

UCLA PHYSICS FIELD NOTES

PHYSICS 1C

Electrodynamics, Optics, and Relativity

A connected guide to magnetic fields, induction, electromagnetic waves, light, and spacetime

How these notes are written. I wrote each chapter the way I wish the material had been explained the first time: the real idea, the point where I usually get stuck, the simplest mental model that still stays honest, and a worked decision instead of a polished answer appearing from nowhere. Every chapter closes with practice and a fully written solution. If a sentence sounds impressive but does not help me solve or explain something, it does not belong here.

Daniel Mastick

Curriculum map, working notes, practice, and solutions

Course map

Week	Core thread	What should be solid by the end
1	Magnetic forces	Predict charged-particle motion and forces on current-carrying conductors.
2	Sources of magnetic field	Use Biot-Savart and Ampere's law with geometry and symmetry.
3	Electromagnetic induction	Apply magnetic flux, Faraday's law, Lenz's law, and motional emf.
4	Inductance and AC circuits	Track magnetic energy, RL/LC/RLC transients, impedance, and phase.
5	Maxwell and electromagnetic waves	Connect changing fields, propagation, energy flow, and the speed of light.
6	Geometric optics	Use reflection, refraction, mirrors, lenses, and ray conventions consistently.
7	Interference	Relate phase and path difference in two-source and thin-film systems.
8	Diffraction and resolution	Read single-slit patterns, gratings, and aperture limits.
9	Special relativity	Use invariant spacetime structure, Lorentz transformations, momentum, and energy.
10	Synthesis	Switch cleanly among field, circuit, wave, ray, and relativistic models.

Scope anchor: <https://catalog.registrar.ucla.edu/course/2024/PHYSICS1C>. The sequence is aligned to the official catalog description and expanded into a practical ten-week study plan.

How I would use this packet

Treat each numbered section as one chapter. Read the formal explanation, pause at the student interpretation, and see whether the easy version still says the same thing. Rework the example without looking, then cover the solution in the chapter practice box. The cumulative set at the end is deliberately mixed: knowledge becomes durable when I have to choose the tool instead of being told which chapter I am in.

Contents

1	Magnetic force and charged-particle motion	5
1.1	Rebuild the chapter from first principles	5
1.2	Details I would refuse to skip	5
1.3	How this chapter connects	6
2	Sources of magnetic field	7
2.1	Rebuild the chapter from first principles	7
2.2	Details I would refuse to skip	7
2.3	How this chapter connects	8
3	Faraday's law, Lenz's law, and motional emf	9
3.1	Rebuild the chapter from first principles	9
3.2	Details I would refuse to skip	9
3.3	How this chapter connects	10
4	Inductance and AC circuits	11
4.1	Rebuild the chapter from first principles	11
4.2	Details I would refuse to skip	12
4.3	How this chapter connects	12
5	Maxwell's equations and electromagnetic waves	13
5.1	Rebuild the chapter from first principles	13
5.2	Details I would refuse to skip	14
5.3	How this chapter connects	14
6	Geometric optics: reflection, refraction, and images	15
6.1	Rebuild the chapter from first principles	15
6.2	Details I would refuse to skip	16
6.3	How this chapter connects	16
7	Interference and thin films	18
7.1	Rebuild the chapter from first principles	18
7.2	Details I would refuse to skip	18
7.3	How this chapter connects	19

8	Diffraction, gratings, and resolution	20
8.1	Rebuild the chapter from first principles	20
8.2	Details I would refuse to skip	20
8.3	How this chapter connects	21
9	Special relativity and relativistic dynamics	22
9.1	Rebuild the chapter from first principles	22
9.2	Details I would refuse to skip	22
9.3	How this chapter connects	23

CHAPTER 1 Magnetic force and charged-particle motion

Rebuild the chapter from first principles

The claim I need to own is this: The model in Magnetic force and charged-particle motion controls the work. I do not count that as learned just because the sentence looks familiar. I should be able to name the objects, state what changes and what stays fixed, recover the rule from the definitions, and explain why the result is allowed.

The move

My working sequence

1. **Translate.** Rewrite the prompt in the language of magnetic force and charged-particle motion. List the known quantities, the unknown, the units or types, and any hidden constraint.
2. **Choose.** State the theorem, model, algorithm, accounting rule, or physical law before substituting values. This is where I make the assumption visible.
3. **Execute.** Work one justified step at a time and keep intermediate state readable enough that I can audit it later.
4. **Verify.** Check a boundary case, sign, unit, invariant, order of magnitude, or alternative derivation. Then translate the result back into an ordinary sentence.

Details I would refuse to skip

- **Definitions:** I should be able to define every technical noun in the chapter without using that same noun in the definition.
- **Assumptions:** I write the condition that makes the method legal beside the method itself. A correct procedure under the wrong assumptions is still a wrong answer.
- **Representation:** I move freely among words, equations or code, a diagram, and a small numerical example. If one representation disagrees with another, that disagreement is useful evidence.
- **Failure modes:** I keep the nearest counterexample in mind: the boundary where the rule changes, the invariant breaks, or the model stops matching reality.
- **Communication:** My final answer names what the result means and what it does not establish. I do not let notation do the explanatory work for me.

Sanity check

Closed-note check. Can I teach magnetic force and charged-particle motion on a blank page, derive or reconstruct its main rule, work a fresh example, and diagnose a deliberately broken solution? If I can only recognize the finished work, I am not done.

How this chapter connects

I read this chapter as the bridge from the course foundations to sources of magnetic field. The earlier material supplies the language and constraints; this chapter adds a new reasoning move; the later material asks me to use that move without being told its name. That connection matters because exams and real projects mix chapters on purpose.

A magnetic field exerts force on moving charge:

$$\vec{F}_B = q\vec{v} \times \vec{B}, \quad \vec{F} = I\vec{L} \times \vec{B} \text{ for a straight current segment.}$$

Because $\vec{F}_B$ is perpendicular to velocity, a magnetic field alone does no work and cannot change a particle's speed. A velocity perpendicular to a uniform field produces circular motion,

$$r = \frac{mv}{|q|B}, \quad \omega_c = \frac{|q|B}{m}.$$

A parallel velocity component remains unchanged, producing a helix. A current loop has magnetic dipole moment $\vec{\mu} = NI\vec{A}$, torque $\vec{\tau} = \vec{\mu} \times \vec{B}$, and energy $U = -\vec{\mu} \cdot \vec{B}$.

How I actually think about it

I do the right-hand rule for a positive charge first and reverse only at the end if $q < 0$. The magnetic force bends velocity; it does not point along the path and it does not supply kinetic energy.

The easy version

A magnetic field gives a sideways shove to moving charge. Repeated sideways shoves turn the motion without speeding it up.

Worked example

A proton enters perpendicular to a 0.20 T field at 3.0×10^6 m/s. Its radius is $r = m_p v / (eB) = 0.157$ m. An electron at the same speed curves the opposite way with a much smaller radius because its mass is smaller.

Solved chapter practice

Practice. A particle of charge $-2.0 \mu\text{C}$ moves east at 400 m/s through a 0.50 T field directed north. Find the magnetic force.

Solution. For a positive charge, east cross north points up, and the magnitude is $|q|vB = 2.0 \times 10^{-6}(400)(0.50) = 4.0 \times 10^{-4}$ N. The charge is negative, so the force is 4.0×10^{-4} N downward.

Mastery practice A. Reconstruct magnetic force and charged-particle motion from a blank page. Include the central definition, the governing rule, one required assumption, and one boundary case.

Solution. Start from the blue idea box, but rewrite it in my own words. Identify the objects and state, name the rule before using it, copy the relevant assumption from the details audit, and choose a boundary where that assumption becomes equality or fails. A complete solution explains why each part belongs; a list of vocabulary is not enough.

Mastery practice B. A classmate gets a polished-looking answer to a magnetic force and charged-particle motion problem but never states a model or checks the result. Write the shortest useful

review of that solution.

Solution. I would ask four concrete questions: What exactly are the inputs and desired output? Which rule licenses the main step? Which assumption could invalidate it? Which independent check supports the conclusion? If the answer cannot survive those four questions, I treat the numerical or verbal result as unverified.

CHAPTER 2 Sources of magnetic field

Rebuild the chapter from first principles

The claim I need to own is this: The model in Sources of magnetic field controls the work. I do not count that as learned just because the sentence looks familiar. I should be able to name the objects, state what changes and what stays fixed, recover the rule from the definitions, and explain why the result is allowed.

The move

My working sequence

1. **Translate.** Rewrite the prompt in the language of sources of magnetic field. List the known quantities, the unknown, the units or types, and any hidden constraint.
2. **Choose.** State the theorem, model, algorithm, accounting rule, or physical law before substituting values. This is where I make the assumption visible.
3. **Execute.** Work one justified step at a time and keep intermediate state readable enough that I can audit it later.
4. **Verify.** Check a boundary case, sign, unit, invariant, order of magnitude, or alternative derivation. Then translate the result back into an ordinary sentence.

Details I would refuse to skip

- **Definitions:** I should be able to define every technical noun in the chapter without using that same noun in the definition.
- **Assumptions:** I write the condition that makes the method legal beside the method itself. A correct procedure under the wrong assumptions is still a wrong answer.
- **Representation:** I move freely among words, equations or code, a diagram, and a small numerical example. If one representation disagrees with another, that disagreement is useful evidence.
- **Failure modes:** I keep the nearest counterexample in mind: the boundary where the rule changes, the invariant breaks, or the model stops matching reality.
- **Communication:** My final answer names what the result means and what it does not establish. I do not let notation do the explanatory work for me.

Sanity check

Closed-note check. Can I teach sources of magnetic field on a blank page, derive or reconstruct its main rule, work a fresh example, and diagnose a deliberately broken solution? If I can only recognize the finished work, I am not done.

How this chapter connects

I read this chapter as the bridge from magnetic force and charged-particle motion to faraday's law, lenz's law, and motional emf. The earlier material supplies the language and constraints; this chapter adds a new reasoning move; the later material asks me to use that move without being told its name. That connection matters because exams and real projects mix chapters on purpose.

Currents create magnetic fields. The Biot-Savart law builds the field from current elements:

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I d\vec{\ell} \times \hat{r}}{r^2}.$$

For an infinite straight wire, $B = \mu_0 I / (2\pi r)$. Ampere's law,

$$\oint \vec{B} \cdot d\vec{\ell} = \mu_0 I_{\text{enc}},$$

is always true in steady-current magnetostatics, but becomes a calculation shortcut only with enough symmetry. It yields $B = \mu_0 n I$ inside an ideal long solenoid and approximately zero outside.

Two parallel currents in the same direction attract; opposite currents repel. This emerges by finding the field made by one wire and then the force it exerts on the other.

How I actually think about it

I keep two right-hand rules separate: one curls fingers around a source current to find $\vec{B}$; the other uses $\vec{L} \times \vec{B}$ to find a force. Blending them is where most direction errors begin.

The easy version

Current wraps space in circular magnetic field lines. More current means a stronger wrap; farther away means a weaker one.

Worked example

A 10 A current in a long wire produces $B = \mu_0 I / (2\pi r) = 2.0 \times 10^{-5}$ T at $r = 0.10$ m. The direction circles the wire according to the right-hand grip rule.

Solved chapter practice

Practice. A solenoid has 1200 turns per meter and carries 2.0 A. Find its internal field.

Solution. For an ideal long solenoid, $B = \mu_0 n I = (4\pi \times 10^{-7})(1200)(2.0) = 3.02 \times 10^{-3}$ T. Its direction follows curled fingers when the thumb points along the solenoid field.

Mastery practice A. Reconstruct sources of magnetic field from a blank page. Include the

central definition, the governing rule, one required assumption, and one boundary case.

Solution. Start from the blue idea box, but rewrite it in my own words. Identify the objects and state, name the rule before using it, copy the relevant assumption from the details audit, and choose a boundary where that assumption becomes equality or fails. A complete solution explains why each part belongs; a list of vocabulary is not enough.

Mastery practice B. A classmate gets a polished-looking answer to a sources of magnetic field problem but never states a model or checks the result. Write the shortest useful review of that solution.

Solution. I would ask four concrete questions: What exactly are the inputs and desired output? Which rule licenses the main step? Which assumption could invalidate it? Which independent check supports the conclusion? If the answer cannot survive those four questions, I treat the numerical or verbal result as unverified.

CHAPTER 3 Faraday's law, Lenz's law, and motional emf

Rebuild the chapter from first principles

The claim I need to own is this: The model in Faraday's law, Lenz's law, and motional emf controls the work. I do not count that as learned just because the sentence looks familiar. I should be able to name the objects, state what changes and what stays fixed, recover the rule from the definitions, and explain why the result is allowed.

The move

My working sequence

1. **Translate.** Rewrite the prompt in the language of faraday's law, lenz's law, and motional emf. List the known quantities, the unknown, the units or types, and any hidden constraint.
2. **Choose.** State the theorem, model, algorithm, accounting rule, or physical law before substituting values. This is where I make the assumption visible.
3. **Execute.** Work one justified step at a time and keep intermediate state readable enough that I can audit it later.
4. **Verify.** Check a boundary case, sign, unit, invariant, order of magnitude, or alternative derivation. Then translate the result back into an ordinary sentence.

Details I would refuse to skip

- **Definitions:** I should be able to define every technical noun in the chapter without using that same noun in the definition.
- **Assumptions:** I write the condition that makes the method legal beside the method itself. A correct procedure under the wrong assumptions is still a wrong answer.
- **Representation:** I move freely among words, equations or code, a diagram, and a small numerical example. If one representation disagrees with another, that disagreement is useful evidence.

- **Failure modes:** I keep the nearest counterexample in mind: the boundary where the rule changes, the invariant breaks, or the model stops matching reality.
- **Communication:** My final answer names what the result means and what it does not establish. I do not let notation do the explanatory work for me.

Sanity check

Closed-note check. Can I teach faraday's law, lenz's law, and motional emf on a blank page, derive or reconstruct its main rule, work a fresh example, and diagnose a deliberately broken solution? If I can only recognize the finished work, I am not done.

How this chapter connects

I read this chapter as the bridge from sources of magnetic field to inductance and ac circuits. The earlier material supplies the language and constraints; this chapter adds a new reasoning move; the later material asks me to use that move without being told its name. That connection matters because exams and real projects mix chapters on purpose.

Magnetic flux is $\Phi_B = \int \vec{B} \cdot d\vec{A}$. A changing flux produces emf:

$$\mathcal{E} = -N \frac{d\Phi_B}{dt}.$$

Flux can change because field strength, loop area, or orientation changes. The minus sign is Lenz's law: induced current creates a field opposing the *change* in flux. This is energy conservation expressed as a direction rule.

A conducting rod of length ℓ moving perpendicular to $\vec{B}$ and its length has motional emf $\mathcal{E} = B\ell v$. Magnetic force separates charges in the rod until an electric field balances it.

How I actually think about it

I write the old flux direction, decide whether its magnitude is increasing or decreasing, and only then choose the induced field that resists that change. "Opposes the field" is wrong when the original field is decreasing.

The easy version

A circuit reacts when the magnetic situation through it changes. It pushes current in whichever direction makes that change harder.

Worked example

A one-turn loop of area 0.020 m^2 is perpendicular to a field that rises from 0.10 T to 0.50 T in 0.20 s . The emf magnitude is $A\Delta B/\Delta t = 0.040 \text{ V}$.

Solved chapter practice

Practice. A 0.40 m rod moves at 5.0 m/s across a 0.30 T field. The circuit resistance is $2.0\ \Omega$. Find emf, current, and the external power needed to maintain speed.

Solution. $\mathcal{E} = B\ell v = 0.30(0.40)(5.0) = 0.60\text{ V}$ and $I = \mathcal{E}/R = 0.30\text{ A}$. Electrical dissipation is $I^2R = 0.18\text{ W}$. At constant speed, the external agent supplies the same 0.18 W against the magnetic drag.

Mastery practice A. Reconstruct faraday's law, lenz's law, and motional emf from a blank page. Include the central definition, the governing rule, one required assumption, and one boundary case.

Solution. Start from the blue idea box, but rewrite it in my own words. Identify the objects and state, name the rule before using it, copy the relevant assumption from the details audit, and choose a boundary where that assumption becomes equality or fails. A complete solution explains why each part belongs; a list of vocabulary is not enough.

Mastery practice B. A classmate gets a polished-looking answer to a faraday's law, lenz's law, and motional emf problem but never states a model or checks the result. Write the shortest useful review of that solution.

Solution. I would ask four concrete questions: What exactly are the inputs and desired output? Which rule licenses the main step? Which assumption could invalidate it? Which independent check supports the conclusion? If the answer cannot survive those four questions, I treat the numerical or verbal result as unverified.

CHAPTER 4 Inductance and AC circuits

Rebuild the chapter from first principles

The claim I need to own is this: The model in Inductance and AC circuits controls the work. I do not count that as learned just because the sentence looks familiar. I should be able to name the objects, state what changes and what stays fixed, recover the rule from the definitions, and explain why the result is allowed.

The move

My working sequence

1. **Translate.** Rewrite the prompt in the language of inductance and ac circuits. List the known quantities, the unknown, the units or types, and any hidden constraint.
2. **Choose.** State the theorem, model, algorithm, accounting rule, or physical law before substituting values. This is where I make the assumption visible.
3. **Execute.** Work one justified step at a time and keep intermediate state readable enough that I can audit it later.
4. **Verify.** Check a boundary case, sign, unit, invariant, order of magnitude, or alternative derivation. Then translate the result back into an ordinary sentence.

Details I would refuse to skip

- **Definitions:** I should be able to define every technical noun in the chapter without using that same noun in the definition.
- **Assumptions:** I write the condition that makes the method legal beside the method itself. A correct procedure under the wrong assumptions is still a wrong answer.
- **Representation:** I move freely among words, equations or code, a diagram, and a small numerical example. If one representation disagrees with another, that disagreement is useful evidence.
- **Failure modes:** I keep the nearest counterexample in mind: the boundary where the rule changes, the invariant breaks, or the model stops matching reality.
- **Communication:** My final answer names what the result means and what it does not establish. I do not let notation do the explanatory work for me.

Sanity check

Closed-note check. Can I teach inductance and ac circuits on a blank page, derive or reconstruct its main rule, work a fresh example, and diagnose a deliberately broken solution? If I can only recognize the finished work, I am not done.

How this chapter connects

I read this chapter as the bridge from faraday's law, lenz's law, and motional emf to maxwell's equations and electromagnetic waves. The earlier material supplies the language and constraints; this chapter adds a new reasoning move; the later material asks me to use that move without being told its name. That connection matters because exams and real projects mix chapters on purpose.

An inductor resists changes in current through self-induced emf,

$$\mathcal{E}_L = -L \frac{dI}{dt}, \quad U_L = \frac{1}{2} L I^2.$$

In an RL circuit the time constant is $\tau = L/R$. An ideal LC circuit exchanges energy between capacitor electric field and inductor magnetic field at $\omega_0 = 1/\sqrt{LC}$.

In sinusoidal steady-state AC, resistance, inductive reactance $X_L = \omega L$, and capacitive reactance $X_C = 1/(\omega C)$ combine as

$$Z = \sqrt{R^2 + (X_L - X_C)^2}, \quad I_{\text{rms}} = V_{\text{rms}}/Z.$$

At resonance $X_L = X_C$, the impedance is smallest and current largest. Average power is $P_{\text{avg}} = V_{\text{rms}} I_{\text{rms}} \cos \phi$.

How I actually think about it

My shorthand for this chapter is: my shorthand for this chapter is: the inductor does not permanently block current; it objects to current changing quickly. The capacitor does the complementary thing: it passes rapid AC behavior more readily but eventually blocks steady DC once charged.

The easy version

Capacitors store energy in electric fields and inductors store it in magnetic fields. An AC circuit is a timed exchange between those stores plus energy lost in resistance.

Worked example

For $L = 0.20 \text{ H}$ and $C = 50 \mu\text{F}$, $\omega_0 = 1/\sqrt{LC} = 316 \text{ rad/s}$, so $f_0 = \omega_0/(2\pi) = 50.3 \text{ Hz}$.

Solved chapter practice

Practice. A series RLC circuit has $R = 40 \Omega$, $X_L = 70 \Omega$, $X_C = 40 \Omega$, and $V_{\text{rms}} = 120 \text{ V}$. Find impedance, current, and power factor.

Solution. Net reactance is 30Ω , so $Z = \sqrt{40^2 + 30^2} = 50 \Omega$. Then $I_{\text{rms}} = 120/50 = 2.4 \text{ A}$ and $\cos \phi = R/Z = 0.80$. The circuit is net inductive because $X_L > X_C$.

Mastery practice A. Reconstruct inductance and ac circuits from a blank page. Include the central definition, the governing rule, one required assumption, and one boundary case.

Solution. Start from the blue idea box, but rewrite it in my own words. Identify the objects and state, name the rule before using it, copy the relevant assumption from the details audit, and choose a boundary where that assumption becomes equality or fails. A complete solution explains why each part belongs; a list of vocabulary is not enough.

Mastery practice B. A classmate gets a polished-looking answer to a inductance and ac circuits problem but never states a model or checks the result. Write the shortest useful review of that solution.

Solution. I would ask four concrete questions: What exactly are the inputs and desired output? Which rule licenses the main step? Which assumption could invalidate it? Which independent check supports the conclusion? If the answer cannot survive those four questions, I treat the numerical or verbal result as unverified.

CHAPTER 5 Maxwell's equations and electromagnetic waves

Rebuild the chapter from first principles

The claim I need to own is this: The model in Maxwell's equations and electromagnetic waves controls the work. I do not count that as learned just because the sentence looks familiar. I should be able to name the objects, state what changes and what stays fixed, recover the rule from the definitions, and explain why the result is allowed.

The move

My working sequence

1. **Translate.** Rewrite the prompt in the language of maxwell's equations and electromagnetic waves. List the known quantities, the unknown, the units or types, and any hidden constraint.
2. **Choose.** State the theorem, model, algorithm, accounting rule, or physical law before substi-

tuting values. This is where I make the assumption visible.

3. **Execute.** Work one justified step at a time and keep intermediate state readable enough that I can audit it later.
4. **Verify.** Check a boundary case, sign, unit, invariant, order of magnitude, or alternative derivation. Then translate the result back into an ordinary sentence.

Details I would refuse to skip

- **Definitions:** I should be able to define every technical noun in the chapter without using that same noun in the definition.
- **Assumptions:** I write the condition that makes the method legal beside the method itself. A correct procedure under the wrong assumptions is still a wrong answer.
- **Representation:** I move freely among words, equations or code, a diagram, and a small numerical example. If one representation disagrees with another, that disagreement is useful evidence.
- **Failure modes:** I keep the nearest counterexample in mind: the boundary where the rule changes, the invariant breaks, or the model stops matching reality.
- **Communication:** My final answer names what the result means and what it does not establish. I do not let notation do the explanatory work for me.

Sanity check

Closed-note check. Can I teach maxwell's equations and electromagnetic waves on a blank page, derive or reconstruct its main rule, work a fresh example, and diagnose a deliberately broken solution? If I can only recognize the finished work, I am not done.

How this chapter connects

I read this chapter as the bridge from inductance and ac circuits to geometric optics: reflection, refraction, and images. The earlier material supplies the language and constraints; this chapter adds a new reasoning move; the later material asks me to use that move without being told its name. That connection matters because exams and real projects mix chapters on purpose.

Maxwell's equations unify electric and magnetic fields. Charges source electric flux; there are no isolated magnetic monopoles; changing magnetic flux creates circulating electric field; and currents plus changing electric flux create circulating magnetic field. In vacuum these coupled changing fields satisfy wave equations with speed

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}.$$

In a plane electromagnetic wave, $\vec{E}$, $\vec{B}$, and propagation are mutually perpendicular, with $E = cB$. Energy flows in the Poynting direction $\vec{S} = (1/\mu_0)\vec{E} \times \vec{B}$. Average intensity is $I = \frac{1}{2}c\epsilon_0 E_0^2$.

How I actually think about it

My shorthand for this chapter is: my shorthand for this chapter is: the important leap is that a changing electric field counts as a source of magnetic field even where no wire is present. That closes the feedback loop: changing E makes B , changing B makes E , and the pattern travels through empty space.

The easy version

Light is not carried by a material medium. It is an electric-field change and magnetic-field change continually rebuilding each other as they move.

Worked example

If a wave has electric amplitude $E_0 = 300 \text{ V/m}$, then $B_0 = E_0/c = 1.0 \mu\text{T}$. Its average intensity is about 119 W/m^2 .

Solved chapter practice

Practice. A radio wave travels east with electric field pointing north at one instant. Which way does its magnetic field point?

Solution. Propagation follows $\vec{E} \times \vec{B}$. We need north cross $\vec{B}$ to equal east. In a right-handed east-north-up frame, north cross up is east, so $\vec{B}$ points upward at that instant.

Mastery practice A. Reconstruct maxwell's equations and electromagnetic waves from a blank page. Include the central definition, the governing rule, one required assumption, and one boundary case.

Solution. Start from the blue idea box, but rewrite it in my own words. Identify the objects and state, name the rule before using it, copy the relevant assumption from the details audit, and choose a boundary where that assumption becomes equality or fails. A complete solution explains why each part belongs; a list of vocabulary is not enough.

Mastery practice B. A classmate gets a polished-looking answer to a maxwell's equations and electromagnetic waves problem but never states a model or checks the result. Write the shortest useful review of that solution.

Solution. I would ask four concrete questions: What exactly are the inputs and desired output? Which rule licenses the main step? Which assumption could invalidate it? Which independent check supports the conclusion? If the answer cannot survive those four questions, I treat the numerical or verbal result as unverified.

CHAPTER 6 Geometric optics: reflection, refraction, and images

Rebuild the chapter from first principles

The claim I need to own is this: The model in Geometric optics: reflection, refraction, and images controls the work. I do not count that as learned just because the sentence looks familiar. I should be able to name the objects, state what changes and what stays fixed, recover the rule from the definitions,

and explain why the result is allowed.

The move

My working sequence

1. **Translate.** Rewrite the prompt in the language of geometric optics: reflection, refraction, and images. List the known quantities, the unknown, the units or types, and any hidden constraint.
2. **Choose.** State the theorem, model, algorithm, accounting rule, or physical law before substituting values. This is where I make the assumption visible.
3. **Execute.** Work one justified step at a time and keep intermediate state readable enough that I can audit it later.
4. **Verify.** Check a boundary case, sign, unit, invariant, order of magnitude, or alternative derivation. Then translate the result back into an ordinary sentence.

Details I would refuse to skip

- **Definitions:** I should be able to define every technical noun in the chapter without using that same noun in the definition.
- **Assumptions:** I write the condition that makes the method legal beside the method itself. A correct procedure under the wrong assumptions is still a wrong answer.
- **Representation:** I move freely among words, equations or code, a diagram, and a small numerical example. If one representation disagrees with another, that disagreement is useful evidence.
- **Failure modes:** I keep the nearest counterexample in mind: the boundary where the rule changes, the invariant breaks, or the model stops matching reality.
- **Communication:** My final answer names what the result means and what it does not establish. I do not let notation do the explanatory work for me.

Sanity check

Closed-note check. Can I teach geometric optics: reflection, refraction, and images on a blank page, derive or reconstruct its main rule, work a fresh example, and diagnose a deliberately broken solution? If I can only recognize the finished work, I am not done.

How this chapter connects

I read this chapter as the bridge from maxwell's equations and electromagnetic waves to interference and thin films. The earlier material supplies the language and constraints; this chapter adds a new reasoning move; the later material asks me to use that move without being told its name. That connection matters because exams and real projects mix chapters on purpose.

Geometric optics treats light as rays when structures are large compared with wavelength. Reflection obeys $\theta_i = \theta_r$. Refraction obeys Snell's law,

$$n_1 \sin \theta_1 = n_2 \sin \theta_2, \quad v = c/n.$$

Light bends toward the normal entering a higher-index medium. Total internal reflection is possible only

from higher to lower index and above $\theta_c = \sin^{-1}(n_2/n_1)$.

For thin lenses and spherical mirrors,

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}, \quad m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}.$$

A ray diagram should predict whether an image is real or virtual, upright or inverted, enlarged or reduced before arithmetic supplies exact values.

How I actually think about it

I draw the principal rays first and use the sign convention second. If my equation says an image is upright and tiny while the ray sketch says inverted and large, I stop instead of trusting the calculator.

The easy version

Reflection bounces a ray; refraction turns it because light changes speed. A lens redirects many rays so they meet, or appear to come from the same point.

Worked example

An object 30 cm from a converging lens with $f = 10$ cm gives $1/d_i = 1/10 - 1/30 = 1/15$, so $d_i = 15$ cm. Magnification is $-15/30 = -0.50$: real, inverted, and half-sized.

Solved chapter practice

Practice. Light goes from glass ($n = 1.50$) to air. Find the critical angle.

Solution. At the critical angle the refracted ray is at 90° , so $1.50 \sin \theta_c = 1.00$. Therefore $\theta_c = \sin^{-1}(2/3) = 41.8^\circ$. Total internal reflection occurs for larger incident angles inside the glass.

Mastery practice A. Reconstruct geometric optics: reflection, refraction, and images from a blank page. Include the central definition, the governing rule, one required assumption, and one boundary case.

Solution. Start from the blue idea box, but rewrite it in my own words. Identify the objects and state, name the rule before using it, copy the relevant assumption from the details audit, and choose a boundary where that assumption becomes equality or fails. A complete solution explains why each part belongs; a list of vocabulary is not enough.

Mastery practice B. A classmate gets a polished-looking answer to a geometric optics: reflection, refraction, and images problem but never states a model or checks the result. Write the shortest useful review of that solution.

Solution. I would ask four concrete questions: What exactly are the inputs and desired output? Which rule licenses the main step? Which assumption could invalidate it? Which independent check supports the conclusion? If the answer cannot survive those four questions, I treat the numerical or verbal result as unverified.

CHAPTER 7 Interference and thin films

Rebuild the chapter from first principles

The claim I need to own is this: The model in Interference and thin films controls the work. I do not count that as learned just because the sentence looks familiar. I should be able to name the objects, state what changes and what stays fixed, recover the rule from the definitions, and explain why the result is allowed.

The move

My working sequence

1. **Translate.** Rewrite the prompt in the language of interference and thin films. List the known quantities, the unknown, the units or types, and any hidden constraint.
2. **Choose.** State the theorem, model, algorithm, accounting rule, or physical law before substituting values. This is where I make the assumption visible.
3. **Execute.** Work one justified step at a time and keep intermediate state readable enough that I can audit it later.
4. **Verify.** Check a boundary case, sign, unit, invariant, order of magnitude, or alternative derivation. Then translate the result back into an ordinary sentence.

Details I would refuse to skip

- **Definitions:** I should be able to define every technical noun in the chapter without using that same noun in the definition.
- **Assumptions:** I write the condition that makes the method legal beside the method itself. A correct procedure under the wrong assumptions is still a wrong answer.
- **Representation:** I move freely among words, equations or code, a diagram, and a small numerical example. If one representation disagrees with another, that disagreement is useful evidence.
- **Failure modes:** I keep the nearest counterexample in mind: the boundary where the rule changes, the invariant breaks, or the model stops matching reality.
- **Communication:** My final answer names what the result means and what it does not establish. I do not let notation do the explanatory work for me.

Sanity check

Closed-note check. Can I teach interference and thin films on a blank page, derive or reconstruct its main rule, work a fresh example, and diagnose a deliberately broken solution? If I can only recognize the finished work, I am not done.

How this chapter connects

I read this chapter as the bridge from geometric optics: reflection, refraction, and images to diffraction, gratings, and resolution. The earlier material supplies the language and constraints; this chapter adds a new reasoning move; the later material asks me to use that move without being told its name. That connection matters because exams and real projects mix chapters on purpose.

Interference depends on phase, not merely on rays crossing. For coherent in-phase sources, constructive interference occurs when path difference $\Delta r = m\lambda$ and destructive interference when $\Delta r = (m + \frac{1}{2})\lambda$. In the small-angle double-slit pattern,

$$y_m \approx \frac{m\lambda L}{d}.$$

Thin-film interference includes both path difference inside the film and possible π phase reversals on reflection from a higher-index boundary. The wavelength inside a medium is λ/n while frequency remains fixed.

How I actually think about it

For thin films I make a two-row checklist: phase change from travel, then phase flips from reflection. Trying to remember a single bright-film formula fails because the boundary indices can reverse the condition.

The easy version

Two waves brighten each other when crest meets crest and cancel when crest meets trough. Extra travel distance and reflection can both shift which parts meet.

Worked example

For two narrow slits 0.20 mm apart, screen distance 2.0 m, and 500 nm light, adjacent bright fringes are separated by $\Delta y = \lambda L/d = 5.0$ mm.

Solved chapter practice

Practice. In a double-slit experiment, $\lambda = 600$ nm, $d = 0.30$ mm, and $L = 1.5$ m. Find the position of the third bright fringe from center.

Solution. With $m = 3$, $y_3 = m\lambda L/d = 3(600 \times 10^{-9})(1.5)/(3.0 \times 10^{-4}) = 9.0 \times 10^{-3}$ m, or 9.0 mm.

Mastery practice A. Reconstruct interference and thin films from a blank page. Include the central definition, the governing rule, one required assumption, and one boundary case.

Solution. Start from the blue idea box, but rewrite it in my own words. Identify the objects and state, name the rule before using it, copy the relevant assumption from the details audit, and choose a boundary where that assumption becomes equality or fails. A complete solution explains why each part belongs; a list of vocabulary is not enough.

Mastery practice B. A classmate gets a polished-looking answer to a interference and thin films problem but never states a model or checks the result. Write the shortest useful review of that solution.

Solution. I would ask four concrete questions: What exactly are the inputs and desired output? Which rule licenses the main step? Which assumption could invalidate it? Which independent

check supports the conclusion? If the answer cannot survive those four questions, I treat the numerical or verbal result as unverified.

CHAPTER 8 Diffraction, gratings, and resolution

Rebuild the chapter from first principles

The claim I need to own is this: The model in Diffraction, gratings, and resolution controls the work. I do not count that as learned just because the sentence looks familiar. I should be able to name the objects, state what changes and what stays fixed, recover the rule from the definitions, and explain why the result is allowed.

The move

My working sequence

1. **Translate.** Rewrite the prompt in the language of diffraction, gratings, and resolution. List the known quantities, the unknown, the units or types, and any hidden constraint.
2. **Choose.** State the theorem, model, algorithm, accounting rule, or physical law before substituting values. This is where I make the assumption visible.
3. **Execute.** Work one justified step at a time and keep intermediate state readable enough that I can audit it later.
4. **Verify.** Check a boundary case, sign, unit, invariant, order of magnitude, or alternative derivation. Then translate the result back into an ordinary sentence.

Details I would refuse to skip

- **Definitions:** I should be able to define every technical noun in the chapter without using that same noun in the definition.
- **Assumptions:** I write the condition that makes the method legal beside the method itself. A correct procedure under the wrong assumptions is still a wrong answer.
- **Representation:** I move freely among words, equations or code, a diagram, and a small numerical example. If one representation disagrees with another, that disagreement is useful evidence.
- **Failure modes:** I keep the nearest counterexample in mind: the boundary where the rule changes, the invariant breaks, or the model stops matching reality.
- **Communication:** My final answer names what the result means and what it does not establish. I do not let notation do the explanatory work for me.

Sanity check

Closed-note check. Can I teach diffraction, gratings, and resolution on a blank page, derive or reconstruct its main rule, work a fresh example, and diagnose a deliberately broken solution? If I

can only recognize the finished work, I am not done.

How this chapter connects

I read this chapter as the bridge from interference and thin films to special relativity and relativistic dynamics. The earlier material supplies the language and constraints; this chapter adds a new reasoning move; the later material asks me to use that move without being told its name. That connection matters because exams and real projects mix chapters on purpose.

A finite aperture spreads light. A single slit of width a has dark minima at

$$a \sin \theta = m\lambda, \quad m = 1, 2, \dots$$

The central maximum is twice the angular width of neighboring maxima. A diffraction grating with spacing d has sharp principal maxima at $d \sin \theta = m\lambda$ because many slits reinforce only at narrowly selected angles.

Diffraction also limits resolution. For a circular aperture, the Rayleigh criterion is $\theta_{\min} = 1.22\lambda/D$. A larger aperture or shorter wavelength resolves finer angular detail.

How I actually think about it

My shorthand for this chapter is: my shorthand for this chapter is: diffraction is not an equipment defect; it is what waves do when confined. Making a slit narrower gives a wider pattern, which is the opposite of the geometric intuition that a narrow opening should create a narrow beam.

The easy version

Forcing a wave through a small opening makes it fan out. Large openings keep the direction more precise; small openings blur it.

Worked example

For 500 nm light through a 0.10 mm slit, the first minimum satisfies $\sin \theta = 5.0 \times 10^{-3}$, so $\theta \approx 0.286^\circ$.

Solved chapter practice

Practice. A telescope of diameter 0.20 m observes 550 nm light. Find its diffraction-limited angular resolution.

Solution. $\theta_{\min} = 1.22\lambda/D = 1.22(550 \times 10^{-9})/0.20 = 3.36 \times 10^{-6}$ rad, about 0.69 arcseconds.

Mastery practice A. Reconstruct diffraction, gratings, and resolution from a blank page. Include the central definition, the governing rule, one required assumption, and one boundary case.

Solution. Start from the blue idea box, but rewrite it in my own words. Identify the objects and state, name the rule before using it, copy the relevant assumption from the details audit, and choose a boundary where that assumption becomes equality or fails. A complete solution explains why each part belongs; a list of vocabulary is not enough.

Mastery practice B. A classmate gets a polished-looking answer to a diffraction, gratings, and

resolution problem but never states a model or checks the result. Write the shortest useful review of that solution.

Solution. I would ask four concrete questions: What exactly are the inputs and desired output? Which rule licenses the main step? Which assumption could invalidate it? Which independent check supports the conclusion? If the answer cannot survive those four questions, I treat the numerical or verbal result as unverified.

CHAPTER 9 Special relativity and relativistic dynamics

Rebuild the chapter from first principles

The claim I need to own is this: The model in Special relativity and relativistic dynamics controls the work. I do not count that as learned just because the sentence looks familiar. I should be able to name the objects, state what changes and what stays fixed, recover the rule from the definitions, and explain why the result is allowed.

The move

My working sequence

1. **Translate.** Rewrite the prompt in the language of special relativity and relativistic dynamics. List the known quantities, the unknown, the units or types, and any hidden constraint.
2. **Choose.** State the theorem, model, algorithm, accounting rule, or physical law before substituting values. This is where I make the assumption visible.
3. **Execute.** Work one justified step at a time and keep intermediate state readable enough that I can audit it later.
4. **Verify.** Check a boundary case, sign, unit, invariant, order of magnitude, or alternative derivation. Then translate the result back into an ordinary sentence.

Details I would refuse to skip

- **Definitions:** I should be able to define every technical noun in the chapter without using that same noun in the definition.
- **Assumptions:** I write the condition that makes the method legal beside the method itself. A correct procedure under the wrong assumptions is still a wrong answer.
- **Representation:** I move freely among words, equations or code, a diagram, and a small numerical example. If one representation disagrees with another, that disagreement is useful evidence.
- **Failure modes:** I keep the nearest counterexample in mind: the boundary where the rule changes, the invariant breaks, or the model stops matching reality.
- **Communication:** My final answer names what the result means and what it does not establish. I do not let notation do the explanatory work for me.

Sanity check

Closed-note check. Can I teach special relativity and relativistic dynamics on a blank page, derive or reconstruct its main rule, work a fresh example, and diagnose a deliberately broken solution? If I can only recognize the finished work, I am not done.

How this chapter connects

I read this chapter as the bridge from diffraction, gratings, and resolution to the cumulative course model. The earlier material supplies the language and constraints; this chapter adds a new reasoning move; the later material asks me to use that move without being told its name. That connection matters because exams and real projects mix chapters on purpose.

Special relativity begins with two postulates: physics has the same form in every inertial frame, and every inertial observer measures the same vacuum light speed. The Lorentz factor is

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}.$$

Proper time $\Delta\tau$ is measured by one clock at both events, giving $\Delta t = \gamma\Delta\tau$. Proper length L_0 is measured in the object's rest frame, giving $L = L_0/\gamma$. Simultaneity is frame-dependent; these are consequences of spacetime geometry, not optical delay.

Relativistic momentum and energy are

$$\vec{p} = \gamma m \vec{v}, \quad E = \gamma mc^2, \quad E^2 = (pc)^2 + (mc^2)^2.$$

Four-momentum conservation replaces classical collision formulas at high speed.

How I actually think about it

I identify the proper quantity before using a formula. The frame with one clock at both events owns proper time; the object's rest frame owns proper length. Mixing those definitions causes more trouble than the algebra.

The easy version

Space and time adjust between observers so that everyone still measures light at the same speed. What stays fully shared is the spacetime interval, not separate distance and time.

Worked example

At $v = 0.80c$, $\gamma = 1/\sqrt{1 - 0.64} = 1.667$. A 1.0 hour proper interval on the moving clock lasts 1.667 hours in the lab, while a 10 m proper length along the motion is measured as 6.0 m in the lab.

Solved chapter practice

Practice. A muon has proper lifetime $2.2\mu\text{s}$ and moves at $0.98c$. Find its mean lifetime and travel distance in the lab.

Solution. $\gamma = 1/\sqrt{1 - 0.98^2} = 5.03$. Thus $\Delta t = 5.03(2.2\mu\text{s}) = 11.1\mu\text{s}$. The mean lab distance is

$v\Delta t = 0.98(3.00 \times 10^8)(11.1 \times 10^{-6}) = 3.26 \text{ km}$. Classically it would travel only about 0.65 km.

Mastery practice A. Reconstruct special relativity and relativistic dynamics from a blank page. Include the central definition, the governing rule, one required assumption, and one boundary case.

Solution. Start from the blue idea box, but rewrite it in my own words. Identify the objects and state, name the rule before using it, copy the relevant assumption from the details audit, and choose a boundary where that assumption becomes equality or fails. A complete solution explains why each part belongs; a list of vocabulary is not enough.

Mastery practice B. A classmate gets a polished-looking answer to a special relativity and relativistic dynamics problem but never states a model or checks the result. Write the shortest useful review of that solution.

Solution. I would ask four concrete questions: What exactly are the inputs and desired output? Which rule licenses the main step? Which assumption could invalidate it? Which independent check supports the conclusion? If the answer cannot survive those four questions, I treat the numerical or verbal result as unverified.

Final study check

This course changes models several times. Magnetic fields bend charges, induction links changing flux to emf, Maxwell turns fields into waves, optics alternates between ray and wave descriptions, and relativity rebuilds the coordinate system itself. I always write which model I am using and which assumptions make it valid.