UCLA PHYSICS FIELD NOTES

PHYSICS 1B

Oscillations, Waves, and Electric Fields

A student-readable route from periodic motion to circuits and the electric field

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	**Simple harmonic motion**	Connect restoring forces, sinusoidal motion, phase, and energy.
2	**Driven oscillations**	Read damping, resonance, and transients as competing physical effects.
3	**Traveling waves**	Use a wave function to track shape, direction, speed, and phase.
4	**Superposition and sound**	Build standing waves, beats, and normal modes from interference.
5	**Charge and electric field**	Move from Coulomb's law to field superposition and continuous distributions.
6	**Gauss's law**	Exploit symmetry to connect flux and enclosed charge.
7	**Electric potential**	Use scalar energy accounting to understand fields and conductors.
8	**Capacitance**	Relate geometry, charge storage, dielectric response, and field energy.
9	**Current and DC circuits**	Combine microscopic current ideas with Kirchhoff's rules and time-dependent RC behavior.
10	**Synthesis**	Choose between force, field, potential, energy, and circuit descriptions.

Scope anchor: https://catalog.registrar.ucla.edu/course/2024/PHYSICS1B. 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 Simple harmonic 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 Damping, driving, and resonance **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 Traveling waves and the wave function **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 Superposition, standing waves, and sound **11**

4.1 Rebuild the chapter from first principles 11

4.2 Details I would refuse to skip 11

4.3 How this chapter connects 12

5 Electric charge, Coulomb's law, and electric field **13**

5.1 Rebuild the chapter from first principles 13

5.2 Details I would refuse to skip 13

5.3 How this chapter connects 14

6 Electric flux and Gauss's law **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 Electric potential and electrostatic energy **17**

7.1 Rebuild the chapter from first principles 17

7.2 Details I would refuse to skip 18

7.3 How this chapter connects 18

8 Capacitance, dielectrics, and stored energy **19**
8.1 Rebuild the chapter from first principles . . . 19
8.2 Details I would refuse to skip . . . 20
8.3 How this chapter connects . . . 20

9 Current, resistance, and DC circuits **21**
9.1 Rebuild the chapter from first principles . . . 21
9.2 Details I would refuse to skip . . . 22
9.3 How this chapter connects . . . 22

CHAPTER 1 Simple harmonic motion

Rebuild the chapter from first principles

The claim I need to own is this: The model in Simple harmonic 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 simple harmonic 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 simple harmonic 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 damping, driving, and resonance. 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 equilibrium is stable when a small displacement produces a force back toward equilibrium. For an ideal spring, $F = -kx$, so Newton's law becomes

$$m\ddot{x} + kx = 0, \qquad x(t) = A\cos(\omega t + \phi), \qquad \omega = \sqrt{k/m}.$$

Amplitude A and phase ϕ come from initial conditions; angular frequency comes from the system. Velocity is one-quarter cycle out of phase with position, and acceleration is exactly opposite position. Total energy stays fixed:

$$E = \tfrac{1}{2}mv^2 + \tfrac{1}{2}kx^2 = \tfrac{1}{2}kA^2.$$

Small-angle pendulum motion is approximately harmonic because $\sin\theta \approx \theta$, giving $\omega = \sqrt{g/L}$.

How I actually think about it

I picture SHM as energy passing back and forth. At the endpoints the oscillator has all spring potential and no speed; at equilibrium it has maximum speed and minimum spring potential. The sine curve is the record of that exchange.

The easy version

Pull a system away from its comfortable position and it tries to return. Inertia carries it past the center, so the correction repeats.

Worked example

A 0.50 kg mass on a 200 N/m spring has $\omega = \sqrt{200/0.50} = 20$ rad/s and $T = 2\pi/\omega = 0.314$ s. If $A = 0.10$ m, its maximum speed is $A\omega = 2.0$ m/s.

Solved chapter practice

Practice. An oscillator has $x(t) = 0.08\cos(5t + \pi/3)$ m. Find its position, velocity, and acceleration at $t = 0$.
Solution. $x(0) = 0.08\cos(\pi/3) = 0.040$ m. Since $v = -A\omega\sin(\omega t + \phi)$, $v(0) = -0.40\sin(\pi/3) = -0.346$ m/s. Since $a = -\omega^2 x$, $a(0) = -25(0.040) = -1.00$ m/s^2.

Mastery practice A. Reconstruct simple harmonic 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 simple harmonic 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 Damping, driving, and resonance

Rebuild the chapter from first principles

The claim I need to own is this: The model in Damping, driving, and resonance 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 damping, driving, and resonance. 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 damping, driving, and resonance 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 simple harmonic motion to traveling waves and the wave function. 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 damped oscillator loses mechanical energy, often through a force $-b\dot{x}$. A driven oscillator also receives energy from an external periodic force:

$$m\ddot{x} + b\dot{x} + kx = F_0 \cos(\omega_d t).$$

The transient remembers the initial conditions but fades; the steady-state response follows the driving frequency. The amplitude is largest near resonance, where the driver efficiently replaces energy lost each cycle. Damping lowers and broadens the resonance peak.

How I actually think about it

My shorthand for this chapter is: my shorthand for this chapter is: resonance is not “the frequency makes it explode.” It is repeated, correctly timed energy transfer. With damping, the outgoing energy eventually balances the incoming energy, so the steady amplitude remains finite.

The easy version

Push a swing at the right moment and small pushes add up. Push at the wrong rhythm and one push partly undoes the previous one.

Worked example

A weakly damped $m = 1.0$ kg, $k = 100$ N/m oscillator has natural angular frequency $\omega_0 = 10$ rad/s. A driver near 10 rad/s produces a much larger steady response than one at 2 or 30 rad/s.

Solved chapter practice

Practice. Two oscillators have the same m and k, but oscillator B has larger damping. Compare their resonance curves.
Solution. B’s peak is lower and wider, and its resonant frequency is shifted slightly below the undamped ω_0. More damping removes more energy per cycle, so the same driving force cannot maintain as large an amplitude; the response is less selective in frequency.

Mastery practice A. Reconstruct damping, driving, and resonance 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 damping, driving, and resonance 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 Traveling waves and the wave function

Rebuild the chapter from first principles

The claim I need to own is this: The model in Traveling waves and the wave function 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 traveling waves and the wave function. 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 traveling waves and the wave function 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 damping, driving, and resonance to superposition, standing waves, and sound. 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 wave transports energy and information while the medium's particles oscillate locally. A sinusoidal wave traveling in the $+x$ direction can be written

$$y(x,t) = A\cos(kx - \omega t + \phi), \qquad k = \frac{2\pi}{\lambda}, \qquad \omega = 2\pi f, \qquad v = \frac{\omega}{k} = f\lambda.$$

Changing $kx - \omega t$ to $kx + \omega t$ reverses the travel direction. On a stretched string, $v = \sqrt{T/\mu}$, where T is tension and μ is linear mass density.

How I actually think about it

I test a wave's direction by holding the phase constant. If $kx - \omega t$ is constant, increasing time requires increasing x, so the pattern moves right. This is more reliable than memorizing a sign slogan.

The easy version

The shape slides through space. Each bit of the medium only moves around its own neighborhood; the pattern is what travels far.

Worked example

For $y = 0.02\cos(4x - 20t)$ in SI units, $A = 0.02$ m, $k = 4$ rad/m, $\omega = 20$ rad/s, and $v = \omega/k = 5$ m/s in the $+x$ direction.

Solved chapter practice

Practice. A string under 90 N tension has linear density 0.010 kg/m. A 30 Hz wave travels on it. Find speed and wavelength.
Solution. $v = \sqrt{T/\mu} = \sqrt{90/0.010} = 94.9$ m/s. Then $\lambda = v/f = 94.9/30 = 3.16$ m.

Mastery practice A. Reconstruct traveling waves and the wave function 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 traveling waves and the wave function 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 Superposition, standing waves, and sound

Rebuild the chapter from first principles

The claim I need to own is this: The model in Superposition, standing waves, and sound 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 superposition, standing waves, and sound. 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 superposition, standing waves, and sound 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 traveling waves and the wave function to electric charge, coulomb's law, and electric 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.

In a linear medium, overlapping disturbances add. Two equal waves traveling oppositely create a standing wave:

$$A\cos(kx-\omega t)+A\cos(kx+\omega t)=2A\cos(kx)\cos(\omega t).$$

Nodes remain at zero displacement; antinodes oscillate most strongly. A string fixed at both ends has $\lambda_n = 2L/n$ and $f_n = nv/(2L)$. An open-open air column has the same harmonic pattern, while a tube closed at one end supports odd harmonics $f_n = nv/(4L)$ for odd n.

Sound intensity is power per area and follows an inverse-square law for a point source. The decibel scale is logarithmic: $\beta = 10\log_{10}(I/I_0)$.

How I actually think about it

My shorthand for this chapter is: my shorthand for this chapter is: a standing wave is not a frozen string. The material is moving, but the nodes pin the pattern in place. Boundary conditions decide which wavelengths fit; the source cannot force an arbitrary normal mode.

The easy version

Only wave patterns that fit the boundaries cleanly can reinforce themselves. Every other pattern partly cancels after repeated reflections.

Worked example

A 0.80 m string with wave speed 160 m/s has fundamental frequency $f_1 = v/(2L) = 100$ Hz. Its next two harmonics are 200 and 300 Hz.

Solved chapter practice

Practice. Two tuning forks at 440 Hz and 446 Hz sound together. What beat frequency is heard, and what does it represent?
Solution. $f_{\text{beat}} = |446-440| = 6$ Hz. The listener hears a tone near the average frequency whose

loudness rises and falls six times per second as the two waves alternate between constructive and destructive interference.

Mastery practice A. Reconstruct superposition, standing waves, and sound 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 superposition, standing waves, and sound 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 Electric charge, Coulomb's law, and electric field

Rebuild the chapter from first principles

The claim I need to own is this: The model in Electric charge, Coulomb's law, and electric 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 electric charge, coulomb's law, and electric 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 electric charge, coulomb's law, and electric 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 superposition, standing waves, and sound to electric flux and gauss's law. 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.

Charge is conserved and quantized. Point charges interact through

$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}\hat{r}, \qquad \vec{E} = \frac{\vec{F}}{q_{\text{test}}}.$$

The field belongs to the source configuration and exists independently of the test charge. Multiple sources combine by vector superposition. For a continuous distribution,

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\epsilon_0}\int \frac{dq}{R^2}\hat{R}.$$

Symmetry can cancel components before integration, but it cannot replace a clear source-to-field-point vector.

How I actually think about it

I separate source charges from the test charge. First the sources create $\vec{E}$; then a particular object feels $\vec{F} = q\vec{E}$. A negative object accelerates opposite the field arrows.

The easy version

The field is a map drawn by source charges. At every point, the arrow says which way a tiny positive charge would be pushed and how strongly.

Worked example

Two equal positive charges lie symmetrically about the origin. At a point on their perpendicular bisector, horizontal field components cancel while vertical components add. Drawing the vectors first prevents treating field magnitudes as scalars.

Solved chapter practice

Practice. Charges $+q$ are at $x = \pm a$. Find the field at the origin and describe the field direction at a point high on the positive y axis.
Solution. At the origin the two equal fields point oppositely, so $\vec{E} = 0$. At $(0, y)$, the x components still cancel and the y components add upward. Its magnitude is $E = 2kq\,y/(a^2 + y^2)^{3/2}$.

Mastery practice A. Reconstruct electric charge, coulomb's law, and electric 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 electric charge, coulomb's law, and electric 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 6 Electric flux and Gauss's law

Rebuild the chapter from first principles

The claim I need to own is this: The model in Electric flux and Gauss's law 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 electric flux and gauss's law. 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 electric flux and gauss's law 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 electric charge, coulomb's law, and electric field to electric potential and electrostatic energy. 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.

Electric flux measures field passing through an oriented surface:

$$\Phi_E = \int \vec{E} \cdot d\vec{A}, \qquad \oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enclosed}}}{\epsilon_0}.$$

Gauss's law is always true, but it is only a shortcut for finding E when symmetry makes the field magnitude constant on useful parts of a closed surface and fixes its direction relative to $d\vec{A}$. Spherical, cylindrical, and planar symmetry are the standard cases.

In electrostatic equilibrium, a conductor has zero field inside its material, excess charge on its surface, and an external field perpendicular to that surface.

How I actually think about it

I do not choose a Gaussian surface because it resembles the object in a sketch. I choose it because symmetry lets me pull E out of the flux integral. Enclosed charge controls net flux; outside charge can still affect the local field.

The easy version

A closed surface is an imaginary bubble. Net electric field flowing out of the bubble counts the net charge trapped inside.

Worked example

For a point charge, choose a sphere of radius r. Symmetry gives E constant and radial, so $E(4\pi r^2) = q/\epsilon_0$ and $E = q/(4\pi\epsilon_0 r^2)$.

Solved chapter practice

Practice. An infinite sheet has uniform surface charge density σ. Find the field magnitude on either side.
Solution. Use a pillbox of face area A crossing the sheet. Flux leaves through both flat faces: $2EA$. Enclosed charge is σA. Gauss's law gives $2EA = \sigma A/\epsilon_0$, so $E = \sigma/(2\epsilon_0)$, directed away from a positive sheet.

Mastery practice A. Reconstruct electric flux and gauss's law 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 electric flux and gauss's law 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 Electric potential and electrostatic energy

Rebuild the chapter from first principles

The claim I need to own is this: The model in Electric potential and electrostatic energy 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 electric potential and electrostatic energy. 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 electric potential and electrostatic energy 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 electric flux and gauss's law to capacitance, dielectrics, and stored energy. 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.

Potential is potential energy per unit charge. It is a scalar, which often makes superposition easier:

$$\Delta V = -\int_a^b \vec{E}\cdot d\vec{\ell}, \qquad V(\vec{r}) = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}, \qquad U = qV.$$

The field points toward decreasing potential, with $\vec{E} = -\nabla V$. Equipotential surfaces are perpendicular to field lines, and moving along one requires no electrostatic work.

How I actually think about it

My shorthand for this chapter is: my shorthand for this chapter is: voltage is not energy by itself; it is energy per coulomb. A positive charge naturally moves toward lower V, while a negative charge can lower its energy by moving toward higher V because $U = qV$.

The easy version

Potential is an electric height map. Field arrows point downhill on that map, but the sign of the moving charge decides whether downhill in potential is downhill in energy.

Worked example

Moving a proton through a potential drop of 100 V changes its potential energy by $q\Delta V = -100$ eV. If only electrostatic forces act, its kinetic energy increases by 100 eV.

Solved chapter practice

Practice. A $+3.0\,\mu$C charge and a $-2.0\,\mu$C charge are each 0.50 m from a point. Find the potential there.
Solution. Potential adds algebraically: $V = k(q_1/r_1 + q_2/r_2) = 8.99 \times 10^9[(1.0 \times 10^{-6})/0.50] = 1.80 \times 10^4$ V. No vector components are needed.

Mastery practice A. Reconstruct electric potential and electrostatic energy 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 electric potential and electrostatic energy 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 Capacitance, dielectrics, and stored energy

Rebuild the chapter from first principles

The claim I need to own is this: The model in Capacitance, dielectrics, and stored energy 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 capacitance, dielectrics, and stored energy. 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 capacitance, dielectrics, and stored energy 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 electric potential and electrostatic energy to current, resistance, and dc 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.

Capacitance measures how much separated charge a geometry stores per potential difference:

$$C = \frac{Q}{\Delta V}, \qquad C_{\text{parallel plate}} = \frac{\epsilon A}{d}, \qquad U_C = \frac{Q^2}{2C} = \frac{1}{2}C(\Delta V)^2.$$

Capacitors in parallel share voltage and add directly. Capacitors in series carry equal charge and add reciprocally. A dielectric polarizes, reducing the internal field for fixed free charge and increasing capacitance.

The phrase "battery connected" matters. Connected means voltage is fixed and charge can flow. Disconnected means free charge is fixed, so inserting a dielectric changes voltage instead.

How I actually think about it

I write FIXED V or FIXED Q before a dielectric problem. The same physical insertion gives different energy changes depending on whether the battery can exchange charge with the plates.

The easy version

A capacitor stores separated charge. Bigger plates give charge more room; smaller spacing makes the same charge separation produce less voltage, so capacitance rises.

Worked example

Two capacitors $3\,\mu$F and $6\,\mu$F in series have $C_{\text{eq}} = (1/3 + 1/6)^{-1} = 2\,\mu$F. In parallel they have $C_{\text{eq}} = 9\,\mu$F.

Solved chapter practice

Practice. A $4.0\,\mu$F capacitor is charged to 12 V and disconnected. A dielectric with $\kappa = 3$ fills it. Find new C, Q, V, and stored energy.
Solution. Disconnected means Q stays $CV = 48\,\mu$C. New $C' = \kappa C = 12\,\mu$F, so $V' = Q/C' = 4.0$ V. The energy is $U' = Q^2/(2C') = 96\,\mu$J, one third of the original $288\,\mu$J.

Mastery practice A. Reconstruct capacitance, dielectrics, and stored energy 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 capacitance, dielectrics, and stored energy 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 Current, resistance, and DC circuits

Rebuild the chapter from first principles

The claim I need to own is this: The model in Current, resistance, and DC 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 current, resistance, and dc 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 current, resistance, and dc 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 capacitance, dielectrics, and stored energy 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.

Current is charge flow rate, $I = dQ/dt$. In an ohmic material, $V = IR$ with $R = \rho L/A$. Electric power can be written $P = IV = I^2R = V^2/R$. Kirchhoff's junction rule expresses charge conservation; the loop rule expresses energy conservation.

For an RC charging circuit,

$$Q(t) = C\mathcal{E}\left(1 - e^{-t/RC}\right), \qquad I(t) = \frac{\mathcal{E}}{R}e^{-t/RC}.$$

The time constant $\tau = RC$ sets the response scale. After one τ, charging reaches about 63.2% of the final value; discharge leaves about 36.8%.

How I actually think about it

I mark current directions arbitrarily and let the algebra correct me. A negative answer means the real direction is opposite my arrow, not that I failed. At a junction, current does not get "used up"; energy is transferred while charge is conserved.

The easy version

Voltage is the energy push per charge, current is how much charge passes each second, and resistance measures how strongly the material opposes that flow.

Worked example

A $6\,\Omega$ and $3\,\Omega$ resistor in parallel have $R_{\text{eq}} = 2\,\Omega$. Across a 12 V battery, total current is 6 A, split as 2 A through $6\,\Omega$ and 4 A through $3\,\Omega$.

Solved chapter practice

Practice. A $10\,\mu$F capacitor charges through a 200 kΩ resistor from a 9.0 V battery. Find τ, the charge after one time constant, and the initial current.
Solution. $\tau = RC = (2.0 \times 10^5)(1.0 \times 10^{-5}) = 2.0$ s. The final charge is $C\mathcal{E} = 90\,\mu$C, so at $t = \tau$, $Q = 0.632(90) = 56.9\,\mu$C. Initially the uncharged capacitor acts like a wire, giving $I_0 = \mathcal{E}/R = 45\,\mu$A.

Mastery practice A. Reconstruct current, resistance, and dc 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 current, resistance, and dc 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.

Final study check

For oscillations and waves I track phase, boundaries, and energy flow. For electricity I decide whether a vector field, scalar potential, or circuit model is the cleanest language. In every case, the diagram and limiting cases should tell the same story as the algebra.