Fundamental Nature of Physical Phenomena
(Waves vs. Particles)

Core of Course
Ch 11. (Waves Intro), Ch. 12 (Sound), Ch. 24 (Wave Thry of light),
Ch. 25 (Optical Instruments), Ch. 27 Wave-Particle Duality

Ch. 28 (Quantum Mechanics)

Ch. 30 Nuclear Physics

Ch. 26 Relativity
Three theories of light: geometric optics, wave theory of light, photon theory

Mirrors, Lenses, Camera, Microscope
Reflection, refraction, dispersion

**Geometric Optics** (a particle theory)
Explains most phenomena

Diffraction  Interference

**Wave optics** explains additional phenomena
When we can neglect diffraction, wave optics
gives same results as geometric optics

BB radiation      Photoelectric effect      Compton Effect

**Photon theory** explains all of the phenomena explained by Wave optics (and Geometric optics) and explains even more phenomena. Photons are a very special kind of particle that (somehow?) can do interference and diffraction.
Ch. 11 Waves: Introduction

General properties of all waves
Similarities of different kinds of waves

General properties: $\lambda, f, \nu, A, I(P,E)$

$\nu = f \lambda$

Amplitude

$a$: string, water $\Delta y$
sound $\Delta p, \Delta x$
light $\bar{E}$
de Broglie $\Psi$

$I(P,E)$: Energy = $E$ (joules, eV)

Power = $P = \frac{\Delta E}{\Delta t}$ Energy/time (W)

Intensity = $I = \frac{\text{power}}{\text{Area}}$ (W/m$^2$)
Ch. 11 cont’d

For all waves: \[ I \propto |a|^2 \]

Later, \( I, P \), will be seen to be \( \propto \) # of particles (e.g. photons)

3-D waves, intensity falls off with distance: \[ I \propto \frac{1}{r^2} \]

**INTERFERENCE** (characteristic of waves): add amplitudes of 2 or more waves

String waves:

Standing waves = interference of right going wave & left going wave

Resonance, harmonics
DIFFRACTION (characteristic of waves): waves spreading or bending around corners

\[ \Delta \theta \sim \frac{\lambda}{D} \]
Ch. 12 Sound

Pitch = \( f \)  
Loudness = \( I \)  
\( v = 343 \text{ m/s} \) in room temperature air

\( a: \Delta p, \Delta x \) pressure and displacement pictures (both are very small)

\[ I \propto |a|^2 \propto |\Delta p|^2 \propto |\Delta x|^2 \]

Intensity level: decibels, \( \beta = 10 \log \frac{I}{I_0} \)

\( \beta = 0 \text{ dB} \) is softest sound you can hear

\( \beta = 120 \text{ dB} \) is threshold of pain

factor of two in intensity: add 3 dB
factor of ten in intensity: add 20 dB
Ch. 12 Cont’d

Ear: Basic anatomy; How it works; Understand sensitivity to $f$ (Fig. 12-7)

Pipes: standing sound waves (resonance): fundamental, harmonics, overtones, know rules for both open and closed.

Other interference of sound wave: Beats, “double slit” (= 2 speakers)

$$l_B - l_A = m\lambda \text{ (constructive), } = (m+1/2)\lambda \text{ (destructive)}$$

Doppler Effect: understand its origin; get signs right
Ch. 24 Wave Theory of Light

Understand evidence that light is a wave:

**INTERFERENCE:**

Double slit: \( l_B - l_A = m\lambda \iff d\sin\theta = m\lambda \)

Diffraction Grating (compare w/ double slit)

Thin film

Michelson Interferometer

**DIFFRACTION:**

\[
\sin\theta_{1/2} = \frac{\lambda}{D}
\]

Same idea as in Ch. 11 --- just more precise
Ch. 24 cont’d

Misc. properties:

**Dispersion**: rainbow, prism
know what the word means: index of refraction in a material is different for different frequencies/wavelengths of light.

**Polarization**: Transverse waves
know how Polaroid sunglasses work
rules: unpolarized light: cut by $\frac{1}{2}$
polarized light: $I = I_0 \cos^2 \phi$
Ch. 25 Optical Instruments

Camera: Basic parts
- f/ stop vs. shutter speed
- overall operation

Eye: anatomy
- analogy with parts of camera
- overall operation (near point, far point)

Corrective lenses: review, there WILL be a question on the final

Simple Magnifier: “lets eye get closer to object”

\[ M = \frac{N}{f} \]

Compound Microscope: Understand operation
1. Objective makes an enlarged image of object
2. Eyepiece views that image (= simple magnifier)
Ch. 25 cont’d

\[ RP = \frac{0.61\lambda}{n\sin \alpha} \]

Understand what this equation means (know NA)

“It is not possible to resolve the details of an object [much] smaller than the wavelength of the radiation used.” pg 778
Ch. 26: Special Relativity

Postulates: 1. Physics same in all inertial frames
   2. Speed of light is same in all inertial frames

Time dilation: Understand in terms of postulate 2 and “light clocks”

Length contraction

Mass increase and how this is consistent with $c$ as an ultimate speed.

Relativistic momentum

$E=mc^2$ Understand how to use. Also: Kinetic Energy
Ch. 27: Wave-Particle Duality

Surprise: light as particles: **PHOTONS**
   evidence: BB radiation, Photoelectric effect, Compton scattering

Surprise: electrons as waves: **DE BROGLIE WAVES**
   evidence: H-atom as standing wave explains H-spectrum
   (why H atom is stable),
   Davisson-Germer: interference of electron waves off
   “diffraction grating” made by planes of atoms in crystal
   Double slit (see Ch. 28)

Understand qualitatively all of the experiments and, quantitatively,
   Photoelectric effect, Bohr atom, and double slit.

\[ E = hf \]
\[ p = \frac{h}{\lambda} \]
   Intensity \( \leftrightarrow \) Number of Photons

Bohr atom: assumptions

\[ E_n = -\frac{13.6 \text{eV}}{n^2} \]  \( (E=0 \text{ is for electron far away from proton with no KE}) \)
Ch. 28: Quantum Mechanics

Wave theory applied to matter:

\[ \lambda = \frac{h}{p}, \quad f = \frac{E}{h} \quad \text{Amplitude Quantity} = \Psi \]

\( \Psi^2 \sim I \sim \# \text{ of particles or probability of finding a single particle} \)

H atom: it is impossible to watch (e.g. with short wavelength photons) an electron go around proton as suggested by Bohr. The first photon to scatter from the electron would give it a large and unknown momentum. First example of “Uncertainty principle:”

\[ \Delta x \Delta p \geq \frac{h}{2\pi} \]

In quantum mechanics, electron in the hydrogen atom is a standing “probability wave.” (compare w/ Bohr)

All physical phenomena (light, electrons, atoms . . .) obey Quantum Mechanics --- sometimes particle-like, sometimes wave-like. All quantum particles somehow (?) are able to do interference (p 862 for electrons)

For photons in the “photon theory of light,” the uncertainty principle is responsible for the behavior we saw called “diffraction” in the wave theory of light.
Ch. 30: Nuclear Physics

Nucleons: $n, p$, are like hard spheres --- billiard balls

Binding: the energy (mass) of nuclei is less than the sum of the individual nucleons this difference is the “binding energy.”

The “strong force”: strong and short-ranged holds the nucleus together

There are 4 fundamental forces: gravity, electricity, strong, weak

For large nuclei a competition develops between the strong force: strong but short-ranged, and the electrical repulsions between the protons.

Know the identities and properties of $\alpha, \beta, \gamma$ radiations and the products of the different types of nuclear decay.

Reaction energy, Q-values
Activity, half-life, decay constant

Medical Applications: physics considerations = lifetime & penetrating power

Understand how $^{14}_6C$ dating works