Physics, Quantum Mechanics, Quantum Computing, and Energy

From conservation laws and field theory to qubits, noisy hardware, and disciplined reasoning about energy claims.

Split from the core technical omnibus and expanded into a standalone zero-to-frontier teaching book.

Prepared on March 21, 2026

Purpose	Teach this technical family as its own coherent discipline rather than as a compressed chapter bundle.
Reader	Motivated beginner through advanced builder who wants a roadmap toward frontier contribution.
Method	Read • solve • simulate • build • measure • explain.

Contents

Navigation note: read Chapter 1 first, then work straight through or jump to the project and resource chapters when you are ready to turn theory into experiments, notebooks, code, or design reviews.

Chapter 1. How to use this volume

What this volume is trying to do

Physics teaches you to ask a special class of questions: what is the state, what is conserved, what symmetries apply, what is being approximated away, and what measurements would distinguish competing explanations? Those questions remain useful whether you are analyzing a falling object, an electromagnetic cavity, a chemical reactor, a transistor, or a noisy qubit.

This volume moves from classical mechanics and fields into quantum mechanics and then into quantum computing. That sequence matters. Quantum theory is not a replacement for classical thought but an extension of disciplined mathematical modeling into regimes where superposition, operator structure, and measurement statistics become unavoidable.

Treat quantum computing with the same seriousness you would bring to any other engineering field: algorithms matter, but so do hardware constraints, calibration, error sources, control electronics, and realistic performance limits.

Dependency ladder

- Comfort with algebra, calculus, vectors, complex numbers, linear algebra, and probability makes the physics chapters dramatically more readable.
- Measurement discipline comes before elegance: units, signs, reference frames, and order-of-magnitude checks prevent most mistakes.
- Quantum computing depends on both mathematics and hardware awareness; it is best learned as a synthesis of theory, software, and experiment.

Study engine for this book

- Read for structure first: identify state variables, conserved quantities, interfaces, approximations, and failure modes before trying to memorize details.
- Solve something by hand: equations become usable only after you manipulate them yourself and check limiting cases.
- Simulate early: small Python notebooks expose scaling, sensitivity, stiffness, and numerical fragility faster than prose alone.
- Build or instrument when possible: code, circuits, data pipelines, and experimental setups reveal assumptions hidden by clean derivations.
- Measure against reality: compare models to logs, unit tests, bench data, public datasets, and reproducible calculations.
- Explain what changed in your understanding: the act of writing, teaching, or diagramming usually reveals what you still do not understand.

Chapter 2. Classical physics and unified dynamics

Classical physics supplies the conservation laws and constitutive relationships from which most engineering models are built. Mechanics, thermodynamics, electromagnetism, optics, and statistical reasoning all appear repeatedly in the chapters that follow.

Mechanics: kinematics, dynamics, and constraints

Kinematics describes motion without asking why. Dynamics connects motion to forces and moments. Start from a free-body diagram, choose coordinates, declare constraints, and write Newton-Euler or Lagrange equations. In many systems, the hardest part is not solving the equation but formulating the correct one.

MECHANICAL RELATIONS

Resonance, damping, friction, backlash, compliance, fatigue, and manufacturability are often more important than a textbook-perfect equation. Real mechanisms also have tolerances, misalignment, thermal drift, lubrication limits, and nonlinear contact behavior.

Thermodynamics and statistical thinking

Thermodynamics tracks energy, entropy, temperature, work, and equilibrium. The first law is an accounting principle. The second law introduces directionality, irreversibility, and the cost of extracting useful work. Statistical mechanics explains macroscopic thermodynamics from microscopic populations.

THERMODYNAMIC ESSENTIALS

Heat transfer breaks into conduction, convection, and radiation. Whenever temperatures matter in electronics, lasers, batteries, propulsion, or biochemical reactors, thermal design is a first-class discipline, not an afterthought.

Electromagnetism

Electromagnetism unifies electrostatics, magnetostatics, waves, radiation, and circuits. Maxwell's equations are the field equations; circuit laws are the low-frequency lumped approximations that emerge when dimensions are small relative to the wavelength.

FIELD LAWS THAT BECOME DESIGN RULES

In practice, EM design means controlling field distributions with geometry, materials, shielding, grounding, return paths, and boundary conditions. Signal integrity, antenna radiation, EMC, microwave matching, and photonics all grow from the same field theory.

Waves, optics, and materials

Waves appear in strings, fluids, acoustics, electromagnetic fields, optical cavities, and quantum amplitudes. Key ideas are superposition, phase, dispersion, interference, group velocity, attenuation, impedance, and boundary reflection. Optics adds refraction, diffraction, polarization, coherence, lenses, resonators, and detectors.

Materials science sits underneath nearly every engineering decision. Structure determines properties: crystal order, defects, grain boundaries, dopants, polymer chains, composite layups, phase transformations, and microstructure all shape electrical, thermal, optical, and mechanical behavior.

Dimensionless reasoning and scaling

Dimensionless numbers tell you what physics dominates. They let you compare laboratory prototypes, manufactured products, aircraft, electrochemical cells, and simulations. Examples include Reynolds, Mach, Prandtl, Nusselt, Biot, Peclet, Damkohler, magnetic Reynolds, and Hartmann numbers.

- If Reynolds number is low, viscosity dominates; if high, inertia dominates and turbulence may matter.

- If Mach number is small, incompressible approximations often work; near or above unity, compressibility and shocks matter.
- If a circuit or interconnect length becomes a meaningful fraction of wavelength, lumped approximations fail and transmission-line thinking is required.
- If the magnetic Reynolds number is small, induced magnetic fields are weak; if large, the flow can advect magnetic flux significantly.

Chapter 3. Quantum mechanics

Quantum mechanics is the theory of physical systems whose states live in complex vector spaces and whose observables are operators. It is central to semiconductor devices, lasers, chemistry, quantum information, and much of modern physics.

Postulates and intuition

A quantum state is represented by a normalized vector in Hilbert space or by a density operator for mixed states. Physical observables are represented by Hermitian operators. Time evolution is unitary for isolated systems. Measurement returns eigenvalues with probabilities given by state overlap.

The theory is linear, but measurements appear probabilistic. Interference arises because amplitudes, not probabilities, add before squaring. Entanglement arises because composite systems use tensor products, allowing correlations that cannot be decomposed into independent subsystem states.

QUANTUM ESSENTIALS

Canonical systems

- Particle in a box: quantized energy from boundary conditions.
- Harmonic oscillator: ladder operators, phonons, photons, and Gaussian states.
- Spin-1/2 and qubits: two-level systems, Pauli matrices, Bloch sphere intuition.
- Hydrogenic atoms: orbital structure, quantum numbers, spectroscopy, and chemistry roots.
- Tunneling and band structure: central to diodes, transistors, STM, Josephson physics, and nanotechnology.

Approximation methods and open systems

Real quantum problems often require approximation: perturbation theory, variational methods, semiclassical models, adiabatic reasoning, and numerical diagonalization. Open quantum systems interact with environments, causing decoherence and dissipation. Density matrices, Lindblad models, and noise channels matter whenever coherence is not perfectly protected.

Why engineers need quantum mechanics

- Semiconductor band engineering depends on quantum states in periodic lattices.
- Lasers depend on quantized transitions, stimulated emission, cavity modes, and population inversion.
- Magnetic resonance, superconducting circuits, Josephson junctions, and photonics all require quantum descriptions.
- Quantum chemistry, material discovery, and certain sensors all use quantum-mechanical models even when the end product is classical.

Chapter 4. Quantum computing

Quantum computing uses controllable quantum systems to perform computation through unitary gates, measurement, and entanglement. The field combines quantum mechanics, information theory, hardware engineering, control, cryogenics, and software.

Qubits, gates, circuits, and algorithms

A qubit is a controllable two-level system with state alpha|0> + beta|1>. Multi-qubit states occupy tensor-product spaces whose dimension doubles with each added qubit. Computation consists of state preparation, gate application, idle periods with noise, and measurement.

COMPUTING PRIMITIVES

- Superposition alone is not an advantage; the advantage comes from interference structure, entanglement, and algorithm design.
- Not every problem is improved by quantum hardware. The field is strongest where amplitudes, hidden structure, or quantum simulation matter.
- Canonical algorithms include phase estimation, Shor-style period finding, Grover-style amplitude amplification, and variational hybrid methods.

Hardware modalities

REPRESENTATIVE HARDWARE FAMILIES

Noise, error correction, and realistic expectations

Noise channels include dephasing, relaxation, crosstalk, leakage, control miscalibration, and readout error. Because quantum information cannot be copied arbitrarily, error correction uses carefully structured redundancy such as surface-code style stabilizer measurements. Logical qubits therefore require substantial overhead.

- NISQ-era work focuses on characterization, calibration, noise mitigation, hybrid algorithms, and domain-specific simulation.
- Scalable fault-tolerant quantum computing demands improvements in materials, fabrication, packaging, cryogenics, microwave engineering, control electronics, and compiler/runtime stacks.
- Quantum computing should be viewed as one specialized compute substrate among many, not a universal replacement for classical computing.

Chapter 5. Energy, thermodynamic free energy, and scientific discipline

Energy links all the fields in this book. This chapter clarifies what free energy means in physics and chemistry, how real systems extract useful work from gradients, and how to evaluate extraordinary energy claims rigorously.

Energy conversion and storage

- Energy exists in mechanical, electrical, chemical, thermal, electromagnetic, nuclear, and field configurations.
- Useful devices convert one form into another with losses imposed by material limits, irreversibility, parasitics, and control overhead.
- Batteries, capacitors, fuel cells, engines, turbines, solar cells, thermoelectrics, motors, and generators each have distinct trade spaces in power density, energy density, efficiency, lifetime, and safety.

What free energy means in established science

In thermodynamics, free energy is not 'energy from nowhere.' It is the portion of a system's energy that is available to do useful work under specific constraints. Helmholtz free energy is appropriate for constant temperature and volume; Gibbs free energy is appropriate for constant temperature and pressure and is central to chemistry, electrochemistry, and biological energetics.

FREE-ENERGY RELATIONS

How to think about 'free energy' claims

Real systems can harvest ambient gradients: sunlight, wind, geothermal heat, salinity gradients, vibration, radio waves, or waste heat. That is energy harvesting, not a violation of thermodynamics. Claims of indefinitely outputting net work without an energy source or with hidden accounting errors should be evaluated using conservation laws, controlled measurements, and full-system boundary definitions.

1. Define the system boundary and every energy input path: electrical, thermal, mechanical, chemical, radiative, and environmental.

2. Measure both average and transient power with calibrated instruments.

3. Account for startup energy, stored energy, control electronics, and hidden couplings.

4. Check whether the device simply shifts where the energy enters the boundary rather than creating it.

5. Compare with known physical limits and ask whether the proposed mechanism changes established conservation laws or only exploits overlooked gradients.

Chapter 6. Deep physics from mechanics to quantum

Physics is the study of lawful structure in matter, motion, fields, and information-bearing systems. The reason it matters so much to engineering is simple: design quality depends on whether your abstractions still respect the real conservation laws, constitutive laws, and scale limits of the physical world.

Mechanics, fields, and conservation

Mechanics begins with kinematics, forces, momentum, angular momentum, and energy, but deep understanding goes beyond Newtonian force balance. Lagrangian and Hamiltonian formulations teach you to think in terms of constraints, generalized coordinates, symmetries, and stationary action. This matters in robotics, orbital motion, resonant devices, vibration, and multi-body systems.

Conservation laws are the spine. If a model seems to create momentum, energy, or charge from nowhere, it is almost certainly wrong or incomplete. The language of fields generalizes the same idea: rather than tracking only particles, you track distributed quantities such as temperature, pressure, charge density, or electromagnetic field strength.

Thermodynamics and statistical mechanics

Thermodynamics teaches which transformations are possible, which are efficient, and which are forbidden. State variables, equations of state, chemical potential, entropy, free energies, and exergy are not niche topics; they determine batteries, engines, phase change, biological metabolism, semiconductor processing, refrigeration, and chemical reactors.

Statistical mechanics explains why thermodynamics works by connecting macroscopic observables to microscopic distributions. Once you understand ensembles, partition functions, fluctuations, and irreversible tendencies, ideas such as noise, diffusion, mixing, activation, and thermal limits become much less mysterious.

Electromagnetism, optics, and materials

Electromagnetism is not just about electricity. Maxwell's equations unify electrostatics, magnetostatics, wave propagation, optics, antennas, transmission lines, microwave components, radiation pressure, imaging, and much of modern sensing. Boundaries and materials matter just as much as the equations themselves because devices live at interfaces.

- Electrostatics leads to capacitors, MEMS actuation, shielding intuition, and field-induced failure modes.
- Magnetostatics leads to motors, inductors, transformers, magnetic sensors, and plasma confinement ideas.
- Wave optics leads to interferometry, lasers, fiber links, lithography, microscopy, and photonic devices.
- Microwave and RF thinking leads to matching, filters, oscillators, antennas, propagation, and radar.
- Material response links microscopic structure to conductivity, permittivity, permeability, band structure, and loss.

Quantum mechanics as disciplined linear algebra

Quantum mechanics becomes less alien once it is seen as linear algebra plus measurement rules. States live in vector spaces, observables are operators, dynamics follow the Schrodinger equation or related open-system descriptions, and measurement connects amplitudes to probabilities. Superposition and interference are natural consequences of this structure.

For engineering, the value is broad: semiconductors, lasers, magnetic resonance, superconductors, tunneling devices, quantum sensing, and quantum computing all depend on quantum structure. Deep competence also requires learning where classical approximations re-emerge through decoherence, averaging, or coarse-graining.

PHYSICS MASTERY LADDER
- Level 1: kinematics, forces, energy, circuits-as-physics, and dimensional analysis.

- Level 2: fields, waves, materials, and boundary conditions.
- Level 3: thermodynamics, statistical reasoning, and quantum postulates.
- Level 4: solid-state, transport, open systems, nonlinear dynamics, and continuum models.
- Level 5: research-level specialization in condensed matter, plasma, photonics, fluid turbulence, biophysics, or other subfields.

Chapter 7. Projects, laboratory habits, and contributor path

Project ladder

- Simulate a pendulum, damped oscillator, or orbital transfer and compare the numerical solution with limiting analytical cases.
- Build a short notebook on a one-dimensional quantum well or harmonic oscillator and inspect how basis truncation changes the answer.
- Create and analyze a noisy single-qubit or two-qubit circuit, then compare ideal output distributions with sampled output distributions.
- Write a short essay evaluating an extraordinary energy claim by checking conservation laws, hidden inputs, measurement protocol, and system boundary definitions.
- Reproduce a result from an introductory quantum-computing or condensed-matter paper and document every approximation involved.

Habits that separate serious learners from casual readers

Physics becomes powerful when you continuously translate between words, diagrams, equations, simulation, and measurement. If you can only do one of those, your understanding will break under pressure.

Keep a table of scales: masses, temperatures, wavelengths, frequencies, voltages, field strengths, energies, and error rates. Frontier work depends as much on magnitude sense as on formal derivation.

Be especially suspicious of results that improve every metric at once, ignore losses, or never state the control volume. In energy and propulsion discussions, system boundaries are where fantasy often hides.

Compact example

```
from qiskit import QuantumCircuit

qc = QuantumCircuit(1, 1)
qc.h(0)
qc.measure(0, 0)
print(qc)
```

Chapter 8. Current official/open resources and requested-topic coverage

Open and official learning stack

- OpenStax College Physics — broad introductory path through mechanics, electricity, waves, and thermodynamics.
- MIT OpenCourseWare — deeper courses in mechanics, electromagnetism, quantum physics, thermodynamics, and statistical mechanics.
- Qiskit and IBM Quantum documentation/learning resources — quantum circuits, workflow patterns, and hardware-facing tooling.

Requested topics covered here

- physics
- quantum physics
- quantum mechanics
- quantum computing
- energy and thermodynamic free energy
- scientific reasoning about so-called 'free energy' claims

How to use these resources in practice

Use introductory resources to stabilize notation and units, then move quickly into simulation and hardware-aware documentation. Physics understanding grows when the same idea survives multiple representations: diagram, derivation, code, and measurement.

For quantum topics in particular, avoid treating software demonstrations as proof of hardware advantage. Use official documentation to understand workflow, but preserve a separate notebook of assumptions about noise, calibration, and scaling.