: Spin is an intrinsic quantum property of electrons, like mass or charge. It is not a literal physical spinning motion, but a form of angular momentum that contributes to the magnetic moment of atoms.)

32.10

Answer: **B**)

The magnetic moment is determined by the combined contribution of both the electron spins and the orbital motion.



32.11

Answer: **C**)

(Explanation: Materials like iron, where many electrons' spins align in the same direction, are called ferromagnetic materials. This alignment results in a strong overall magnetic field and permanent magnetism.)

33 Electromagnetic waves

33.1

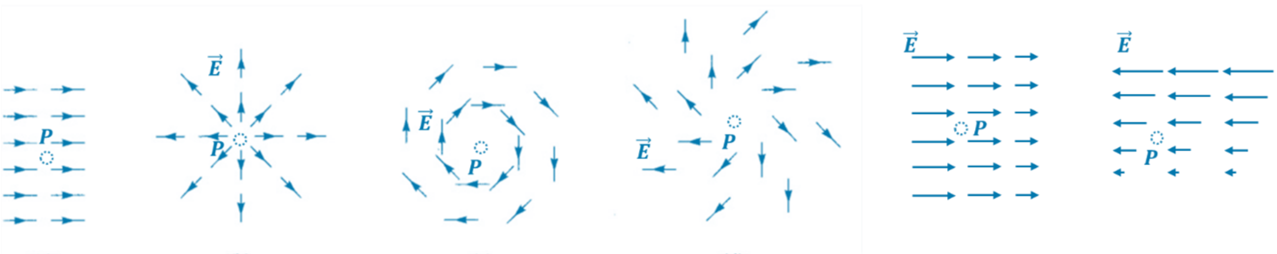
1) Correct answer. A

You can see that this vector field will have positive divergence. This can be seen since the vectors grow larger as they move away from the origin in any direction.

Correct answer. B

You can see that this vector field will have positive divergence. This can be seen since the vectors grow larger as they move away from the origin in any direction.

2)



A.	B.	C.	D.	E.	F.
$\nabla.\vec{E}=0$	$\nabla.\vec{E}>0$	$\nabla.\vec{E}=0$	$\nabla.\vec{E}>0$	$\nabla.\vec{E}<0$	$\nabla.\vec{E}=0$
$\nabla\times\vec{E}=0$	$\nabla\times\vec{E}=0$	$\nabla\times\vec{E}<0$	$\nabla\times\vec{E}<0$	$\nabla\times\vec{E}=0$	$\nabla\times\vec{E}>0$

33.2

	Integral form	Differential form
Maxwell - Gauss for electrostatics Relates the electric flux to the enclosed electric charge	$\oiint \vec{E}.d\vec{A} = \frac{q_{enc}}{\epsilon_0}$	$\nabla.\vec{E} = \frac{\rho}{\epsilon_0}$
Maxwell - Gauss for magnetostatics There is no magnetic monopole	$\oiint \vec{B}.d\vec{A} = 0$	$\nabla.\vec{B} = 0$
Maxwell-Faraday Relates the induced electric field to the varying magnetic field	$\oint \vec{E}.d\vec{S} = -\frac{d\phi_B}{dt}$	$\nabla\times\vec{E} = -\frac{\partial\vec{B}}{\partial t}$
Maxwell-Ampere Relates the induced magnetic field to the current and the varying electric field	$\oint \vec{B}.d\vec{S} = \mu_0\epsilon_0\frac{d\phi_E}{dt} + \mu_0 i_{enc}$	$\nabla\times\vec{B} = \mu_0\epsilon_0\frac{\partial\vec{E}}{\partial t} + \mu_0 j_{enc}$

33.3

1) If the electric field is along the y-axis and the magnetic field is along the z-axis, the wave will travel **along the x-axis**. This is because in an electromagnetic wave, the electric field, magnetic field, and wave propagation direction are all perpendicular to each other, following the right-hand rule.

2) in (**a**), because the electric field is parallel to the wire, accelerating the electrons

3) in (**a**), because the factors affecting the strength of induced current are: the strength of the magnetic field, the area of the loop, and the orientation of the loop with respect to the magnetic field.

If the angle between the loop and the magnetic field is $\frac{\pi}{2}$, the induced current will be at its maximum.

4) (step 1) : **Maxwell - Faraday's law** $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ and (step 2) : **Maxwell – Ampère's law** : $\nabla \times \vec{B} = \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t} + \mu_0 j_{enc}$

5) in free space ($\rho = 0$ and $j = 0$) and according to x our Maxwell - Faraday's law becomes

$$\begin{pmatrix} 0 \\ 0 \\ \frac{\partial}{\partial x} E_0 \sin(kx - \omega t) \end{pmatrix} = -\frac{\partial}{\partial t}\begin{pmatrix} 0 \\ 0 \\ B_0 \sin(kx - \omega t) \end{pmatrix}$$

that leads simply to: $kE_0 \sin(kx - \omega t) = +\omega B_0 \sin(kx - \omega t)$

or to : $\frac{E_0}{B_0} = \frac{\omega}{k} = c$

6) And from Maxwell – Ampère's law we obtain:

$$\begin{pmatrix} 0 \\ -\frac{\partial}{\partial x} B_0 \sin(kx - \omega t) \\ 0 \end{pmatrix} = \mu_0 \epsilon_0 \frac{\partial}{\partial t}\begin{pmatrix} 0 \\ E_0 \sin(kx - \omega t) \\ 0 \end{pmatrix}$$

$$\Longrightarrow -k\, B_0 \sin(kx - \omega t) = -\omega \mu_0 \epsilon_0 E_0 \sin(kx - \omega t)$$

$$\Longrightarrow kB_0 = \omega \mu_0 \epsilon_0 E_0$$

$$\Longrightarrow \underbrace{\frac{E_0}{B_0}}_{c} \underbrace{\frac{\omega}{k}}_{c} = \frac{1}{\mu_0 \epsilon_0} \text{ so } c^2 = \frac{1}{\mu_0 \epsilon_0}$$

7) The directions of wave propagation, of the **E** field, and of **B** field are all mutually perpendicular.

- The speed of the electromagnetic wave is the speed of light $c = \sqrt{\frac{1}{\mu_0 \epsilon_0}}$ independent of frequency.
- The ratio of electric and magnetic field amplitudes is $E/B = c$.

33.4

We are given E, and c is the speed of light. Entering these into the expression for B yields

$$B = \frac{1000\ V/m}{3.00 \times 10^8\ m/s} = 3.33 \times 10^{-6} T$$

The B-field strength is less than a tenth of Earth's admittedly weak magnetic field. This means that a relatively strong electric field of 1000 V/m is accompanied by a relatively weak magnetic field.

33.5

The intensity of the laser beam is $I = \frac{1}{2} c\varepsilon_0 E_0^2$

The amplitude of the electric field is therefore

$$E_0 = \sqrt{\frac{2}{c\varepsilon_0} I} = \sqrt{\frac{2}{(3.00\times10^8 m/s)(8.85\times10^{-12} F/m)}(1.0 \times 10^{-3}\ W/m^2)} = 0.87\ V/m$$

The amplitude of the magnetic field can be obtained from:

$$B_0 = \frac{E_0}{c} = 2.9 \times 10^{-9} T$$

33.6

The power radiated as visible light is then $I = \frac{P}{A_{sphere}} = \frac{P}{4\pi r^2} = \frac{c\varepsilon_0 E_0^2}{2}$

$$E_0 = \sqrt{2\frac{P}{4\pi r^2 c\varepsilon_0}} = \sqrt{2\frac{5.00\ W}{4\pi\ (3.0\ m)^2 (3.00\times10^8 m/s)(8.85\times10^{-12} F/m)}} = 5.77\ N/C \text{ or } V/m$$

$$B_0 = \frac{E_0}{c} = 1.92 \times 10^{-8} T$$

33.7

Using the proportionality of the areas to the squares of the distances, and solving, we obtain from the diagram

$$\frac{r_2^2}{r_1^2} = \frac{A_1}{A_2} = \frac{90\ W}{60\ W} \quad so \quad r_2 = \sqrt{\frac{90}{60}}(100\ km) = 122\ km$$

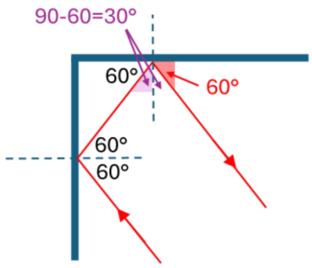
34 Geometrical optics

34.1

Refraction / Index of refraction / Towards / Critical angle

34.2

The beam hits Mirror 1 at 60° to the normal and reflects at the same angle. Since the mirrors are at a 90° angle to each other, the beam then strikes Mirror 2 at 30° to its normal (90° - 60°). By the law of reflection, it reflects off Mirror 2 at the same angle, 30°. Thus, the angle θ at which the beam is reflected from Mirror 2 is 60°.



34.3

answer **B**

The image formed by the plane mirror is **virtual and erect**, i.e. image cannot be projected or focused on a screen. It means **you have to look through the optical system (here the mirror) to see the image**. The distance of the image "behind" the mirror is the same as the distance of the object in front of the mirror. The size of the image is the same as the size of the object

34.4

answer **A, B and D**

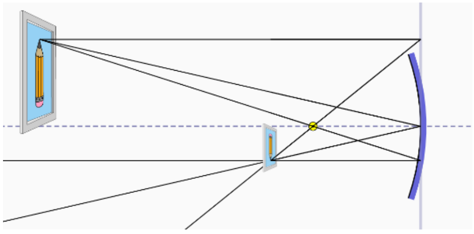
- Virtual images are indeed always erect (upright). This is because they are formed by the divergence of light rays, which does not involve an inversion.
- Virtual images can be either magnified or diminished, depending on the specific optical setup and the positions of the object and image.
- Virtual images cannot be projected onto a screen because the light rays do not actually converge at the image point.
- Virtual images can be seen when looking through the optical device (e.g., a magnifying glass or a mirror) because the light rays appear to diverge from the image point.

34.5

answer **A**

34.6

answer **A**



34.7

answer **B**

34.8

answer **B**

A light ray passing through the center of a lens continues in a straight line without any deviation. This is because the optical axis is a line of symmetry for the lens, and there is no refraction at the center.

34.9

answer**C**

34.10

answer **C**

A magnifying glass is a **convex lens** used to make an object appear larger than it actually is. This works when the object is placed at a distance less than the focal length from the lens. These lenses cause light rays to converge, or come together.

34.11

answer **C**

34.12

answer **A and C**

34.13

answer **D**

Using the generalized formula $\frac{1}{f} = \frac{1}{p} + \frac{1}{i}$ from Activity 1 we got $i = \left(\frac{1}{f} - \frac{1}{p}\right)^{-1} = \frac{1}{\frac{1}{15\,cm} - \frac{1}{20\,cm}} = 60cm$

34.14

Negative Magnification: The image is inverted (upside down).

Magnification Less Than 1: The image is smaller than the object.

34.15

Start with the equation for magnification $m = -\frac{i}{p}$

So $i = \ -mp = -0.032 \times 12cm = -0.384cm$ (the image is smaller and inverted)

Solve the mirror equation for the focal length: $\frac{1}{f} = \frac{1}{p} + \frac{1}{i}$ and insert the known values for the object and image distances. The result is:

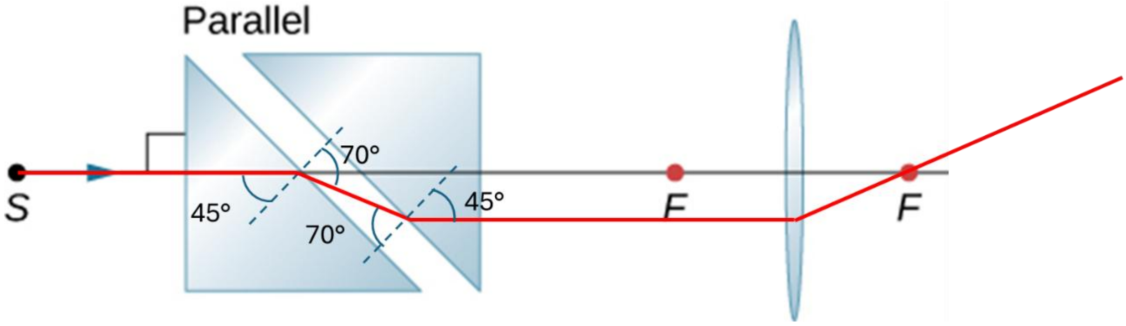
$$f = \left(\frac{1}{p} + \frac{1}{i}\right)^{-1} = \frac{1}{\frac{1}{12\ cm} + \frac{1}{0.384\ cm}} = -40cm$$

The radius of curvature is then twice the focal length, so : $\boldsymbol{R = 2f = -0.80cm}$

Significance : The focal length is negative, so the focus is virtual, as expected for a concave mirror and a real object. The radius of curvature found here is reasonable for a cornea. The distance from cornea to retina in an adult eye is about 2.0 cm. In practice, corneas may not be spherical, which complicates the job of fitting contact lenses. Note that the image distance here is negative, consistent with the fact that the image is behind the mirror. Thus, the image is virtual because no rays actually pass through it.

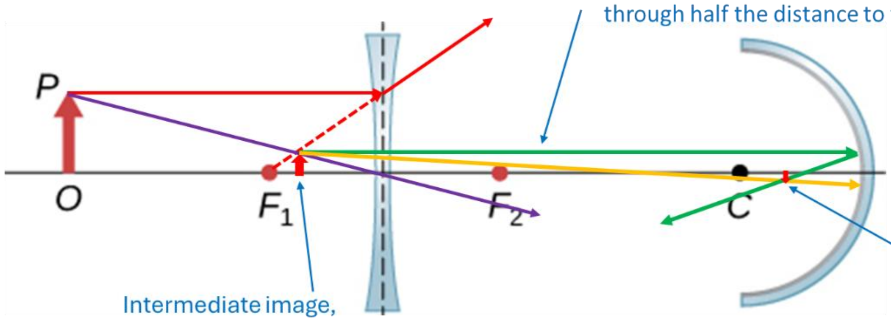
34.16

1)



2)

The green ray came from the intermediate image; it bypasses the lens and bounces again off the spherical mirror, passing through half the distance to the center of curvature



Final image

Intermediate image, act now like an object for the mirror

35 Interferences

35.1
Answer **B**

35.2
Answer **B**

35.3
Answer **C**
Different media affect the speed of light, causing a phase shift. This shift alters the interference pattern when the waves recombine.

35.4
answer **C**
Phase difference refers to how the positions of points on two waves compare at a given time, affecting how they interfere.

35.5
Answer **D**
Phase differences arise from variations in path length or speed, not amplitude. Amplitude affects intensity, not phase.

35.6
Answer **C**
Destructive interference occurs when the crest of one wave aligns with the trough of another, resulting in a phase difference of 180 degrees, which cancels out the waves.

35.6
Answer **B**
Light reflecting off the top and bottom surfaces of a thin film travels different distances, leading to phase differences that create colorful interference patterns.

35.7
Answer **C**

35.8
Answer **B**

35.9
1) Answer **C**
2) Answer **D**

35.10. Monochromatic light is used in the double-slit experiment to ensure coherence, which is essential for producing clear and predictable interference patterns. This allows the light waves to interfere constructively or destructively in a consistent manner, resulting in distinct fringes.

35.11. No, the same interference pattern would not be obtained with two independent light sources like car headlights. Unlike Young's double-slit experiment, where light from a single coherent source is split into two, independent sources emit light with random phase relationships. This lack of coherence means the light waves do not consistently interfere constructively or destructively, resulting in no stable interference pattern.

35.12

Solving $m\lambda = d\ sin\ \theta$ for the wavelength λ gives $\lambda = \frac{dsin\theta}{m}$

Substituting known values yields

$$\lambda = \frac{(0.0100 \times 10^{-3} m)\ \times sin\ (10.95°)}{3} = 6.33 \times 10^{-7} m = 633nm$$

To three digits, this is the wavelength of light emitted by the common He-Ne laser. Not by coincidence, this red color is similar to that emitted by neon lights. More important, however, is the fact that interference patterns can be used to measure wavelength. Young did this for visible wavelengths. This analytical technique is still widely used to measure electromagnetic spectra. For a given order, the angle for constructive interference increases with λ, so that spectra (measurements of intensity versus wavelength) can be obtained.

35.13

Solving the equation for **m** gives $\mathrm{m} = \frac{\mathrm{dsin\theta}}{\lambda}$. Taking sinθ=1 and substituting the values of d and λ from the preceding example gives $\mathrm{m} = \frac{(0.0100 \times 10^{-3} \mathrm{m}) \times \sin (90°)}{633 \times 10^{-9} \mathrm{m}} = 15.8$

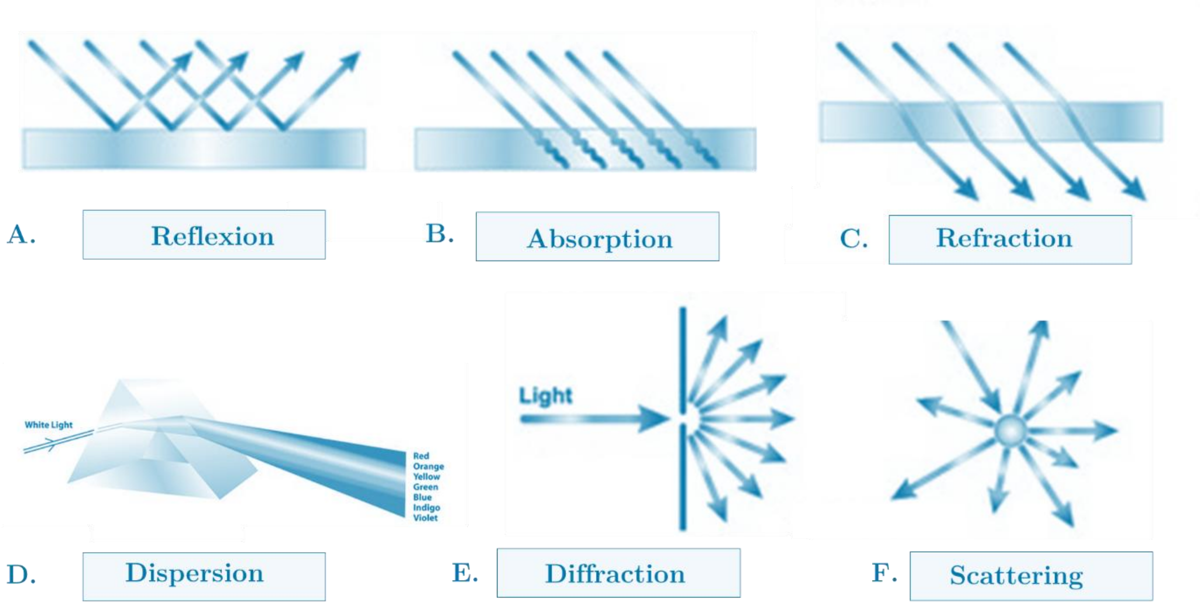
Therefore, the largest integer m can be is 15, or m=15.

35.14

3.63° and 7.27°, respectively

36 Diffraction

36.1



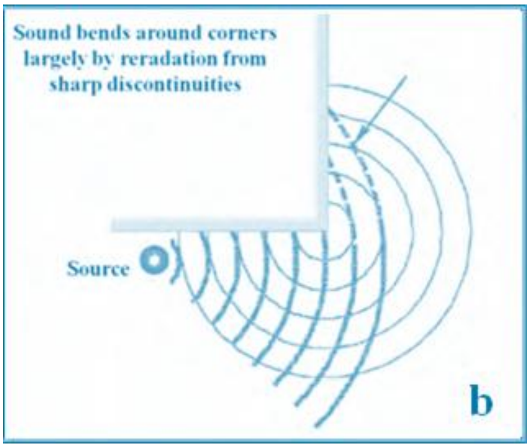
35.2

Answer **D**

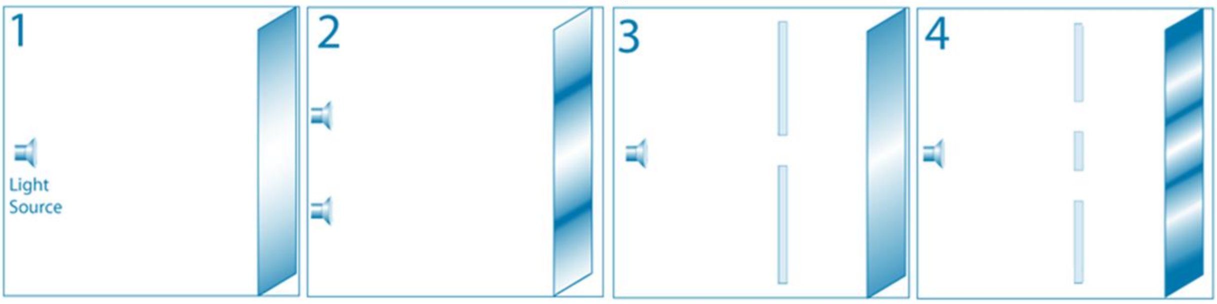
35.3

Answer: **B**

Diffraction is the bending of waves around a corner. Sound waves can also be diffracted. The fact that we can hear sounds around corners and around barriers is due to the diffraction of sound as well as its reflection.



35.4



35.5

1) We are given that $\lambda = 550\text{nm}, m = 2,$ and $\theta_2 = 45.0°$. Solving the equation $a \sin\theta = m\lambda$ for a and substituting known values gives

$$a = \frac{m\lambda}{\sin\theta_2} = \frac{2(550\times10^{-9})}{\sin(45°)} = \frac{1100\times10^{-9}}{0.707} = 1.56\times10^{-6}m$$

2) Solving the equation a $\sin\theta = m\lambda$ for $sin\theta_1$ and m=1 and substituting the known values gives

$$sin\theta_1 = \frac{m\lambda}{a} = \frac{1(550\times10^{-9})}{1.56\times10^{-6}} = 0.354$$

Thus the angle θ_1 is $\theta_1 = \sin^{-1}(0.354) = 20.7°$

We see that the slit is narrow (it is only a few times greater than the wavelength of light). This is consistent with the fact that light must interact with an object comparable in size to its wavelength in order to exhibit significant wave effects such as this single-slit diffraction pattern. We also see that the central maximum extends 20.7° on either side of the original beam, for a width of about 41°. The angle between the first and second minima is only about 24°(45.0°−20.7°). Thus, the second maximum is only about half as wide as the central maximum.

3) 17.8°, 37.7°, 66.4° ; no

35.6

Answer **C**

As the whole apparatus is now immersed in water, the wavelength of the light will change.

$\lambda' = \lambda\frac{n_{air}}{n_{water}}$. Therefore, as the refractive index of water is greater than the air, the wavelength of light will decrease.

Width of central maxima to the wavelength. Therefore, as the wavelength decreases, the width of the central maxima decreases.

35.6

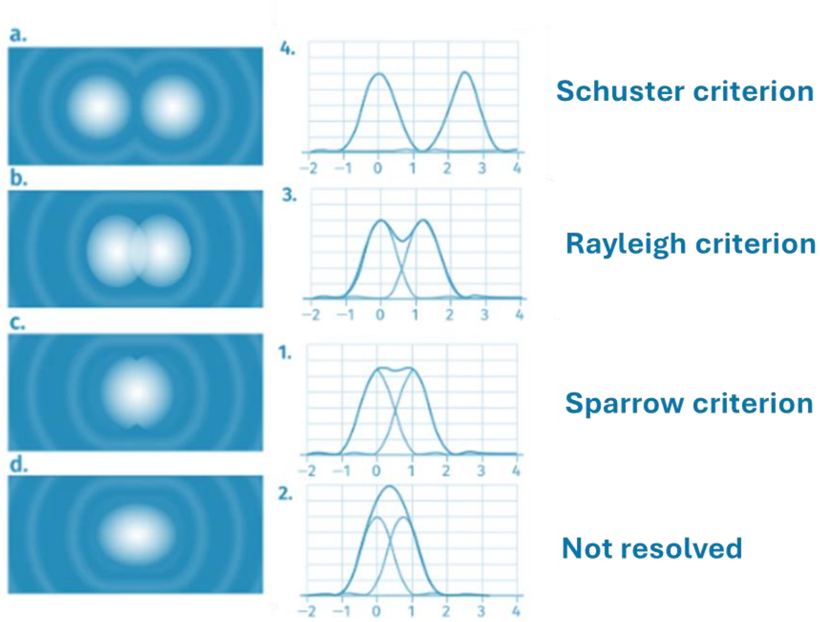
Answer **C**

When white light is used instead of monochromatic light, then the central maximum remains white as all seven wavelengths meet there in the same phase. The first minimum and second maximum will be formed by violet color due to its shortest wavelength while the last is due to the red color as it has the longest wavelength. Thus, a colored pattern is observed. However, after the first few colored bands, the clarity of the band is lost, due to overlapping.

35.8

Answer **C**

35.9



35.10

Answer **A**

The diameter of a satellite can act as an aperture, affecting how light waves are diffracted as they pass around or through it. This is similar to how light behaves when passing through any opening or around any obstacle, leading to diffraction patterns.

Why not the others?

Satellites typically do not produce their own light; they reflect sunlight or emit signals but do not generate visible light.

Option C is unrelated to the physical properties of a satellite even if it’s can bother some astronomer.

While option D is partially correct, it is more accurate to say that the satellite's diameter acts as an aperture, influencing the diffraction pattern.